The Colorado Water Plan

Technical Memorandum

Prepared for:

Colorado Water Conservation Board

Project Title:

Planning Scenarios: State of the Science and Recommendations

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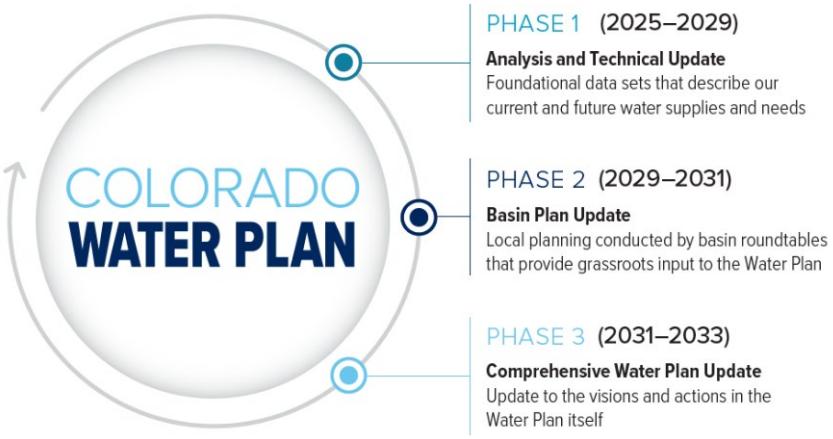
Section 1: Introduction

Scenario planning is a strategic method used by organizations to prepare for variable and uncertain futures. It involves identifying uncertainties, forecasting a variety of potential future outcomes, and formulating strategies to mitigate risks. Scenario planning gives decision makers and water users the flexibility to track changes in water resource drivers (such as climate, social, and regulatory drivers) over time to provide insight into which future conditions might become more likely as time passes. The method can identify strategies to address water resources issues, implement the strategies, and adapt them to meet the challenges that emerge as the future unfolds.

Colorado utilizes scenario planning within an adaptive management framework for future water planning. The framework has functioned in recent years within the Colorado Water Conservation Board's (CWCB) water planning cycle:

- In 2015, the Water Plan set an adaptive management framework for future water planning activities and described five plausible futures (or planning scenarios).
- In 2019, the Analysis and Technical Update to the Colorado Water Plan (Technical Update) estimated the demands, supplies, and gaps for the planning scenarios through 2050.
- In 2022, the basin roundtables updated the Basin Implementation Plans (BIP) and focused on projects strategies to address the estimated gaps described in the planning scenarios.
- In 2023, the updated Water Plan focused on stakeholder (or "partner") actions needed to secure our water future and supporting Agency Actions.

CWCB's cyclical water planning process is about to reinitiate, and the scenario planning process will be foundational to refreshing the Analysis and Technical Update to the Water Plan.



This technical memorandum (TM) documents the state of the science on scenario-based planning through review of various case studies and examples in which planning scenarios are used for water resources planning and decision making. This TM also provides recommendations for updating Colorado's planning scenarios.

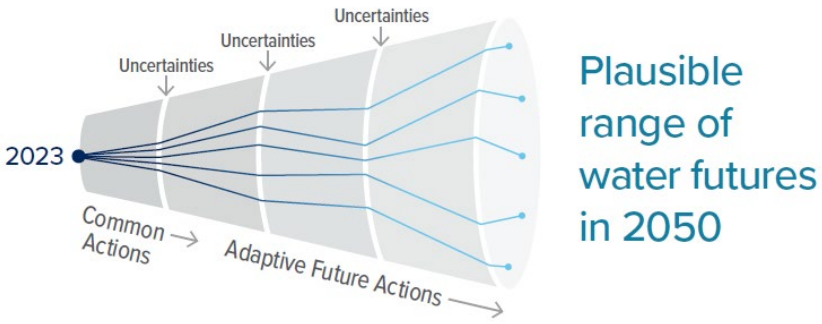
- Section 2 describes the background of Colorado's planning scenarios.
- Section 3 provides summaries of the case studies.
- Section 4 presents recommendations for updating drivers, scenarios, and strategies.
- Section 5 proposes a plan for implementation and concludes the TM.

Section 2: Planning Scenarios Background

Scenario planning is a decision support framework that acknowledges the future is uncertain. Colorado's Water Plan uses scenario planning to consider a wide range of possible futures according to the best available science and stakeholder input. The approach embraces inherent uncertainties in future climate conditions, social conditions (such as values and economics), and supply-demand conditions (such as energy, agricultural, and municipal needs).

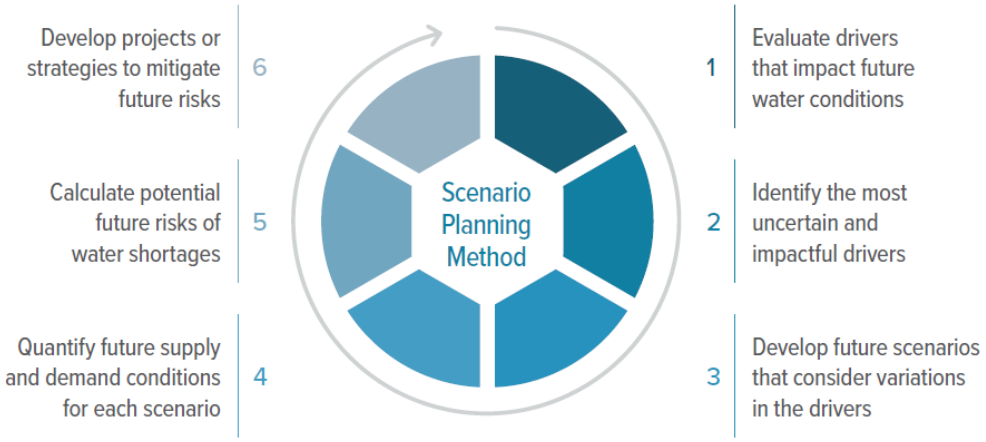
The 2015 Water Plan introduced scenario planning and outlined five plausible futures (planning scenarios) that describe Colorado's potential water situation in 2050, under which demands, supplies, and gaps were to be estimated. The scenarios included new considerations, such as climate change, that were not a part of prior statewide water planning analyses.

The scenario planning process recognizes that uncertainties exist in the future environmental state and social values of Colorado. As the planning horizon increases, the uncertainty of these conditions increases as well. Scenarios can be based on assumptions, or best guesses, about the states of future conditions.



The six general steps below describe the scenario planning method, which is intended to be cyclical and adaptive. CWCB has engaged in these steps throughout various phases of the Water Plan development and update process.

- Steps 1 through 3 were conducted by the Interbasin Compact Committee (IBCC) in 2012. CWCB will reinitiate these steps soon in the context of reviewing and updating scenarios.
- Steps 4 and 5 were documented in the Technical Update
- Step 6 was completed through BIP updates and the update to the Water Plan



The remainder of **Section 2** provides a summary of the drivers and planning scenarios created for the most recent Technical Update and overall cycle of the Water Plan. For a more detailed description, refer to **Section 2.1** in the 2019 Analysis and Technical Update to the Colorado Water Plan (link: Analysis and Technical Update).

2.1 DRIVERS

Drivers are the key factors or variables that shape the different scenarios and influence the water-related future described in each scenario. CWCB used a collaborative process to identify and describe drivers. Before developing the 2015 Water Plan, CWCB initiated a multi-year stakeholder dialogue in conjunction with the nine basin roundtables and the IBCC to develop a methodology for projecting future water needs. The IBCC then developed a list of nine high-impact drivers that could greatly influence the direction of Colorado's water future (see **Table 1**) which were used in the 2019 Technical Update. Several of the drivers are interrelated and can have overlapping or synergistic effects. For example, social values that lean toward environmental protection (Driver #1 in **Table 1**) can lead to increased regulatory oversight (Driver #6 in **Table 1**). Identifying these nine drivers is important to understanding the direction of future water supply and demand and for adapting strategies to meet future water-related challenges.

Table 1. Summary of Planning Scenario Drivers

Driver	Driver Description
1. Social/Environmental Values	Social/environmental values reflect the public's perception of water use, support of water and energy conservation, and allocation of water supply toward environmental uses. Social values influence drivers such as regulations and adoption of water efficiency technologies, but they also affect the types of solutions that Coloradans pursue to meet future water needs or respond to climate change. For example, social values can impact the degree to which residents voluntarily adopt water-efficient technologies that may cost them money. They can also influence the demand for local agricultural products and the desire to maintain open space. Personal experiences, education, and outreach impact the degree of public awareness of water issues, which in turn can affect the public's perception of the water supply solutions as well as recreation and environmental protections that are pursued.

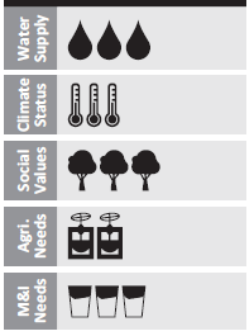
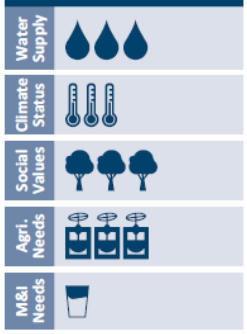
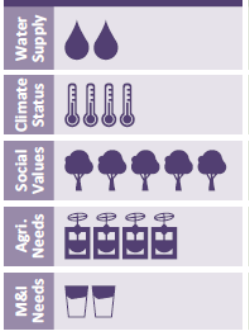
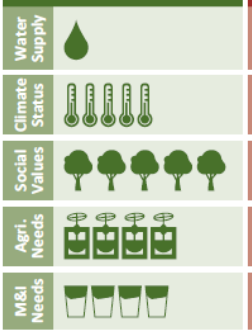
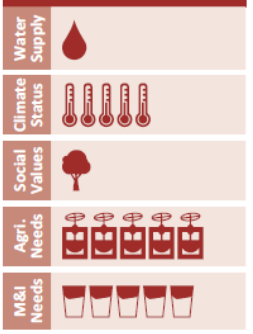
Table 1. Summary of Planning Scenario Drivers	
Driver	**Driver Description**
2. Population/Economic Growth	Population growth is driven by both state and national economic trends and land use planning and development statewide (see Driver #3). Colorado's moderate climate and quality of life draw both permanent residents and tourists. Population and economic growth/decline is forecasted by the State Demography Office (SDO) using census data and economic drivers.
3. Urban Land Use/Urban Growth	Urban land use and growth considers both density and type of development, as well as urbanization of undeveloped and agricultural lands. Zoning and other decisions affecting population density in cities and towns impacts how water is used inside and outside of single- and multi-family housing and businesses. It also impacts the degree to which urban sprawl may occur in the future. Denser redevelopment is influenced by water resource availability and social values with a preference for low water use, low energy use, and green infrastructure.
4. Availability of Water Efficient Technologies	Availability and adoption of water efficiency technology drives water demands from municipal, industrial, and agricultural perspectives. Increased efficiency can be implemented in all sectors (municipal, industrial, energy, agricultural) and can offset growth through decreased demand by individual users.
5. Climate Change	Climate change is the long-term shift in temperature and regional weather patterns that results in a range of projected future conditions that include a warmer and potentially drier future for Colorado. A range of climate-adjusted conditions were developed statewide through the multi-phase Colorado River Water Availability Study and are used to adjust hydrology and the demand for water reflective of the future climatic conditions.
6. Level of Regulatory Oversight/Constraint	Regulatory oversight includes the legal framework in Colorado and nationwide through which water is administered, developed, and managed. This includes oversight from DWR, Colorado Department of Public Health & Environment (CDPHE), U.S. Environmental Protection Agency (EPA), and others.
7. Agricultural Economics/Water Demand	Agricultural conditions, such as the amount of irrigated land in production, crops grown, and climate, influence demand for irrigation supplies. Urbanization, municipal transfers of agricultural water supply, availability of surface and groundwater supplies, and in some basins, interstate compact compliance, all influence the amount of agricultural land that will be in production in the future. Demands and prices for local agricultural products also affect the economic sustainability of continued agriculture and resulting demands for water.
8. Energy Economics/Water demand	The energy sector uses water in a variety of ways, including direct use for hydropower, or indirect uses such as steam generation or cooling. Water needs for energy shift in response to population growth and current regulations, policies, and planning for the energy industry. These needs are also affected by the type of energy production that is used in the future and can be influenced by state and national energy policies.
9. Municipal and Industrial Water Demands	The municipal and industrial sector serves the residents and businesses of Colorado with water. Municipal water demands are influenced by changes in

Table 1. Summary of Planning Scenario Drivers	
Driver	Driver Description
	other drivers such as population, urban land use, adoption of conservation measures, and climate.

2.2 PLANNING SCENARIOS

Using the drivers in **Table 1**, the IBCC developed five scenarios that represent how Colorado's water future might look in 2050, knowing that the future is unpredictable and will contain a mix of multiple scenarios. A simplified graphic and descriptions of the five scenarios are shown below. The icons for each scenario illustrate the increase and decrease in levels for the generalized drivers compared to current levels (the five icons represent the combined effects of the nine drivers). The scenario names portray the overall story that each scenario tells in its respective view of the future.

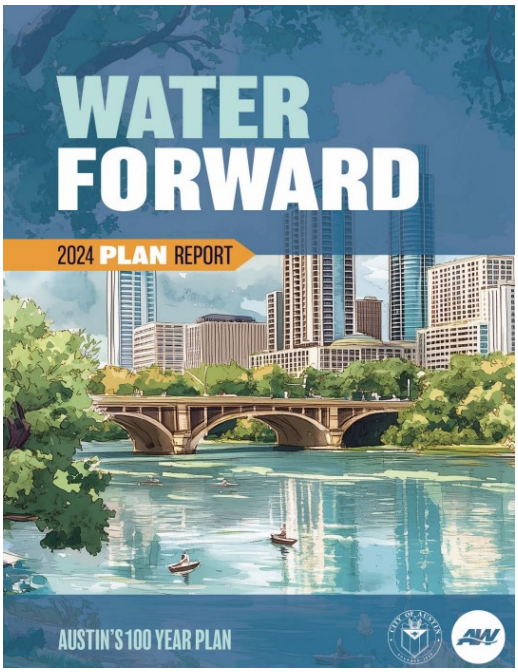
Simplified description of planning scenarios:

A Business as Usual	**B** Weak Economy	**C** Cooperative Growth	**D** Adaptive Innovation	**E** Hot Growth
				
- Population growth increases at trends predicted by the State Demography Office (SDO). - Future hydrology, per capita water demands, and adoption of conservation measures are similar to what's recently occurred.	- The world's economy slows, and the state's population growth is less than predicted. - Hydrology is similar to recent patterns. - This scenario puts the least amount of stress on future water supplies and is a bookend for scenarios (i.e., the lowest gap).	- Climate is moderately warmer, and irrigation demands increase. - Statewide population is similar to predictions by SDO, but it is distributed differently across the state. - People seek to offset increased demands by more aggressively adopting water conservation.	- Both scenarios assume that the climate is much warmer and drier and that population growth is higher than projected. - The scenarios' primary differences revolve around conservation. In the Adaptive Innovation scenario, the state aggressively adopts conservation measures in both municipal and agricultural sectors. In the Hot Growth scenario, conservation is not a focus.	

Section 3: Planning Scenarios Examples & Case Studies

This section highlights case studies that use scenario planning for water resource planning and decision making. Each example provides key insights and elements that can inform the update to the planning scenarios in the Water Plan. The case studies are summarized below and further described in Section 4 recommendations where applicable. Case study reports are included as Appendix A.

3.1 CASE STUDY: WATER FORWARD 2024 PLAN



Austin Water (in Austin, Texas) developed a utility-level integrated water resource plan that involved identifying uncertainties, assessing future water supply needs and water strategies (conservation, reuse, and water supply), and outlining an implementation plan with an emphasis on adaptive management under the backdrop of climate change. Water Forward 2024 used various climate futures and projections of water demand and regional water supplies to develop modeling scenarios as plausible future conditions to identify water strategies that are reliable across as many future conditions as possible.

The Water Forward 2024 Plan included a planning horizon to 2080 focusing on water strategy implementation to meet future needs. It also included a 100-year planning horizon framework to 2120 based on future conditions that consider climate, including drought worse than the drought of record, water demand, and regional water supply development. The primary drivers for possible futures were climate change, growth of water demands due to population increase, and new water supply projects in the Lower Colorado River basin. These primary drivers were identified as the key areas of uncertainty in planning for Austin's water resources. Modeling scenarios were developed to include a range of future conditions for each driver. Three climate futures were included in modeling scenarios: low, medium, and higher warming conditions, which were translated into possible future Colorado River Basin flows. Low, medium, and high projections for future water demand and regional water supplies were also created. For baseline water demand projections, census data were compared to water billing data to quantify retail and wholesale population, employment, and residential unit estimates at the parcel level. From this, 100-year total served population projections and baseline water use factors (water use per housing unit for the residential customer sectors and water use per employee for the non-residential customer sectors) that account for passive conservation were developed by sector for low, medium, and high scenarios at key planning years. Future baseline water demands with passive conservation, but without additional active conservation and reuse savings, were calculated and compared with estimated demands that included savings from water efficiency strategies to demonstrate the effectiveness of those strategies. Various portfolios of water efficiency and supply strategies were modeled against many plausible future scenarios for 2080. The top ten most effective portfolios were identified. The top portfolios were assessed based on the greatest water supply reliability across a range

of costs using a multi-criteria decision making framework. A selected portfolio was chosen based on factors including water reliability, equity, and economic, environmental, and implementation benefits. The portfolio of strategies will be monitored and evaluated over time to support the adaptive management approach. Additionally, the Water Forward 2024 Plan established a 5-year review and update cycle and quarterly and annual public progress reports to incorporate new data and share progress. The 50-year planning horizon focuses more on near-term strategies and guidance, while the 100-year planning horizon focuses on alternative long-term strategies based on future conditions beyond 2080.

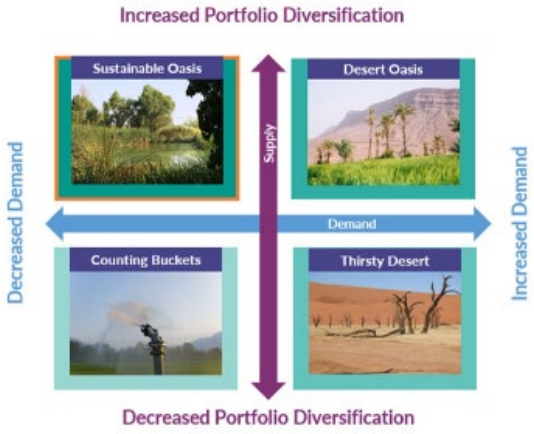
Key Insights:

Water Forward 2024 Plan Report, Austin Water, November 4, 2024

For more information, see: Water Forward 2024 Plan Report

- The Water Forward 2024 Report presents two timelines in the analysis – a 50-year strategy implementation and 100-year planning horizon. From Brown and Caldwell's perspective, it was confusing to reference two separate planning horizons rather than one.
- Water Forward 2024 includes various portfolios of water efficiency strategies, and the portfolios were modeled to identify cost and level of performance. The top 10 portfolios were identified and compared against performance metrics.
- The analysis considered land conservation as a source protection water strategy that could also reduce demands.
- Water Forward 2024 included extensive modeling that may have been consolidated by doing upfront sensitivity analyses.

3.2 CASE STUDY: ONE WATER 2100 PLAN



Tucson Water (in Tucson, Arizona) created the One Water 2100 Plan (Plan) as a long-range water resource plan which focuses on the One Water approach. City of Tucson's (City) One Water approach emphasizes community outreach, stakeholder feedback, partnerships, and collaboration to help identify vulnerabilities and develop strategies to utilize all of the City's supply sources and demand management to mitigate risks.

The role of the Plan is to serve as a guide for City leaders, elected officials, staff, and the community to inform water management and investment decisions, and to develop, change, and implement local water policy and regulations. The City was completely reliant on groundwater until the 1980s, when over-pumping depleted the aquifer and caused land subsidence. Now, the City mainly relies on Colorado River water supplies. Planning scenarios were developed through a series of workshops to identify critical drivers and uncertainties in collaboration with stakeholders. A matrix of four future plausible scenarios were created based on key uncertainties of future supply and future demand, and the scenarios were given names such as "Sustainable Oasis" and "Thirsty Desert." Brown and Caldwell's observation is that while the names are engaging, they seemed to distract from the substance of the scenarios involving water demands and

water supply portfolio diversification. Projections for increasing and decreasing water demands and supply availability were developed based on population growth and per capita water use along with assumptions based on the City's future supply availability, respectively. The combinations of future supply and future demand correspond to the assumptions in the four future scenarios. The City developed strategies to achieve an increased supply and decreased demand, which aligns with the "Sustainable Oasis" scenario. For the other scenarios, the City developed strategies to mitigate the risks of decreased supply and mitigate the risks of increased demand. Additional input was gathered through community stakeholder workshops, a public town hall, public event booths, presentations, interviews, and an online survey to capture priority concerns and interests related to water management to ensure that the Plan captured community needs.

One Water 2100 Plan, Tucson Water, September 2023

For more information, see: One Water 2100 Plan

Key Insights:

- The Tucson Water 2100 plan took a traditional scenario planning approach and developed four plausible scenarios based on future demands and supplies.
- From Brown and Caldwell's perspective, although the matrix and drivers were relatively simple to communicate, the applied scenario names, which included Desert Oasis, Sustainable Oasis, Counting Buckets, and Thirsty Oasis, added unnecessary complexity.

3.3 CASE STUDY: NEVADA IRRIGATION DISTRICT PLAN FOR WATER



Nevada Irrigation District (NID) is an independent special district which provides water, power, and recreation to parts of Nevada, Placer, and Yuba counties in California. NID developed a Plan for Water which reviewed and assessed historical and projected available water supply and demands. Three models, which focused on hydrology, water demand, and operations (respectively) were developed to evaluate alternative operating strategies and capability to meet future needs.

The water demand model incorporated scenario planning. Demands were estimated for eleven different scenarios, including a current demand scenario (using recent historical demand) and ten projected demand scenarios. Sensitivity analyses were performed with the water demand model to identify which factors, or inputs, most impact demand. Higher and lower demand conditions were considered in each sensitivity analysis around a current baseline for the following factors: raw water customers, treated water customers, total evapotranspiration, evapotranspiration with temperature changes, and system losses. The results were considered in the development of the projected demand scenarios. The 10 projected demand scenarios encompass low, baseline, and high demands across wet, median, and dry hydrologic

conditions from 2022 to 2071 in addition to a constant baseline. NID selected three scenarios that reflected low, medium, and high water stress and the constant baseline for further analysis.

Plan for Water, Nevada Irrigation District, July 17, 2024

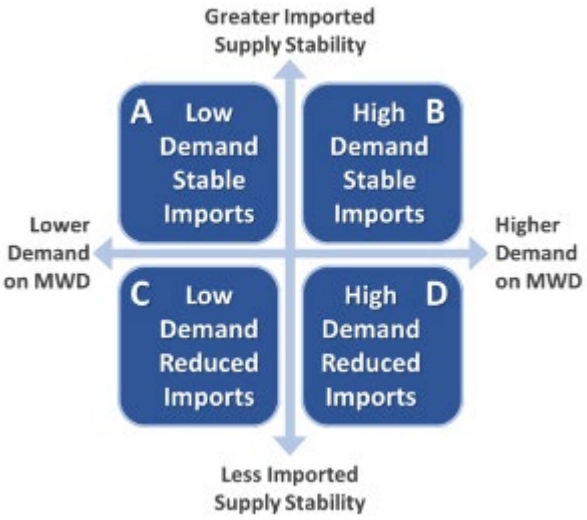
For more information, see: Plan for Water

Key Insights:

- The NID Plan for Water prepared sensitivity analyses of the drivers, resulting in an understanding of the driver's impacts on demands (higher or lower) and the magnitude of that impact
- The Plan for Water developed three models, which focused on hydrology, water demand, and operations (respectively), to evaluate alternative operating strategies and capability to meet future needs.
- The planning scenarios included a baseline in addition to an array of planning scenarios. The planning scenarios looked at several hydrologic assumptions (dry, median, and wet) along with a range in water demands (high, baseline, and low). From the array of scenarios, three scenarios were selected for further analysis along with the baseline. The three scenarios include Low Bookend (high demand and dry hydrology), Middle Scenario (baseline demand and median hydrology), and High Bookend (low demand and wet hydrology).
- The scenarios were compared back to the "baseline" generated from median hydrology with constant baseline demand.

3.4 CASE STUDY: 2020 INTEGRATED WATER RESOURCES PLAN – REGIONAL NEEDS ASSESSMENT

The Metropolitan District of Southern California (Metropolitan) serves Los Angeles, Orange, Riverside, San Bernardino, San Diego, and Ventura counties. Metropolitan developed an Integrated Water Resources Plan (IRP) in 1996, and they recently conducted their fourth update. The first phase of the update, a Regional Needs Assessment, was completed in 2020 which incorporated scenario planning for the first time. The second phase of the IRP Update is a One Water approach, which involves extensive collaboration among Metropolitan's Board, member agencies, and other interested parties. This phase aims to develop an adaptive management strategy that will establish a process for monitoring key reliability indicators and find joint approaches to the regional problems and resource needs identified in this assessment.



Four scenarios were developed based on higher and lower imported supply stability and water demands. Reliability assessments were performed, and supply-demand gaps were quantified for each scenario. The gap estimates did not consider mitigation strategies and assumed existing supplies and trends extend into the future. Levels of reliability were determined based on the supply-demand gap. The reliability assessment results were used to develop resource mixes (or portfolios) for each scenario that could mitigate supply-demand gaps. Portfolio strategies focused on supplies and storage were broken up into categories of core and flexible actions. The analysis revealed that it was more practical in every scenario to pursue a more balanced and diversified mix of portfolio actions instead of relying on any single category of portfolio actions. The assessment identified vulnerabilities in Metropolitan's reliability goal, which will allow Metropolitan to take actions to address the identified gap aligned with the portfolio analysis as they move into Phase 2: One Water Implementation.

A Retrospective of the 2015 Integrated Resources Plan was prepared in 2020 to review and compare 2015 planning assumptions with observations, describe lessons learned, and provide context and reasoning for using scenario planning in the 2020 IRP.

2020 Integrated Water Resources Plan Regional Needs Assessment, Metropolitan Water District of Southern California, 2020

For more information, see: 2020 IRP

Key Insights:

- Metropolitan developed four scenarios based on higher and lower imported supply stability and water demands.
- The Metropolitan IRP case study included a comparison back to the previous IRP to compare predicted trends with actual trends in the water resources drivers. The comparison included an assessment of demographic data, weather and climate data, retail demand, Metropolitan demand, supplies, and water use efficiency.
- Their planning process included a reliability assessment. After the scenarios were quantified in terms of supply and demand, the reliability assessment established what was projected to occur if trends identified in the scenarios continued without intervention. This "take no action" case shows what would happen if Metropolitan relied solely on existing supply resources and if existing trends in population growth and conservation adoption extend into the future.

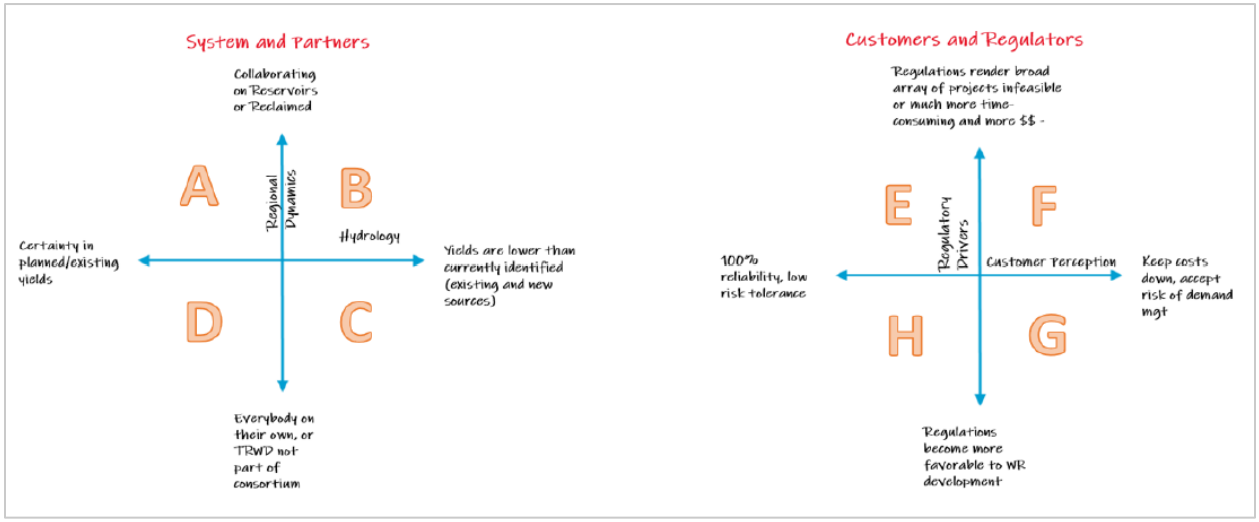
3.5 CASE STUDY: INTEGRATED WATER SUPPLY PLAN UPDATE STRATEGY

Tarrant Regional Water District (TRWD) serves an 11-county service area in northern Texas, centering on Fort Worth. TRWD released its first Integrated Water Supply Plan (IWSP) in 2013 which explored various supply alternatives against demand projections, recommended near-term "No-Regrets" projects, and

identified an adaptive management plan for the future. Recently, TRWD developed an IWSP Update Strategy to map how TRWD will approach their update to the IWSP. The goal of the IWSP Update Strategy was to develop a thoughtful sequence of planning activities or investments that will help TRWD avoid inefficiencies or rework, incomplete steps, missed opportunities, or unnecessary steps. The IWSP Update Strategy identified drivers and scenarios for the planning process, important focal points, and potentially impactful risks to inform the IWSP Update. The IWSP Update Strategy took a detailed, step-by-step approach to show how each suggestion was developed and how the recommended plan was formulated. TWRD staff participated in four workshops to develop strategies and determine risk factors specific to TRWD. Through the workshops, the four most potentially impactful risks to the planning process were identified:

- Hydrologic uncertainty: Understanding available water is a cornerstone of subsequent tasks.
- Regional dynamics: Understanding regional partnership potential on large regional water supply alternatives allows TRWD to integrate all water supply strategies into a prioritized and sequenced development plan or supply portfolio.
- Customer perceptions: Water users' perceptions impact their tolerance to risk and can range from wanting reliable supplies (low risk tolerance) to prioritizing low costs and accepting risks of demand management.
- Regulatory drivers: Regulations may render supply options infeasible or be more favorable to water resource development.

These four risks were used to develop two risk matrices to represent eight equally plausible near-term futures (A through G) that could inform the IWSP update. Activities that will be described, prioritized, or sequenced in the IWSP update were tested in the setting of the risk matrices to create a strategy that orchestrates the activities in an efficient, productive way. For example, it was determined that essential early steps are Hydrologic Updates and a better understanding of regional partnership potential to help mitigate uncertainty and avoid inefficiencies in planning the IWSP update.



Integrated Water Supply Plan Update Strategy, Tarrant Regional Water District, 2020

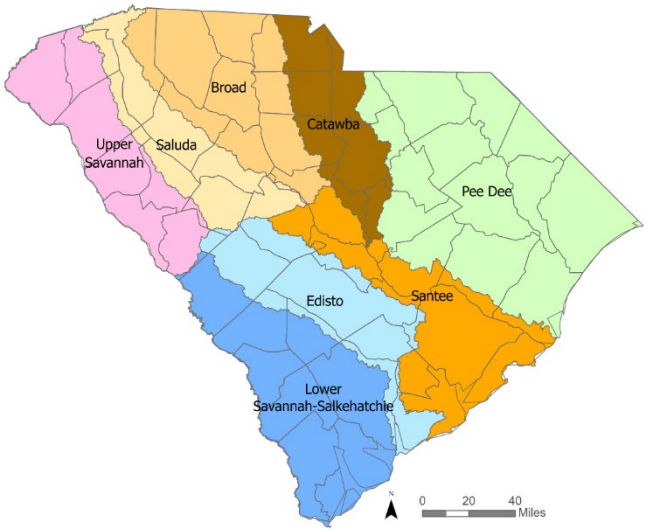
For more information, see: TRWD Integrated Water Supply Plan

Key Insights:

- TRWD developed an IWSP Update Strategy to map how to approach their update to the IWSP. The goal of the IWSP Update Strategy was to develop a thoughtful sequence of planning activities or investments that will help TRWD avoid inefficiencies or rework, incomplete steps, missed opportunities, or unnecessary steps.
- TRWD staff participated in a workshop to review and prioritize drivers that have the most potentially impactful uncertainty (highest risk), including hydrologic uncertainty, regional dynamics, customer perceptions, and regulatory drivers.
- The four risks were used to develop two risk matrices to represent eight equally plausible near-term futures that could affect inform the IWSP update. Activities that will be described, prioritized, or sequenced in the IWSP update were tested in the setting of the risk matrices to create a strategy that orchestrates the activities in an efficient, productive way.

3.6 CASE STUDY: SOUTH CAROLINA BASIN AND STATE WATER PLANNING

The South Carolina Water Resources Planning and Coordination Act requires the development of a statewide, comprehensive water resources policy. Accordingly, the State developed their first state water plan—the South Carolina Water Plan—in 1998. The state water plan has since been updated and expanded to consider regional plans covering South Carolina's eight major river basins.



Planning basins of South Carolina.

Each of the basin-focused water resource plans is called a River Basin Plan. The plans are defined by South Carolina as "a collection of water management strategies supported by a summary of data and analyses designed to ensure the surface water and groundwater resources of a river basin will be available for all uses for years to come, even under drought conditions." Diverse stakeholder groups (i.e., "River Basin Councils") developed the River Basin Plans. The next update to the State Water Plan will build on the analyses and recommendations developed in the eight River Basin Plans.

The River Basin Plans consider demands, supplies, and potential shortages (for both surface water and groundwater supplies) under five scenarios:

- Current Surface Water Use Scenario (Current): Current operations, infrastructure, and water use.
- Permitted and Registered Surface Water Use Scenario (P&R): Modeled demands are set to permitted or registered values for all water users. The scenario provides information to determine whether surface water is currently over-allocated in each basin.
- Moderate Water Demand Scenario (Moderate): Modeled demands are set to projected 2070 levels based on an assumption of moderate population and economic growth.
- High Water Demand Scenario (High Demand): Modeled demands are based on aggressive growth to the year 2070.
- Unimpaired Flow Scenario (UIF): All water demands and discharges in the model were set to zero to represent "naturalized" surface water conditions in the basin.

While the impacts of future development to surface water and groundwater resources are considered, potential future impacts from climate change are not specifically incorporated. The five planning scenarios do, however, consider a wide range of future conditions and potential risks to surface water and groundwater supplies and the ability of water providers to meet future municipal, industrial, and agricultural demands. Risks to various fish species and other ecological characteristics are considered through the application of flow-ecology relationships to projected future hydrologic regimes throughout each basin. Current and future hydrology, available surface water supplies, and potential shortages were evaluated using distributed link-node models developed for each basin. Groundwater supplies and potential shortages were evaluated using a groundwater model developed by the U.S. Geological Survey. Each River Basin Plan includes proposed actions to mitigate future risks to municipal, industrial, agricultural, and ecological water uses.

For more information on South Carolina's statewide water planning process, see:

Water Planning | South Carolina Department of Environmental Services

Key Insights:

- South Carolina projects future supplies, demands, and shortage risks to municipal, industrial, and agricultural water users out to the year 2070.
- Future planning scenarios contemplate moderate and high demands.
- Ecological risks are evaluated using flow-ecology relationships applied to modeled future hydrologic regimes.
- Conclusions and recommendations from each of South Carolina's eight River Basin Plans will be considered and incorporated into a forthcoming update to the State Water Plan.

Section 4: Recommendations

4.1 DRIVERS

The Technical Update identified nine high-impact drivers that could greatly influence the direction of Colorado's water future, which are defined in Section 2.1. All drivers influenced the planning scenario modeling. Some drivers directly impacted the modeling, while other drivers had indirect impacts. Appendix B includes a summary matrix that describes the drivers, their impact on water resources, the underlying data, and how the drivers were applied to the planning scenarios. Drivers such as agricultural demands and municipal and industrial demands were highly dependent on other drivers (like climate change and population growth) and were more a result of quantitative modeling than independent variables. Other drivers, such as regulatory oversight and social values, were not directly applied but were instead reflected in underlying conservation assumptions. The scenario narratives informed how the drivers were applied and dictated the relative amount of municipal and industrial demand that each scenario should exhibit. However, in some cases, the scenario descriptions created offsetting conditions with certain drivers that created complications in calculating the relative demands described in each scenario.

In the Technical Update refresh, we recommend CWCB review the high-impact drivers and prioritize the most impactful drivers. Some drivers affect Colorado's water future, but they are not directly quantified in the modeling. For example, social and environmental values reflect public perception and behaviors, which may *influence* Colorado's water future, but this was not modeled explicitly. Rather, it was used to influence the assumptions about the future water demands. Other drivers are quantified and directly impact modeling, such as population growth. Certain drivers can influence water demands and address *solutions* to reduce water demands, such as water efficient technologies. Table 2 below places the drivers into categories for "*direct impact*", "*influencer*," "*analysis result*", and "*solution*."

Table 2. High-Impact Drivers Categories

Drivers	Category			
	Direct Impact	Influencer	Analysis Result	Solution
1. Social/Environmental Values		X		X
2. Population/Economic Growth	X			
3. Urban Land Use/Urban Growth		X		X
4. Availability of Water Efficient Technologies		X		X
5. Climate Change	X			
6. Level of Regulatory Oversight/Constraint		X		X
7. Agricultural Economics/Water Demand			X	
8. Energy Economics/Water demand			X	
9. Municipal and Industrial Water Demands			X	

Separating out the analysis result and solution categories, six drivers remain in the modeling category bucket that directly impact or influence (indirectly) the planning scenarios modeling. These drivers can be ranked or prioritized to reflect their level of impact on the planning scenarios. Analyses can be conducted to evaluate the sensitivity of "direct impact" and "influencer" drivers to estimates of water demands,

supplies, and potential gaps. The importance and range of driver values can be determined through workshop brainstorming, public polling, and technical analyses. Ultimately, once the most impactful drivers are identified, the drivers could be reorganized, altered, or removed. Population growth and climate change are anticipated to have the highest impact on the planning scenarios. See Table 3 below for an example reorganization of the high-impact drivers.

Table 3. Example Reorganization of High-Impact Drivers

Direct Impact	Influencer, Solution	Analysis Result
Population/Economic Growth	Social/Environmental Values	Agricultural Economics/Water Demand
Climate Change	Availability of Water Efficient Technologies	Energy Economics/Water demand
	Level of Regulatory Oversight/Constraint	Municipal and Industrial Water Demands
	Urban Land Use/Urban Growth	

**The above table is provided for example purposes only. Final reorganization and prioritization will occur with stakeholder input.*

The case studies used varying approaches to prioritize drivers. In TRWD's IWSP Update Strategy, staff participated in a workshop to review and identify the top five factors (i.e., drivers) that have the most potentially impactful uncertainty (highest risk). They included hydrologic uncertainty, regional dynamics, customer perceptions, and regulatory drivers. These four risks were used to develop two risk matrices to represent eight equally plausible near-term futures that could affect inform the IWSP update. Activities that will be described, prioritized, or sequenced in the IWSP update were tested in the setting of the risk matrices to create a strategy that orchestrates the activities in an efficient, productive way. A clear understanding of drivers, risks, and opportunities to mitigate uncertainties and avoid inefficiencies laid a strong foundation for TRWD strategy before proceeding with the IWSP update.

In the NID project, sensitivity analyses of the drivers resulted in an understanding of their impact on demands (higher or lower) and the magnitude of that impact, see Figure 1. For example, raw water customers had the highest impact on both lowering and increasing demands, followed by total evapotranspiration (ET) changes. System losses were impactful but almost exclusively in increasing water demands. Treated water customers were the least impactful due to the magnitude of their water use on the overall average water requirement.

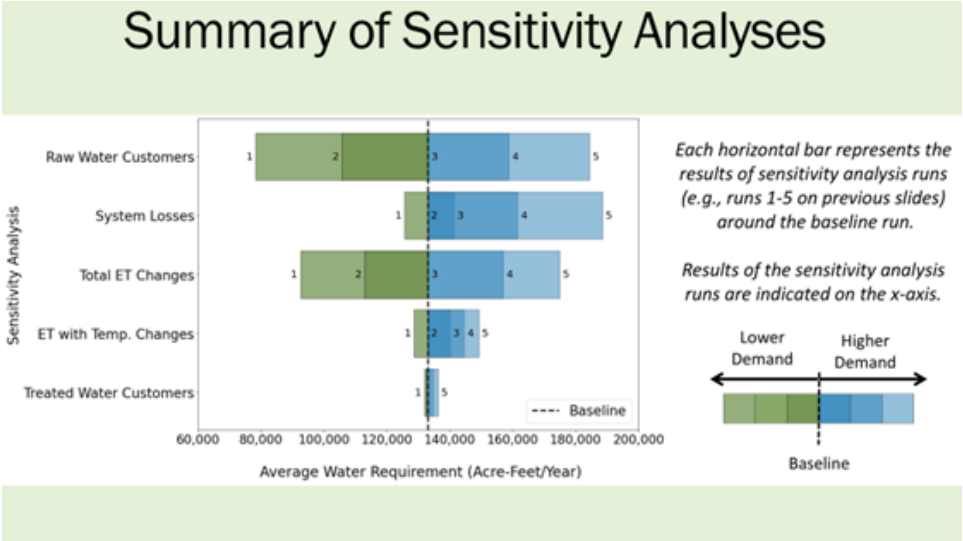


Figure 1. Summary of NID Sensitivity Analyses

Our future is uncertain, and reviewing the best available science and understanding trends in water resource drivers can help us better understand the uncertainties and develop credible projections of potential future conditions. Assessing trends in water resource drivers also informs the degree to which actions taken by Coloradans have lowered our water-related risks and can lower them even more in the future.

Long-term trends in many drivers in the Technical Update cannot be effectively assessed over short time periods. For example, population, climate, per capita water savings, economic, and hydrologic patterns require years of data to identify statistically significant trends. **We recommend CWCB assess trends in drivers, influencers, and solutions that will impact Colorado's water future during interval updates to the Technical Update.** This includes monitoring the drivers that impact our future water supplies and demands to understand how conditions are changing, where resources should be focused and how well Colorado is progressing toward the main vision statements described in the Water Plan.

While the appropriate time period for assessing and reporting trends can vary by driver, the update cycle for the Water Plan is sufficient to track long-term trends in some drivers and identify recent patterns that can inform perspective on long-term trends in other drivers. Updates to and assessments of data sets describing drivers will be conducted with future Technical Updates to the Water Plan and reassessments of planning scenarios. Drivers that could be assessed are included in **Table 4**. The monitoring of drivers could compare the Technical Update baseline conditions (2012) to conditions today (2025). The trends identified would carry forward into the future. For example, Colorado has made significant progress on indoor water conservation, and additional indoor water conservation gains are increasingly more difficult to accomplish. On the contrary, there are significant strides that can be made in outdoor water conservation moving forward.

Table 4. Proposed drivers, influencers, and solutions to be assessed, organized by Water Plan Action Area				
	Vibrant Communities	Robust Agriculture	Thriving Watersheds	Resilient Planning
Driver	- Population growth by county - Per capita water use broken down by indoor and outdoor uses as well as residential and non-residential use and water loss - Climate/warming impacts on outdoor water demand - Urban land uses as well as impervious (paved areas and buildings) and pervious (grassed areas and other green landscapes) areas - Industrial water demands	- Irrigated acres by basin including loss of irrigated land due to urbanization, water transfers, and retirement of lands due to declining groundwater supplies - Crops grown in each basin - Changes in irrigation methods and associated efficiency - Climate/warming impacts on irrigation demand	- Changes in hydrology (runoff timing and amounts) from forested areas	- General water supply data including stream flows (amounts and monthly/seasonal timing), groundwater level trends, and water in storage - Climate/warming impacts on hydrology

Table 4. Proposed drivers, influencers, and solutions to be assessed, organized by Water Plan Action Area				
	Vibrant Communities	Robust Agriculture	Thriving Watersheds	Resilient Planning
Influencer, Solution	- Degree to which communities integrate land use and water planning - Transmountain diversion amounts - Social values, technology drivers, and regulations related to water conservation and reuse	- Implementation of CWSAs. While CWSAs also can involve municipal, environmental, and recreational partners, they are identified under Robust Agriculture because they typically involve a senior agricultural water right as the source of supply	- Areas across Colorado where stream and watershed management plans such as SMPs and IWMPs have been initiated and completed - Communicating risk & environmental attributes: - Mapping that describes the location of E&R attributes - Mapping that describes risk factors for E&R attributes as well as water supply infrastructure. Risk factors could include data sets such as impaired streams identified in the 303(d) list and disturbed areas from wildfires	- Public knowledge of and opinions on water resources issues - Water quality trends in streams and reservoirs - Changes in participation regarding water-related activities and collaborative efforts such as roundtable meetings, outreach activities, and educational workshops

The results of this assessment can be used to create a "report card" that formally communicates the performance and progress of the drivers. For example, the Metropolitan IRP case study included a comparison back to the previous IRP to compare predicted trends with actual trends in the water resources drivers. The comparison included an assessment of demographic data, weather and climate data, retail demand, Metropolitan demand, supplies, and water use efficiency. This analysis was summarized and presented in a 2015 Retrospective PowerPoint. They include charts and tables that visually display the predicted versus actual values within each trend.

4.2 PLANNING SCENARIOS

The Technical Update used five planning scenarios that looked to 2050 and envisioned how Colorado's water future could unfold, see Section 2.2. The scenarios were included in the BIP Updates, described in the Colorado Water Plan, mentioned in public feedback and questions, and used for other stakeholder studies and/or planning. About six years have passed since the Technical Update was finalized, and CWCB

has considered feedback, lessons learned, and expressed several considerations regarding how the scenarios should be updated for the next Technical Update.

- Ease of communication: CWCB has observed challenges in communicating the five scenarios due to complexity, confusion over scenario inputs, and misunderstanding of scenario names.
- Climate change in all scenarios: The last Technical Update included climate change impacts in three of the five planning scenarios. Although scenarios that omit climate change can be useful for comparison, scientific evidence, stakeholder feedback, and the Colorado Climate Change Report all point to incorporating impacts of climate change in all future scenarios.
- Planning horizon timeline: The last Technical Update focused on a planning horizon out to the year 2050, but the upcoming Technical Update should extend the horizon. The availability of population and climate projections impact the selected planning horizon. CWCB is aware that existing climate data sets describing projected changes in naturalized stream flow and consumptive irrigation requirements are available at locations statewide for the year 2070 from the Colorado River Water Availability Study. In addition, SDO will work with CWCB to extend population projections to 2070.
- Conservation as an independent consideration: The last set of planning scenarios incorporated varying levels of municipal, industrial, and agricultural water conservation. However, conservation was not maximized in any of the scenarios, and stakeholders wondered how much overall benefit could be derived from water conservation as a solution. Solutions like new storage, new reuse projects, or collaborative water sharing agreements were not modeled.

In the Technical Update refresh, we recommend CWCB utilize three planning scenarios that extend the planning horizon timeline to 2070 and consider climate change. Figure 2 illustrates the transition from five planning scenarios down to three that maintain a broad range of future water-related conditions and considerations but may be easier to communicate. The five scenarios can be reduced by removing the Business as Usual scenario (which did not consider climate change in the last Technical Update) and reducing the remaining scenarios to three that represent warm and wet climate with low population and agricultural demands (low/low), in-between climate with medium population and agricultural demands (mid/mid), and hot and dry climate with high population and agricultural demands (high/high).

Figure 2 also illustrates a concept of considering water conservation independently and outside of the planning scenarios. By considering water conservation independently, CWCB would be treating it like other strategies and projects that reduce the risk of future shortages. In the last Technical Update, the Adaptive Innovation and Hot Growth scenarios included similar assumptions of climate change and population growth, but they differed in their assumption of future water conservation. The comparison of gaps in these scenarios was used to describe the benefits of conservation. The two scenarios highlighted different key storylines: the Hot Growth scenario emphasized the potential gap estimate without conservation, while the Adaptive Innovation scenario demonstrated the benefit of conservation measures in narrowing that gap. Figure 2 shows how the storylines from the former Hot Growth and Adaptive Innovation scenarios can be maintained by assuming severe climate change and high population growth in one scenario (instead of two), resulting in a conservatively high gap estimate, and then estimating the benefits of conservation separately in a subsequent analysis step.

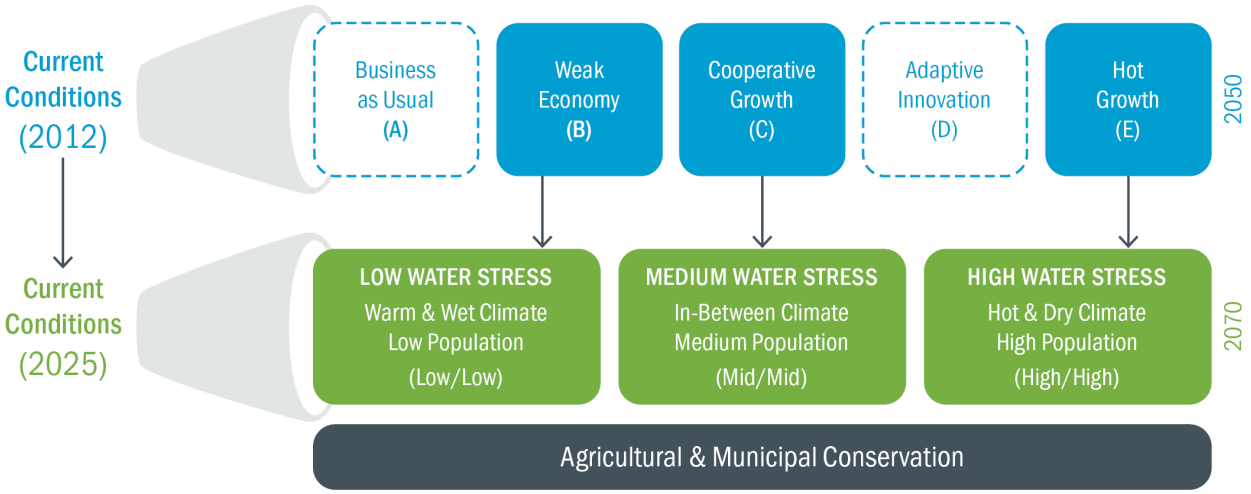


Figure 2. Proposed Planning Scenarios

**Baseline models will be updated to extend the period of record and reflect current agricultural demands, municipal and industrial demands, and water supply operations.*

Using the three scenarios Low Water Stress, Medium Water Stress and High Water Stress will simplify communication of the plausible futures and modeling results. Additionally, the nomenclature of low, medium, and high is simple and clear. From a technical perspective, the intent of the low and high scenarios would be to capture the plausible range of potential future conditions and reflect a high degree of variability and uncertainty.

The three proposed scenarios do not include a Business as Usual scenario; however, the following case studies summarized below provide examples of comparing back to "best guess," "current use," and "take no action". They demonstrate different ways to compare scenarios based on each studies' planning context, objectives, and audience.

For example, the mid-range scenario could represent a "best guess" scenario that reflects a likely future condition given that Colorado has already experienced impacts from climate change. Multiple case studies included a "baseline" or "best guess" scenario. For example, in NID's Plan for Water, the planning scenarios included a baseline in addition to an array of planning scenarios. The planning scenarios looked at several hydrologic assumptions (dry, median, and wet) along with a range in water demands (high, baseline, and low). From the array of scenarios, three scenarios were selected for further analysis along with the baseline. The three scenarios include Low Bookend (high demand and dry hydrology), Middle Scenario (baseline demand and median hydrology), and High Bookend (low demand and wet hydrology). These were compared back to the "baseline" generated from median hydrology with constant baseline demand. Because the Plan for Water informs planning and operational decisions, NID wanted to explore a wide range of conditions but also wanted a "best guess" to help them create a robust future plan.

The South Carolina River Basin Plans did not include an overt "baseline" scenario. Instead, a range of scenarios were evaluated based on varying use conditions and projected demands. The Moderate and High Demand Scenarios projected surface and groundwater demands to 2070 under modest growth and climate conditions and more extreme growth and climate conditions, respectively. The scenarios compared demands to the Current Use scenario and evaluated water availability to identify potential shortages under various plausible conditions.

In the Metropolitan IRP, the planning process included a reliability assessment. After the scenarios were quantified in terms of supply and demand, the reliability assessment established what was projected to occur if trends identified in the scenarios continued without intervention. This "take no action" case

shows what would happen if Metropolitan relied solely on existing supply resources and if existing trends in population growth and conservation adoption extend into the future. The resulting "supply demand gap," which was calculated by the difference in supplies and demands, quantifies the level of reliability. Evaluating results against the "take no action" created like-for-like comparisons between scenarios.

From Brown and Caldwell's perspective, the case studies included elements that could be improved upon.

- The Tucson Water Plan utilized four planning scenarios that were focused on two principal drivers, supply and demand, organized into a matrix. Although the matrix and drivers were relatively simple to communicate, they applied scenario names such as Desert Oasis, Sustainable Oasis, Counting Buckets, and Thirsty Oasis. The naming convention added unnecessary complexity when the scenarios looked at high and low water portfolio diversification paired with high and low demands.
- The Austin Water Forward 2024 Plan included two timelines in the analysis – a 50-year strategy implementation and 100-year planning horizon. The report alternated between timelines throughout, which occasionally made it hard to follow. It may have been more effective to communicate the timelines separately or use only one timeline. For example, the South Carolina River Basin Plans utilizes one timeline and project future supplies, demands, and shortage risks to municipal, industrial, and agricultural water users out to the year 2070.
- The Austin Water Forward 2024 Plan included extensive modeling that may have been consolidated by doing upfront sensitivity analyses.

4.3 CONSERVATION IN WATER MANAGEMENT AS A STRATEGY

The Adaptive Innovation scenario as part of the 2019 Technical Update assumed extensive future adoption of municipal and agricultural conservation measures. With conservation built-in, the Adaptive Innovation scenario effectively conveyed that conservation efforts can reduce the risk of future gaps compared to the Hot Growth scenario in both the municipal and agricultural sectors. It also showed that prioritizing water conservation can significantly help, but not completely mitigate, the effects of climate change and population growth. However, incorporating conservation measures directly into a scenario does not allow the flexibility to vary assumed levels of conservation, test consistent levels of conservation across scenarios, or determine which conservation solutions are optimal. "Overlaying" conservation as a solution across the scenarios can show its impact independently on demands, supplies, and gaps in different climate and population futures.

Figure 3 includes the steps to overlay conservation measures in the municipal and agriculture sectors as strategies. Initial demand, supply, and gap modeling of all three scenarios without conservation as an overlay provides a baseline for each scenario. Then, conservation strategies can be modeled across scenarios to evaluate different strategies. **We recommend that CWCB overlay conservation strategies across the planning scenarios to evaluate how different strategies reduce demand, alter supplies, and reduce the gap.**

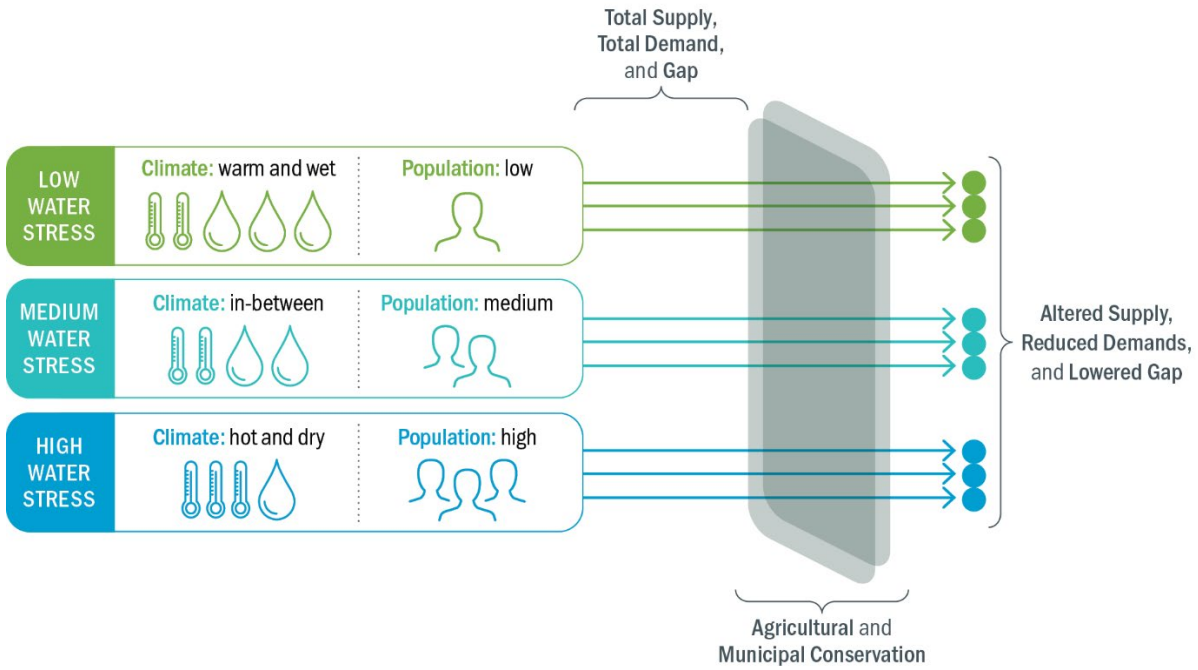


Figure 3. Conservation Strategy Overlay

The Low Water Stress scenario assumes a warm and wet climate with low population growth. The Medium Water Stress scenario assumes a warm climate, less precipitation, and with medium population growth. In the High Water Stress scenario, climate warming and population growth exceeds Low and Medium Water Stress scenarios. The following municipal and agricultural conservation strategies are included as potential examples to overlay:

Municipal	Agricultural
Water efficient technologies (distribution)	Increased water efficiency (delivery)
Water efficient technologies (end use)	Increased water efficiency (on-farm irrigation)
Turf removal/replacement	Climate resilient crops
Municipal demand management	Demand management
	Regenerative agriculture/conservation tillage

New demand, supply, and gap values will be evaluated based on conservation strategy implementation through 2070 to quantify reduction in water demands due to conservation strategies. The gap without conservation and gap with conservation can be compared against one another to inform water supply savings and reductions in demand.

The Austin Water Forward 2024 Plan Report implements a similar approach to identify optimal groupings of conservation, reuse, and supply strategies against future scenarios for 2080 to select a portfolio of strategies that meet reliability and cost metrics. Potential water savings and costs were developed for each reuse and water conservation strategy. Combinations of these strategies (portfolios) were modeled to identify portfolios with the lowest cost that still meet a determined level of performance in relation to a theoretical highest benefit and highest cost. The top 10 portfolios were assigned quantitative and qualitative values against 11 performance metrics, including a reliability, resiliency, and vulnerability score, net return flows, portfolio diversity, implementation and operation risk, and others. Based on these results, a portfolio was chosen based on its performance score. Estimated acre-feet per year savings from

2030 to 2080, five-year implementation actions, and capital and annual costs are included for each strategy in the Water Forward 2024 Plan.

Although this section focuses on water conservation as a strategy, this overlay approach could be applied to other solutions including storage, supply, ordinances, and legislation to determine the top-performing strategies to invest in.

4.4 PLANNING SCENARIO COMMUNICATION

Effective communication of the planning scenarios and calculation results is important so the public can understand and engage with the data. In the Technical Update, the main report, appendices, and modeling data were shared via CWCB's website and FTP site. CWCB also created the Colorado Water Plan Interactive Tool to communicate the drivers, planning scenarios, and results. The tool, developed with support of RS-21, allows users to dive into context, data and map, tools, and solutions as further described below:

- The context provides an overview and background on sectors, drivers, scenarios, and results.
- The data and map display risk layers and Technical Update results.
- The tool allows users to interact with the core drivers of climate, growth, agricultural conservation, and municipal and industrial conservation to estimate risk across sectors. The solution areas, which include agricultural efficiency, storage, watershed restoration, and public engagement and education, illustrate specific actions and future opportunities and summarize potential benefits and drawbacks.

Technical Update is available at:

Technical Update to the Water Plan | DNR CWCB

Colorado Water Plan Interactive Tool is available at:

Colorado Water Plan Interactive Tool

Although the Colorado Water Plan Interactive Tool was extensive and detailed, challenges remained after exhausting the budget. The map and data tab displayed some data either incorrectly, not at all, or required troubleshooting. CWCB was unable to update underlying data or content without assistance of RS-21, and the site was ultimately not launched publicly.

We recommend CWCB visualize and communicate the Technical Update results in a graphical and consumable way utilizing a platform that is easily changeable and updatable by CWCB. CWCB should evaluate alternatives and select an appropriate platform, identify the intended audience, lay out site design and content, and populate it with Technical Update results. Potential platforms or applications could include ArcGIS Experience Builder, PowerBI Dashboard, or a custom web application. ArcGIS Experience Builder is a highly configurable app builder product that creates immersive web apps by combining maps, data, and interactive widgets with little to no coding. The app could be developed by CWCB or a consultant while maintaining CWCB ownership and editing powers with their ESRI user account.

During platform development, CWCB should work with stakeholders to ensure the platform articulates the planning scenarios and results understandably and clearly through strong, aesthetic visuals. Stakeholders could include CWCB directors and staff, state officials, basin roundtables, water professionals, and other interested parties. Stakeholder outreach will achieve buy-in and ensure the visualization tools are user-friendly. The framework for the platform can be developed concurrently with the Technical Update refresh using results from the 2019 analyses to populate it with content and test app capabilities. The platform can be updated with the new results after they are finalized.

For more information on ESRI Experience Builder:

ArcGIS Experience Builder | Esri Developer

Experience Builder Examples:

City of Tucson – Climate Action Community Survey

Balsam Wooly Adelgid in Northern Utah

Justice in the Sewers: Mapping Houston's Sewage Overflows

Main Stream New Mexico Dashboard

Section 5: Conclusion

Colorado utilizes scenario planning within an adaptive management framework to inform future water decisions. Scenario planning involves identifying uncertainties, forecasting outcomes, and formulating strategies to navigate risks. CWCB is approaching the Technical Update refresh within their water planning cycle. To help inform the process, this TM documents the state of the science on planning scenarios by highlighting key elements of case studies and provides recommendations for updating Colorado's planning scenarios. The recommendations include:

Review the high-impact drivers and prioritize the most impactful drivers. The 2019 Technical Update identified nine high-impact drivers that influence Colorado's water future. CWCB and IBCC with support of the hired consultants can review and prioritize the drivers though workshops and technical analyses.

Assess trends in drivers, influencers, and solutions that will impact Colorado's water future. This includes evaluating the drivers that impact our future water supplies and demands to understand how conditions are changing, where resources should be focused, and how effectively Colorado is progressing towards the vision statements and objectives described in the Water Plan.

Develop three planning scenarios that look to 2070. We recommend using three planning scenarios, simplified from the five scenarios previously used, to clearly communicate variable climate and population futures.

Overlay conservation strategies across planning scenarios out to 2070 to evaluate how different strategies reduce demand, alter supplies, and reduce the gap. "Overlaying" conservation as a solution across three proposed scenarios can show the impact of a solution, or combination of solutions, on demand, supply, and gap in different plausible futures.

Visualize and communicate the Technical Update Results in a graphical and consumable way utilizing a platform that is easily changeable and updatable by CWCB. CWCB will work with the consultant to select and develop a visually strong and appealing platform or application that articulates the planning scenarios and associated outcomes clearly and accurately.

The graphic below summarizes the recommendations, sequencing, participants, and work product or outcome. The recommendations span the Technical Update refresh timeline, and include participation from CWCB, IBCC, and hired consultants.

	Preparing for the Technical Update			Technical Update Final Report	
Recommendation	Review the high-impact drivers and prioritize the most impactful drivers	Develop three planning scenarios that look to 2070	Assess trends in drivers, influencers, and solutions that will impact Colorado's water future	Overlay conservation strategies across planning scenarios out to 2070 to evaluate how different strategies reduce demand, alter supplies, and reduce the gap	Visualize and communicate the Technical Update results in a graphical and consumable way utilizing a platform that is easily changeable and updatable by CWCB
Participants	IBCC, CWCB, Consultant	IBCC, CWCB, Consultant	CWCB, Consultant	CWCB, Consultant	CWCB, Consultant
Work Product or Outcome	Updated list of drivers	Updated planning scenarios	Drivers Report Card	Technical Update modeling and results	Platform / Web App

This document is intended to be updatable and editable by project participants. Additional comments and edits can be documented as CWCB initiates their updated planning process.

Appendix A: Case Studies

CASE STUDY: WATER FORWARD 2024 PLAN

WATER FORWARD

2024 PLAN REPORT



AUSTIN'S 100 YEAR PLAN

Water Forward 2024 Plan Report

FINAL – November 4, 2024

Director's Message

Austin Water is doing important work to make sure Austin has a strong and reliable water supply, even as our city faces the challenges of growth, drought, and a changing climate.

Over the past few years, Austin Water has put smart strategies in place that have already made a big difference. We've focused on conservation, encouraging our customers to use water wisely through recent hot and dry years. We've also launched GoPurple, a program that will expand our reclaimed water system and includes requirements and incentives for developments to reuse water onsite. We are pursuing water storage strategies to stretch our existing supplies. And working closely with our regional partners, we've strengthened Austin's ability to bridge droughts and provide a sustainable water supply to meet all our community's water needs.

Our work doesn't stop here. Climate science tells us that we must do even more to protect our future. The challenges we face are real, and we need to stay ahead of them. That's why we're committed to learning from our past efforts and adjusting as we go. We've been using an adaptive management approach to closely monitor how our plans are working and make changes as needed. This is a key part of Water Forward 2024, which provides a roadmap for Austin's water future.

We've been working hand in hand with the Water Forward Task Force, a group of dedicated community members who help inform our efforts. Together, we've updated the 2018 plan, adjusted our strategies, and responded to the needs we've identified along the way. This collaborative approach has resulted in updates that not only address today's needs but also prepare us for tomorrow's challenges.

At Austin Water, work is already underway to carry out this updated plan. We're focused on staying transparent and accountable to you, our community, as we move forward. We know that water is essential to our quality of life, and we're determined to protect this precious resource.

As we look to the future, we at Austin Water hold a hopeful vision. Austin is a leader in water conservation and sustainability and we see a future where our city continues to thrive, and where every resident has access to clean and reliable water, no matter what challenges come our way. Together, we can build a water-secure future for Austin, and I'm excited to continue this journey with you.

Thank you for your support and for being a part of Austin's water story.



Shay Ralls Roalson, P.E.

Austin Water Director

ACKNOWLEDGMENTS

Austin Water prepared the Water Forward 2024 Plan with support from the Council-appointed Water Forward Task Force, Community Ambassadors Group, and Climate Technical Advisory Group. Thank you to the many community members who took part in the process to update the plan. Your feedback helped to create a plan that is reflective of Austin's values and will create a sustainable future for our community.

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ABBREVIATIONS

AF	Acre Feet
AF/yr	Acre Feet Per Year
AMI	Advanced Metering Infrastructure
ASR	Aquifer Storage and Recovery
AW	Austin Water
BCP	Balcones Canyonlands
CIP	Capital Improvement Project
City	City of Austin
COA	City of Austin
COM	Commercial
CTAG	Climate Technical Advisory Group
DCP	Drought Contingency Plan
DDM	Disaggregated Demand Model
DPR	Direct Potable Reuse
DTI	Delphi, Trends, and Imagine Austin
DWDR	Drought Worse than the Drought of Record
GCM	Global Circulation Model
GIS	Geographic Information Systems
GPCD	Gallons Per Capita Per Day
IPR	Indirect Potable Reuse
LCRA	Lower Colorado River Authority
MFR	Multifamily Residential
MGD	Million Gallons Per Day
OWRS	Onsite Water Reuse System
Plan	Water Forward 2024 Plan
SER	Service Extension Request
SFR	Single Family Residential
SOP	Standard Operating Procedure
TCEQ	Texas Commission on Environmental Quality
TM	Technical Memorandum

TWDB ..... Texas Water Development Board

UT Austin ..... The University of Texas at Austin

WAM ..... Water Availability Model

WCP ..... Water Conservation Plan

WF18 ..... Water Forward 2018 Plan

WF24 ..... Water Forward 2024 Plan

WHL ..... Wholesale Customers

WQPL ..... Water Quality Protection Lands

WTP ..... Water Treatment Plant

WWTP ..... Wastewater Treatment Plant

EXECUTIVE SUMMARY

Introduction and Purpose

Water Forward 2024 is Austin's 100-year integrated water resource plan. The purpose of Water Forward is to develop and implement diverse and environmentally conscious water management strategies to adapt to growth, drought, and climate change and ensure a sustainable, resilient, equitable, and affordable water future for our community for the next 100 years. Austin Water has developed this plan to address near- and long-term water needs through a collaborative process in alignment with guiding principles crafted to reflect the Austin community's values.



Water Forward Guiding Principles

Water Forward 2024 was created through a collaborative process led by Austin Water and involving the Water Forward Task Force, outside experts and consultants, and community stakeholders. This approach allowed for the integration of community values and scientific expertise, making the plan both data-driven and responsive to public concerns. Public workshops, surveys, and one-on-one meetings with community organizations provided valuable insights into community priorities, particularly around affordability, equity, and conservation. The Climate Technical Advisory Group and other technical experts provided climate projections and technical data to guide plan development.

The resulting plan includes a suite of conservation, reuse, and supply strategies for the next 50 years and an adaptive management plan through 2120. It builds on the original 2018 Water Forward Plan, integrating new climate and water demand data into an updated approach to plan for future uncertainty. The plan is strategic in nature and is intended to guide the development of future projects, programs, and policies, which are summarized in terms of near-term five-year implementation actions.

Planning for Uncertainty

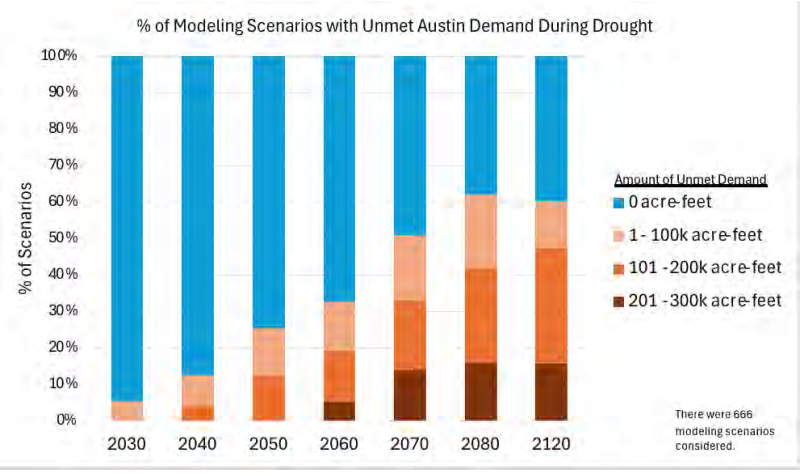
Water Forward 2024 identified three key areas of uncertainty in planning for Austin's water resources: 1) growth in population and water demands, 2) drought and climate change, and 3) development of regional supplies.

1. **Population and Demand Growth:** The plan included low, medium, and high population growth scenarios, with Austin Water's current served population of just over a million people growing to approximately 3.2 million people by 2120 in the medium projection. Water Forward anticipates increased water demand from residential, commercial, and other customers. The plan also considered the impact of regional growth within the Colorado River basin.
2. **Drought and Climate Change:** Austin depends on the Colorado River and Lakes Travis and Buchanan for its water. During the 2008-2016 drought and again in 2022 and 2023, inflows to these reservoirs reached record lows. Climate models project higher temperatures, increased evaporation, and more variable rainfall patterns, which will lead to more intense droughts and lower river flows in the future. Water Forward incorporated updated climate data and plans for droughts worse than those we have experienced in the past.
3. **Regional Supply Development:** The Lower Colorado River Authority (LCRA) has plans to develop additional supply projects that would contribute to the shared resources of the lower Colorado River and help meet growing water needs for the City of Austin and others in the basin. To address the uncertainty of how much water would be produced by these projects and when they would be completed, Water Forward incorporated low, medium, and high projections of regional supply development.

The Water Forward plan used a more robust approach by testing many water management strategies against hundreds of plausible future scenarios to plan for these uncertainties.

Future Water Supply Needs

Austin's projected water supply needs increase with climate change impacts over time and with the increasing demands of other water users within the Colorado River basin. By 2070, if no new strategies are implemented, about half of the more than 600 scenarios modeled show no additional need, 13% of scenarios show a need of less than 100,000 acre feet per year, and 37% of scenarios show a need of more than 100,000 and less than 300,000 acre feet per year. Addressing these potential shortfalls requires a diversified water resource portfolio sized to meet this range of future water supply needs. With Water Forward 2024 strategies in place, less than 3% of scenarios evidence a shortage through 2060 and approximately 15% of scenarios in 2070 and 2080 evidence a shortage.

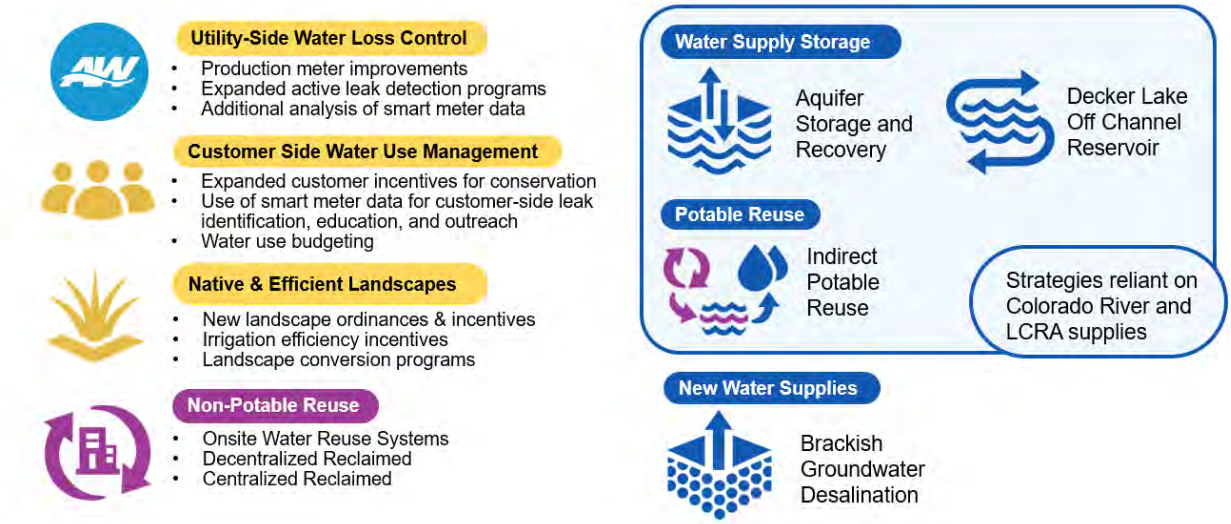


Acknowledging that the lack of a reliable and affordable water supply would likely have the greatest impacts on marginalized communities, Austin Water created an Equity and Affordability

Roadmap to help identify strategies that had greater benefits for marginalized communities and to find ways to mitigate potentially inequitable impacts of strategies. Austin Water also evaluated portfolios of water management strategies against objectives like water supply reliability, protecting the environment, being cost-effective, and reducing risks in the implementation of strategies.

Future Water Strategies

Water Forward 2024 includes multiple strategies that, together, form a resilient water resource portfolio. These strategies include conservation and non-potable reuse strategies to reduce potable water demands, potable water storage and reuse strategies to stretch our Colorado River supplies, and new water supplies. The plan also includes land conservation strategies to protect Colorado River water quality.



1. **Conservation:** Water conservation is a cornerstone of the plan. Austin Water will enhance its conservation programs through rebates, public education, and regulations that promote efficient water use. This will include leveraging the data and insights provided by the My ATX Water smart meter program and working toward establishing customer water use budgets. Austin Water will also seek to reduce utility-side water losses by implementing actions identified in a third-party evaluation of the utility's water loss programs.
2. **Non-Potable Reuse:** Austin Water's GoPurple Program includes requirements for connection to Austin's centralized and decentralized reclaimed water systems or installation of onsite reuse, while offsetting affordability impacts through cost-sharing, incentives, and funding mechanisms. Water Forward envisions future expansion of these systems and requirements to further reduce potable water demands.
3. **Potable Supply:** Storage strategies to stretch our existing supplies include Aquifer Storage and Recovery (ASR) and use of Lake Water E. Long ("Decker Lake") as an off-channel reservoir with the lake level fluctuating only during drought periods.
4. **Land Conservation:** Conserving land in the Colorado River Basin upstream of Austin helps preserve drinking water quality for the City. Austin Water will begin further community engagement to develop a land conservation program that will expand the utility's current and ongoing wildland conservation efforts.

Water Forward Strategies	Average/ Drought	Estimated Yield (Acre Feet per Year) 2030	2040	2050	2060	2070	2080	Total Annual Community Cost ($ per acre foot per year)*
Water Conservation Strategies								
Utility-Side Water Loss Control	Both	2,800	7,500	9,400	11,300	13,200	15,000	$267
Customer-Side Water Use Management	Both	2,400	4,700	6,400	8,100	9,800	11,400	$52
Native & Efficient Landscaping	Both	1,300	2,700	3,800	4,800	5,900	7,000	$5,112
Water Conservation Strategies Sub-Total	-	**6.500**	**14,900**	**19,600**	**24,200**	**28,900**	**33,400**	
Non-Potable Water Reuse Strategies								
Centralized Reclaimed	Both	1,100	8,200	12,900	17,600	22,300	26,900	$2,243
Decentralized Reclaimed	Both	0	200	500	800	1,100	1,300	$5,158
Onsite Reuse	Both	1,100	4,000	5,700	7,300	9,000	10,600	$8,957
Non-Potable Reuse Strategies Sub-Total	-	**2,200**	**12,400**	**19,100**	**25,700**	**32,400**	**38,800**	
Potable Water Supply Strategies								
Aquifer Storage and Recovery	Both	0	44,500	44,500	44,500	44,500	44,500	$2,003
Lake Walter E. Long (Decker) Off Channel Reservoir	Both	0	18,300	18,300	18,300	18,300	18,300	$3,033
Indirect Potable Reuse	Drought	**	**	22,400	22,400	22,400	22,400	$880
Capture Local Inflows to Lady Bird Lake***	Average	0	0	3,000	3,000	3,000	3,000	***
Brackish Groundwater Desalination	Both	0	0	0	0	20,000	40,000	$2,688
Water Supply Strategies Sub-Total	-	**0**	**62,800**	**88,200**	**88,200**	**108,200**	**128,200**	
Water Forward Strategies Overall Total		**8,700**	**90,100**	**126,900**	**138,100**	**169,500**	**200,400**	
Current Supplies								
Colorado River and Highland Lakes Supply	Both	325,000						
Centralized and Decentralized Reclaimed Water System	Both	5,000						

* Community cost = Utility cost + Customer cost
** May be implemented earlier in severe drought conditions
*** Infrastructure is included in Indirect Potable Reuse strategy

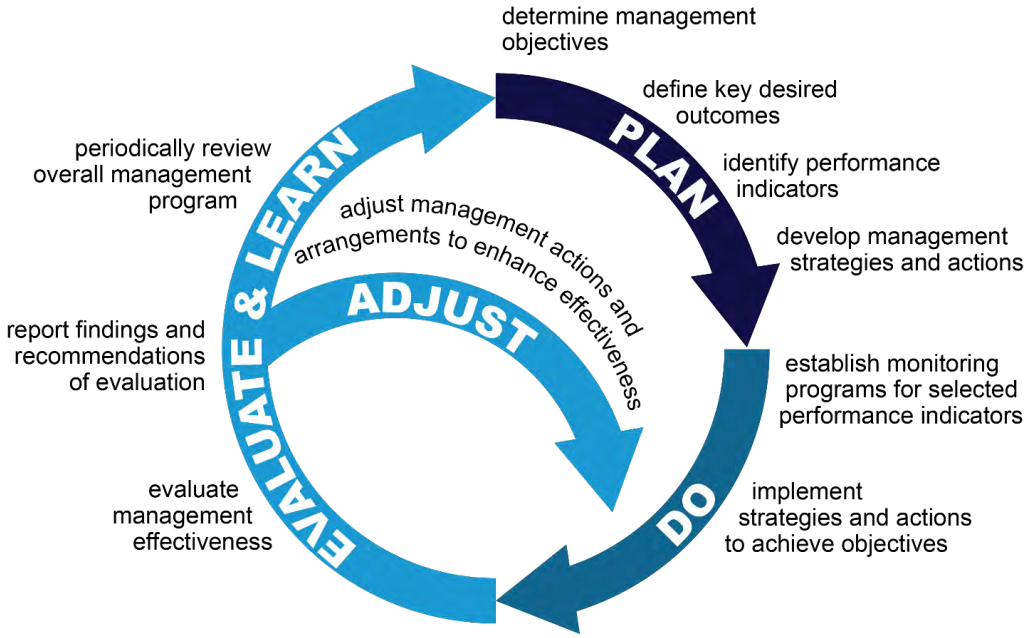
Water Forward 2024 estimates that implementing these strategies will require significant investment. Costs included in the plan are planning level estimates that will be refined through further capital and operations planning. Austin Water is an enterprise department of the City of Austin, funded by water, wastewater, and reclaimed water rates and fees, as well as capital recovery fees (connection fees for new development. Capital investments are funded through a combination of operating cash and debt financing, including low interest loans from state and federal water infrastructure funding programs. The utility will identify various sources of funding for projects and programs through its ongoing financial planning processes with a focus on maintaining affordability metrics and reducing financial impacts on customers.

Plan Implementation

The plan outlines Austin Water's approach to monitoring, evaluation, reporting, and proactive adaptation of near-term strategies. The plan also includes a 100-year adaptive management framework that maps out alternative long-term strategy implementation pathways. These pathways identify alternatives to respond to changing demand, supply, and climate conditions. The plan's implementation will be guided by near-term five-year implementation actions for each strategy. The plan also includes best management practices that the utility will seek to move forward during the next five years.

Monitoring and Adaptive Management: Austin Water will use an adaptive management approach to track the plan's progress, adjusting strategies as necessary to meet goals. By conducting regular evaluations of implementation progress and strategy effectiveness, Austin Water can make informed adjustments to meet evolving needs. This includes:

- Reviewing strategy yield data and tracking milestones to adjust conservation, reuse, and supply efforts.
- Creating a dashboard to share information and creating systems for community feedback and input on strategy imeplementation
- Quarterly and annual public progress reports and a major Water Forward plan update every five years to incorporate new data and progress made on plan implementation.



Moving Forward

The development of Water Forward 2024 represents a significant step in securing Austin's water future. Through in-depth analysis, collaboration, and proactive adaptation, Austin Water has created a robust plan that addresses the needs of a growing city in a changing climate. The process of updating the plan has highlighted the importance of adaptability in water planning. As conditions change, Austin Water must remain proactive to effectively meet its goals. The 2024 update adds strength to the original plan by integrating new data, responding to community feedback, and incorporating lessons learned to move us forward in achieving our goals.

CHAPTER 1

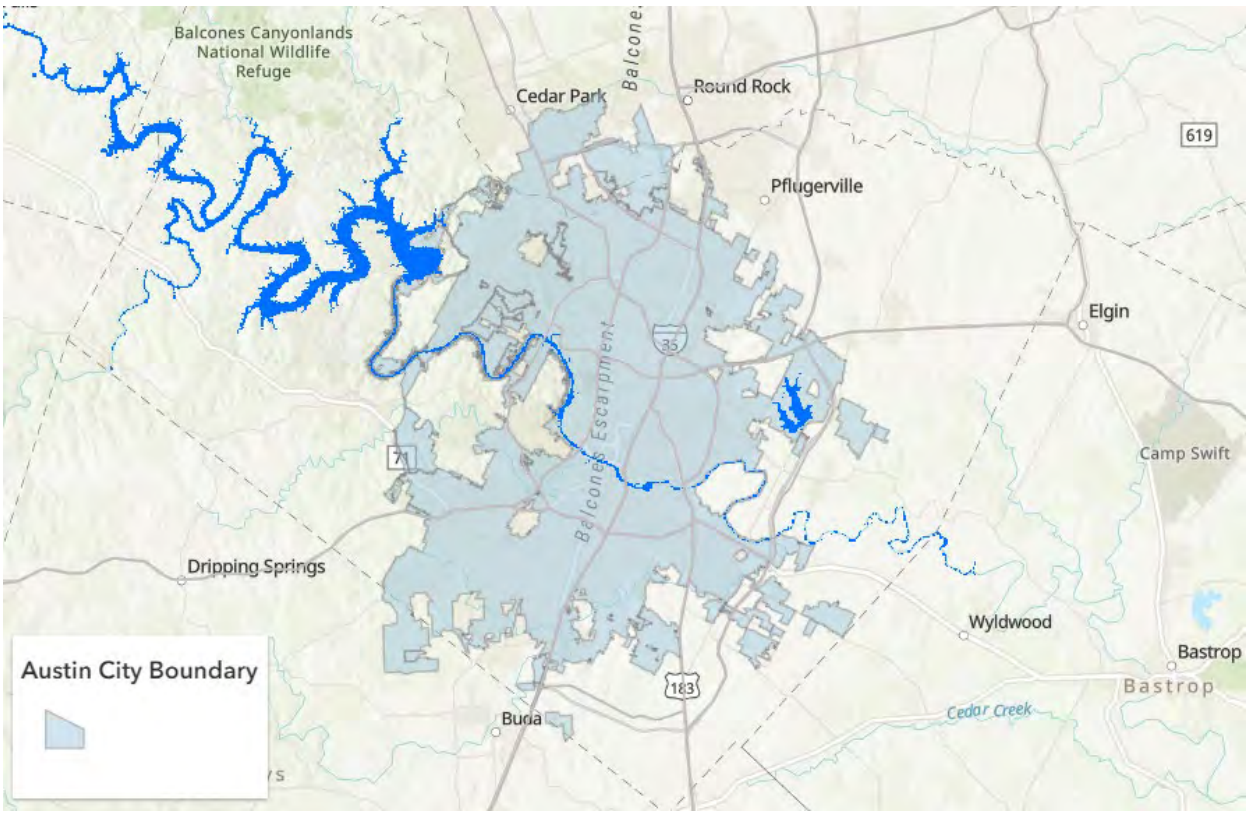
INTRODUCTION

Water is essential to Austin's quality of life.

Austin's water supply comes from the lower Colorado River and Lakes Travis and Buchanan. These two water supply reservoirs, which are managed by the Lower Colorado River Authority, are a part of a chain of lakes called the Highland Lakes. In the future, the lower Colorado River system will likely experience impacts from regional growth, droughts, and climate change. Water Forward provides a roadmap for Austin to meet these challenges and provide a sustainable, resilient, equitable, and affordable water future for our community for the next 100 years. The plan includes a suite of conservation, reuse, and supply strategies to be implemented over the next 50 years. The plan also includes a 100-year adaptive management framework to respond to changing conditions.

About the City of Austin

The City of Austin is the capital of the State of Texas. The City is home to over a million people, with a growing number of residents in small cities surrounding Austin. The Greater Austin area has experienced strong and rapid growth in recent years, with a population of over 2.4 million people. Major employers in Austin include government, higher education, and high-tech industries.



Austin is located on the banks of the Colorado River between the drier Texas Hill Country to the west and the wetter Blackland prairies to the east. Austin falls within a humid subtropical climate zone characterized by long, hot summers and short, mild winters, with an average annual precipitation of 34 inches. The City and the lower Colorado River upstream of Austin receive the highest rainfall amounts during the months of May, June, September, and October.

The City of Austin has a number of plans which are a part of the City's overall approach to preparing for a climate resilient future for the Austin community. Water Forward is one piece of that approach, with a focus on water supply reliability. Austin Water works closely with other City departments on climate resilience initiatives including and beyond Water Forward. Examples of how Water Forward reinforces and complements other key City departments and plans are listed below.

Key City Plan Interactions

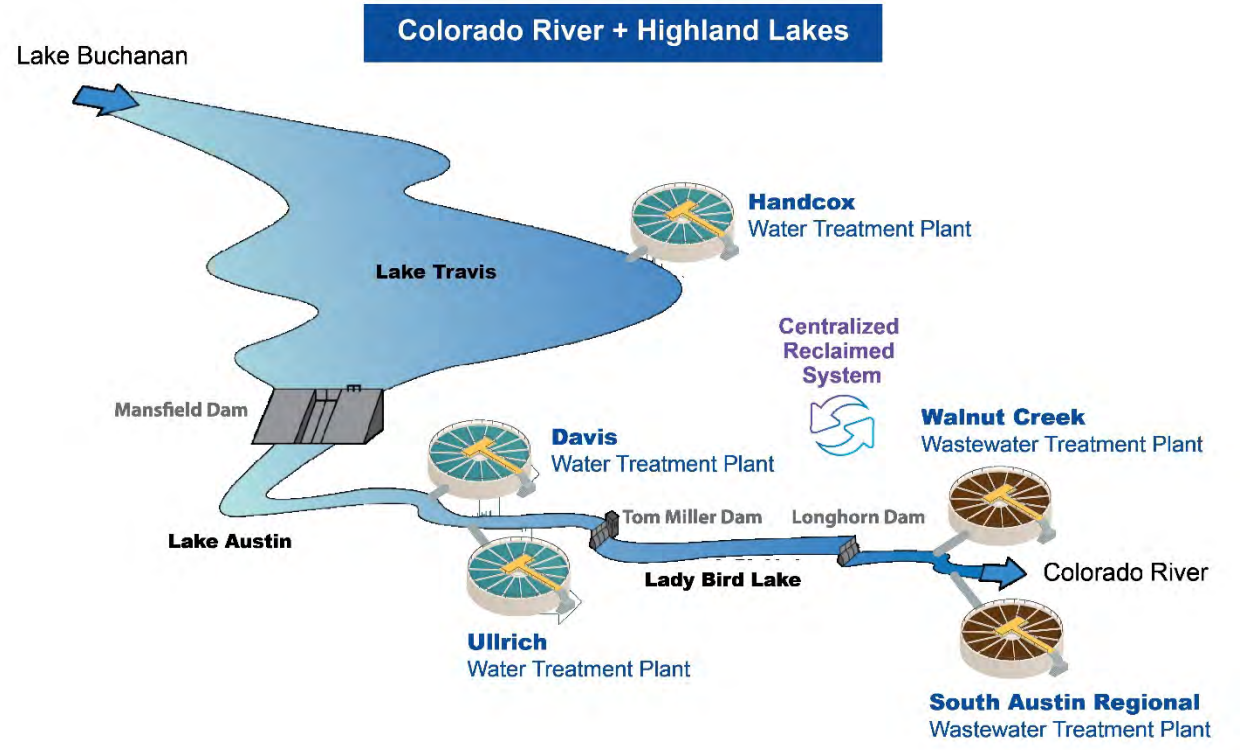
- **Rain to River: A Strategic Plan to Protect Austin's Creeks and Communities** – The mission of the City of Austin's Watershed Protection Department is to protect lives, property, and the environment by reducing the impact of flood, erosion, and water pollution. Rain to River is a strategic plan that will guide the work of the Watershed Protection Department for the next ten years. Austin Water and Watershed Protection coordinate on policies that provide local water quality and water conservation benefits. That includes requirements for green stormwater infrastructure, such as rain or storm water harvesting.
- **Imagine Austin, the City's Comprehensive Plan** – Prepared by the City's Planning Department, Imagine Austin is Austin's 30-year plan for our future growth and development. Austin Water and Watershed Protection staff co-lead the Sustainably Manage Our Water Resources Priority Program. The departments coordinate on water resource management efforts from the local to regional scale.
- **Austin Climate Equity Plan** – the City's Office of Sustainability developed the Climate Equity Plan to achieve net-zero greenhouse gas emissions by 2040. The plan includes water conservation strategies to reduce the energy used to treat and distribute water.
- **One Austin: Resilience Framework for Action** – The City's Office of Resilience has created a summary of climate shocks and stresses that impact Austin. The framework includes an outline of key issues and aspirations as documented in existing City plans.



About Austin Water

Austin Water is a department of the City of Austin. The department serves as the City's water, wastewater, and reclaimed water utility. Austin Water serves 1.17 million retail and wholesale customers across a 538 square mile service area. Austin Water owns and operates three major water treatment plants with a combined treatment capacity of 335 million gallons per day. Austin Water's water distribution system has over 4,000 miles of pipe and 21 major pump stations. This system delivers water to customers in nine major pressure zones.

Austin Water operates two major wastewater treatment plants with a combined treatment capacity of 150 MGD. These plants discharge treated effluent into the Colorado River. The utility also operates several smaller wastewater treatment plants, a biosolids management plant, and participates in the Brushy Creek Regional Wastewater System. Austin Water consistently meets or exceeds state and federal drinking water quality and treated wastewater discharge standards.



Austin Water employs sustainable water practices through its Water Conservation and Reclaimed Water programs. To protect water quality and endangered species habitat, Austin Water manages 14,000 acres in the Balcones Canyonlands Preserve and 34,000 acres of Water Quality Protection Lands.

Recognizing the importance of strong regional partnerships, Austin Water has established a Water Partnership with the Lower Colorado River Authority. The Partnership collaboratively addresses issues related to water supply, water quality, and water conservation. Austin Water is also an active participant in the State Water Planning process through the Lower Colorado (Region K) Regional Water Planning Group. Strategies included in the Water Forward plan are included in the Region K water plan.

Planning for Drought and Climate Change

During the most recent drought from 2008 to 2016, rainfall and the flow of water into Lakes Travis and Buchanan (known as “inflows”) were at historic lows. In 2011, the worst year of the drought, inflows were 11% of the historical average. In response to this severe drought, Austin City Council created the 2014 Austin Water Resource Planning Task Force to evaluate the City's water needs and make recommendations regarding future water planning. The 2014 Task Force recommended that Austin Water develop an Integrated Water Resource Plan. Council then created the Austin Integrated Water Resource Planning Community Task Force, informally called the Water Forward Task Force, to support the plan’s creation. Austin Water worked with the Water Forward Task Force, consultants, and the community over a three period to develop the first Water Forward plan. The resulting plan was unanimously approved by Council in November 2018.

Following Council approval of the 2018 Water Forward plan, Austin Water began implementing near term plan strategies. The Water Forward Task Force continued to meet regularly to participate in the implementation phase. Key implementation milestones during this time included:

- Including the Water Forward 2018 strategies in the 2021 Region K Water Plan, making these projects eligible for low-interest State loans
- Council adoption of an onsite reuse regulatory framework and pilot incentive
- Council adoption of code requiring water use benchmarking applications with all new site plan submittals
- Completing the OSCAR and CLARA onsite reuse pilot project at the City’s Permitting and Development Center
- Council adoption of the GoPurple program to increase use of onsite reuse and centralized reclaimed water through regulatory requirements, cost-sharing, grants, and other incentives
- Replacing all 250,000 analog meters in Austin Water’s service area with digital meters as part of the My ATX Water Advanced Metering Infrastructure (AMI) project (currently 95% complete)
- Developing an Aquifer Storage and Recovery (ASR) desktop analysis to identify favorable areas for an ASR pilot project
- Initiating emergency Indirect Potable Reuse planning and permitting activities
- Completing a third-party evaluation of Austin Water’s water loss program
- Initiating landscape transformation code changes for new single family residential homes

Austin Water celebrates these achievements, and we recognize the need to do more, as well as to proactively adjust strategies in response to lessons learned. Austin Water began updating the Water Forward plan in late 2021. In 2022 and 2023, exceptionally hot and dry weather resulted again in record-breaking low inflows to the Highland Lakes. These historic conditions so soon after a severe drought have reinforced the importance of implementing strong and effective drought response, water conservation, reuse, and supply strategies.

During the update to Water Forward, Austin Water also completed updates to the state-mandated Water Conservation Plan (WCP) and Drought Contingency Plan (DCP). In response to feedback from the Water Forward Task Force, Austin Water committed to revising these plans and bringing them back to Council alongside Water Forward 2024. Austin Water has aligned Water Forward with these revised plans, including the Water Conservation Plan 5- and 10-year gallon per capita per day goals.

Role of the Water Forward Plan

Water Forward 2024 includes a suite of conservation, reuse, and supply strategies for the next 50 years. The plan is strategic in nature and is intended to guide the development of projects, programs, and policies. The plan includes a timeline of five-year actions for near-term strategies. The plan outlines Austin Water's approach to monitoring, evaluation, reporting, and proactive adaptation of near-term strategies. The plan also includes a 100-year adaptive management framework that maps out alternative long-term strategy implementation pathways. These pathways identify alternatives to respond to changing demand, supply, and climate conditions. Austin Water will continue to update Water Forward every five years. Each update will incorporate progress made, new data, and lessons learned.

CHAPTER 2

COLLABORATIVE PLAN UPDATE

Mission Statement

Austin Water and the Water Forward Task Force worked collaboratively to update the 2018 Water Forward Statement of Purpose and reflect a refreshed vision for the 2024 plan.

Water Forward Mission Statement

The purpose of Water Forward is to develop and implement diverse and environmentally conscious water management strategies to adapt to growth, drought, and climate change and ensure a sustainable, resilient, equitable, and affordable water future for our community for the next 100 years.

Guiding Principles

Austin Water, in collaboration with the Water Forward Task Force, updated the plan's guiding principles to reflect the Austin community's values. The guiding principles informed the process to update the plan and the objectives the plan is trying to achieve.

Water Forward Guiding Principles

1. Create a plan that is resilient to growth, drought, and climate change.
2. Include diverse water management strategies that make use of all water sources, including reuse, conservation, and efficiency.
3. Use a holistic and inclusive approach to water resource planning that incorporates the Austin community's values.
4. Use an equity and affordability lens to develop and implement the plan.
5. Protect the health of the Colorado River and natural environment.
6. Minimize implementation and operational risk.
7. Focus on locally available water supplies.

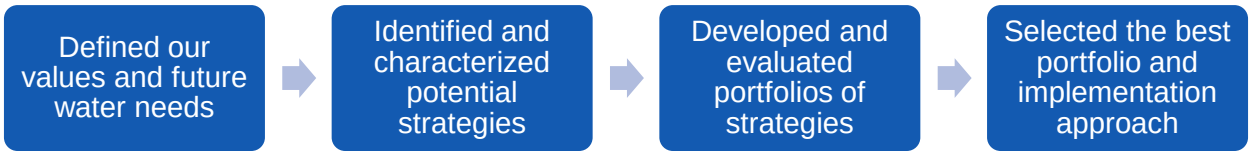
Planning Objectives

The Water Forward plan objectives are the broad goals of the plan. They include ensuring water reliability, increasing equity, protecting the environment, being cost-effective, and reducing risks in implementing strategies. Each objective is related to one or several sub-objectives. Each sub-objective is tied to a performance measure. Portfolios of water strategies were evaluated using these performance measures. The results of the evaluation were translated into scores that were weighted by the relative importance of the sub-objective. These weighted scores were then combined to create an overall portfolio score that was used to compare portfolios.

Objective	Objective Weight	Sub-Objective	Sub-Objective Weight
Water Supply Benefits	40%	Maximize reliability and resiliency, minimize vulnerability	35%
		Maximize portfolio diversity	5%
Economic Benefits	20%	Maximize cost-effectiveness	20%
Equity Benefits	8%	Maximize positive benefits and minimize negative impacts for marginalized communities	8%
Environmental Benefits	20%	Minimize ecosystem impacts	4%
		Minimize net energy use	6%
		Maximize water use efficiency	6%
		Minimize water quality impacts	4%
Implementation Benefits	12%	Minimize implementation and operational risk	3.5%
		Maximize distribution and collection system resiliency	3.5%
		Maximize local control/local resource	5%

Planning Process

Austin Water prepared the Water Forward 2024 plan with support from the Water Forward Task Force, Community Ambassadors Group, and Climate Technical Advisory Group. Feedback from advocacy organizations and the community also informed the plan. The plan builds on the Water Forward 2018 plan and followed the planning process outlined below and further described in Appendix C:



1. **Defined our values and future water needs** – Austin Water, in collaboration with the Water Forward Task Force, incorporated the Austin community's values into an updated plan mission statement, guiding principles, and objectives. Austin Water also updated projections of water demand, climate, hydrology, and future regional supplies. These projections were combined to create many different plausible future scenarios that were modeled to define the range of potential future water supply needs.

2. **Identified and characterized potential strategies** – Austin Water compiled a list of potential conservation, reuse, and supply strategies based on the strategies that had been considered in Water Forward 2018. Community input and input from the Water Forward Task Force added strategies to this list. Austin Water then consolidated similar strategies to create a list of 17 strategies to characterize in terms of potential water yield and cost.

3. **Developed and evaluated portfolios of strategies** – Austin Water tested many groupings of conservation, reuse, and supply strategies against many plausible future scenarios to identify groupings that provided the greatest water supply reliability across a range of costs. Top performing groupings were selected for further evaluation as water resource portfolios. Ten portfolios were evaluated using a multi-criteria decision making framework to understand which portfolio did the best job of meeting objectives such as water reliability, equity, environmental benefits, economic benefits, and implementation benefits.

4. **Selected the best portfolio and implementation approach –** Working with the Water Forward Task Force, Austin Water selected the portfolio that did the best job of achieving multiple objectives. Austin Water and the Water Forward Task Force collaborated to define an actionable implementation approach for the strategies in the preferred portfolio.

Community Engagement



Austin Water engaged the community through public workshops and open houses, webinars, surveys, social media, event tabling, and digital newsletters. Austin Water also held one-on-one meetings with advocacy organizations. Key themes from community feedback included concern about growth in Austin, concerns about water supply reliability through drought, and concerns about affordability. Community feedback related to specific water strategies included support for prioritizing conservation and demand management strategies, support for more restrictions and enforcement for outdoor water usage, support for considering innovative supply strategies like direct potable reuse, concerns and potential misunderstandings about Aquifer Storage and Recovery, and support for land conservation activities. The table below includes a summary of community engagement activities, with further detail provided in Appendix A.

Community Engagement Activity	Engagement
Number of Workshops/Open Houses Held	6
Number of Workshop/Open House Attendees	167
Number of One on One Meetings with Community Organizations	25
Number of Surveys Launched	3
Number of Survey Responses	694
Number of Webinars Held	4
Number of Webinar Attendees	61
Number of Impressions of Water Forward Related Social Media	45,052
Number of newsletters sent	26

Representatives from organizations serving marginalized communities shared that thinking about water supply reliability or source water quality may not be a high priority for marginalized people who may have other concerns related to their day-to-day needs. A key question asked was, “Why should black and brown people care about this?” Other feedback pointed out that it's easy to forget the load that is on marginalized people with decision making and stress and that solutions should be designed to provide them with easily accessible benefits. The importance of establishing relationships with people connected to marginalized communities to expand Austin Water’s reach was emphasized.

Equity and Affordability

Acknowledging that the lack of a reliable and affordable water supply would likely have the greatest impacts on marginalized communities, Austin Water created a Community Ambassadors Group to help develop an Equity and Affordability Roadmap for the Water Forward 2024 plan. This document emphasizes the importance of addressing inequities faced by marginalized communities in Austin by ensuring equitable access to water resources. For the purposes of the plan, marginalized communities were defined as communities of color and low-income communities. The Roadmap is grounded in a historical understanding of racial and economic disparities in Austin and uses the key concepts of procedural and distributive equity to identify best practices related to transparent decision-making processes and equitable distribution of the benefits and burdens from implementing Water Forward strategies. The Equity and Affordability Roadmap is included in Appendix B.



Reliable Supply Protect Public Health Accountable Affordable

The Community Ambassadors Group guided the development of the Equity and Affordability Tool that was used by Austin Water to assess the impacts of conservation, reuse, and supply strategies. The Tool includes themes related to areas of community concern, including water supply reliability, public health, accountability, and affordability, all viewed through an equity lens. The Tool identifies key questions associated with each of these themes, creating a framework to evaluate water strategies. One of the goals of this evaluation was to identify strategies that had greater benefits for marginalized communities and to find ways to mitigate potentially inequitable impacts of strategies. The results of this evaluation are included in Appendix G.

CHAPTER 3

CURRENT WATER RESOURCES

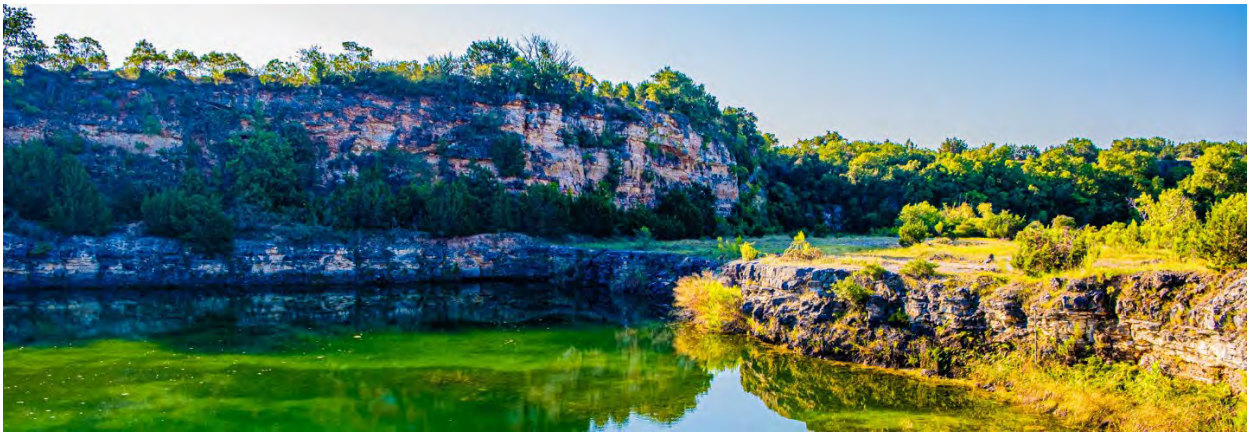
Austin's Water Supplies

All of Austin's drinking water comes from the lower Colorado River. The lower Colorado River is generally known as the section of the river downstream of Lakes O.H. Ivie and Brownwood down to the Gulf of Mexico. The lower Colorado is dammed six times upstream from Austin, forming the Highland Lakes. Two of the Highland Lakes, Lakes Buchanan and Travis, act as the region's water supply and flood control reservoirs. The Lower Colorado River Authority (LCRA) manages Lakes Buchanan and Travis in alignment with a State approved LCRA Water Management Plan that was last updated in 2020.

Austin Water sources its potable water supply from the lower Colorado River. Three separate major water treatment plant intake facilities on Lakes Travis and Austin divert water from the river. To use river water, Austin Water has senior run-of-river water rights granted by the State. The City also has a water supply contract with the LCRA for firm water, which is water that is expected to be available without shortage through a repeat of the drought of record. The drought of record in the Lower Colorado River Basin was the 1950s drought for many decades. However, the recent historic drought in this basin from 2008 to 2016 has become the new drought of record.

Austin's firm water supply contract was approved in October 1999, when Austin entered into a key agreement with LCRA. This agreement was an amendment to a previous 1987 agreement and provides firm backup (including stored water from Lakes Travis and Buchanan) for Austin's run-of-river rights and additional firm water totaling up to 325,000 acre feet per year. Under the 1999 agreement, Austin prepaid $100 million for supply reservation and use fees. Future water use payments to LCRA will be triggered when Austin's annual average use for two consecutive calendar years exceeds 201,000 acre feet per year. The year after this trigger is reached, Austin will begin paying LCRA for diversions of water above 150,000 acre feet per year. The term of the 1999 agreement extends through the year 2050 with an option for the City to renew the agreement for an additional 50-year period through the year 2100.

Existing Land Conservation Programs



Water Quality Protection Lands

Since 1998, Austin Water's Water Quality Protection Lands (WQPL) Program has conserved over 34,000 acres of land through a mix of fee simple land acquisition and conservation easements. The goal of the program is to protect Barton Springs in perpetuity. The program protects land located in the recharge and contributing zones of the Barton Springs segment of the Edwards Aquifer. These lands drain into the Colorado River Basin below Lake Travis. Management of these lands focuses on the ecological restoration of vegetation to native prairie and savanna ecosystems. These ecosystems enhance water recharge and provide biodiversity. Activities to restore vegetation combined with active karst aquifer management effectively protect water quality and quantity.

Balcones Canyonlands Preserve

Since 1996, the City's Balcones Canyonlands Preserve (BCP) Program has protected over 14,000 acres via fee simple land acquisition. The BCP system includes a number of partners including Travis County, the Nature Conservancy, Travis Audubon and others. Lands protected by the BCP program and partners total over 32,000 acres in Western Travis County. The goal of the BCP program is to protect the habitat of endangered songbirds and karst invertebrates. BCP lands are managed to provide habitat for seven endangered species and twenty-eight species of concern that call the preserve home. This Preserve system is required to be permanently protected and provides mitigation for a streamlined permitting process for habitat impacts from development and infrastructure in Western Travis County. One of the secondary goals of the BCP lands is to protect water quality in the City's drinking water basins. Most of the land is located within the Lake Travis and Lake Austin watersheds. Research has shown that land conservation leads to higher water quality downstream.

Existing Water Conservation Programs

For many years, the City has emphasized water conservation in normal weather as well as during a drought. Austin Water has both a Water Conservation Plan and a Drought Contingency Plan, as required in Texas for large municipal water suppliers. Both plans were last updated on May 2, 2024, in compliance with the 5-year review and update cycle. They are currently undergoing revision in coordination with the 5-year review and update of the Water Forward plan. The City's Water Conservation Plan details incentive programs, educational efforts and regulations designed to reduce both peak and average day water use. The City's Drought Contingency Plan specifies how the City will respond and manage the water system during drought, as well as during demand or infrastructure events that constrain water supply.

Education and Outreach

Austin Water leads extensive water conservation efforts, engaging the community through education, outreach, and innovative programs. Austin Water raises awareness about water use restrictions by participating in a variety of community events, as well as through school programs, such as the Dowser Dan School Assembly and the Mobile River exhibit, which target young students with interactive learning. The Water Conservation Speakers Bureau further extends Austin Water's educational reach.

Austin Water also employs marketing campaigns across various media platforms to promote water conservation, using branded materials for consistency. In 2024, Austin Water transitioned to online fillable forms for conservation programs, improving customer access and processing efficiency. The utility leverages social media and the My ATX Water portal to share information and engage with the public. Workshops, including the WaterWise Irrigation Professionals

Seminar, provide targeted education, while Austin Water collaborates with regional partners through the Central Texas Water Efficiency Network.

Residential and Commercial Customer Programs

Austin Water offers a variety of residential and commercial programs to promote water conservation. For residential customers, Austin Water provides digital garden hose meters and sunlight calculators through the Austin Public Library to help manage water use. Free water-saving tools like showerheads and soil moisture meters are also available, with distribution now streamlined through direct mailing. Austin Water also offers rebates for irrigation upgrades, landscape improvements, and graywater systems.

For commercial customers, Austin Water's "Bucks for Business" program incentivizes water-efficient practices, offering rebates for equipment upgrades and process changes that reduce water consumption. Additional rebates are available for installing rainwater harvesting systems, efficient kitchen equipment, and pool filter upgrades. Austin Water also supports the connection of commercial properties to reclaimed water mains and offers rebates for converting landscapes to native plants.

Regulatory Programs

Austin Water enforces a comprehensive Water Conservation Code that applies to all retail customers, with year-round restrictions such as limiting automatic irrigation to once a week and hose-end watering to twice a week. Additional restrictions apply during drought stages, including time-of-day limitations and specific watering schedules based on property type. Austin Water also prohibits water waste and offers variances for newly installed xeriscape landscapes.

To ensure compliance, Austin Water conducts routine patrols, investigates public reports, and enforces penalties, with a progressive penalty structure that increases based on usage tiers. AustinWater also mandates water efficiency assessments for commercial facilities, irrigation systems, cooling towers, and vehicle washes, with penalties for non-compliance.

Water Loss Program

Austin Water ensures all customer water connections are metered, meeting American Water Works Association accuracy standards. Large meters undergo rigorous testing before and after installation, with annual checks to maintain accuracy. The My ATX Water smart metering program, set to be completed in 2025, will replace analog meters, enhancing accuracy and reducing apparent losses. Austin Water conducts annual Water Loss Audits and has partnered with a consulting firm to improve water loss management. The results of this study are documented in the Water Loss Program Review, Analysis, and Optimization report.. Leak detection is prioritized, with $2 million annually allocated for inspecting over 500 miles of water lines using advanced technology. The "Renewing Austin" program focuses on replacing aging water lines to prevent future leaks, while an accelerated leak response program addresses most emergency leaks within a day. Austin Water also works to reduce non-revenue water through data analysis, investigating suspicious usage patterns, and preventing water theft.

Water Use Benchmarking

Since 2021, Austin Water has required that Water Benchmarking Applications be submitted with each site plan. This helps applicants assess how water will be used within their development projects and identify water reuse and water conservation opportunities before construction begins. Applicants of large developments with 250,000 gross square feet or greater are also required to meet with Austin Water staff to review their Water Benchmarking Application and

available incentives for conservation and reuse. Each applicant is provided with a set of recommendations for how to improve water use efficiency within their specific project as well as information on the benefits of incorporating these recommendations into their project, such as water utility bill savings and available rebates or incentives. This initiative aims to establish annual water budgets for commercial development projects, with 439 applicants having undergone this process by December 31, 2023. Eventually, AustinWater may institute excess usage charges for commercial projects that exceed an annual water budget. Following the effective date of the mandatory onsite reuse requirement, water benchmarking meetings have also included ensuring compliance with onsite water reuse and reclaimed water connection ordinances.

Existing Reuse Programs

Centralized and Decentralized Reclaimed Water Programs

Austin Water began providing reclaimed water in 1974. Reclaimed water is used for non-potable uses including irrigation of golf courses, ballfields, parks, and commercial properties. Other major non-potable uses include cooling towers, manufacturing, and toilet flushing. Austin's reclaimed water system provides a low-priced source of non-potable water, helps conserve treated potable water, contributes to deferral of treatment plant construction and water contract payments, and provides other environmental benefits.

Historically, Austin Water directed reclaimed system growth toward existing large-volume commercial and industrial potable water users that could convert a portion of their potable water use to reclaimed water. As a result, the system grows from the east, where the reclaimed water is generated, to the City's center, where most customers can be found.

Austin Water's reclaimed water is treated and distributed via the centralized reclaimed water system from Austin Water's two major wastewater treatment plants. The centralized reclaimed water system is made up of four pump stations, two pressure zones, 72.8 miles of main, and six water storage facilities. An additional 12.9 miles of reclaimed main pipelines are either in the design phase or under construction. Additionally, three public bulk water filling stations facilitate reclaimed water distribution. The system supplies approximately 5,100 acre feet of water to 185 properties annually. Austin Water also treats and provides reclaimed water from three small-scale decentralized wastewater treatment plants. Bulk reclaimed water is also available to customers at three bulk fill stations.

Centralized reclaimed water system construction has two current priorities. The first priority is referred to as "Completing the Core" and can be described as main looping. Increased looping of the distribution system improves the reliability of system operations in the event of power outages and main breaks. The second priority is an additional transmission main from the South Austin Regional Wastewater Treatment Plant to the Montopolis Reclaimed Water Reservoir. This main will help meet growing demands in the Central Service Area and allow the Montopolis Reservoir to better support those growing demands.

The Reclaimed Water Mandatory Connection Ordinance, adopted by Austin City Council in September 2021, mandates that any development project within 250 feet of a reclaimed water line must connect to the reclaimed water system for irrigation, cooling, toilet flushing, and other significant non-potable water uses. For large developments with 250,000 square feet or more of gross floor area, the connection mandate extends to 500 feet. In April of 2024, Austin City Council updated the ordinance to exempt certain affordable housing projects but directed staff

to look at the feasibility of fully subsidizing the cost of reclaimed connections and dual plumbing for these projects by April 2025.

Onsite Reuse Program

Austin Water has been promoting onsite water reuse for over a decade, encouraging the utilization of non-potable water sources like rainwater, graywater, reclaimed water, and others for irrigation, cooling, and toilet flushing. Several changes to City Codes and Ordinances have facilitated this while ensuring public health and safety. Since September of 2017, new commercial and multi-family projects with cooling towers have been required to reuse condensate or utilize non-potable water to compensate for evaporative losses.

The Onsite Water Reuse System (OWRS) Program was initiated to implement code changes adopted in December 2020 that regulate the collection, treatment, and use of alternative water sources for non-potable uses in multi-family and commercial buildings. Effective April 1, 2024, the collection and treatment of rainwater and condensate for reuse in commercial and multi-family developments of 250,000 gross square feet or greater is required. Additionally, the Onsite Water Reuse Incentive Program provides project reimbursements of up to $500,000 for voluntarily incorporating onsite water reuse systems. Similar to the Reclaimed Water Mandatory Connection Ordinance, certain affordable housing projects are exempt from onsite water reuse requirements, but staff is looking at the feasibility to fully subsidize onsite water reuse for these projects.

GoPurple Program

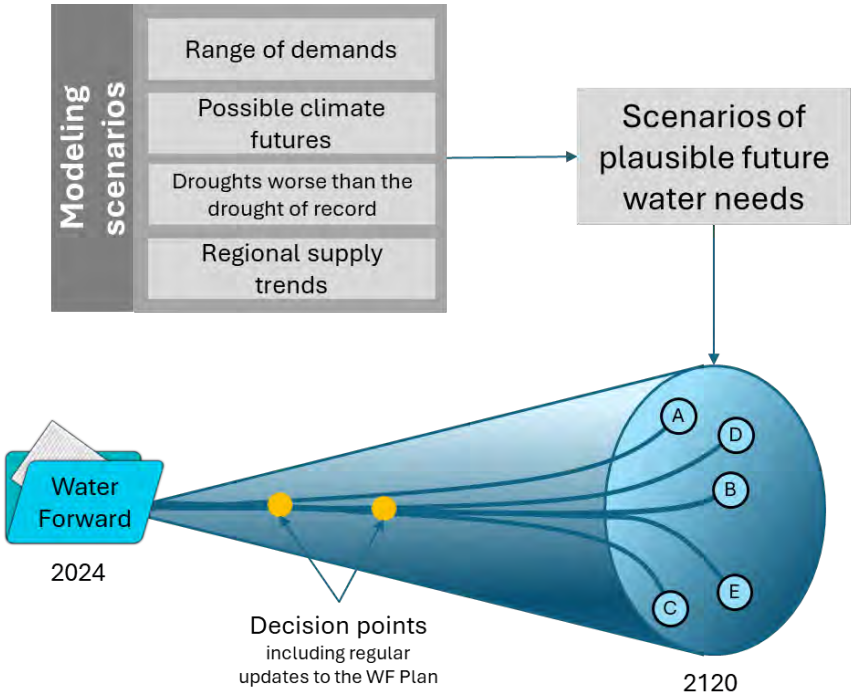
In March of 2024 Austin Water launched a new GoPurple program to increase use of reclaimed water and onsite water reuse systems in and around Austin. The program aims to support various measures like cost-sharing, grants, and other incentives for reuse. It is funded through a new Community Benefit Charge for Austin Water customers and a voluntary rate dedicated to water reuse. Any new commercial or multi-family development that is connecting to the reclaimed water system or installing an onsite water reuse system is eligible to participate in the program and receive financial incentives from Austin Water to reduce the cost of installing water reuse piping or treatment systems. For more information regarding the GoPurple requirements, incentives, and funding sources, please visit the GoPurple website at www.austintexas.gov/page/go-purple.

CHAPTER 4

PLANNING FOR UNCERTAINTY

Modeling Scenarios

The Water Forward planning horizon extends 100 years into the future. There are a wide range of futures that could occur over this timeframe with potential impacts on the City's water supplies. These possible futures include three main drivers: the effects of climate change, growth of Austin's demand for water as population increases, and new water supply projects in the Lower Colorado River basin. Each of these drivers are more uncertain further into the future. Rather than trying to estimate the levels of uncertainty for each driver and select a single future pathway, Water Forward modeling explored a wide range of possibilities for each driver. The combinations of climate change effects on water supply, demand growth, and regional supply development were paired together to explore many possible outcomes, also known as modeling scenarios. The purpose of the modeling scenarios is to find solutions that are reliable across as many possible future conditions as possible.



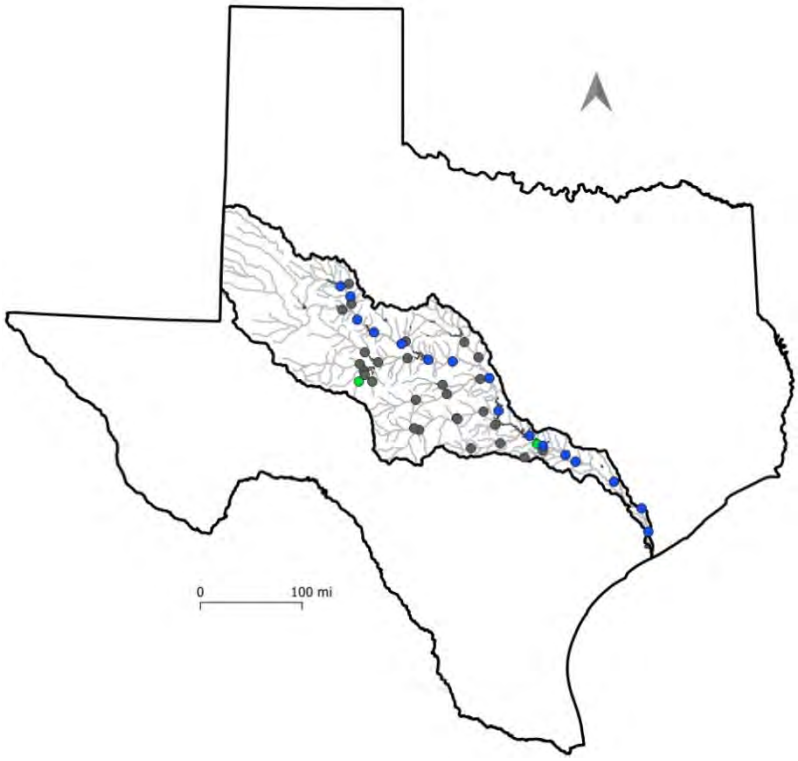
Austin Water selected three climate futures to include in the modeling scenarios. These reflected lower, medium, and higher warming conditions. The temperature and precipitation of the climate models (discussed below) for each warming condition were translated into possible future streamflows for the Colorado River Basin. In general, streamflows during drought were found to decrease in warmer climate futures. Austin Water also created low, medium, and high projections of Austin's water demand and regional supplies. Austin's water demands were estimated based on population growth trends and the water use characteristics of the different

customer sectors, such as residential, commercial, and industrial users. Levels of regional supply growth were developed using the most recent report by the Lower Colorado Regional Water (Region K) Planning Group which is one of 16 planning areas that form the basis of the Texas State Water Plan. Regional supply projects are defined as projects implemented by entities other than the City of Austin that contribute to the shared resources of the lower Colorado River and help meet growing future water needs in the basin.

Climate Change

Austin Water worked with researchers at the University of Texas at Austin (UT Austin) to develop climate projections from Global Circulation Models (GCMs). A GCM is a tool that scientists use to understand how the Earth's climate works and how temperatures, rainfall, and other weather patterns might change in the future. Austin Water also formed a group of climate experts to review and provide input into the Water Forward Climate and Hydrology Analysis. This group was called the Water Forward Climate Technical Advisory Group or CTAG.

The project team assessed and selected GCMs that accurately replicated historical climate data for the Texas Colorado River Basin. Five GCMs were chosen based on factors including their performance and availability of data. The selected models were downscaled and bias-corrected to match the specific needs of the Water Forward plan. Austin Water's consulting hydrologist, Dr. Richard Hoffpauir, then translated the downscaled GCM data into hydrologic data to be used in water availability modeling. This process summarized historical rainfall, temperature, and evaporation data and used an algorithm to select the weather variables that did the best job of predicting historical streamflow at 45 points throughout the lower Colorado River Basin. These weather variables were used to create flow models for each point. Future climate data was fed into these flow models to create projections of future streamflow with climate change.



Colorado River Basin and water availability model control points.

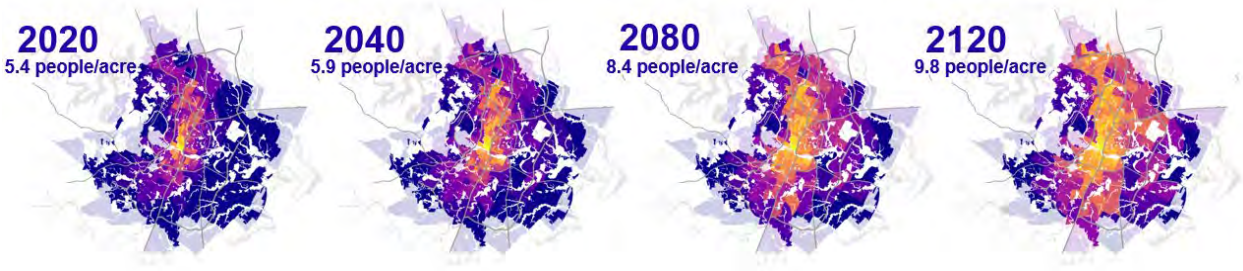
The results of the climate and hydrology analysis show increasing average and maximum monthly temperatures and greater variability in precipitation. This will likely result in more frequent, longer-duration, and more severe droughts as well as more intense rainfall events. These impacts will generally cause lower streamflow in the Colorado River and less inflow into Lakes Travis and Buchanan.

Future Baseline Water Demands

Austin Water used a model developed by the utility, called the Disaggregated Demand Model (DDM), to project future water demands for retail and wholesale customers. The DDM creates estimates of spatially-disaggregated water use by customer sector, subsector, and end use.

To develop growth inputs for the model, Austin Water worked with the City Demographer to perform a detailed evaluation of 2020 Census data in comparison to 2020 water billing data and develop 2020 retail and wholesale population, employment, and residential unit estimates at the parcel level. From this, 100-year total served population projections were developed for low, medium, and high scenarios at key planning years: 2040, 2080, and 2120. Population and employment projections were developed based on historical trends and subject matter expertise and distributed across the City at a small-polygon level in alignment with the Imagine Austin Growth Concept Map and development data.

The table below presents the population projections at each planning year. The graphic shows the spatial distribution of population growth for the medium projection, with more dense population in the brighter colors.

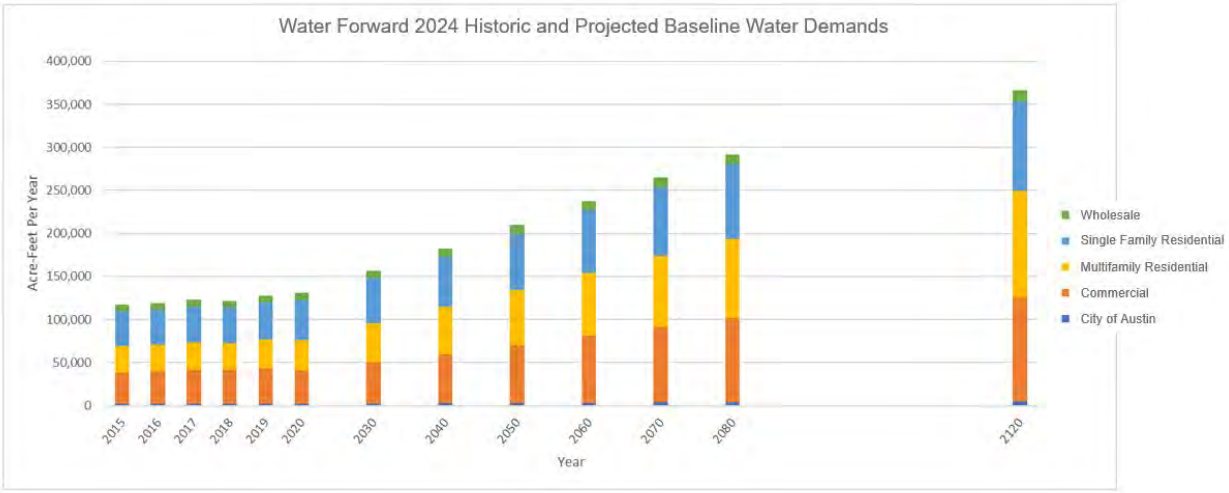


Austin Water Served Population Projections			
Year	Low Projection	Medium Projection	High Projection
2020	1,065,000	1,065,000	1,065,000
2040	1,475,000	1,524,000	1,576,000
2080	2,321,000	2,458,000	2,602,000
2120	2,866,000	3,209,000	3,594,000

Historical billing data from 2015-2020 were categorized by sector, including single-family, multi-family, and commercial customers, as well as City of Austin departments. The model used these data points to calculate baseline indoor and outdoor water use factors. Water use factors also

incorporated adjustments for weather impacts, the effects of the COVID-19 pandemic, and continued passive conservation efforts, such as efficiency improvements in water fixtures. To create water demand projections, residential units and employees were multiplied by the relevant water use factor at the small-polygon level, and demand projections for each polygon were aggregated to create City-wide demand projections. Appendix D includes more information about the development and results of the demand projection process.

Austin Water Baseline Water Demand Projections (Consumption – Acre Feet)			
Year	Low Projection	Medium Projection	High Projection
2020	130,740	130,740	130,740
2040	177,780	182,960	188,310
2080	277,950	291,870	306,620
2120	332,930	366,470	405,390



Projected Baseline Water Demands,
Without Additional Conservation and Reuse Savings

Future Water Supply Needs

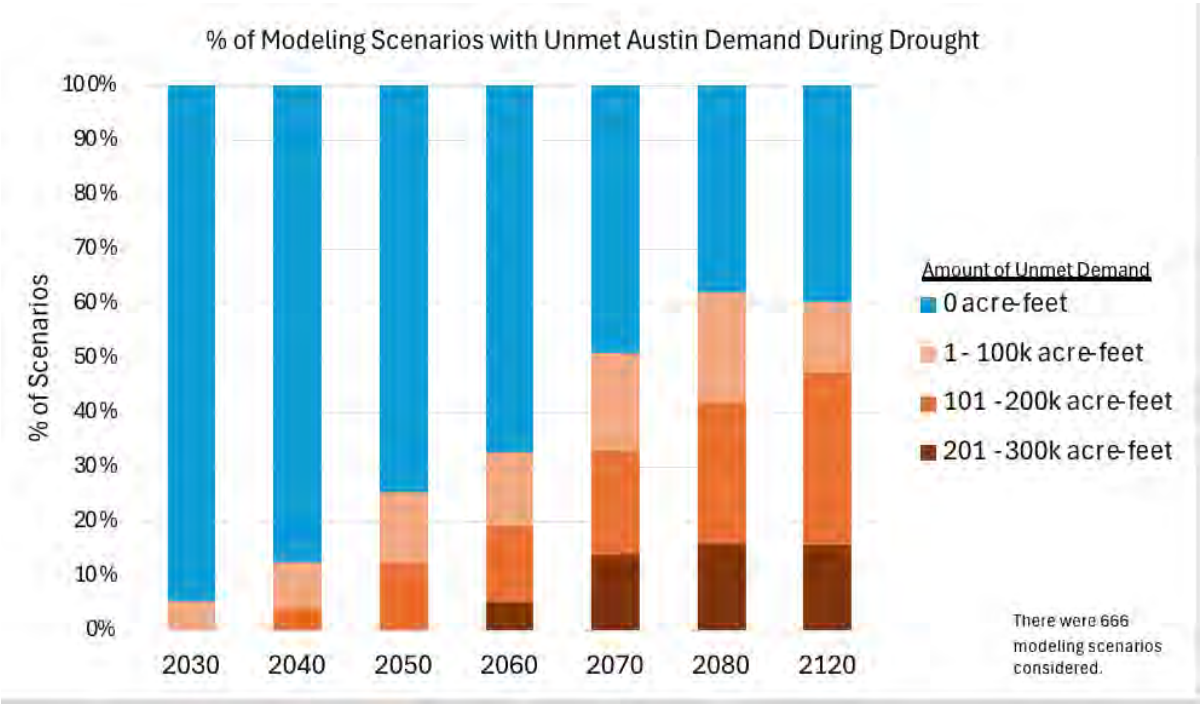
For each future decade from 2030 to 2080, the municipal water supply needs of Austin were estimated using the Texas Commission on Environmental Quality (TCEQ) Water Availability Model (WAM). The WAM is the main model used for evaluating water availability to water rights within the state's river basins. The WAM was used because Austin depends on its state-granted water rights to the Colorado River and its contracts with the LCRA. Using the WAM, Austin's water rights and contractual supplies were considered alongside all other water rights within the shared resources of the Colorado River basin. In the model, as Austin's water demands grow over time along with those of other users, the WAM combines information from all users in the basin to model water availability.

In the model, City of Austin water supply needs occur during times of severe drought when there is insufficient Colorado River flow and Highland Lakes storage to meet Austin customer demand.

Water supply needs can arise outside of droughts in later decades as the City's demand exceeds its water supply contract with LCRA for 325,000 AFY. Potential future water supply needs cover a range in each decade since the modeling scenarios that were used incorporate a wide range of possible future conditions, from varying levels of climate change impacts to differing Austin demands and regional supply developments.

The results of this modeling show that future water supply needs due to extreme drought increase with climate change impacts over time and with increasing needs of other water users within the basin. Hotter and drier climate change impacts result in lower levels of run-of-river supplies as well as lower inflows that replenish storage in the upstream reservoirs. At the same time, other users with water supply contracts with LCRA or their own state run-of-river rights have increasing demands as time progresses. The additional conservation, reuse, and supply strategies identified in this plan were sized to meet this range of future water supply needs.

The chart below shows the extent of "unmet needs" (when projected water demands exceed available supplies) by decade. For example, in 2070, about half of the modeled scenarios show no unmet needs, while the other half show unmet needs of varying severity up to 300,000 AF. This illustrates the "many possible outcomes" described in the Modeling Scenarios section above.

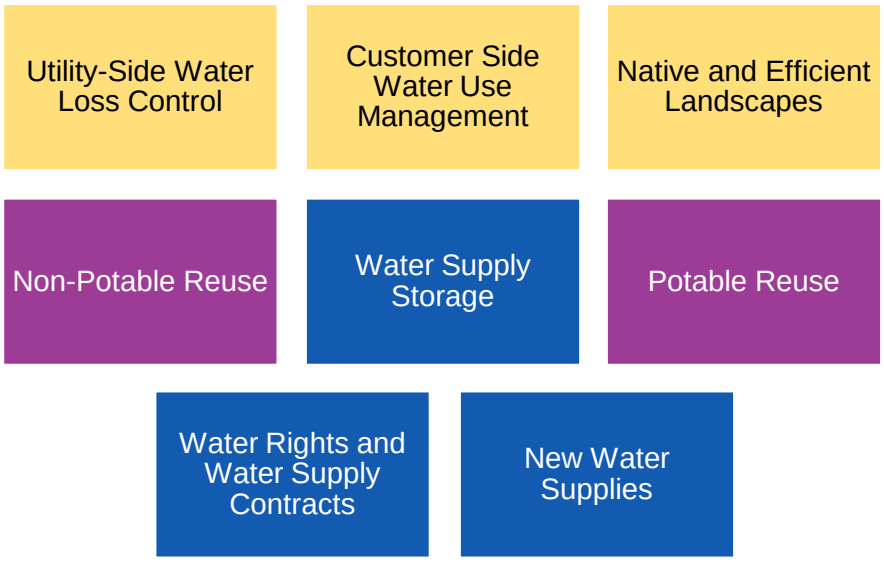


Estimated Future Supply Needs by Volume and Decade

Water Strategy Identification

Austin Water compiled a list of potential conservation, reuse, and supply strategies based on Water Forward 2018 strategies. All strategies considered in the 2018 planning effort were included in the Water Forward 2024 initial strategy list. All strategies were included so that costs and yields could be updated and strategies could be re-evaluated. The Water Forward Task Force provided input on strategies to consider and potential strategy adjustments. Community input gathered at in-person and virtual workshops and an online survey provided community perspectives on the strategies. In total, 38 strategies were included in the initial list of strategies.

These strategies can be broadly categorized as shown below. The top row represents conservation strategies that reduce our overall water use. The middle row represents strategies that maximize the use of our existing water supplies. The bottom row represents strategies that increase our available water supplies.



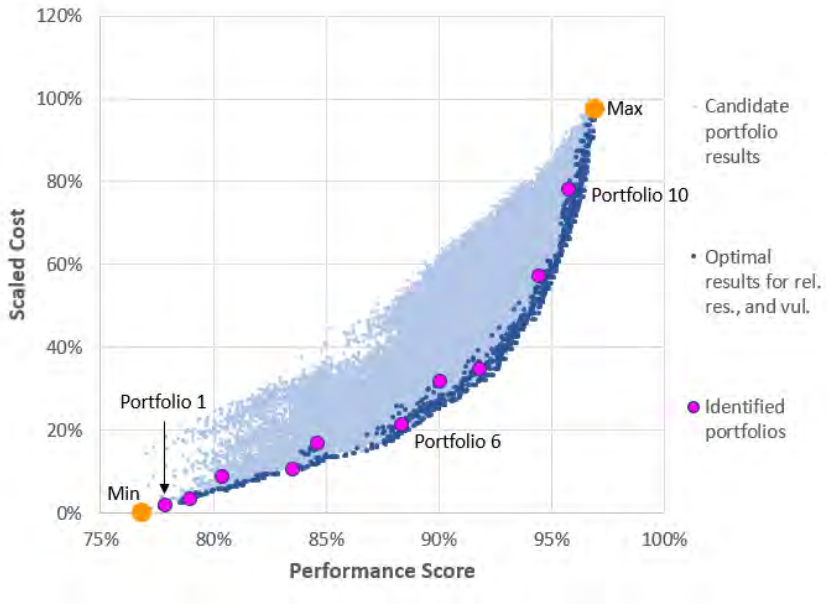
Categories of initially identified water strategies

Austin Water consolidated similar strategies from the initial list to create a streamlined list of 17 strategies. Plummer Associates, Inc. worked with Austin Water to refine strategy definitions and to identify key programs, policies, and infrastructure components for each strategy. The project team estimated potential savings for conservation and reuse strategies using detailed future water demand projections from the Disaggregated Demand Model. Conservation and reuse savings estimates were developed to avoid double counting of potable demand reductions. Plummer then used the Unified Cost Model, a tool developed by the Texas Water Development Board for use in the state water planning process, to create standardized capital, operations and maintenance, and annual costs for each strategy. Strategy costs and modeling yields can be found in Appendix F.

Water Resource Portfolio Development and Evaluation

Austin Water and its consultant RAND Corporation tested many groupings of the identified conservation, reuse, and supply strategies against many plausible future scenarios for 2080, the 50-year planning horizon. This work helped to identify groupings that provided a balance between reliability in meeting future water needs and the overall cost of each portfolio. From this analysis, ten candidate groupings, or portfolios, were identified as optimal, offering the best trade-off between reliability and cost.

This graphic shows all the portfolios modeled as blue and gray dots. The benefit (performance in terms of water supply reliability, resiliency, and vulnerability) and cost of each portfolio was compared against the theoretical highest benefit and highest cost. The blue dots represent the "optimal" portfolios, which have the lowest cost for a given performance. For example, portfolio six has a cost score of 20% of the highest cost, whereas other portfolios that provide the same level of performance have a higher cost score.



Results of water strategy grouping evaluation to identify candidate portfolios

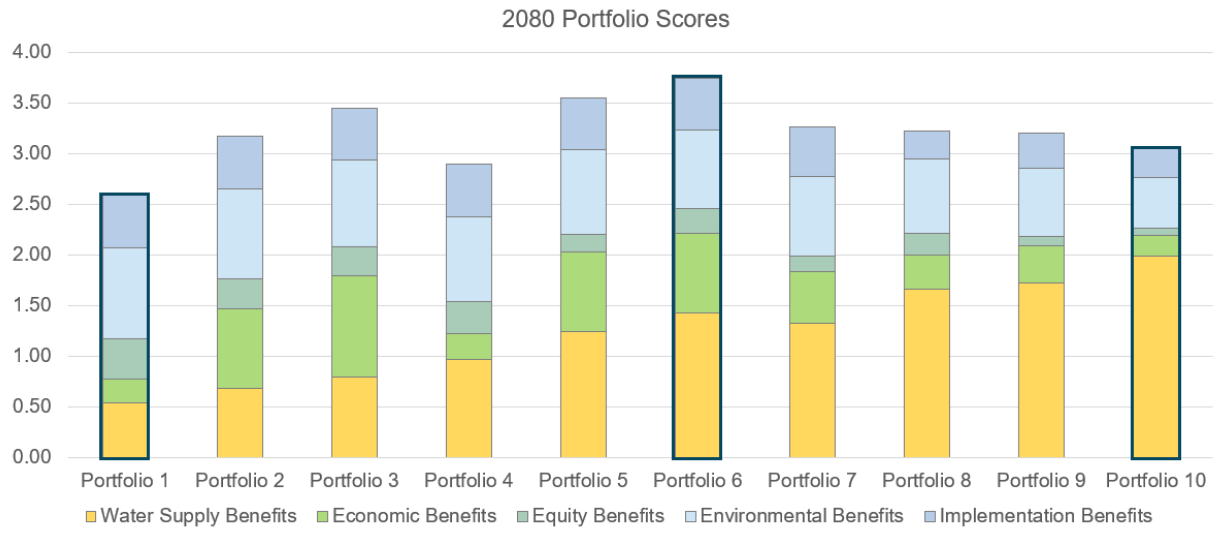
All ten candidate portfolios included Aquifer Storage and Recovery and the most aggressive set of conservation and reuse strategies. For each of the ten portfolios, the project team identified an implementation pathway for the decades leading up to 2080 that gradually built up to the 2080 yield targets of each individual strategy.

		2080 Portfolios									
	Strategy	1	2	3	4	5	6	7	8	9	10
Conservation	Utility-Side Water Loss Control	x	x	x	x	x	x	x	x	x	x
	Customer-Side Water Use Management	x	x	x	x	x	x	x	x	x	x
	Native & Efficient Landscaping	x	x	x	x	x	x	x	x	x	x
Non-Potable Reuse	Centralized Reclaimed	x	x	x	x	x	x	x	x	x	x
	Decentralized Reclaimed	x	x	x	x	x	x	x	x	x	x
	Onsite Reuse	x	x	x	x	x	x	x	x	x	x
Potable Supplies	Aquifer Storage and Recovery	x	x	x	x	x	x	x	x	x	x
Water Supply Storage	New Off Channel Reservoir							x	x		
	New Off Channel Reservoir with Reuse									x	
	Decker Lake Off Channel Reservoir	x	x		x	x	x				
Potable Reuse	Direct Potable Reuse					x		x		x	x
	Indirect Potable Reuse		x	x		x	x	x		x	x
Contracts	New Lower Colorado River Supply										
New Water Supplies	Brackish Groundwater Desalination				x	x	x	x	x	x	x
	Seawater Desalination										x
	Interbasin Transfer										x
	Conventional Groundwater								x	x	x

Top ten candidate portfolio make-up at the 2080 timestep

The ten portfolios were then evaluated using the objectives, sub-objectives, and measures discussed in Chapter 2 and identified in more detail in Appendix J. These ten portfolios underwent further evaluation, emphasizing planning objectives such as water supply, economics, equity, environmental impact, and feasibility. Based on the scores from this detailed assessment, portfolio six was selected as the preferred portfolio for the Water Forward 2024 plan. The strategies in this portfolio are further described in Chapter 5 and the detailed results of the portfolio evaluation are included in Appendix J.

The graphic below shows the scores for the ten portfolios. As shown, while portfolio six has a lower water supply benefits score (yellow bar) compared to portfolio ten, it has the overall highest total score due to factors of cost, equity, environmental impact, and feasibility.



2080 Portfolio Evaluation Results

Colorado River Land Analysis

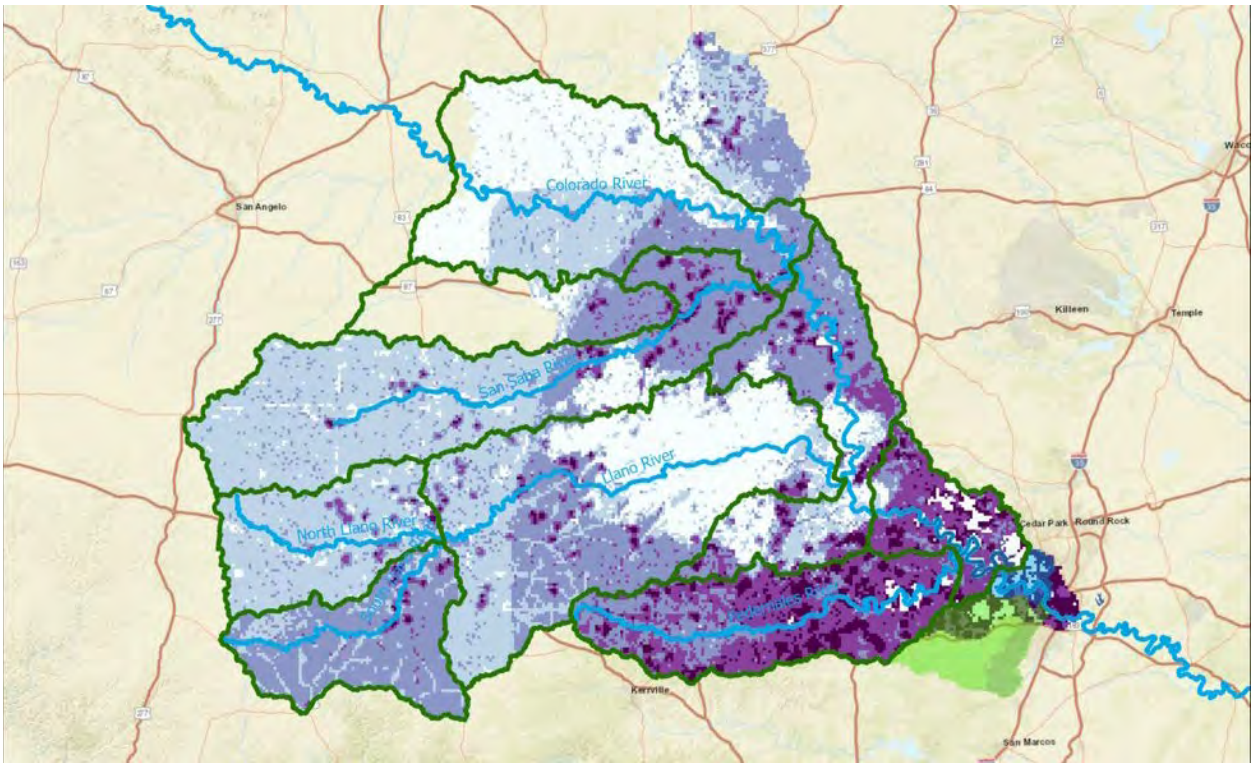
Austin's drinking water supply has benefited from a landscape of rural, largely working lands throughout the Highland Lakes' watershed. However, land use in Texas is changing rapidly as the state's population grows. According to Texas A&M Natural Resources Institute, the 20 counties in the lower Colorado basin have seen an 87% increase in population and the loss of over 108,000 acres of working lands since 1997. The working lands that remain are increasingly being subdivided into smaller and smaller parcels. These trends are likely to continue, emphasizing the need to plan for upstream water quality protection.

Source Water Protection refers to the management of areas through which water travels and the regulation of activities on these lands to prevent pollution and contaminants from entering public drinking water sources. The quality and quantity of a city's drinking water supply, as well as other water bodies used for recreational, environmental, and drainage purposes, can be influenced by both natural and human activities. One of the most effective ways to protect source water is to acquire land over which the water flows or to restrict development on such land through conservation easements or other mechanisms. These protections allow the land to continue acting as a natural filtration system for water as it nears water sources, preventing additional contaminants from development activities.

Austin Water conducted the Colorado River Analysis to evaluate areas in the lower Colorado river basin upstream of Austin and rank land protection opportunities based on water supply and environmental factors. . Water supply factors included stream flow, spring location, recharge zones, and location of undesirable features such as oil and gas wells. Environmental factors included vegetation, slope incline, impervious cover, protected land, and riparian and flood plain areas. Each factor was assigned a relative weight, as described in more detail in Appendix H.

This analysis was done with the use of geographic information systems (GIS) mapping tools to overlay these factors and combine the assigned point values. The results of this analysis are shown in the image below, with darker purple areas indicating areas with the highest

cumulative scores. These high scores indicate areas that contribute most significantly to water quality and quantity.



Colorado River Land Analysis Study Area, higher priority conservation areas shown in darker shades of purple. Areas shown in green reflect the Barton Springs Zone, which will continue to be an area of higher priority for conservation for the City of Austin.

Additional detail regarding this analysis is available in Appendix H. Next steps for further analysis and engagement related to land conservation strategies are included in Chapter 5, Future Water Strategies.

CHAPTER 5

FUTURE WATER STRATEGIES

The outcome of the Water Forward planning process is to identify future conservation, non-potable reuse, and potable water supply strategies so that all community needs for water are met. Estimated yield targets from 2030-2080 and total annual community costs for these strategies are summarized in the table below. The following strategy sections include further information about each strategy, including a strategy description, further cost information, and actions Austin Water will take over the next five years to implement the strategy.

Summary of Water Forward 2024 Strategies, 2030-2080

Water Forward Strategies	Average/ Drought	Estimated Yield (Acre Feet per Year)						Total Annual Community Cost ($ per acre foot per year)*
		2030	2040	2050	2060	2070	2080	
Water Conservation Strategies								
Utility-Side Water Loss Control	Both	2,800	7,500	9,400	11,300	13,200	15,000	$267
Customer-Side Water Use Management	Both	2,400	4,700	6,400	8,100	9,800	11,400	$52
Native & Efficient Landscaping	Both	1,300	2,700	3,800	4,800	5,900	7,000	$5,112
Water Conservation Strategies Sub-Total	-	**6.500**	**14,900**	**19,600**	**24,200**	**28,900**	**33,400**	
Non-Potable Water Reuse Strategies								
Centralized Reclaimed	Both	1,100	8,200	12,900	17,600	22,300	26,900	$2,243
Decentralized Reclaimed	Both	0	200	500	800	1,100	1,300	$5,158
Onsite Reuse	Both	1,100	4,000	5,700	7,300	9,000	10,600	$8,957
Non-Potable Reuse Strategies Sub-Total	-	**2,200**	**12,400**	**19,100**	**25,700**	**32,400**	**38,800**	
Potable Water Supply Strategies								
Aquifer Storage and Recovery	Both	0	44,500	44,500	44,500	44,500	44,500	$2,003
Lake Walter E. Long (Decker) Off Channel Reservoir	Both	0	18,300	18,300	18,300	18,300	18,300	$3,033
Indirect Potable Reuse	Drought	**	**	22,400	22,400	22,400	22,400	$880
Capture Local Inflows to Lady Bird Lake***	Average	0	0	3,000	3,000	3,000	3,000	***
Brackish Groundwater Desalination	Both	0	0	0	0	20,000	40,000	$2,688
Water Supply Strategies Sub-Total	-	**0**	**62,800**	**88,200**	**88,200**	**108,200**	**128,200**	
Water Forward Strategies Overall Total		**8,700**	**90,100**	**126,900**	**138,100**	**169,500**	**200,400**	
Current Supplies								
Colorado River and Highland Lakes Supply	Both	325,000						
Centralized and Decentralized Reclaimed Water System	Both	5,000						

* Community cost = Utility cost + Customer cost
** May be implemented earlier in severe drought conditions
*** Infrastructure is included in Indirect Potable Reuse strategy

Water Conservation Strategies

Utility-Side Water Loss Control



Utility Side Water Loss Control is a strategy to decrease water lost from the City's water system. Austin Water's efforts to control water loss include managing leaks, reducing non-revenue water, and improving data quality. This strategy will include additional efforts to improve the accuracy of meters at water treatment plants, expanding active leak detection programs, and using new methods to analyze water loss data.

Implementation of water loss control actions is projected to result in savings of 1.92 gallons per capita per day by 2030 and 4.39 gallons per capita per day by 2040.

Total GPCD =

(Total Gallons in System ÷ Permanent Population) ÷ 365

Annual Yield Targets (acre feet per year)					
2030	2040	2050	2060	2070	2080
2,800	7,500	9,400	11,300	13,200	15,000

Capital Cost	Capital Cost including Contingencies	Annual Cost O&M and Debt Service ($ per year)	Total Annual Cost ($ per acre foot per year)
$45,000,000	$69,655,000	$7,031,000	$267

Five Year Implementation Actions
• Continue replacement of polybutylene service lines through the Renewing Austin Program (2024) • Launch a cross-functional Austin Water Water Loss team to implement the recommendations of the water loss report (2024) • Pilot the implementation of two District Metering Areas (DMAs) to reduce water loss through pressure management (2024) • Develop an Austin Water Production Meter SOP which includes production meter measurement improvement recommendations (2025) • Update the Austin Water Meter Testing SOPs for meter testing, sizing, and replacement (2025) • Develop an Austin Water Unauthorized Consumption Mitigation SOP (2025) • Develop an Austin Water Data Handling Errors Mitigation SOP (2025) • Develop an Austin Water Leak Detection Standard Operating Procedure (SOP) for leak detection practices, data management, and continuous training requirements (2025) • Expand the use of District Management Areas across the city and consider partial conversion to Pressure Management Areas (PMAs) (2026) • Update Austin Water operations response procedures to improve management of service line failures (To Be Determined) • Update Austin Water asset management program to improve management of service line failures (To Be Determined) • Create dashboards to integrate SCADA, AMI, pressure monitoring and leak detection data (To Be Determined)

Customer-Side Water Use Management



Existing customer-side water use management efforts include requiring that all site plans for new development include water benchmarking applications, replacing all meters in the City with new smart meters, rolling out the My ATX Water customer portal, and many conservation and reuse rebates and incentives. This strategy includes expanded customer incentives for conservation, use of benchmarking and My ATX Water data to create water use budgets for customers and to expand identification of customer-side water leaks, and water use reduction from customer behavior changes based on near real-time water use data.

Implementation of customer-side water use management actions is projected to result in savings of 1.64 gallons per capita per day by 2030 and 2.75 gallons per capita per day by 2040.

Annual Yield Targets (acre feet per year)					
2030	2040	2050	2060	2070	2080
2,400	4,700	6,400	8,100	9,800	11,400

Capital Cost	Capital Cost including Contingencies	Annual Cost O&M and Debt Service ($ per year)	Total Annual Cost ($ per acre foot per year)
$325,000	$325,000	$681,000	$52

Five Year Implementation Actions
• Provide customer leak alerts (Ongoing) • Pilot an increased rebate for commercial water use audits (2025) • Begin the development of necessary data and program design for water use benchmarking and budgeting of single-family residential, commercial, and industrial customers (2025) • Develop data regarding commercial, industrial, and institutional (CII) customer categorization to assist in benchmarking and the identification of facilities for water conservation outreach (2025) • Work with My ATX Water contractor to develop the necessary data and reports to focus customer engagement (2025) • Investigate additional methods to encourage residential customers to use the My ATX Water portal and water-saving alerts (2025/2026) • Conduct pilot outreach activities to learn the best ways to encourage customers to save water (2025/2026) • Identify opportunities for CII facility owners/managers to benefit from the My ATX Water alerts and information (2026) • Conduct pilot outreach activities to learn the best ways to encourage customers to set and strive towards voluntary water budgets (2026)Undertake public and stakeholder engagement regarding potential residential and commercial mandatory water budgets (2027)

Native and Efficient Landscapes



Austin Water currently has rebate and incentive programs to help customers transition to native and efficient landscapes. This strategy includes additional efforts including new landscape transformation ordinances and incentives, irrigation efficiency incentives, and other approaches to promote conversion to native and efficient landscapes.

Implementation of customer-side water use management actions is projected to result in savings of 0.89 gallons per capita per day by 2030 and 1.58 gallons per capita per day by 2040.

Annual Yield Targets (acre feet per year)					
2030	2040	2050	2060	2070	2080
1,300	2,700	2,900	3,900	5,000	6,100

Capital Cost	Capital Cost including Customer Costs	Annual Cost O&M and Debt Service ($ per year)	Total Annual Cost ($ per acre foot per year)
$75,000	$832,815,000	$55,726,000	$5,112

Five Year Implementation Actions
• Coordinate with COA Development Services Department to increase inspections of new-development soil inspections (Ongoing) • Restrict the use of drip irrigation to two days per week in Conservation Stage and Drought Stages 1-2, and to one day per week in Drought Stages 3-4 (2024) • Inspect new residential irrigation systems (2025)Adjust landscaping and grey water incentives to encourage greater participation (2024) • • Council adoption and implementation of local amendments to the 2024 Uniform Plumbing Code (requiring pressure-reduction devices for irrigation systems, limitation of irrigation area, laundry to landscape) (2025) • Develop necessary data to analyze irrigation water use patterns (2025) • Austin Water inspection of all new residential irrigation systems and offering new homeowners follow-up checkups (2025) • Engage commercial and residential irrigators using the My ATX Water portal and outreach, including developing data management tools, conducting pilot testing, and integrating commercial customers into communications portal (2026)

Non-Potable Reuse Strategies

Centralized Reclaimed



Austin's centralized reclaimed water system, or "purple pipe" system, currently provides highly-treated wastewater effluent for non-potable uses such as irrigation, cooling, manufacturing, and toilet flushing to customers. This strategy represents expansion of existing centralized reclaimed water use, including codes and incentives to require or encourage connection to the centralized reclaimed water system.

Annual Yield Targets (acre feet per year)					
2030	2040	2050	2060	2070	2080
1,100	8,200	12,900	17,600	22,300	26,900

Capital Cost of Infrastructure	Capital Cost including Contingencies and Land Acquisition	Annual Cost O&M and Debt Service ($ per year)	Total Annual Cost ($ per acre foot per year)
$899,162,000	$1,407,041,000	$93,530,000	$2,243

Five Year Implementation Actions
• Implement new projects to increase supply and extend the centralized service area (Ongoing) • Conduct water benchmarking with all new commercial and industrial customers to identify uses appropriate for reclaimed water, and require connection to the reclaimed system in accordance with development requirements (Ongoing) • Evaluate the results of implementation of the GoPurple program and recommend revisions to the program, including distance requirements and incentives (rebates) for connection to the centralized reclaimed system (Annually) • Implement projects to Complete the Core (2024-2027) • Complete Reclaimed Water Long Range Plan update (2026)

Decentralized Reclaimed



This strategy was included as "Distributed Wastewater Reuse" in the Water Forward 2018 Plan. Decentralized Reclaimed is defined for Water Forward 2024 as the collection of wastewater from sewer systems separate from the Austin's centralized wastewater system, and treatment and reuse of that wastewater at the neighborhood scale. Reuse of the treated water via a dual (purple) pipe system will supply irrigation, landscaping, toilet flushing, and cooling demands.

Annual Yield Targets (acre feet per year)					
2030	2040	2050	2060	2070	2080
0	200	500	800	1,100	1,300

Capital Cost of Infrastructure	Capital Cost including Contingencies and Land Acquisition	Annual Cost O&M and Debt Service ($ per year)	Total Annual Cost ($ per acre foot per year)
$138,375,000	$215,071,000	15,991,000	$5,158

Five Year Implementation Actions
• Collaborate with new developments through the service extension request (SER) process to identify opportunities for decentralized reclaimed and appropriate cost participation by Austin Water (Ongoing) • Complete Wastewater System Long Range Plan Update, including identifying existing wastewater treatment plants, future sites, and potential future sites/service areas (2025) • Develop infrastructure planning and design guidance (2025-2029)

Onsite Water Reuse



Austin currently has ordinances requiring onsite reuse of rainwater and air conditioning condensate for new developments over 250,000 square feet. This strategy includes implementation of these existing ordinances as well as future phases of onsite reuse implementation. Onsite reuse water can be sourced from rainwater, stormwater, air conditioning condensate, graywater, or black water.

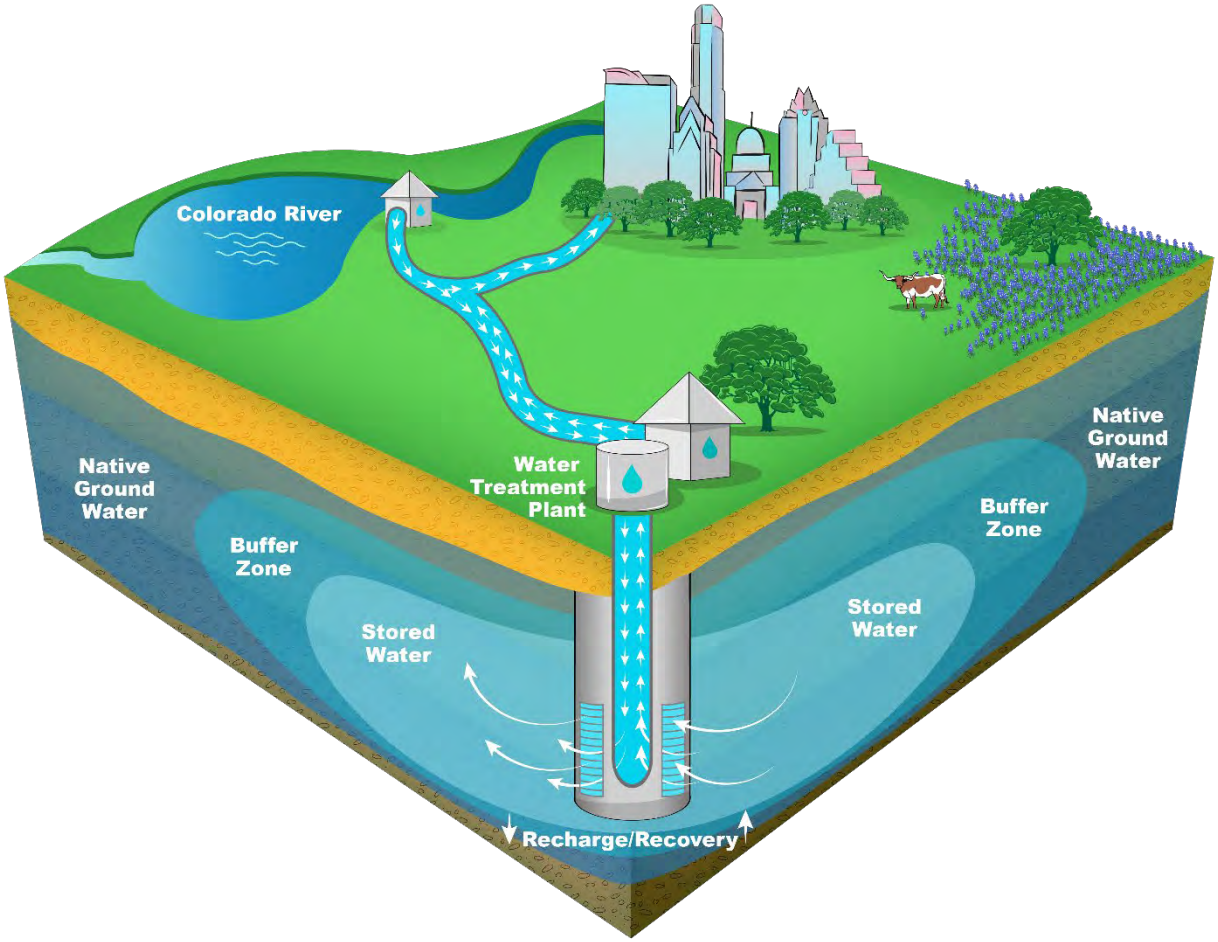
Annual Yield Targets (acre feet per year)					
2030	2040	2050	2060	2070	2080
1,100	4,000	5,700	7,300	9,000	10,600

Capital Cost of Infrastructure	Capital Cost including Contingencies and Land Acquisition	Annual Cost O&M and Debt Service ($ per year)	Total Annual Cost ($ per acre foot per year)
$841,418,000	$950,624,000	$145,994,000	$8,957

Five Year Implementation Actions
• Evaluate the results of implementation of the GoPurple program and recommend revisions to the program, including onsite reuse requirements and incentives (rebates) (Annually) • Determine the feasibility of fully subsidizing the cost of reclaimed connections, onsite water reuse systems, and dual plumbing for deeply affordable housing projects (2025) • Begin planning for expansion of onsite reuse requirements to include new medium-sized developments (2025-2028)

Potable Water Supply Strategies

Aquifer Storage and Recovery



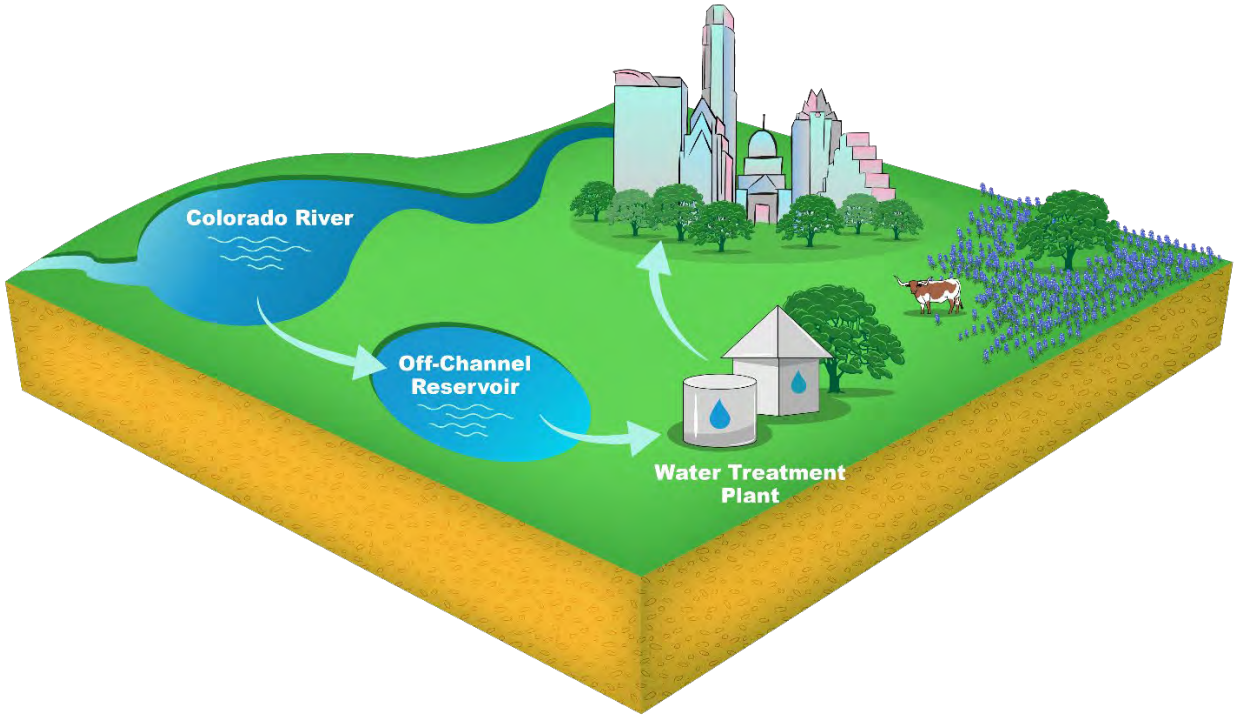
Austin's Aquifer Storage and Recovery (ASR) project will store drinking water from Austin's water treatment plants. This water will be available under Austin's existing water rights and will be stored in the aquifer during periods when water is more plentiful, maximizing Austin's existing supplies. Stored water withdrawn from the ASR project will be treated as needed to be compatible with Austin's drinking water quality and then distributed to customers. Austin Water is currently finalizing a desktop analysis to identify favorable locations for an ASR pilot and full-scale project.

Annual Yield Targets (acre feet per year)					
2030	2040	2050	2060	2070	2080
0	44,500	44,500	44,500	44,500	44,500
Annual Storage Targets (acre feet)					
2030	2040	2050	2060	2070	2080
0	60,000	120,000	180,000	240,000	300,000

Capital Cost of Infrastructure	Capital Cost including Contingencies and Land Acquisition	Annual Cost O&M and Debt Service ($ per year)	Total Annual Cost ($ per acre foot per year)
$941,554,000	$1,526,808,000	$166,747,000	$2,003

Five Year Implementation Actions
• Complete Phase 1A desktop analysis to identify favorable ASR locations (2024) • Conduct Phase 1B field testing and make recommendations for ASR pilot project (2025) • Conduct Phase 2 ASR pilot testing and develop recommendations for full-scale ASR project (2026-2028) • Begin Phase 3 preliminary engineering and design for full-scale ASR project (2029)

Lake Walter E. Long Off-Channel Reservoir



This strategy would use Lake Walter E. Long (formed by Decker Dam) as a water supply reservoir to meet customer demands. Lake Walter E. Long is supplied by water diverted from the Colorado River, and this strategy includes a new intake adjacent to the current intake location. The reservoir would be operated so that lake levels would fluctuate within a limited five-foot range during drought periods. Water from this strategy would be treated for potable use at a new water treatment plant using advanced treatment processes. Lake Walter E. Long is

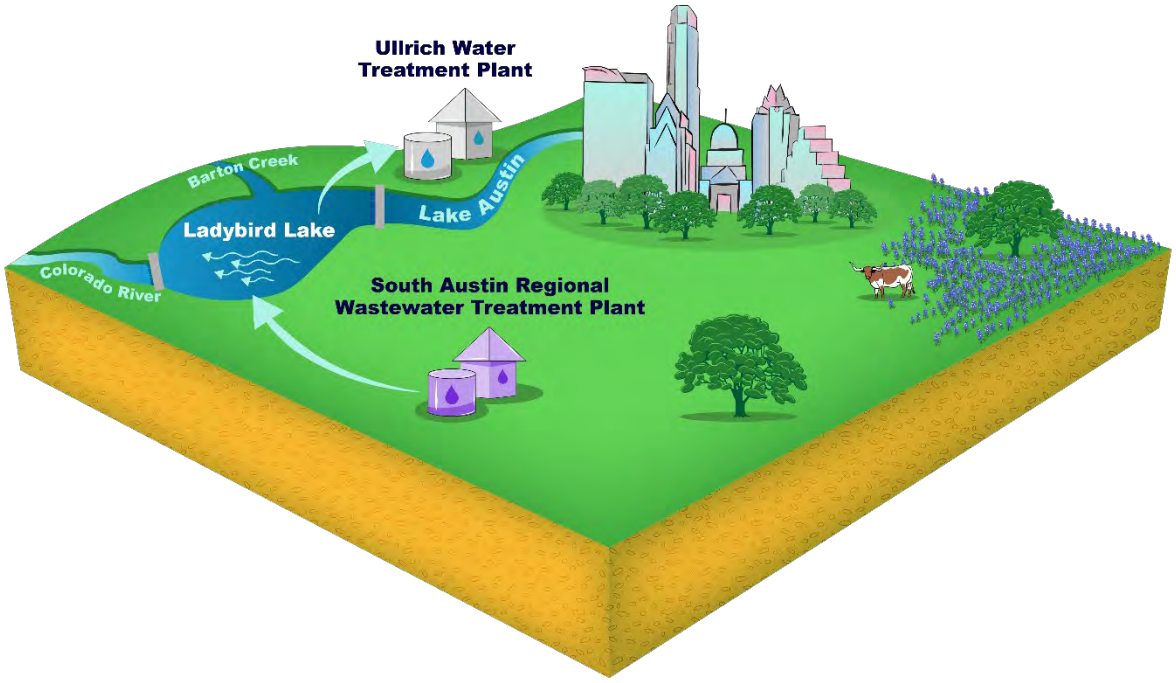
currently used for recreation (managed by the City's Parks and Recreation Department) and for the operation of the Decker Power Plant (managed by the City's electric utility, Austin Energy). This strategy provides co-benefits to those uses and Austin Water is coordinating with those departments in its development.

Annual Yield Targets (acre feet per year)					
2030	2040	2050	2060	2070	2080
0	18,300	18,300	18,300	18,300	18,300
Annual Storage Targets (acre feet)					
2030	2040	2050	2060	2070	2080
0	6,100	6,100	6,100	6,100	6,100

Capital Cost of Infrastructure	Capital Cost including Contingencies and Land Acquisition	Annual Cost O&M and Debt Service ($ per year)	Total Annual Cost ($ per acre foot per year)
$331,634,000	$518,117,000	$55,507,000	$3,033

Five Year Implementation Actions
• Complete feasibility report to evaluate off-channel reservoir configurations and recommend a preferred configuration (2025) • Begin water quality sampling of Lake Walter E. Long (2025) • Begin preliminary engineering of a conceptual project layout for the preferred strategy configuration, including Colorado River infrastructure, improvements to the intake pipeline, water treatment plant infrastructure, intake infrastructure, and distribution system integration. (2026)

Indirect Potable Reuse and Capture Local Inflows to Lady Bird Lake



Indirect Potable Reuse (IPR) through Lady Bird Lake would include pumping highly-treated reclaimed water from new side-stream treatment facilities located near the South Austin Regional Wastewater Treatment Plant into Lady Bird Lake via new reclaimed transmission main. Water would then be pulled from Lady Bird Lake into the Ullrich Water Treatment Plant using a new intake pipe and pump station and treated for potable use. IPR would only be used when the combined storage of Lakes Travis and Buchanan drops below 400,000 acre feet.

Outside of drought emergencies, the intake and pump station from IPR can be used to capture local inflows to Lady Bird Lake, in particular from Barton Creek and Barton Springs. The reclaimed transmission infrastructure would be used to support the centralized reclaimed water system.

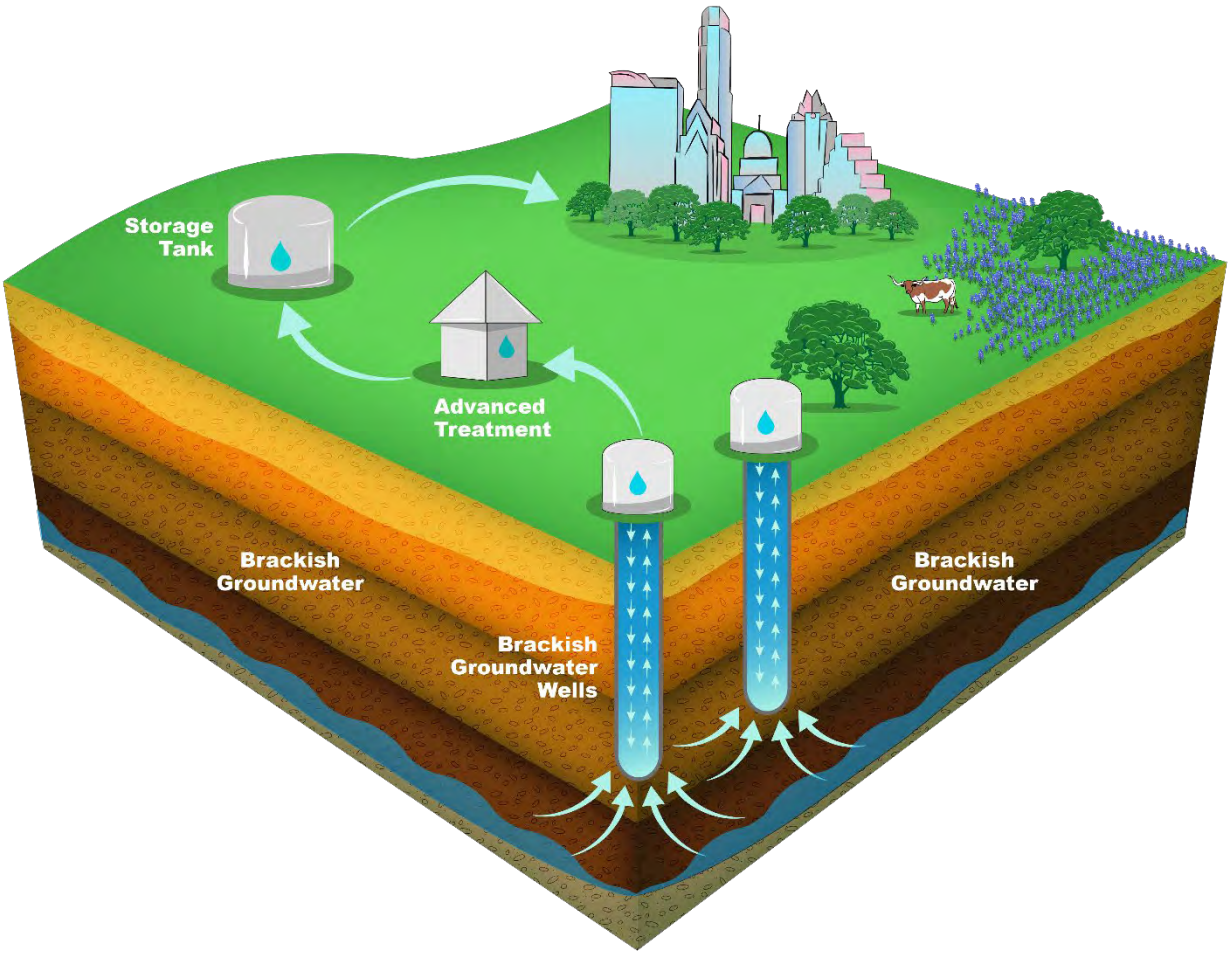
Annual Yield Targets (acre feet per year)					
2030	2040	2050	2060	2070	2080
***	***	22,400	22,400	22,400	22,400

***May be implemented earlier in severe drought conditions.

Capital Cost of Infrastructure	Capital Cost including Contingencies and Land Acquisition	Annual Cost O&M and Debt Service ($ per year)	Total Annual Cost ($ per acre foot per year)
$114,104,000	$180,486,000	$19,710,000	$880

Five Year Implementation Actions
• Develop IPR schematic design, design criteria, technical specifications, to include development of project configuration and sizing components (2024) • Begin design-build procurement process and, pending Council approval, issue design-build contract (2025) • Preliminary target for substantial completion of IPR project construction (2028)

Brackish Groundwater Desalination



Brackish Groundwater Desalination is defined as the withdrawal and desalination of brackish (salty) groundwater for treatment to potable drinking water. This strategy would use water from an aquifer that has salinity levels in excess of TCEQ guidelines and rules for drinking water. The water would be withdrawn through wells, then treated by advanced treatment processes such as reverse osmosis to reduce the salinity and condition the water to be compatible with Austin's drinking water. The water would be conveyed to a connection point with Austin's water distribution system through transmission mains (large pipelines). The treatment process creates

a very salty wastewater (brine) that requires disposal in accordance with state regulations. Development of this strategy will include desktop analysis and pilot testing.

Annual Yield Targets (acre feet per year)					
2030	2040	2050	2060	2070	2080
0	0	0	0	20,000	40,000

Capital Cost of Infrastructure	Capital Cost incl. Contingencies and Land Acquisition	Total Annual Cost – O&M and Debt Service ($ per year)	Annual Cost of Water ($ per acre foot per year)
$429,403,000	$767,453,000	$107,500,000	$2,688

Five Year Implementation Actions
• Begin scoping for desktop analysis to identify favorable locations for brackish groundwater desalination (2028)

Best Management Practices

The following are best management practices for which it may not be possible to calculate a water yield, but which help to achieve the yields of other strategies. These best management practices will be implemented by Austin Water to support successful implementation of the overall plan goals.

- Promote customers' knowledge of watering days through direct customer communications, social media, and collaboration with print, radio, and digital media.
- Continue to provide follow-up information after My ATX Water meters are installed about how to use the portal to monitor and reduce water use.
- Expand the reach of Austin Water's public outreach and education through partnerships with community organizations, nurseries, landscapers, and irrigation installers, among others. Evaluate the budget for these programs annually.
- Clarify and streamline public-facing information on incentive programs. Provide comprehensive and easy-to-understand forms for participating.
- Expand training programs and resources for landscapers, including sample landscape plans and information on native plants.
- Expand outreach to existing developments near the reclaimed system to promote connection.
- Continue to work with new development on "fit-for purpose" water use strategies in accordance with Austin Water's requirements and incentives related to benchmarking, on-site water reuse, and connections to the centralized reclaimed water system. Identify opportunities to leverage the benchmarking process to provide additional transparency related to water use for planned development.

- Investigate the development of a program to provide small grants ($3,000) to community organizations to expand the outreach of water conservation messaging.

Land Conservation Strategies

Water Forward 2024 includes a review of strategies that protect Austin's source water quality and quantity through land management practices. These strategies are in addition to, and work in concert with, Austin Water's management of the Balcones Canyonlands Preserve and Water Quality Protection Lands. Additionally, Austin Water collaborates with the City's Watershed Protection Department and Parks and Recreation Department on streambank restoration, creek water quality protection, and flood risk mitigation, as well as day-to-day land management for environmental outcomes. The strategies below represent both investments to Austin Water's current land protection programs and future opportunities to expand these programs upstream.

Colorado River Land Protection

As described in the Colorado River Land Analysis section, the purpose of the Colorado River Land Analysis was to evaluate how Austin Water could further protect and preserve areas that contribute to Austin's drinking water quality and water quantity in the lower Colorado River basin. Future land conservation efforts upstream of our drinking water intakes could prevent water quality impacts associated with development of impervious surfaces and intense land uses. This protection would not only provide good stewardship of our surrounding natural and working lands, but also help protect water quality and lower costs associated with treating water now and in the future. These lands upstream of Austin represent a future opportunity to implement the types of land conservation and best management practices that have been successful under Austin Water's current land protection programs.

Water Forward land conservation strategies to protect our drinking water supply are just one component of the City of Austin's long term land conservation planning. Multiple City departments will also be working together to define land conservation strategies and funding mechanisms to meet multiple community goals. Austin Water will continue to identify important areas of land and work to conserve those natural resources for future generations. The following conservation strategies are being considered by Austin Water to help protect the City's water supply in the lower Colorado River basin.

- Fee-simple purchase of land
- Purchase of conservation easements
- Direct payments to landowners
- Landowner education and outreach

More information about these land conservation strategies and possible funding mechanisms is available in Appendix H. Austin Water will continue to engage the public and community regarding these land conservation strategies, considering combinations of the strategies in different priority areas, and will continue the important work of protecting the natural environment and our water supply sources

Actions and Next Steps

- Continue to fund existing Austin Water land protection programs and acquire lands as necessary and feasible to meet program goals.
- Continue stakeholder and community engagement to inform Colorado River land protection priorities.
- Further refinement of conservation prioritization model and analysis.

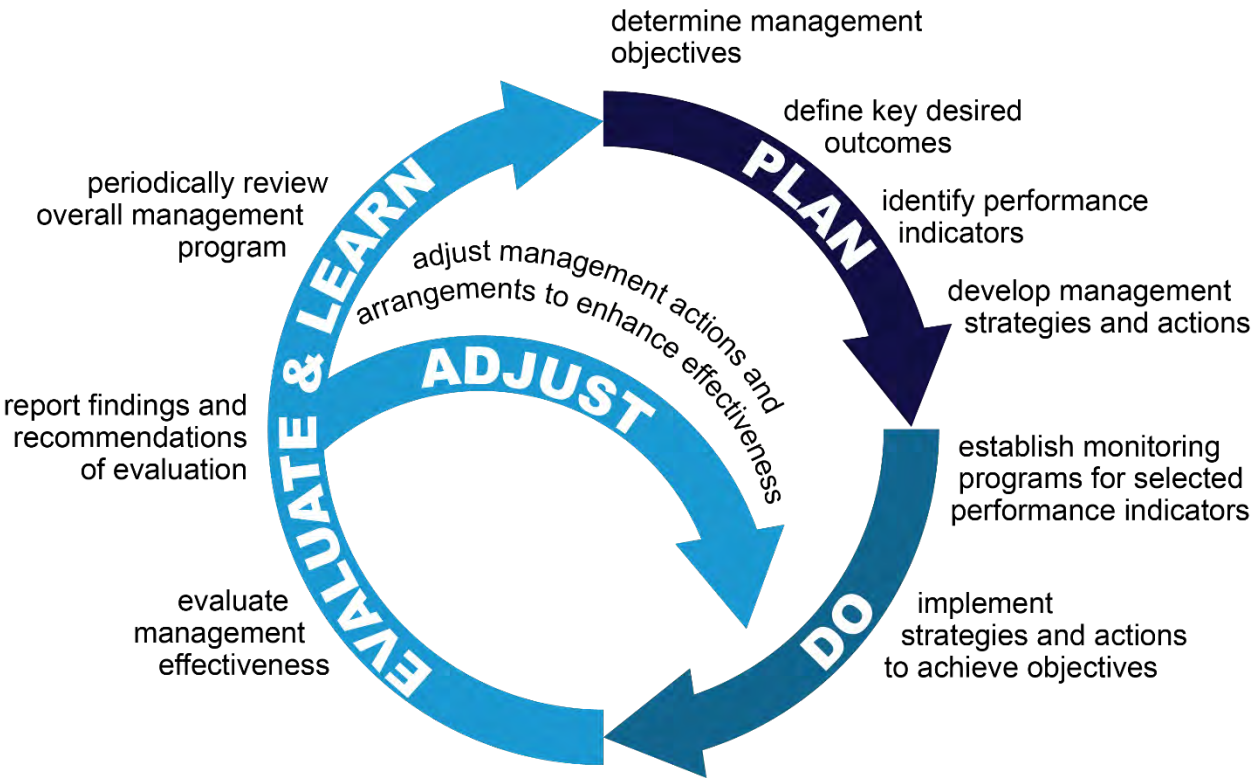
- Narrow conservation priorities based on feasibility and impact.
- Develop a menu of feasible conservation strategies.
- Based upon land protection priorities, identify an effective and cost-efficient mix of land protection strategies to protect source water quality and quantity.
- Work with partners and stakeholders so that future Austin Water investments leverage partnerships, outside funding opportunities, and other opportunities that can maximize land protection outcomes.
- Develop feasible funding strategies, funding levels, and operational support to meet Colorado River land protection goals.

CHAPTER 6

PLAN IMPLEMENTATION

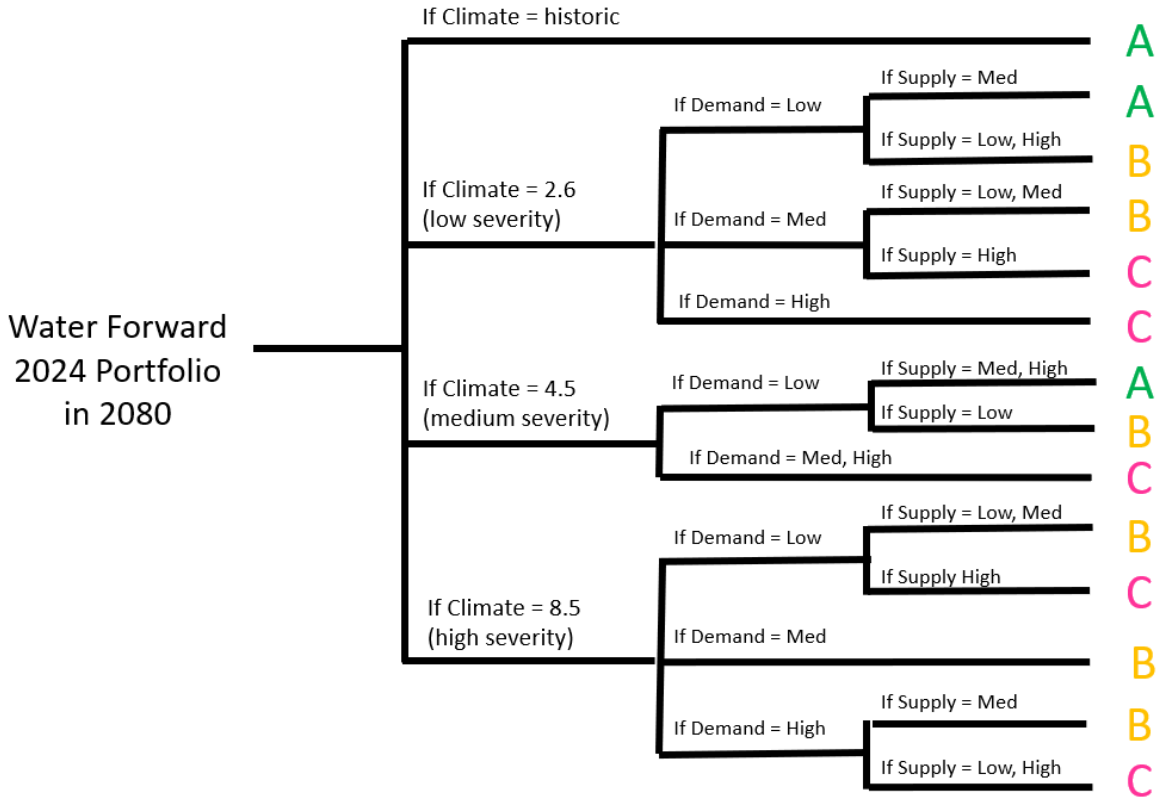
Adaptive Management Approach

Water Forward 2024 provides a roadmap to guide development of future programs, projects, and ordinances. Implementation of Water Forward 2018 strategies are already underway, and Austin Water will begin to implement the additional water strategies included in Water Forward 2024 soon after City Council approval of the Water Forward Plan. During the next five years, Austin Water will act in alignment with the five-year implementation actions included for each strategy in Chapter 5. The plan will use an adaptive management approach. This means that strategy effectiveness will be monitored and evaluated at regular intervals. This evaluation will be publicly reported. The findings will also inform potential adjustments that Austin Water may need to make to specific strategies. The Water Forward plan will also continue to be updated on a five-year cycle to review program effectiveness and incorporate updated data and changing conditions into the overall plan. These steps provide continual feedback that we are on track to meet our goals.



100-Year Adaptive Management Plan

Water Forward 2024 focuses on identifying specific strategies for implementation through 2080. The plan also includes a 100-year adaptive management plan. This plan, outlined below, builds off of the 2080 Water Forward portfolio of strategies. The plan includes a decision tree of potential strategy pathways that Austin Water may need to follow depending on the climate, water demand, and regional supply development scenarios that we experience in the future.



Water Forward 2024 100-Year Adaptive Management Pathways

The outcomes of these potential strategy pathways are characterized as three potential portfolios of strategies for the 2120 planning horizon. These portfolios include the same set of conservation and reuse strategies, building off of the most aggressive 2080 pathway. The portfolios differ in the amount of potable water supply strategies that are developed. For example, in 100 years if Austin experiences a less severe climate change outcome, paired with low water demands and a medium scenario of regional water supply development, Austin Water would only need to develop 20,000 acre feet of additional water supply (2120 Portfolio A) on top of the 2080 Water Forward portfolio to meet community water needs. In a high severity climate change outcome, Austin Water may need to develop more additional water supplies (2120 Portfolio B or C).

There is a high degree of uncertainty regarding future outcomes that Austin may experience in 100 years. This adaptive management plan is a tool to inform pathways Austin Water may need to pursue and is an initial estimate based on current and best available information. This 100 year plan will be updated with every five year update to the Water Forward plan and will serve as a roadmap of potential long term outcomes and needs. This roadmap will change based on the progress we make to implement near term strategies and new information about changing conditions.

Water Forward 2024 100 Year Adaptive Management Portfolios

Water Forward Strategies	Estimated Yield (Acre Feet per Year)			
	Water Forward 2024 Portfolio 2080	**Portfolio A 2120**	**Portfolio B 2120**	**Portfolio C 2120**
Water Conservation Strategies				
Utility-Side Water Loss Control	15,000	26,300	26,300	26,300
Customer-Side Water Use Management	11,400	13,100	13,100	13,100
Native & Efficient Landscaping	7,000	10,900	10,900	10,900
Water Conservation Strategies Sub-Total	**33,400**	**50,300**	**50,300**	**50,300**
Non-Potable Water Reuse Strategies				
Centralized Reclaimed	26,900	41,700	41,700	41,700
Decentralized Reclaimed	1,300	3,100	3,100	3,100
Onsite Reuse	10,600	16,300	16,300	16,300
Non-Potable Reuse Strategies Sub-Total	**38,800**	**61,100**	**61,100**	**61,100**
Potable Water Supply Strategies				
Aquifer Storage and Recovery	44,500	44,500	83,000	44,500
Lake Walter E. Long (Decker) Off Channel Reservoir	18,300	18,300	18,300	18,300
Indirect Potable Reuse	22,400	33,600	22,400	44,800
Capture Local Inflows to Lady Bird Lake	3,000	3,000	3,000	3,000
Brackish Groundwater Desalination	40,000	40,000	40,000	40,000
Additional Colorado River Basin-Independent Supply*	0	20,000	20,000	60,000
Additional Colorado River Basin Supply**	0	0	35,000	30,000
Water Supply Strategies Sub-Total	**128,200**	**159,400**	**221,700**	**240,600**
Water Forward Strategies Overall Total	**200,400**	**280,800**	**343,100**	**362,000**
Current Supplies				
Colorado River and Highland Lakes Supply	325,000			
Centralized and Decentralized Reclaimed Water System	5,000			

* These supplies would be from sources outside of the Colorado River and Highland Lakes basin. The specific make-up of these supplies would be determined in the future.
** These supplies would be from sources inside of the Colorado River and Highlands Lakes Basin. The specific make-up of these supplies would be determined in the future.

Funding

Water Forward 2024 estimates that implementing near-term strategies will require significant investment. Costs included in the plan are planning level estimates that will be refined through further capital and operations planning. Austin Water is an enterprise department of the City of Austin, funded by water, wastewater, and reclaimed water rates and fees, as well as capital recovery fees (connection fees for new development. Capital investments are funded through a combination of operating cash and debt financing, including low interest loans from state and federal water infrastructure funding programs. Austin Water identifies and submits to these funding programs on an ongoing basis and has been successful in securing these funding sources. The utility will identify various sources of funding for projects and programs through its ongoing financial planning processes with a focus on maintaining affordability metrics and reducing financial impacts on customers.

Mitigating Inequitable Impacts

The Equity and Affordability evaluation of water strategies identified possible inequitable impacts of each strategy. Approaches to mitigate these impacts are described in the table below. Many of these approaches are similar across the strategies. These approaches will be incorporated into tailored program, policy, and project planning and design.

Strategy Type	Approaches to Mitigate Inequitable Impacts
Conservation	• Tailor program design and implementation of water budgets to avoid penalizing larger households and imposing inequitable burdens on marginalized communities • Tailor program design, code development, and enforcement of landscape and irrigation requirements to avoid imposing inequitable burdens on marginalized communities • Provide water conservation education, training programs, grants, and financial assistance to marginalized communities to help them keep their water use below water budget allowances and to minimize maintenance burdens
Reuse	• Provide programs for maintenance support, training for building management, etc. for dual plumbed systems. • Promote programs to assist customers in marginalized communities who are trying to navigate the permitting process in accessing education and assistance • Continue to work with the Watershed Protection Department to allow centralized reclaimed water for outdoor irrigation across our community, by mitigating potential water quality impacts from reclaimed irrigation • Continue to identify locations for onsite reuse or sewer mining to make reuse water available in areas of the City where centralized or decentralized reclaimed water is not available • Continued implementation of the GoPurple program, including code exemptions for affordable housing and financial and development incentives
Supply	• Minimize rate impacts through Customer Assistance Programs • Use low cost implementation project funding through Texas Water Development Board (TWDB) programs • Address construction impacts on marginalized communities (traffic, noise, etc.) • Explore options to minimize potential impacts to neighboring communities that may be impacted by strategies located outside of Austin Water's service area • For brackish groundwater desalination, develop effective brine handling methods that consider environmental impacts • For Indirect Potable Reuse, evaluate and implement appropriate treatment processes for water discharged into Lady Bird Lake • Partner with community organizations to provide education on water supply strategies and water quality

Monitoring, Evaluation, and Adaptation

Metrics to monitor implementation and the effectiveness of water strategies are listed below.

Strategy Type	Metric	Adaptation Triggers	Possible Adaptation Actions
Conservation	Strategy yields meet targets based on actual population growth	Annual strategy yield falls below target levels for two years in a row	• Use smart meter data to enhance tailored customer outreach via My ATX Water portal • Re-evaluate and enhance incentive programs • Increase utility water loss control programs • Re-evaluate staffing and funding levels for projects and programs
	Strategy implementation progress	Progress falls behind action timeline	
Reuse	Strategy yields meet targets based on actual population growth	Annual strategy yield falls below target levels for two years in a row	• Re-evaluate and enhance GoPurple incentive program • Re-evaluate and enhance reclaimed marketing • Identify reclaimed system projects that can be accelerated to improve system reliability and meet additional customer demand • Re-evaluate staffing and funding levels for projects and programs
	Strategy implementation progress	Progress falls behind action timeline	
Supply	Annual strategy yield	Annual strategy yield falls below target levels for two years in a row	• Identify supply project delivery methods and tasks that can be accelerated • Evaluate possible alternative supply project configurations or approaches • Accelerate implementation of emergency supply strategies • Re-evaluate staffing and funding levels for projects and programs
	Strategy implementation progress	Progress falls behind action timeline	
	Combined lake storage	Combined lake storage remains below 750,000 AF for four months or longer	

Reporting, Communication, and Collaboration

Austin Water will provide quarterly reports on implementation progress to the Water and Wastewater Commission, the Resource Management Commission, and the Water Forward Task Force. These quarterly reports will include leading demand reduction and supply performance measures. Austin Water will also develop public year-end annual reports including leading performance measures, descriptions of programmatic efforts, conservation performance, and total water use and loss.

Additional best practices that have been identified to incorporate into future strategy implementation phases are listed below.

- Accountability
    - Create an online dashboard providing data and updates about strategy implementation progress including equity and affordability considerations
    - Share implementation progress for strategies in a visually appealing way
    - Create systems for community feedback and input during strategy implementation

- Communication
    - Continue to share and bolster relevant and accessible information about Austin Water programs and incentives
    - Continue to work to provide multiple ways to access information, considering how information may be accessed by people with different abilities and preferences (audio, visual, paper handouts, web content, etc.)

- Collaboration
    - Collaborate with City of Austin departments and workgroups
    - Work closely with regional partners such as the Lower Colorado River Authority and the Lower Colorado River (Region K) Water Planning Group
    - Maintain relationships with community organizations, especially those that serve marginalized communities

APPENDICES

A - Community Engagement Summary

B - Equity and Affordability Roadmap

C - Population, Employment, and Demand Projections

D - Climate and Hydrology Analysis

E – Preliminary Needs Analysis

F - Water Management Strategy Cost and Yield Characterization

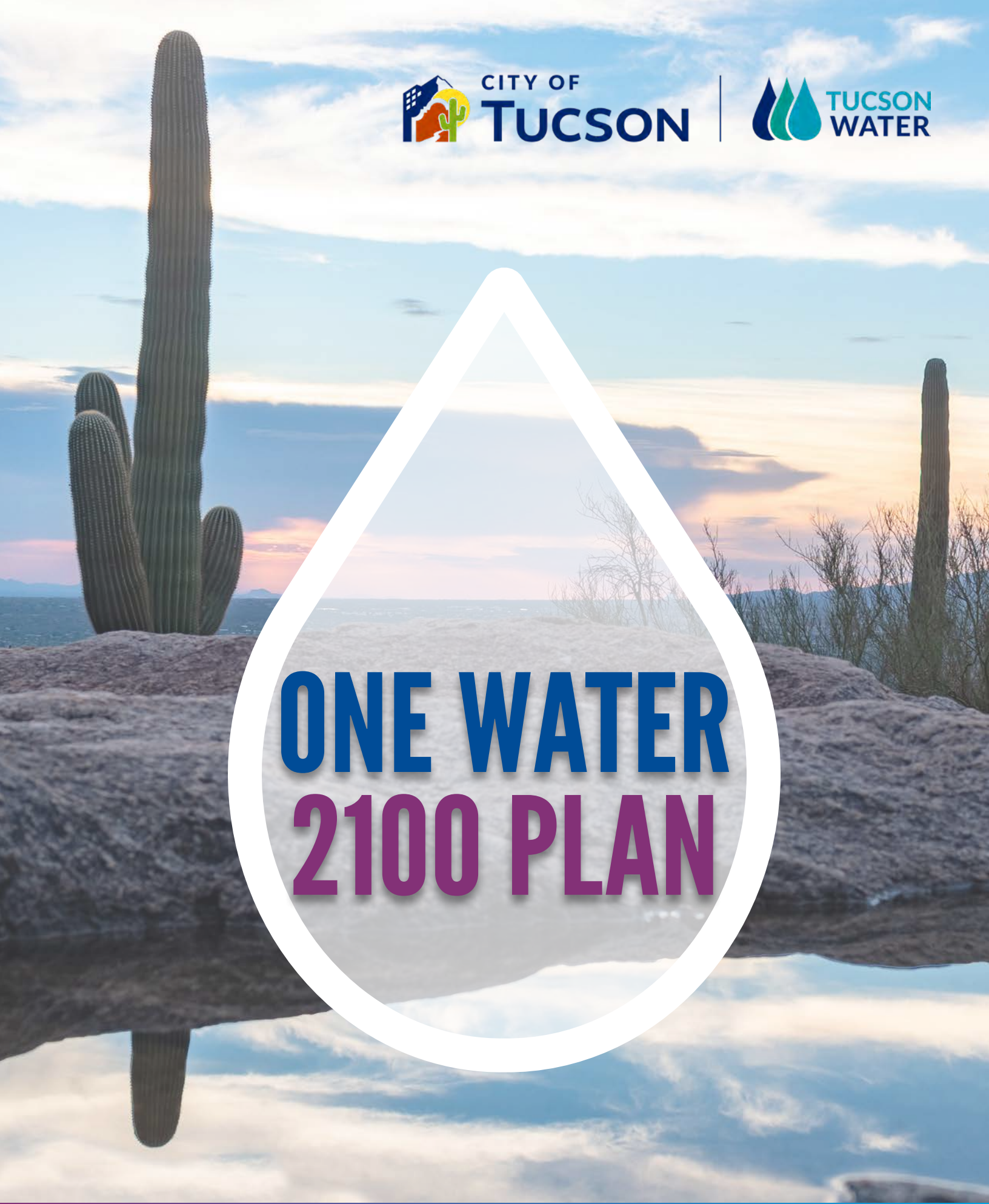
G - Water Management Strategy Equity Evaluation

H - Colorado River Land Analysis Evaluation

I - Water Management Strategy Assessment and Vulnerability Evaluation

J - Portfolio Development and Evaluation

CASE STUDY: ONE WATER 2100 PLAN



CITY OF TUCSON | TUCSON WATER

ONE WATER 2100 PLAN

SEPTEMBER 2023

carollo

Dear Tucsonans,

Tucson's water stewardship has established our community as one of the most resilient cities in the Southwest. Tucson Water, a proud enterprise department of the City of Tucson, is the largest water provider in the region. Tucson's water resilience is largely based on three factors: a diverse water supply portfolio, the community's conservation ethic, and adaptive planning. Recovered Colorado River water, delivered through the Central Arizona Project and recharged into the local aquifer, is the primary source of drinking water. Tucson had been dependent on groundwater until the process of recharge and recovery was completed in the early 2000's. Recycled water, used primarily for irrigation, allows us to use a drop of water more than once and builds on the ethic of the "right water for the right use." Harvested stormwater and rainwater is the latest opportunity to expand our water resource portfolio. The conservation program has over a decade of experience in rebating rainwater harvesting systems and the Storm to Shade program now maintains existing green stormwater infrastructure throughout the City.

Tucson Water's goal is to update its long range, water resource management plan about every ten years. This current update incorporates the One Water approach to water resource management. The One Water approach emphasizes that all water has value. Equity and sustainability are also central to this approach. In order to ensure that the plan reflected the community's water values, a robust public engagement campaign was employed to shape the plan's guiding principles, inform the future scenarios, and develop the strategies. The prioritized strategies in One Water 2100 will be the basis for future investments in our water infrastructure and programming.

Several key infrastructure investments have been made since Tucson Water's last water resource management plan (Water Plan: 2000 – 2050). The Shirley C. Scott South Houghton Area Recharge Project (SHARP) and the Santa Cruz River Heritage Project are both good examples of the One Water approach. These projects recharge recycled water into the aquifer. SHARP's three recharge basins, walking/running trails, and mountain bike trail sit on city-owned property, just west of Houghton and Drexel Roads. It's an active recharge facility designed in harmony with surrounding desert, offering recreation, amenities, and education about water resources, conservation, and environmental stewardship.

The Heritage project adds up to 2.8 million gallons of treated recycled water daily (3,150 acre feet a year) to the Santa Cruz River at a point south of downtown near the heart of the city. This water brings perennial flow to this portion of the river, fostering abundant native vegetation and wildlife along with recreational and economic opportunities.

These are the types of projects that make us more resilient in the face of the prolonged drought on the Colorado River and a changing environment locally. Agreements like the 2019 Drought Contingency Plan, compensated system conservation, and the forthcoming Colorado River Reconsultation decision will have the possibility to impact our future access to Colorado River supplies. But the One Water 2100 plan will ensure that we are prepared for whatever future we face.



John Kmiec
Director, Tucson Water

ONE WATER 2100 PLAN

SEPTEMBER 2023



LUIS MENA, THE FIRST SIGHTING, 2015

Source: The Arts Foundation for Tucson and Southern Arizona



Digitally signed by Corin A. Marron
Contact Info: Carollo Engineers, Inc.
Date: 2023.09.22 12:46:54-07'00'

IN COLLABORATION WITH:

HONORING THE LAND AND ITS ORIGINAL STEWARDS

The City of Tucson acknowledges the tribal nations in the Cuk-Son land. Tucson was founded on the unceded territory of the Tohono O'odham peoples -- caretakers of this land from time immemorial. The City, further, acknowledges the Pascua Yaqui tribe and their multi-millennial presence and stewardship in Cuk-Son.

By learning from indigenous knowledge along with the wealth of Tucson's diverse cultures and experiences, the City seeks to implement an intersectional approach to achieving water resilience for present and future residents of Tucson, while honoring the history of this land and its original stewards.

The City of Tucson will seek to build reciprocity with local sovereign tribal nations and indigenous communities to address local climate change impacts and inspire Tucsonans today and tomorrow to love and care for the land we share and call home.

ACKNOWLEDGMENTS

Thanks to the many representatives of neighborhoods, businesses, working groups, advocacy organizations, and members of the community who attended outreach events, workshops, and provided comments. Your participation in the development of the One Water 2100 Plan is the key to its success.

MAYOR AND COUNCIL

Regina Romero, Mayor

Lane Santa Cruz, Ward 1

Paul Cunningham, Ward 2

Kevin Dahl, Ward 3

Nikki Lee, Ward 4

Richard Fimbres, Ward 5

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Arizona Department of Environmental Quality

Arizona Lodging & Tourism Association

Arizona Multihousing Alliance

BKW Farms

Building Owners & Managers Association

Chicanos Por La Causa

Children's Action Alliance

City of Tucson Landscape Advisory Committee

Coalition for Sonoran Desert Protection

Commission on Climate, Energy, and Sustainability

Community Food Bank

Community Home Repair Projects of Arizona

Community Water Coalition

EcoBlue

Flowers and Bullets Collective

Fourth Avenue Merchants Association

Local First Arizona

Metropolitan Pima Alliance

Paul Ash Management for the Meadows Townhouses

Pima Council on Aging

Pima County Consumer Health and Food Safety

Pima County Cooperative Extension

Pima County Emergency Management

Pima County Food Alliance

Pima County Office of Sustainability

Pima County Wastewater

Primer Pools and Spas

Raytheon

Rotary (Catalina Club)

Santa Cruz Watershed Collaborative

Sonoran Environmental Research Institute

Sonoran Institute

Sonoran Oasis Landscaping

Southern Arizona Chapter of the National Association of Residential Property Managers

Southern Arizona Homebuilders Alliance

Southern Arizona Leadership Council

Startup Tucson

Sunnyside School District

Sustainable Tucson

Technicians for Sustainability

Tohono O'odham Nation

Tortolita Alliance

Trees for Tucson

Tucson Association of Realtors

Tucson Electric Power

Tucson Metro Chamber

Tucson Metropolitan Chamber of Commerce

Tucson Residents for Responsive Government

Tucson Young Professionals

University of Arizona

Visit Tucson

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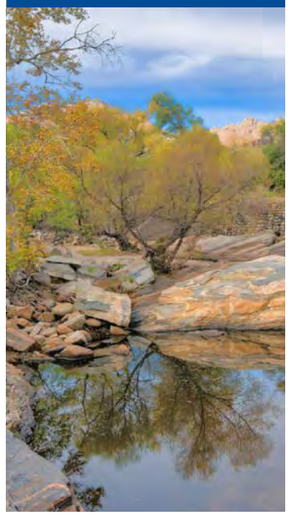
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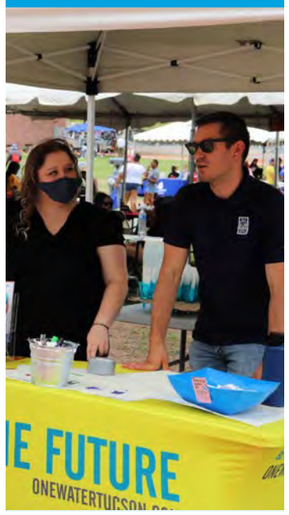
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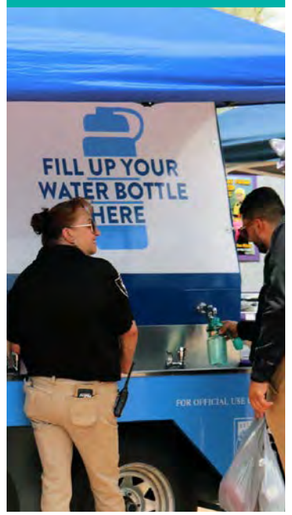
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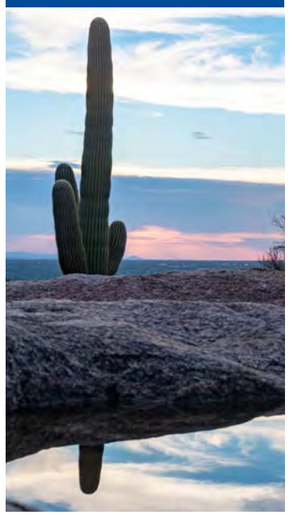
















ABBREVIATIONS

ac-ft ..... acre-feet
Act ..... Arizona Groundwater Management Act
ADEQ ..... Arizona Department of Environmental Quality
ADWR ..... Arizona Department of Water Resources
AFY ..... acre-feet per year
AMA ..... active management area
AMI ..... Advanced Metering Infrastructure
AOP ..... advanced oxidation process
APW ..... Arizona Project WET
ASL ..... American Sign Language
AWBA ..... Arizona Water Banking Authority
AWS ..... Assured Water Supply
BCE ..... Before Common Era
CAGRD ..... Central Arizona Groundwater Replenishment District
CAP ..... Central Arizona Project
CAVSARP ..... Central Avra Valley Storage and Recovery Project
CAWCD ..... Central Arizona Water Conservation District
CCF ..... 100 cubic feet
CE ..... Common Era
CIP ..... Capital Improvement Program
City ..... City of Tucson
County ..... Pima County
CWAC ..... Citizens' Water Advisory Committee
DAWS ..... Designation of Assured Water Supply
DCP ..... Drought Contingency Plan
DPR ..... direct potable reuse
E ..... education
EEExchange ..... Environmental Education Exchange
EPA ..... Environmental Protection Agency
gpcd ..... gallons per capita per day
GSI ..... green stormwater infrastructure
GW ..... groundwater
GWAICC ..... Governor's Water Augmentation, Innovation & Conservation Council
HET ..... high-efficiency toilets
HFPO-DA ..... hexafluoropropylene oxide dimer acid
HI ..... Hazard Index
HOA ..... homeowner association
I ..... incentive
IGA ..... intergovernmental agreement
IPR ..... indirect potable reuse
LID ..... low impact development
LTSC ..... long-term storage credits
MCL ..... maximum contaminant level
MCLG ..... maximum contaminant level goals
MM ..... mandates and measures
msl ..... mean sea level
NPR ..... non-potable reuse
O&M ..... operations and maintenance
PAG ..... Pima Association of Governments
PFAS ..... per- and polyfluoroalkyl substances
PFBS ..... perfluorobutane sulfonic acid
PFHxS ..... perfluorohexane sulfonic acid
PFNA ..... perfluorononanoic acid
PFOA ..... perfluorooctanoic acid
PFOS ..... perfluorooctyl sulfonate
Plan ..... One Water 2100 Plan
PMRRP ..... Pima Mine Road Recharge Project
RW ..... recycled water
S ..... stormwater
S2S ..... Storm to Shade
SAHBA ..... Southern Arizona Home Builders Home Association
SAVSARP ..... Southern Avra Valley Storage and Recovery Project
SHARP ..... Southeast Houghton Area Recharge Project
SW ..... surface water
TARP ..... Tucson Airport Remediation Project
TM ..... technical memorandum
WRF ..... Water Research Foundation

EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

VISION STATEMENT

One Water is Tucson's commitment to resilience, equity, stewardship, and quality of life.

The One Water 2100 Plan (Plan) is a comprehensive, long-range water resource management plan that aims to protect the reliability and quality of Tucson's water supply through 2100. The Plan looks at managing Tucson's water supply under changing and uncertain conditions and is intended to serve as a guide for Tucson Water's capital planning and conservation practices. Tucson has a history of proactive and adaptive water resource planning. Approximately every ten years the utility updates its long-range water resource plan. This Plan centers the One Water approach, which is an approach for managing water resources for long-term resilience and sustainability, meeting both community and ecosystem needs. The One Water approach values all types of water resources recognizing the interconnectedness of the surface water and groundwater supply, recycled water, and rain and stormwater harvesting.

A distinguishing feature of the One Water approach is the emphasis on public engagement, partnerships, and collaboration as keys to achieving progress. Throughout the development of the Plan, public engagement and feedback were key in defining vulnerabilities, opportunities, strategies, and actions for achieving a sustainable and resilient water future for the City of Tucson (City). The robust community engagement process, described in Chapter 2, began with surveys, interviews, and workshops to gather input from Mayor and Council, Tucson Water staff, and the public. The Vision Statement and five Guiding Principles for the Plan were formed based on this feedback.



Tucson takes an integrated water resource management approach that recognizes that all water has value.

GUIDING PRINCIPLES

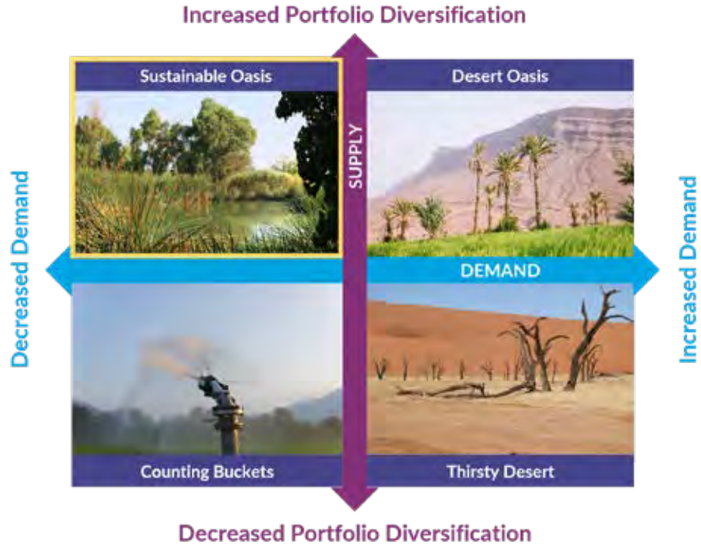
One Water is Tucson's commitment to resilience, equity, stewardship, and quality of life.

1. **Deliver reliability** through water supply diversification, conservation, and innovative improvements to infrastructure.
2. **Reinforce resiliency** by planning for climate change, leading mitigation efforts, and implementing collaborative and adaptive strategies.
3. **Enhance the community's quality of life** by preserving and restoring riparian areas, increasing urban tree canopy, and supporting economic growth.
4. **Achieve affordability, accessibility, and social justice** by committing to fiscal responsibility and prioritizing equitable projects and programs.
5. **Ensure public confidence with safe, high-quality water supplies** and exceptional customer service that includes transparency and responsiveness.

SCENARIO PLANNING

Scenario planning, a foresight tool used to develop flexible strategies under uncertainty, was used to identify vulnerabilities and opportunities for Tucson's water future and to develop potential solutions for the areas of greatest concern. Through the scenario planning process, community stakeholders identified increased supply diversification, with an emphasis on locally controlled supplies, and increased demand management as the most important opportunities. Over-reliance on supplies from the Colorado River, climate change, and factors such as population trends increasing water demand were identified as the biggest vulnerabilities.

Future supply and demand uncertainties were combined into an overarching matrix for four future scenarios. This matrix, shown to the right, ranges from a future world with increased supply portfolio diversification and decreased demands (*Sustainable Oasis*) to a future with decreased supply portfolio diversification and increased demands (*Thirsty Desert*). With input from stakeholders and the community, Tucson Water is planning for a future where the region's water supply portfolio is increasingly diversified and water demands are well managed. Overall, the goal of this Plan is to develop strategies that will lead us toward a *Sustainable Oasis* future and mitigate the risks of the *Thirsty Desert* scenario.



PLAUSIBLE FUTURE SCENARIOS

In this overarching matrix, plausible future scenarios depend on both portfolio diversification and water demands.

COMMUNITY ENGAGEMENT

As described in Chapter 2, the community was engaged in the Plan development through a series of community stakeholder workshops, a public town hall, public event booths, presentations, interviews, and a broad online survey that illuminated the community's priorities, concerns, and interests regarding water management. The community engagement process included outreach with stakeholder groups with diverse backgrounds, languages, and life experiences.

STAKEHOLDER WORKSHOPS

A series of workshops with community members was held focusing on identifying strategies that capitalize on the key opportunities and mitigate the key vulnerabilities identified through the scenario planning process. Strategies developed within these workshops addressed each of the Plan's five Guiding Principles. An emphasis was placed on strategies for demand management and for each water supply type, namely surface water, stormwater, recycled water, and groundwater.

VULNERABILITIES AND OPPORTUNITIES

The scenario planning process for Tucson Water identified key vulnerabilities and opportunities for water supply portfolio diversification and demand management. Supply vulnerabilities include over-reliance on the Colorado River, and the potential for the reduction of available water within each of the existing renewable water supplies due to drought, climate change, and other factors. Opportunities to further diversify the water supply portfolio include increasing the use of locally controlled and distributed sources, such as recycled water and rainwater and stormwater harvesting. Key vulnerabilities related to future water demands include population growth, land use changes, and economic factors. Opportunities for water demand management include developing and implementing a consistent and effective public outreach and education campaign to build on Tucson Water's strong existing water conservation programs.



PUBLIC TOWN HALL

During the public town hall held in August 2022, Tucson Water introduced the Plan and its key elements to the nearly 300 in-person attendees.

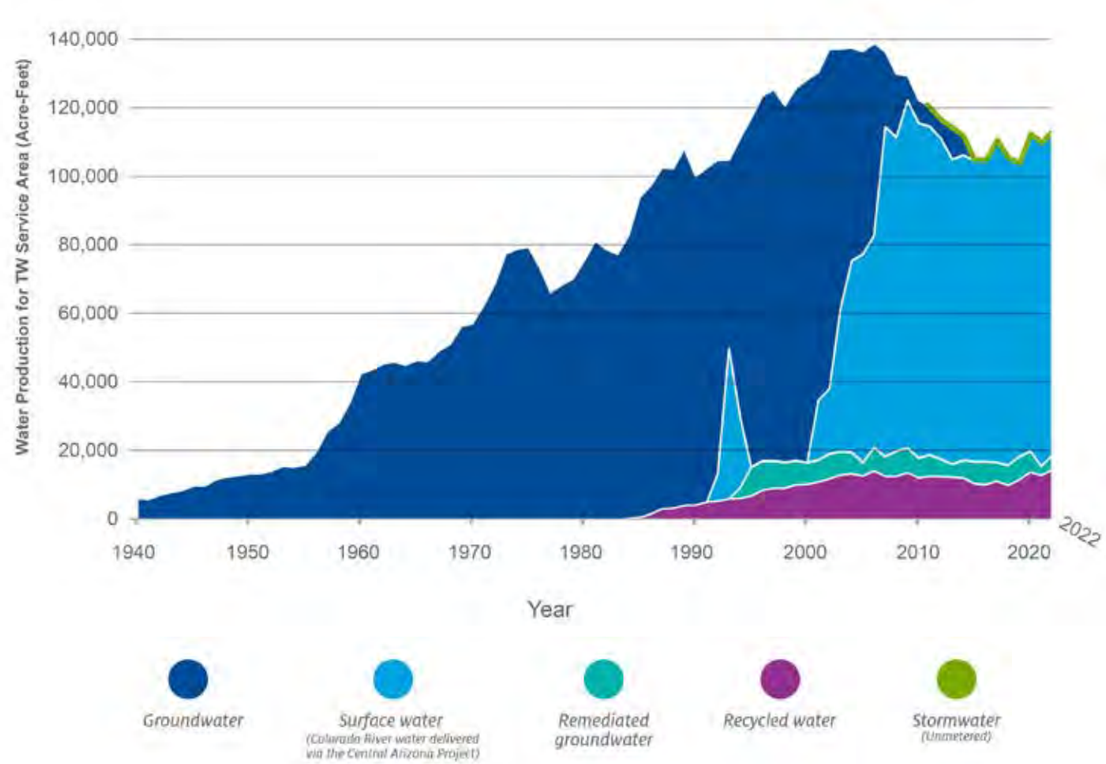


COMMUNITY OUTREACH

One of the stakeholder workshops.

TUCSON WATER MANAGEMENT HISTORY

The evolution of Tucson Water's supply diversification history is depicted in the figure below. As shown, since the early 2000s, there has been a transition from reliance on groundwater to a diverse mix of renewable water supplies. Tucson became one of the first communities in the nation to recycle treated wastewater at a large scale for landscape irrigation. The introduction of renewable Colorado River water delivered via the Central Arizona Project (CAP) has allowed Tucson Water to move toward renewable supplies as the primary source of drinking water. In recent decades, Tucson has become a nationally recognized leader in rainwater harvesting, water recycling, and conservation. The community's commitment to water conservation is also evident as total water use has declined since the early 2000s despite continued population growth in the City's service area. This phenomenon is known as "decoupling," meaning water demand is no longer increasing along with population growth. The use of recycled water and stormwater helps move Tucson Water towards using each drop of water more than once, where possible. This means using less potable, and potentially less reclaimed water, on landscaping and using harvested storm and rainwater to offset these demands. Tucson's water supplies are discussed in Chapter 3 and water use and demand management are covered in Chapter 4.



HISTORICAL USE OF WATER SUPPLY SOURCES FROM 1940-2022

While historically Tucson relied on groundwater, Colorado River water is now the main supply of potable water for Tucson. Additional water sources in Tucson Water's portfolio include recycled water, remediated groundwater, and stormwater.

TUCSON'S WATER FUTURE

Scenario projections were developed to support the Plan process. As described in Chapter 4, a comparison of supply and demand projections through 2100 was completed for the four plausible futures identified in the scenario planning process. Graphs of the projected supply and demand balances are included on pages 53 and 54. The purpose of this comparison is to characterize the uncertainty related to the current water supply portfolio. Each scenario considers a different combination of water demand and water supply portfolio assumptions. The key water demand variables are gallons per capita per day and population growth. The key water supply variable is the City's allocation of Colorado River water. In all four scenarios, Tucson Water has sufficient supplies to meet demand through the year 2100. Under the *Sustainable Oasis* scenario, Tucson Water would be able to meet demands with renewable supplies and continue storing Colorado River water underground for future use. Under the *Thirsty Desert* scenario, storage credits are needed to meet future demand and Tucson Water begins to rely on groundwater resources again.

Tucson Water will use the strategies described in the Plan to avoid the risks of the *Thirsty Desert* scenario and work towards the *Sustainable Oasis* future where the water supplies are diverse, locally controlled, and water demands are well managed.

PRIORITIZATION OF STRATEGIES

Based on feedback from the stakeholders and the community, 40 strategies were crafted by Tucson Water to achieve the Plan vision and five guiding principles. A public survey was conducted to understand the community's opinions on the proposed water supply and demand management strategies and to inform the Plan development. The survey focused on supply and demand management strategies as they were the areas identified as the most important and most uncertain in the scenario planning processes. The results of the survey were used to rank and prioritize the list of strategies. In total, the Plan identifies 16 high priority strategies across the water supply and demand management categories which are listed below.

Supply - Surface Water (SW) Strategies

- SW-1: Maximize the benefits of our current Colorado River water.
- SW-2: Work with the State of Arizona to explore additional water supplies for the Central Arizona Project.
- SW-3: Advocate for Tucson's allocation of Colorado River water through the Central Arizona Project in state and federal negotiations.

Supply - Groundwater (GW) Strategies

- GW-1: Partner with regional water organizations to protect the aquifer.
- GW-2: Accelerate groundwater cleanup efforts to make local supplies more available.
- GW-3: Explore and invest in new treatment technologies to address unregulated, emerging water quality issues.

Supply - Recycled Water (RW) Strategies

- RW-1: Adopt new policies for water reuse in buildings.
- RW-2: Begin purifying recycled water to drinking water standards.
- RW-6: Implement treatment technologies to address unregulated, emerging water quality issues.

Supply - Stormwater (S) Strategies

- S-1: Explore opportunities for large scale stormwater projects with multiple benefits.
- S-2: Integrate and align stormwater standards, policies, and practices across the region.

Demand Management - Incentive (I) Strategies

- I-1: Improve outreach for low-income assistance programs for homeowners and renters.
- I-2: Increase water savings opportunities through incentive programs for residential and commercial customers.

Demand Management - Monitoring and Mandates (MM) Strategies

- MM-1: Install "smart meters" that monitor water use in real time, provide leak alerts, and inform water use habits.

Demand Management - Education (E) Strategies

- E-1: Conduct research on new technologies and approaches.
- E-2: Provide landscape training to reduce outdoor water use, with emphasis on resilient, desert-adapted landscapes.

IMPLEMENTATION ACTIONS

Implementation actions are the specific projects, programs, policies, and/or tools that the City and Tucson Water will use to implement each of the recommended strategies. A total of 66 implementation actions across the water supply and demand management categories were identified and are described in Chapter 6. These implementation actions define sequential efforts that Tucson Water can undertake for each strategy. As an example, for strategy RW-2: *Begin purifying recycled water to drinking water standards*, there are 7 sequential implementation actions identified. These actions start with participation in the regulatory process and conducting a cost-benefit evaluation, a barrier survey, and a public outreach campaign, and ultimately lead to the implementation of a demonstration-scale and full-scale reuse project. Each strategy is accompanied by a relative expense and a relative level of effort while each implementation action has an implementation timeline. The full list of implementation actions is included in Chapter 6. Each of these actions takes time to undertake and adaptive management may be needed to refine the next steps as appropriate. Implementing the highest priority strategies will steer Tucson Water toward a more resilient water future and will help mitigate the risks of climate change.



TUCSON WATER STAFF AT WORK

PLAN IMPLEMENTATION

Several metrics were developed to evaluate progress on Plan implementation and are shown in Chapter 6. These metrics will be used to gather data, update figures and graphs, and promote transparency to the public. The implementation of Plan recommendations must also adapt to changing conditions. While near-term policies can be implemented now to address immediate needs, the mid-term and long-term strategies will be regularly reevaluated as conditions change and new information becomes available and as community priorities evolve. Chapter 6 includes an adaptive management table with metrics, quantitative triggers, and adaptive measures for demand management and the water supply portfolio. Key metrics include the historic water production chart, which will continue to be updated throughout the Plan implementation process to show the total volume produced by new water supply projects, and any changes in water production over time. The gpcd metric will also be a key indicator of whether demand is being reduced. This approach allows for flexibility and agility in response to evolving conditions, while still maintaining a long-term vision for a resilient and sustainable water supply.

REPORTING

An annual progress report will be shared with the public to provide a progress update on the implementation of the Plan recommendations. These annual reports will summarize progress on the metrics described below as well as any other Plan related activities such as the completion of new projects, adoption of new policies, and community engagement activities.

CHAPTER 1
INTRODUCTION

INTRODUCTION

WHY "ONE WATER"?

One Water is an evolving approach for managing water resources for long-term resilience and sustainability, meeting both community and ecosystem needs. This approach values all types of water resources, and considers the water cycle as an integrated system, recognizing the interconnectedness of the surface water and groundwater supply, recycled water, and rain and stormwater harvesting.

The One Water approach represents a shift in the way we manage our water resources. Traditionally, regulatory and governance structures have managed water in separate institutional silos. One Water provides a transition to an integrated planning approach that fosters collaboration between organizations and the communities they serve.

A distinguishing feature of the One Water approach is the engagement of stakeholders and partners. One Water emphasizes the idea that partnerships and collaboration are key to progress. When a diverse group of stakeholders, community members, and organizations come together, a wide variety of interests are considered to define more holistic water management solutions to achieve a more resilient and sustainable water future. Utilizing the One Water approach helps the City of Tucson (City) plan to better meet future conditions by expanding Tucson Water's resource portfolio and laying the foundation for strong lasting partnerships to make Tucson's One Water vision a reality.



Tucson takes an integrated water resource management approach that recognizes that all water has value.

Elements of the One Water Approach

The Water Environment and Reuse Foundation (now the Water Research Foundation or WRF) examined the transition to a One Water approach in Pathways to One Water: A Guide to Institutional Innovation. This 2015 study identified the following six key elements that contribute positively to a One Water approach:

1. Strong leadership and vision from senior positions, at both political and executive levels
2. Partnerships between departments and collaborating organizations
3. Organizational culture that embraces the One Water approach
4. Transparent engagement with the community and stakeholders
5. A conducive economic environment for private investments
6. A conducive regulatory and legislative environment for encouraging public and private participation

Moving toward One Water requires a vision of what cities and water systems can look like, active engagement of local stakeholders, and refinement of roles and responsibilities. For the One Water approach to be integrated into the City's infrastructure planning, an institutional structure needs to be in place, one that encourages innovation and supports alternative and decentralized approaches to integrated water management. These key elements informed the City and Tucson Water's planning process.

WHAT IS THE ONE WATER 2100 PLAN?

The One Water 2100 Plan (Plan) is a comprehensive, long-range water resource management plan that aims to protect the reliability and quality of Tucson's water supply under changing conditions through the year 2100. The Plan guides Tucson Water's capital and financial planning, conservation practices, and provides information to support policy decisions.

Role of the Plan

City leaders, elected officials, staff, and the community should look to the Plan as the guide for developing, implementing, and refining important water policies, as well as making water system management and investment decisions. These Plan partners should use the Plan and its supplements to:

- Provide a framework and common goals for water planning and management within the Tucson Water service area.
- Guide changes to local water policy and regulations.
- Inform the City's resource, budgeting, and demand management decisions.
- Support participation in regional planning and partnerships.
- Promote continuous engagement of the community and stakeholders.
- Evaluate and measure progress toward achieving defined One Water goals.

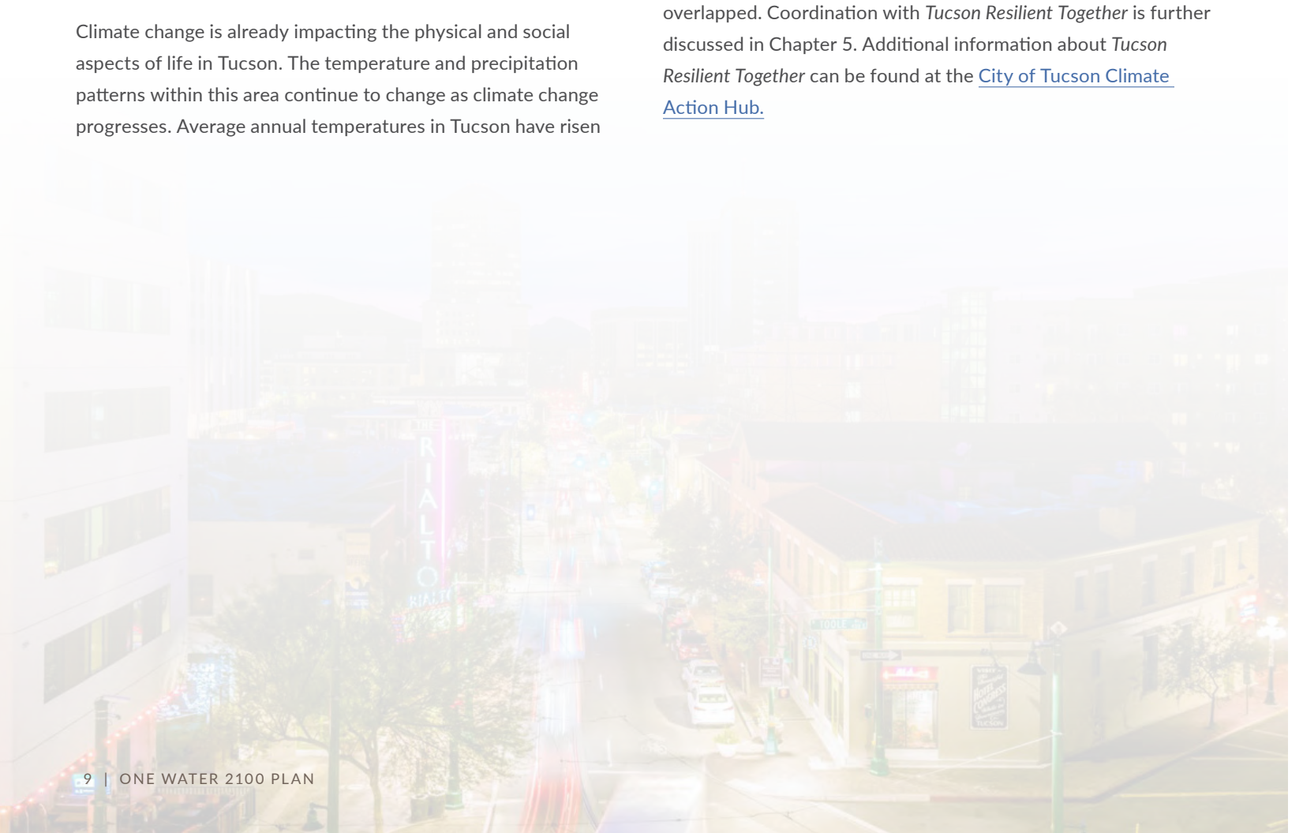
ABOUT TUCSON WATER

The City was founded in 1775 and has since grown to be part of the second largest metropolitan area in Arizona. Tucson is located within Pima County and the City currently has a population of nearly 550,000, while the metropolitan area has a population of just over 1 million. Tucson is located at nearly 2,400 feet above sea level in the Sonoran Desert, a geography that presents substantial water supply challenges for a growing community. The City sits in the Tucson Basin, surrounded by the Rincon, Santa Rita, Santa Catalina, Sierrita, Tortolita, and Tucson Mountains.

The Sonoran Desert is characterized by its arid hot climate and seasonal rainfall pattern. On average, Tucson receives just under 12 inches of rainfall a year, increasing to as much as 29 inches per year on the highest peak above the City, Mount Lemmon. From December to March, frontal storms originating in the North Pacific bring occasional gentle rain. The summer monsoon, from July to mid-September, brings surges of wet tropical air and localized deluges in the form of violent thunderstorms. The area generally has mild winters, but summer months can see prolonged stretches of extreme heat.

Climate change is already impacting the physical and social aspects of life in Tucson. The temperature and precipitation patterns within this area continue to change as climate change progresses. Average annual temperatures in Tucson have risen by nearly 4.5 degrees Fahrenheit from 1970 to 2018, making Tucson among the fastest warming cities in the United States. The National Climate Assessment attributes the increasing temperatures to both climate change and the urban heat island effect (when temperatures increase because of solar energy being absorbed by pavement and other building materials). The impacts of climate change on the Tucson region are further discussed in the Tucson Water November 2021 Technical Memorandum (TM), *One Water 2100 Climate Projections* is included in Appendix A. Additionally, the September 2021 TM, *One Water 2100 Greenhouse Gas Emissions Inventory* looked specifically at Tucson Water's greenhouse gas emissions in 2018. This TM is included in Appendix B.

In early 2023, the Mayor and Council adopted the Climate Action and Adaption Plan also known as *Tucson Resilient Together.* This document outlines the City's roadmap for reducing greenhouse gas emissions and building community-wide resistance to current and future impacts from climate change. In many ways, *Tucson Resilient Together* and the Plan are closely related and the planning process for *Tucson Resilient Together* and the Plan overlapped. Coordination with *Tucson Resilient Together* is further discussed in Chapter 5. Additional information about *Tucson Resilient Together* can be found at the City of Tucson Climate Action Hub.



Geographic Setting



Downtown Tucson

Downtown Tucson with views of the Santa Catalinas and Rincon Mountains.



Santa Catalina Mountains

The Santa Catalinas are a prominent mountain range to the north of Tucson area, with a peak elevation of 9,157 feet on Mount Lemmon.



Sonoran Desert

The saguaro cactus (Carnegiea gigantea) is a large, iconic cactus species native to the Sonoran Desert.



Monsoon Storm in the Sonoran Desert

A summer monsoon storm brings intense rainfall, lightning, and strong winds. More than half of Tucson's annual rainfall occurs during the summer monsoon season.

Water Management

Tucson Water has delivered water to City residents and businesses as a municipally owned and operated water utility since 1901. Tucson Water is responsible for the delivery of high quality, safe, and reliable drinking water, as well as management of Tucson's Reclaimed Water System. The Plan identifies actions that Tucson Water can take to work toward a resilient water future for its service area. Partnership with multiple other agencies will be required to achieve many of the goals and strategies outlined within the Plan.

Key Partner Roles and Responsibilities

Central Arizona Project
Regional surface water importer and distributer.

Arizona Department of Water Resources
Statewide water use regulatory agency.

Arizona Department of Environmental Quality
Administers Arizona's environmental laws and delegated federal programs to prevent air, water, and land pollution and ensure cleanup.

Tucson Department of Transportation and Mobility
Stormwater management infrastructure.

Tucson Department of Parks and Recreation Stormwater management infrastructure.

Pima County Flood Control
Flood monitoring, flood control and floodplain management, activities.

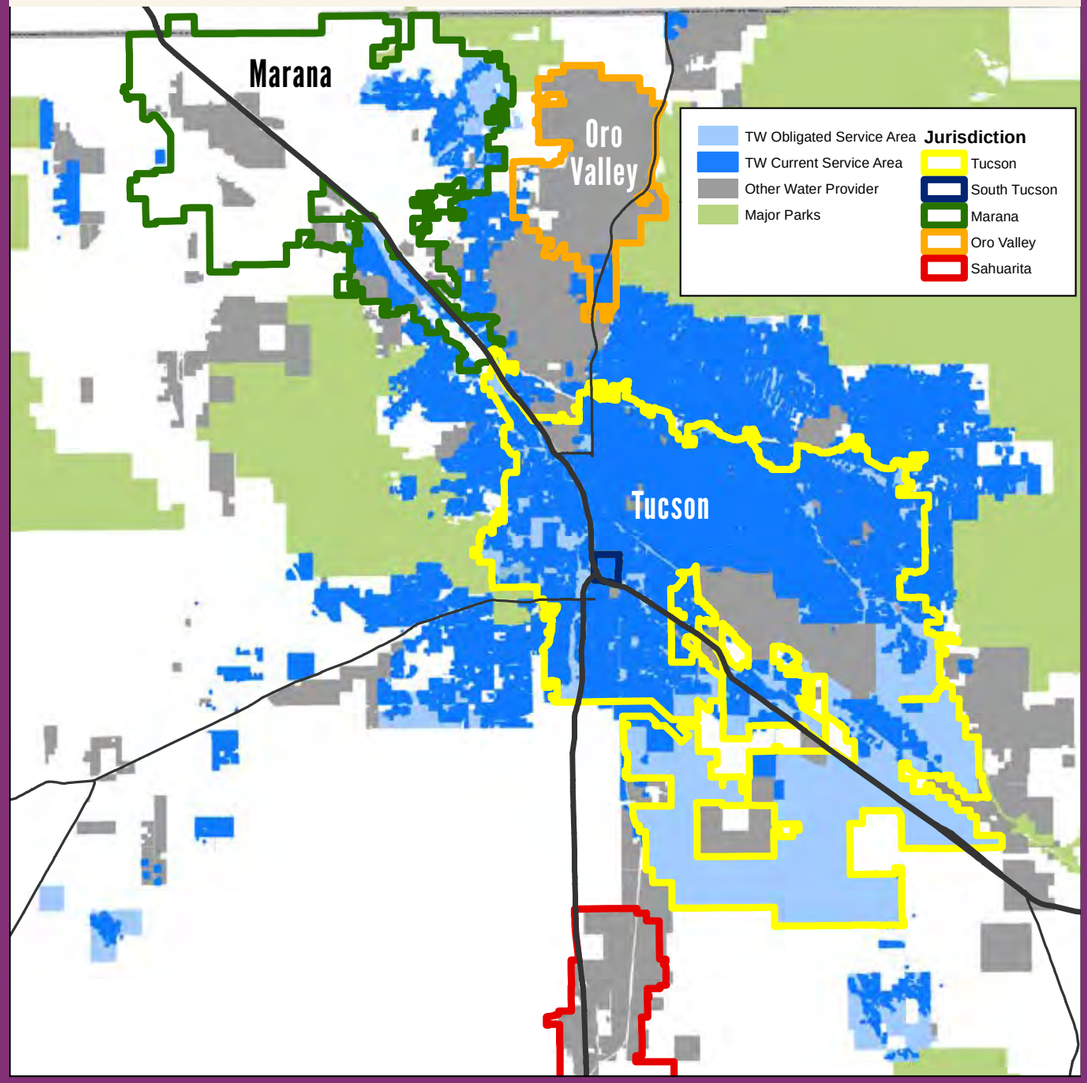
Pima County Regional Wastewater Reclamation Department
Wastewater collection, treatment, and discharge.

Water Service Area

The City established the Tucson Water service area boundary in 2010 with the adoption of a formal Water Service Area Policy. Tucson Water currently serves nearly 750,000 people. The current service area spans 390 square miles across several jurisdictions, with about 42 percent of the geographic area lying within the City limits, nearly 53 percent in unincorporated Pima County, and the remaining 5 percent in the neighboring towns, including Marana and Oro Valley. The following figure illustrates the extent of the current service area. The "Obligated Service Area" includes areas that Tucson Water is required to serve in the future. Outside of the Obligated Service Area, new water service requires submittal to Tucson Water for review with compliance with the Water Service Area Policy and approval of a water availability request subject to review by the Water Service Area Review Board. All new services must comply with the Water Service Area Policy.

Other significant water providers in the area include Metro Water District, the Town of Oro Valley, the Town of Marana, Flowing Wells Irrigation District, and Vail Water. Tucson Water has common interests with these providers and provides some indirect services for areas outside the obligated service area. These include providing emergency backup supplies and helping to recharge and recover water supplies owned by other providers. Mayor and Council have Intergovernmental Agreements (IGAs) with the Pascua Yaqui Indian Nation, the Town of Oro Valley, the Town of Marana, Vail Water Company, and the Metro Water District to take delivery of some or all their CAP allocations and then move the recovered water through Tucson Water's distribution system. These are referred to as wheeling agreements.

Tucson Water Service Area



The Tucson Water service area includes areas within the City of Tucson, unincorporated Pima County, and neighboring towns such as Oro Valley and Marana.

TUCSON WATER MANAGEMENT HISTORY

Tucson's water heritage spans millennia. As early as 2,100 Before Common Era (BCE), there were villages along the Santa Cruz River in the heart of what would become Tucson. By 1,200 Common Era (CE), the Hohokam used the Santa Cruz River for drinking water, irrigation, and fishing. Indigenous peoples have continuously inhabited this arid region from prehistoric times to today, pioneering water harvesting and dryland farming techniques and creating the oldest known irrigation canals in North America.

Throughout the 20th century, Tucson's expansion relied on groundwater, eventually becoming the largest city on the continent to be entirely dependent on groundwater. Over-pumping of groundwater dried up local springs, wells, and creeks including the Santa Cruz River. As the region pulled water from the aquifer faster than it was replenished, the land in some areas began to subside, putting buildings and infrastructure at risk. This period brought with it a recognition that Tucsonans embrace to this day—water is a precious and vulnerable resource in our desert city.

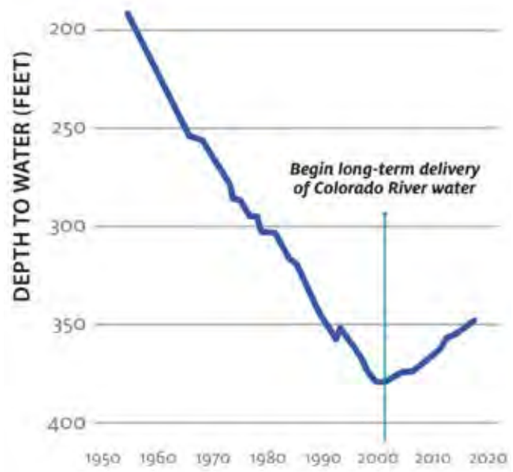
With groundwater levels declining, Tucson started taking steps to plan for and adapt to future water uses. In 1984, Tucson became one of the first communities in the nation to recycle treated wastewater at a large scale for landscape irrigation. Today, most local golf courses and parks rely on Tucson Water's Reclaimed Water System, which has grown to be one of the largest in the country. In the later part of the 20th century, Tucson initiated robust conservation programs including education, rebates, and outreach for residential and commercial customers. Tucson Water's community conservation campaigns were effective in instilling a culture of responsible water resource management among new generations.

The introduction of renewable Colorado River water delivered via the CAP has allowed Tucson Water to move from finite groundwater resources toward renewable Colorado River water as the primary source of drinking water. CAP water is sourced from the Colorado River and delivered to Tucson by a series of canals, then recharged into the aquifer and recovered for use within the Tucson Water service area. A smaller portion of the Colorado River water is used directly by local agriculture recovered by Tucson Water through saved groundwater credits. For more than 20 years, Tucson Water has served this water to customers and stored available excess Colorado River water for the future. Colorado River water stored underground in the Avra Valley has become a "savings account," a backup supply to draw on in drier years. As groundwater pumping has reduced, aquifers have begun to recover, rising more than 100 feet near downtown Tucson.



SANTA CRUZ RIVER

The Santa Cruz River as seen from Sentinel Peak in Tucson in the early 1900's. (Arizona Historical Society)



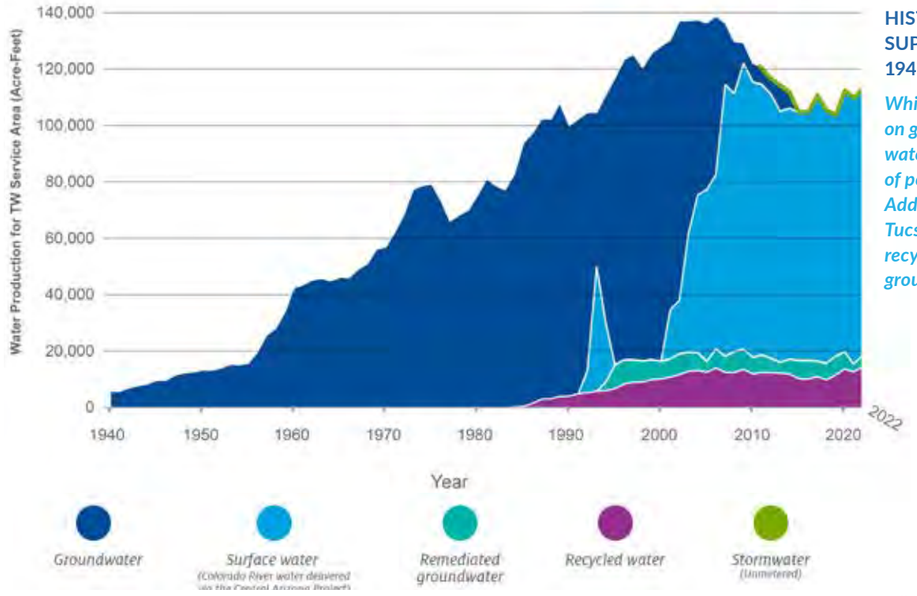
WELL HYDROGRAPH NEAR BROADWAY BOULEVARD AND WILMOT ROAD

This well hydrograph shows rising water levels in an area of the Central Well Field after 2001 when Tucson Water began the long-term delivery of Colorado River water to customers and substantially reduced groundwater pumping in this area.

Water levels in the Central Well Field area began rising in 2001, when Tucson Water began the long-term delivery of Colorado River water to customers and substantially reduced groundwater pumping in this area. The figure on the left shows a well hydrograph of a well near Broadway Boulevard and Wilmot Road. A well hydrograph is a chart of water levels measured over time in a single well.

In recent decades, the Tucson community has become known as a national leader in rainwater harvesting, water recycling, and conservation. One culmination of these efforts came in 2019, when the Santa Cruz River near downtown began to flow again after 100 years due to reclaimed water released from local water reclamation facilities at the Santa Cruz Heritage Project. Tucson Water's diverse water supply portfolio and groundwater savings makes Tucson one of the most water resilient cities in the Southwestern United States.

The evolution of Tucson Water's supply diversification history can be seen in the following figure, with a dramatic transition from its sole reliance on groundwater to a more diverse mix of water supplies in the early 2000s. The community's commitment to water conservation is also evident in the figure, with total water use declining since the early 2000s despite continued population growth in the City's service area.



HISTORICAL USE OF WATER SUPPLY SOURCES FROM 1940-2022

While historically Tucson relied on groundwater, Colorado River water is now the main supply of potable water for Tucson. Additional water sources in Tucson Water's portfolio include recycled water, remediated groundwater, and stormwater.

Tucson Water Plan



Tucson has a history of proactive and adaptive planning, and this has been a cornerstone of the area's water security and resilience. Tucson Water updates its long range plan about every 10 years. In 2004, *"Water Plan: 2000-2050"* was published with a stated purpose "to initiate a dialog between Tucson Water and the community about the water resources challenges that must be addressed in the coming years". This statement reaffirmed Tucson Water's commitment to hearing the voice of the community on water issues. This commitment continues today through the development of this One Water 2100 Plan and can be seen through the wide range of community engagement activities held throughout the Plan development process.

Water Plan: 2000-2050, along with updates to the plan in 2008 and 2012, laid out the challenges and opportunities to maintain water reliability for the Tucson community. The policies identified in these plans led to positive changes in the water supply. Between 1940 and 2000, water levels in Tucson's central well field had dropped significantly. Planning and foresight reversed this and changed the trajectory of groundwater use. Reliance on non-renewable groundwater has reduced and the beneficial use of renewable sources such as Colorado River water delivered through the CAP and recycled water have expanded.

Drought Preparedness and Response Plan



Tucson Water's *Drought Preparedness and Response Plan* was first published in 2006. This plan outlines the City's response measures in the case of a drought on the Colorado River. Minor revisions were made to the plan in 2012 and 2017. A major revision was approved in 2020 to align the drought stages in the City's plan with the *2019 Colorado River Drought Contingency Plan*, an agreement between the seven Colorado River Compact states on how to share Colorado River water.

Response measures in the Drought Preparedness and Response Plan informed the strategies developed for the Plan. Measures focus on the City leading by example and implementing response actions before customers are asked to and developing and communicating water use guidelines to customers. The *Drought Preparedness and Response Plan* may need to be updated if the Drought Contingency Plan is no longer the operational guidance for shortage sharing on the Colorado River.



Plan Tucson



The ongoing update to the City's general plan includes multiple components united under the umbrella of Plan Tucson which aims to take community goals and translate them into City policies and actions. Plan Tucson focuses on the social, economic, built, and natural environments and information about the plan update can be found at Plan Tucson. The One Water 2100 Plan, including its goals and strategies, will be incorporated into Plan Tucson. The following additional plans will also be incorporated into the general plan update:

TUCSON RESILIENT TOGETHER

Adopted in March 2023, this plan provides a strategic pathway to reduce the City's greenhouse gas emissions to net zero by 2030. Many of the strategies and actions defined in *Tucson Resilient Together* also support guiding principles of the Plan.

MOVE TUCSON

Adopted in 2021, this city-wide Transportation Master Plan identifies hundreds of projects that focus on modernizing the transportation network, improving safety for all users, and increasing viable transportation choices and alternatives.

HOUSING AFFORDABILITY STRATEGY FOR TUCSON

Adopted in 2021, this plan introduces housing concepts, key data, and policy initiatives to work toward housing affordability.

THE PEOPLE, COMMUNITIES, AND HOMES INVESTMENT PLAN

Adopted in 2021, this plan builds on previous community plans, public outreach, and up-to-date data to create a framework for investing in vulnerable populations throughout the City.

CHAPTER 2

COLLABORATIVE PLAN DEVELOPMENT

COLLABORATIVE PLAN DEVELOPMENT

THE PLANNING PROCESS

The Plan was developed through an active and collaborative stakeholder-driven process. The robust community and stakeholder engagement process included the following four distinct phases:

2019 - 2020	2021	2022 - 2023	2024
SET THE FOUNDATION	ESTABLISH DIRECTION	COMMUNITY ENGAGEMENT AND ADOPTION	IMPLEMENTATION

Phase 1 – Set the Foundation

The project started in June 2019 with the collection of ideas from The City's leadership including Mayor and Council, Tucson Water's Director's Office, and the Citizens' Water Advisory Committee (CWAC). Information collected from a series of workshops, surveys, and interviews was used in planning for the engagement of a broader community stakeholder group.

Phase 2 – Establish Direction

Tucson Water conducted scenario planning engagement activities from March 2020 to June 2021 that included workshops and surveys with a diverse group of community stakeholders. These workshops were used to explore uncertainties, risks, and develop a range of potential future scenarios. Although the COVID-19 pandemic put a temporary pause on the planning process, Tucson Water was able to pivot and utilize virtual workshops to maintain momentum in the stakeholder engagement process. The areas of greatest concern were identified as future water supplies and demands.

Phase 3 – Community Engagement and Adoption

The community engagement process began with a public Town Hall held in August 2022. Between September and November 2022, three additional stakeholder workshops were hosted to develop strategies and actions related to the areas of greatest concern identified during the scenario planning process. Ambassadors from Tucson Water conducted outreach through community and neighborhood events to increase awareness of the Plan. Presentations were provided upon request and interviews were conducted with several stakeholders. Additionally, a survey was conducted to collect feedback about the supply and demand strategies. An online version of the survey was posted on the City's TucsonOneWater.com website, and a statistically valid version of the survey was conducted to help inform the development of the plan. The Plan went through an extensive vetting process including reviews by Tucson Water leadership, CWAC, and Mayor and Council. During the public comment period, over 80 individuals and organizations submitted comments. Feedback from the community was incorporated into the Plan in 2023.

Phase 4 – Implementation

Following the adoption by the Mayor and Council, the implementation of the Plan will begin in 2024. The prioritized strategies will inform Tucson Water's Capital Improvement Program (CIP). The planning team will monitor progress and evaluate the effectiveness of the Plan through the metrics. Progress reports on the Plan relative to those metrics will be developed and shared with the community. Plan implementation is described in Chapter 6.

SETTING THE FOUNDATION

Workshops, surveys, and interviews with Tucson Water staff, City staff, Mayor, and Council resulted in the identification of the key One Water themes (resilience, equity, stewardship, and quality of life) and five guiding principles for Tucson's water future. Together these themes led to the creation of the following vision statement.

Vision Statement

One Water is Tucson's commitment to resilience, equity, stewardship, and quality of life.

RESILIENCE EQUITY STEWARDSHIP QUALITY OF LIFE

Guiding Principles

1 **Deliver reliability** through water supply diversification, conservation, and innovative improvements to infrastructure.

2 **Reinforce resiliency** by planning for climate change, leading mitigation efforts, and implementing collaborative and adaptive strategies.

3 **Enhance the community's quality of life** by preserving and restoring riparian areas, increasing urban tree canopy, and supporting economic growth.

4 **Achieve affordability, accessibility, and social justice** by committing to fiscal responsibility and prioritizing equitable projects and programs.

5 **Ensure public confidence with safe, high-quality water supplies** and exceptional customer service that includes transparency and responsiveness.



Tucson Earth Day Festival

The City of Tucson's Office of Equality defines equity as addressing the root causes of inequities by eliminating policies, practices, attitudes and cultural messages that reinforce differential outcomes by ethnicity, race, gender, age, sexual orientation, socioeconomic status, education, and persons with disabilities.

ESTABLISHING DIRECTION

Scenario Planning

Scenario planning is a foresight tool used to develop flexible strategies under uncertainty, emphasizing plausible outcomes over probable outcomes. Scenario planning has been used by organizations for decades to help prepare for uncertain futures. Tucson Water used scenario planning during the development and implementation of the recharge and recovery program used to manage Colorado River water received from the CAP.

In scenario planning, future worlds are explored that may look quite different from today by not just using the past as the predictor of the future, but instead evaluating the potential consequences if certain uncertainties evolve to more extreme conditions. Within this framework, today's decisions can be tested to see how resilient they may be to various combinations of the most impactful future uncertainties.

The scenario planning effort was supported by a series of deep dives on technical topics documented in TMs that are provided in the appendices. These TMs, in alphabetical order, include:

- One Water 2100 Benefits and Costs of the Reclaimed System.
- One Water 2100 Climate Projections.
- One Water 2100 Conservation Projections.
- One Water 2100 Greenhouse Gas Emissions Inventory.
- One Water 2100 Land Use Planning.
- One Water 2100 Population Projections.
- One Water 2100 Scenario Planning.
- One Water 2100 Smart Metering.
- One Water 2100 Water Quality Management.
- One Water 2100 Water Use Projections.

A series of scenario planning workshops was conducted to better understand critical drivers of risk and uncertainity for Tucson's water future and develop potential solutions for the areas of greatest concern. Participants in the scenario planning workshops included stakeholders representing various business, environmental, and community groups within the city. The participants developed a list of eight themed areas of concern that are both highly impactful and uncertain. Details for each area of concern are provided in the January *2022 TM One Water 2100 Scenario Planning* which is included in Appendix C.

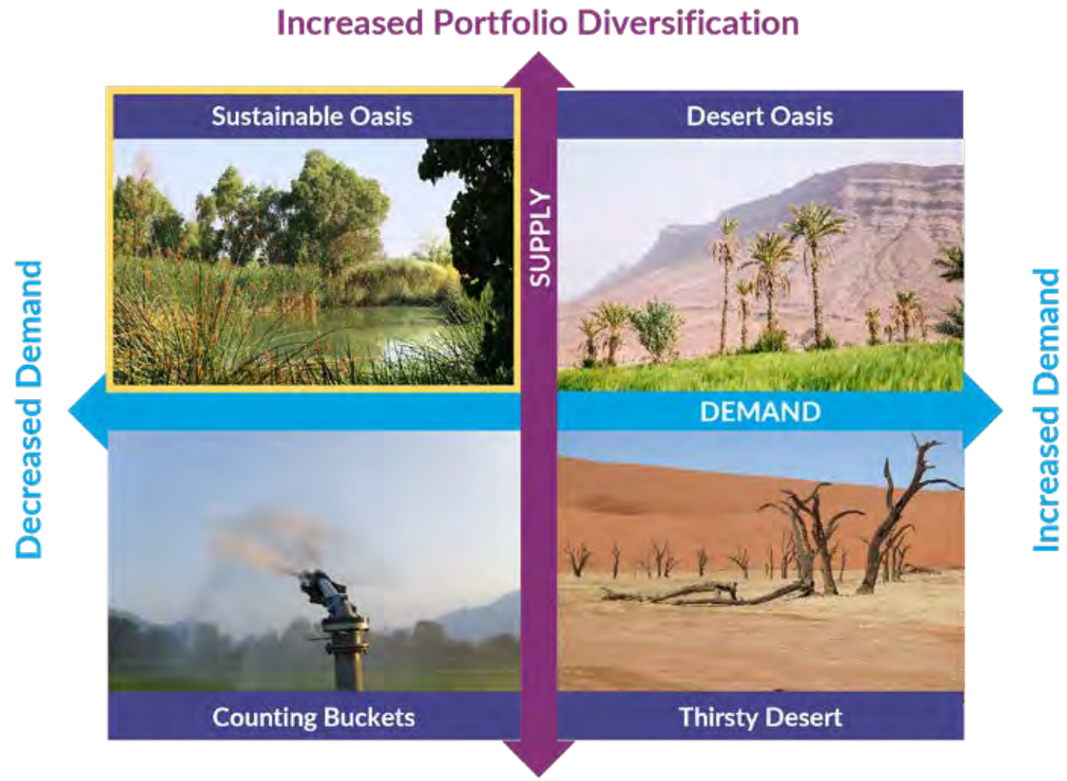
This is a list of areas of concern ranked in order from greatest concern to least:

- **Water Supply Changes –** The over-reliance on supply from the Colorado River, and supply reductions from climate change and political factors, as well as environmental risks and issues of groundwater quality.
- **Water Demand Changes –** Land uses changes due to climate and zoning, population trends, effects of water conservation, and the potential for Tucson Water to acquire other service areas.
- **System Resilience –** Water system reliability, improvements and threats to technology, and the effect of climate change on infrastructure.
- **Community/Educational Factor –** The potential for misinformation, the possibility of widespread community engagement, and public support for increased reclaimed water use.
- **Equity and Affordability –** The cost of service, realization of equality, and the impact of flooding and stormwater in lower income areas.
- **Government/Policy/Regulations –** Policy making and regulatory trends on regional, state, and federal levels, as well as state politics.
- **Water-Energy Nexus –** The ability to provide energy security, incorporate redundancy for resilience, and the ability to reduce carbon footprint.
- **Economic Variability –** Changes in the workforce, including that people entering the workforce and higher education are not choosing the trade professions, changes in business connections to water service, and rapid changes in the economy.

The workshop participants recognized that the most common, most uncertain, and most potentially impactful uncertainties were those associated directly with future supply and future demand. Future supply and demand uncertainties were combined into an overarching matrix of four future scenarios. The matrix, shown below, ranges from a future world with increased supply portfolio diversification and decreased demands *(Sustainable Oasis)* to a future with decreased supply portfolio diversification and increased demands *(Thirsty Desert)*.

To mitigate the risks of the *Thirsty Desert* future and encourage the conditions that foster a *Sustainable Oasis*, stakeholder workshop discussions were held to propose a series of recommendations for future actions. These spanned from universal recommendations to build immunity to future uncertainty to more focused solutions looking at increasing locally controlled and distributed water resources. These recommendations are discussed in further detail in Chapters 3 and 4.

With input from stakeholders and the community, Tucson Water is planning for a future where the region's water supply portfolio is increasingly diversified and water demands are well managed. Overall, the goal of this Plan is to develop strategies that will lead us toward a *Sustainable Oasis* future and mitigate the risks of the *Thirsty Desert* scenario.



PLAUSIBLE FUTURE SCENARIOS

In this overarching matrix, plausible future scenarios depend on both portfolio diversification and water demands.

COMMUNITY ENGAGEMENT

In addition to the Scenario Planning workshops, the community was engaged in the Plan development through a series of community stakeholder workshops, a public town hall, public event booths, presentations, interviews, and a broad online survey that illuminated the community's priority concerns and interests regarding water management.

The community engagement process included outreach with stakeholder groups with diverse backgrounds, languages, and life experiences. These community organizations include, but are not limited to, neighborhood associations, civic groups, chambers of commerce, business associations, medical institutions, educational institutions, environmental groups, agricultural interests, social service agencies, multicultural organizations, and disability advocates. A full list of groups who participated in the engagement process is included in Appendix D. Together, these groups represent an informed constituency who are receptive to learning about current issues facing Tucson and who can assist by disseminating information to their membership and circles of influence.

Tucson Water is focused on ensuring that the Plan is representative of the needs of the community. Through a combination of online surveys, comment cards, and questions at the public Town Hall and workshops, and information gathering at community events, Tucson Water gathered a picture of community priorities and opinions from water customers. Spanish-language materials and Spanish-speaking staff were present at all community outreach events and workshops.

Public Town Hall

A public town hall was hosted by Tucson Water on August 16, 2022 at the Tucson Convention Center. The event served to introduce the goals and key elements of the Plan and address questions from the public. The town hall event was open to the public and welcomed nearly 300 community members with 467 views on YouTube, in addition to over 1,400 views of Instagram, Facebook, and Twitter posts, and over 200 responses to the town hall survey. American Sign Language (ASL) services were provided at the town hall along with Spanish translation headsets. Tucson Water received a number of questions and follow-up comments after the town hall that informed Plan development.



PUBLIC TOWN HALL

During the public town hall held in August 2022, Tucson Water introduced the Plan and its key elements to the nearly 300 in-person attendees.

Stakeholder Workshops

Tucson Water facilitated three workshop discussions and interactive exercises focused on One Water strategies related to conservation, demand management, water supplies, resilience, quality of life, safety, and affordability. The community stakeholders actively participated in the development of these strategies.



STAKEHOLDER WORKSHOP

Stakeholders participate in a discussion about strategies for demand management during the first stakeholder workshop.

Interviews, Speakers Bureau, and Information Sessions

Outreach to community groups included stakeholder interviews conducted with community leaders. A total of twelve interviews were conducted. Of those, two were conducted in person and ten held over video conference. Outreach also included a speakers bureau made up of a core group of speakers within the planning team that met with third party stakeholder groups, opinion leaders, and the community at large, both virtually and in person. Eleven speaker bureau events were held. Tucson Water also held multiple water rates information sessions, with separate sessions held in each of Tucson's six City Council Wards. Plan Ambassadors attended the rate sessions to show community members the work being done for their water future.

Citizens' Water Advisory Committee

The CWAC provides an important link between Tucson Water's planning team, stakeholders, and the community. CWAC was engaged throughout the development of the Plan. The committee was instrumental in reviewing the TMs and the draft Plan. Some members also attended the scenario planning and strategy workshops. Several members were also interviewed during the community engagement campaign.

Community Event Booths

To better understand the needs of our community, Tucson Water listened to voices across the City. Ambassadors from Tucson Water engaged the public at 25 community events and popular gathering places between April and December 2022, including event booths at community events. At these events, audiences ranged from dozens of people to crowds as large as 150,000 at Tucson Meet Yourself.



Earth Day Festival in Downtown Tucson



52nd Annual Tucson Juneteenth Festival at Kennedy Park



The Southern Arizona Home Builders Home & Patio Show at the Tucson Convention Center

Public Surveys

A One Water Awareness survey was conducted to gauge public awareness regarding the Plan in the early stages of the community engagement campaign. The survey gathered input from 215 people and included questions about challenges that could affect a sustainable water future and whether respondents were aware of specific programs being implemented by Tucson Water. When asked what is needed to create a sustainable water future, conservation was the top term used by respondents. Water supply and water demand ranked among the top challenges respondents listed that could affect a sustainable water future for Tucson. The informal survey also found that of the respondents:

- 86 percent knew that Tucson Water customers have among the lowest water consumption rates in the Desert Southwest.
- 72 percent knew that Tucson Water has stored significant amounts of Colorado River water for future use.
- 54 percent knew that Tucson's water comes from multiple sources, with the majority of respondents identifying the Colorado River as the area's primary source of water.

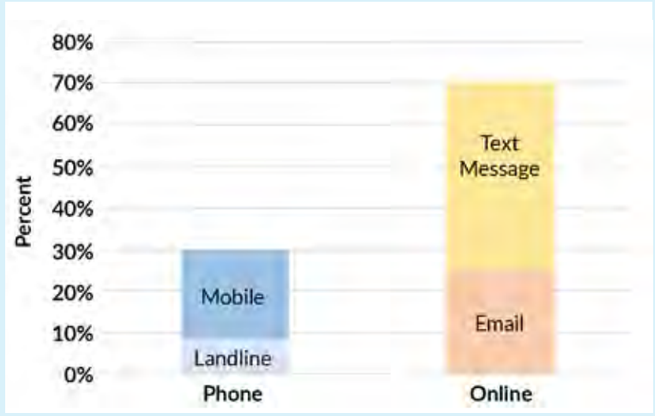
Another survey was conducted in December 2022 to understand the community's opinions on the proposed water management strategies considered for the Plan and to inform the plan development. The survey was conducted in two parts:

1. **Statistically Valid Survey:** Tucson Water hired a national research firm to conduct a statistically valid resident opinion survey based on a demographically representative sample of residents of the Tucson Water service area. The survey included 400 participants with interviews conducted by phone, including landlines and cell phones, and online where respondents were invited to participate by email and text message. The statistically valid survey was conducted in both English and Spanish.
2. **Online Survey:** An online version of the same strategy survey was posted through the Tucson One Water website in English and Spanish. Tucson Water's social media channels were used to encourage community members to participate in the online survey. Participation was also encouraged through Tucson Water's outreach at popular community events and locations, such as the base of Tumamoc Hill, as shown to the right. This survey gathered responses from 1,528 people.



ONLINE SURVEY PARTICIPATION AT TUMAMOC HILL

Tucson Water ambassadors provide members of the public opportunities to participate in the online survey at the base of Tumamoc Hill, a popular walking trail.



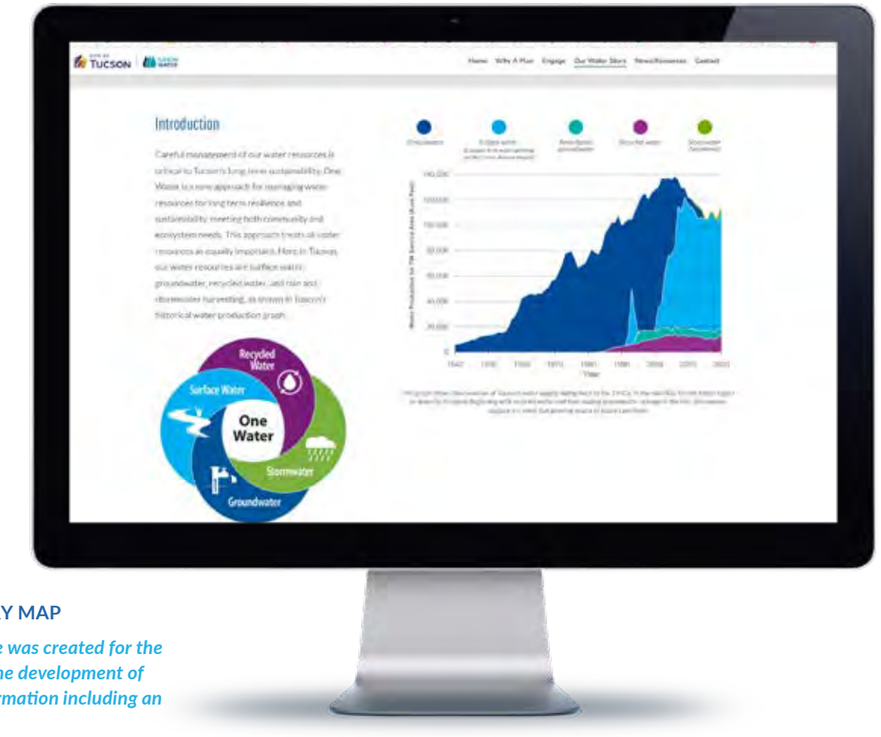
SURVEY MODE FOR STATISTICALLY VALID SURVEY

For the statistically valid survey, interviews were conducted by phone (30 percent) and online (70 percent) modes. Phone interviews were conducted via landline (29 percent) or mobile (71 percent). Online participants were invited by email (36 percent) and text message (64 percent) for the online method.

Online Engagement

A dedicated website was launched for this Plan. This website, TucsonOneWater.com, connects visitors to the latest One Water project documents, upcoming meetings, and input opportunities, including the online survey, and online engagement platforms. It also provides an interactive online Story Map of Tucson's water resource infrastructure. There have been over 13,000 unique visitors to the site since it was launched in 2022. The website will continue to communicate progress on the implementation of the Plan.

Tucson Water also has a One Water 2100 email list with over 2,500 subscribers. Subscribers to this email list have received regular updates about the Plan's progress.



INTERACTIVE ONLINE STORY MAP

A dedicated One Water website was created for the Plan and includes updates on the development of the Plan as well as general information including an interactive online Story Map.

CHAPTER 3

WATER SUPPLIES

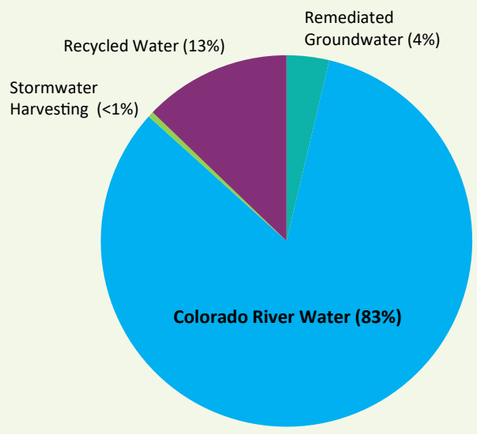
WATER SUPPLIES

TUCSON'S ONE WATER CYCLE

Tucson Water obtains renewable surface water from the Colorado River which originates in the high elevations of the Rocky Mountains, with a watershed that spans seven states. Colorado River water is conveyed to the region through the CAP canal. To optimize use of this resource, Tucson Water recharges its allocation of CAP water in basins in the Avra Valley to the west of Tucson and at the Pima Mine Road Recharge Project (PMRRP), where it mixes with native groundwater. This blended water is then recovered using wells and delivered to homes and businesses. Wastewater is collected and treated at Pima County water reclamation facilities. After treatment, some of this water is sent to the Reclaimed Water System where it is reused for non potable uses such as outdoor irrigation. A portion of the recycled water is also recharged in local aquifers for future use. Stormwater and rainwater are collected at the household and neighborhood scale throughout the Tucson Water service area to provide supplemental water for landscaping. Tucson Water also has a special class of remediated groundwater that receives additional treatment for the removal of various contaminants before being distributed through the Reclaimed Water System.

As shown in the following figure, in 2022, 83 percent of Tucson Water's supply comes from the Colorado River, which is recharged and recovered CAP water. The reclaimed water system accounted for 13 percent of the total water produced. A small percentage (about 4 percent) of supplies are produced with remediated groundwater at the Tucson Airport Remediation Project (TARP).

TUCSON WATER SUPPLY PORTFOLIO (2022)



SURFACE WATER

The Tucson region is located along the Santa Cruz River and its tributaries. Prior to 1880, this was the primary water source for Tucson. With increasing development, groundwater use increased leading to declining groundwater levels, resulting in the disappearance of natural perennial surface-water flows. Today, these rivers primarily flow in response to large precipitation events and periods of snowmelt from the surrounding mountains. The Colorado River is currently the only renewable surface water source available to Tucson Water.

The Colorado River Basin has been in a prolonged drought for over 23 years, which has been exacerbated by climate change. Since the turn of the century, there has been a roughly 20 percent decline in flows on average, resulting in depleted storage conditions in both Lake Powell and Lake Mead, and the first ever shortage declaration in the Lower Colorado River Basin. A lack of precipitation is only partially to blame, as flow losses in the Colorado River have been due in part to record setting temperatures over this period. These rising temperatures have changed the Southwest water cycle and decreased snowpack has resulted in less water to the Colorado River. Further discussion of the impacts of climate change can be found in the November 2021 TM, *One Water 2100 Climate Projections* which is included in Appendix A.



LAKE MEAD DROUGHT CONDITIONS

In August 2022, the federal government declared a tier two water reduction on the Colorado River based on critically low elevations Lake Mead. Tiered shortage levels correspond to water levels within Lakes Powell and Mead. The Tier 2 declaration will require some states to decrease their Colorado River use.



LAKE POWELL DROUGHT CONDITIONS

Drought conditions on Lake Powell in Utah, located upstream of Lake Mead on the Colorado River.

The Colorado River is also over-allocated, meaning that more water is committed to the seven Colorado River Basin States and Mexico than is supplied by the river in an average year. Water users in the seven Basin States have worked to reach important agreements to voluntarily conserve water and better manage the river to mitigate the risk of water levels falling to critical levels in Lake Mead and Lake Powell. As an example, in 2022 the City entered a program to leave a large portion of its Colorado River water allocation in Lake Mead, in exchange for federal compensation. In May 2023, three lower basin states, Arizona, California, and Nevada, proposed a voluntary agreement that would conserve three million acre-feet (ac-ft) through the end of 2026. Federal compensation would be provided for most of the reductions. Tucson's Mayor and Council have expressed their support for this ongoing effort.

The 2019 *Lower Basin Drought Contingency Plan* (DCP) requires Arizona, California, and Nevada to contribute additional water at defined shortage levels based on predetermined elevations in Lake Mead. Tucson Water's preparations for these drought stages and thresholds are described in Tucson Water's *Drought Preparedness and Response Plan*. As the impacts of drought persist, the U.S. Bureau of Reclamation announced planned water cutbacks in 2023 due to increasingly receding water levels in Lake Mead and Lake Powell. While the specific impacts of these cutbacks to Arizona are not yet defined, long-term reductions in the available Colorado River supplies are considered likely. These will almost certainly extend beyond the currently defined shortage levels in the DCP. These reductions are likely to significantly impact all Colorado River water users.

The future management of the river is being addressed through the federal reconsultation process. More information about the work of the Arizona Reconsultation Committee can be found on ADWR's website. Before the end of 2026, the U.S. Secretary of the Interior will develop new guidelines for the long-term management of the Colorado River system. The process involves multiple levels of discussion, negotiation, and coordination within Arizona and among the Basin states. Existing contracts are likely to be revisited as a part of the 2026 reconsultation process and may result in a change to Tucson Water's allocation. The supply assumptions in this Plan all test Tucson Water's resilience against long-term shortage conditions for the City's Colorado River water allocation.

Central Arizona Project

The CAP conveys water from Lake Havasu on the Colorado River to its terminus southwest of the City. Tucson first began receiving renewable Colorado River water from the CAP in the 1990s. The CAP has a total contractual entitlement of roughly 1.415 million ac-ft from the Colorado River per year for all its customers. Of that, Tucson Water has the single largest municipal allocation of CAP water at just over 10 percent with 144,000 acre-feet per year (AFY).

The CAP and the state of Arizona, through the Governor's Water Augmentation, Innovation & Conservation Council (GWAICC), have been actively participating in water supply augmentation and conservation projects. These project ideas include interstate cooperative efforts, such as Brock Reservoir, which improves water supply reliability by reducing excess flows to Mexico, as well as desalination and brackish groundwater projects like the Yuma Desalting Plant, and the proposed binational desalination project with Mexico. More information about the work being done by the GWAICC can be found at the GWAICC website and information on the CAP's augmentation program can be found on the CAP website. The CAP is also exploring opportunities to partner with the Southern Nevada Water Authority to develop new projects and infrastructure.

Recharge and Recovery

Tucson Water's CAP allocation is managed through a process known as "recharge and recovery." There are large, shallow recharge basins and recovery wells at the following three facilities:

- Central Avra Valley Storage and Recovery Project (CAVSARP).
- Southern Avra Valley Storage and Recovery Project (SAVSARP).
- Pima Mine Road Recharge Project (PMRRP – jointly owned by the City and the CAP).

When the Colorado River water fills these basins, it infiltrates down through the pores in between sand and rock and recharges the groundwater aquifer. Through this process, the Colorado River water mixes with native groundwater, producing a blended water supply. At CAVSARP and for a portion of SAVSARP, this blended water is then recovered by groundwater wells and gets pumped through a large transmission pipeline to the Hayden-Udall Treatment Plant and then to the Tucson Water distribution system. CAP allocations not used to meet customer demands remains stored within the groundwater basin, providing a buffer that can help offset future drought reductions in CAP supplies. These are known as long-term storage credits (LTSCs).



CENTRAL ARIZONA PROJECT CANAL

The Central Arizona Project consists of a 336-mile-long conveyance system of canals, tunnels, pipelines, and pumping stations that deliver water to Maricopa, Pinal, and Pima counties in Arizona, serving more than five million people, or more than 80 percent of the state's population.



WATER DELIVERED TO TUCSON WATER SAVSARP FACILITY

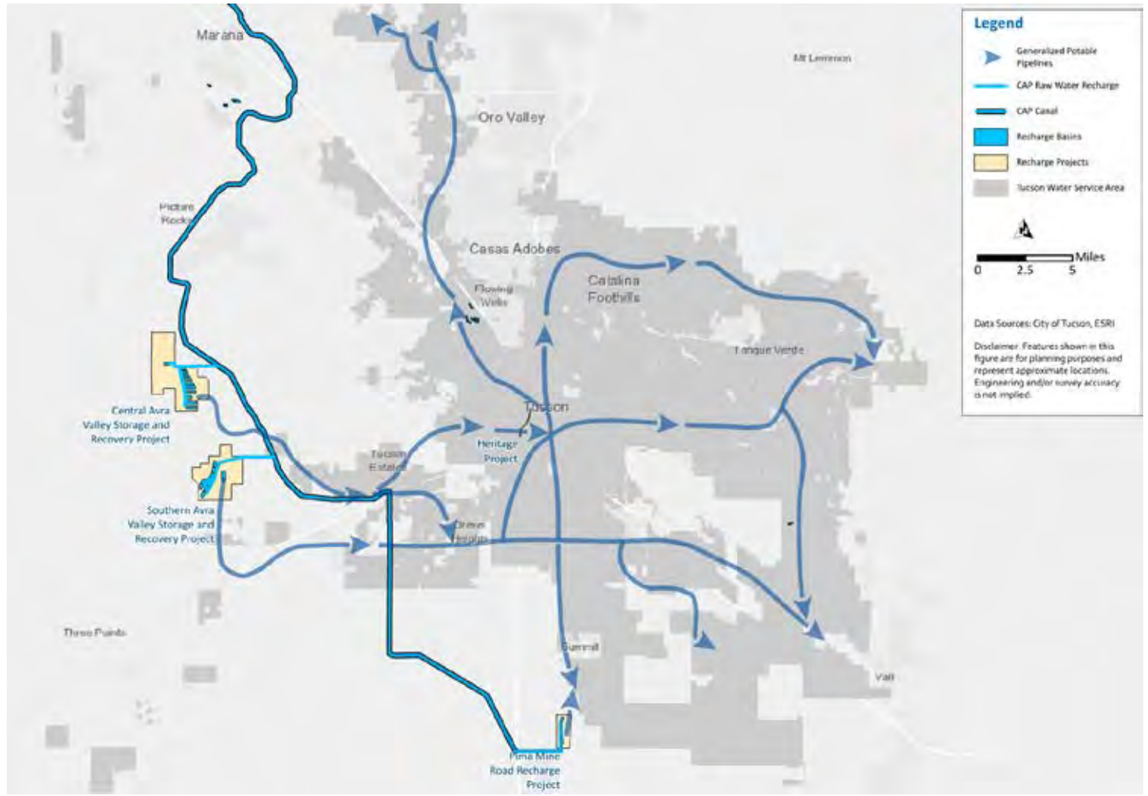
Water delivered to Tucson Water Southern Avra Valley Storage and Recovery Project facility.



AERIAL VIEW OF TUCSON WATER'S CAVSARP FACILITY

Aerial view of Tucson Water's Central Avra Valley Storage and Recovery Project facility.

Additionally, there are also a number of groundwater savings facilities that use raw Colorado River water from the CAP for irrigation and create LTSCs through reduced groundwater pumping. These projects are permitted agreements between Tucson Water, a CAP water allocation holder, and a recipient, usually farmers. Tucson Water delivers renewable Colorado River water to the recipient where it is used in lieu of groundwater pumping to create LTSCs for Tucson Water.



TUCSON WATER DISTRIBUTION AND RECHARGE FACILITIES

Tucson Water's CAP allocation is managed through the use of three large storage and recovery projects.

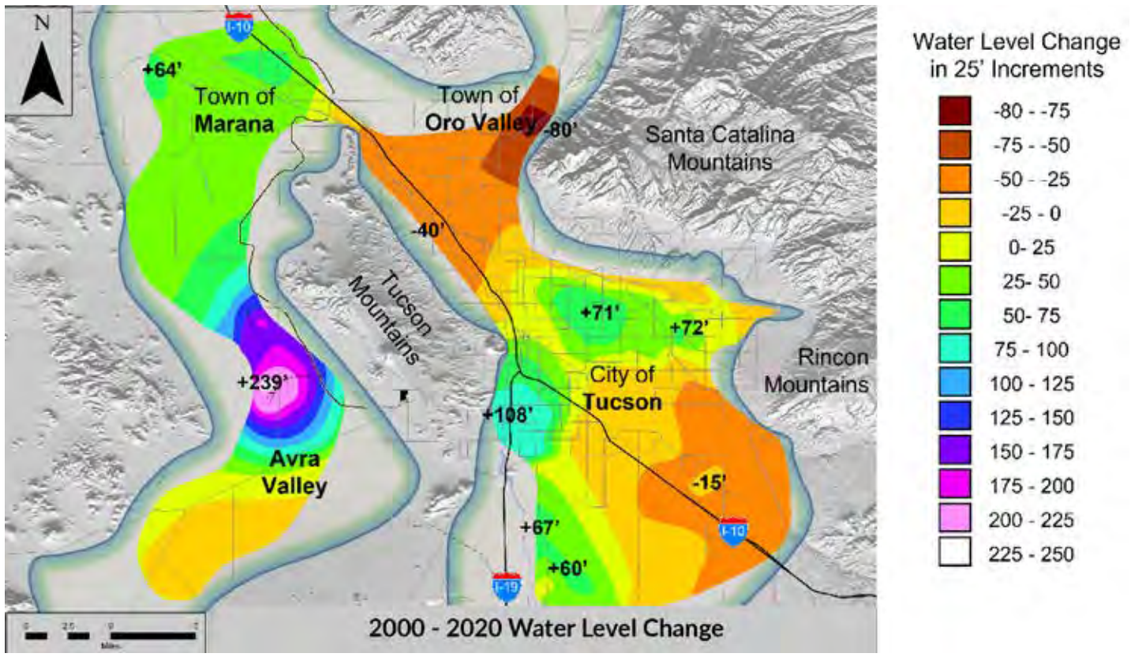
GROUNDWATER

Prior to the introduction of water from the Colorado River, Tucson was completely dependent on groundwater for over a century. Groundwater is considered a finite or non-renewable water resource because the regional aquifers were developed on a geologic timescale and do not receive much natural recharge each year. Historic over-pumping of these groundwater aquifers resulted in significant declines in water levels.

Tucson Water's regional aquifer system includes the Tucson and the Avra Valley aquifers, which are in the Tucson Active Management Area (AMA). Additional discussion regarding AMAs is included later on in this section. Within these aquifers, Tucson Water operates several well fields, including the central well field, that pump native groundwater from the Tucson aquifer directly into Tucson Water's distribution system. The central well field underlies a large portion of the Tucson Water service area. The Avra Valley well field recovers surface water from the Colorado River water recharged at CAVSARP and SAVSARP. The santa cruz well field, located down gradient from PMRRP, also produces a blend of local groundwater and Colorado River water.

Today, renewable Colorado River water supplies have largely replaced groundwater supplies. Since Tucson Water transitioned to renewable water supplies, aquifer levels have been rising in some areas – especially in the vicinity of the recharge and recovery projects as seen in the following figure. Water levels have risen moderately in the north-central area due to reduced pumping in the central well field, while areas to the north and southeast of Tucson continue to experience water level declines due to groundwater pumping by others. Areas with declining aquifer levels depend on a mix of renewable Colorado River water and groundwater.

Despite its finite nature, groundwater continues to be a vital part of Tucson's water resource portfolio. Groundwater from the central well field is used to meet peak water demands during the hottest months of the year, and groundwater stored in the Avra Valley aquifer is used to provide a backup to the Colorado River during emergency interruptions and declared shortages.



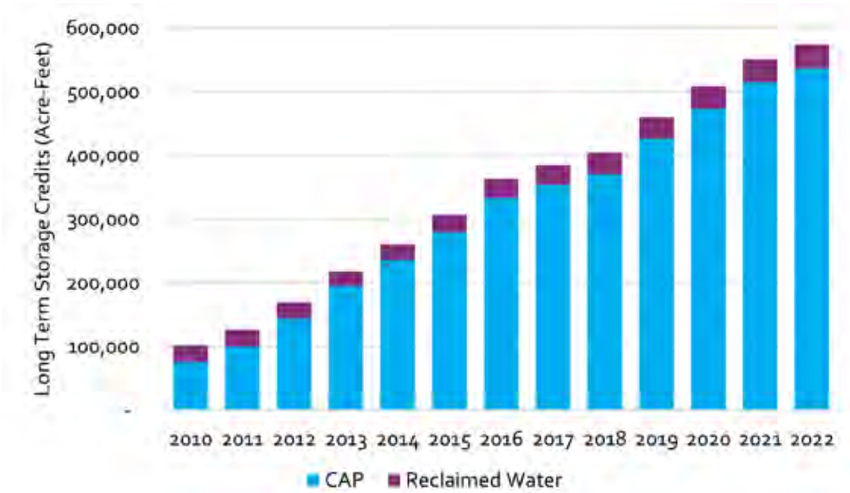
WATER LEVEL CHANGE IN THE TUCSON AND AVRA VALLEY AQUIFERS

Since Tucson Water transitioned to renewable water supplies, aquifer levels have been rising in the vicinity of the recharge and recovery projects and in the north-central area due to reduced pumping in the central well field.

Underground Storage

Over the past two decades, Tucson Water has been developing long-range water resource plans that incorporate drought preparedness. LTSCs are the legal mechanism by which Tucson can recover recharged CAP or reclaimed water using its wells. Tucson currently uses about two-thirds of its annual allocation (144,191 AFY) of Colorado River water based on its current potable water demand. By actively saving and storing the remaining third in groundwater, Tucson Water has accumulated more than 500,000 ac-ft of LTSCs since Tucson Water began recharging its CAP allocation in 2001. This groundwater storage amount alone is enough to provide water to its customers for five years at current demand levels. The following figure shows the cumulative LTSCs accrued between 2010 and 2022.

HISTORICAL CUMULATIVE LONG-TERM STORAGE CREDITS



Assured Water Supply

The Arizona Groundwater Management Act (Act) was established in 1980 to better manage groundwater withdrawals throughout the more populated parts of the state of Arizona. The Act laid out the Assured Water Supply (AWS) rules, which govern the amount of groundwater all water utilities within an AMA can pump or produce with groundwater wells. The Act also created the Arizona Department of Water Resources (ADWR) which established AMAs throughout portions of the state that had experienced significantly depleted groundwater aquifers at the time of establishing the Act. The City is within the Tucson AMA, which consists of the Upper Santa Cruz Valley in the east and Avra Valley in the west, separated by the Tucson Mountains. Tucson Water is committed to meeting requirements set by ADWR's Management Plan to help the Tucson AMA achieve its goal of a sustainable yield by 2025. Safe yield is a long-term balance between annual groundwater withdrawals and annual recharge to the aquifer. Both natural and artificial recharge are considered for total annual recharge.

A Designation of Assured Water Supply (DAWS) is a certification issued by ADWR to water providers that can demonstrate sufficient water supplies for a 100-year period. The supply assumptions used in this Plan all test Tucson Water's resilience against the groundwater resources identified in Tucson Water's 2023 application to modify its DAWS. The application identifies that Tucson Water has over 54,000 AFY of groundwater that is physically, continuously, and legally available. This includes a legal right to groundwater associated with farmland in the Avra Valley that was purchased by the City and retired from irrigation. Although this groundwater resource is not a renewable supply, this supply is included as a backup supply to account for long-term shortages conditions on the Colorado River.

Central Arizona Groundwater Replenishment District

Tucson is also a "Member Service Area" of the Central Arizona Groundwater Replenishment District (CAGRD), a department within the Central Arizona Water Conservation District (CAWCD) that maintains, operates, and manages the CAP and facilitates groundwater replenishment within Maricopa, Pinal, and Pima counties. The CAGRD provides a mechanism to meet increasing demands without pumping groundwater over allowable limits. For Tucson, CAGRD membership represents a "safety net" in water supply management since Tucson Water's current supply portfolio exceeds customer demands. Stored CAGRD water is included as a groundwater resources in the scenario projections found in Chapter 4 of this Plan.

Arizona Water Banking Authority

Another institutional safeguard is the Arizona Water Banking Authority (AWBA) which stores Arizona's unused Colorado River water for use during a declared shortage. The AWBA stores Colorado River water, delivered directly through the CAP and in groundwater savings facilities. Based on population, it is anticipated that the majority of water stored in the Tucson AMA water bank will be available to Tucson Water if needed.

Remediated Groundwater

Tucson also has access to a special class of groundwater through TARP and the Advanced Oxidation Process (AOP) Facility. This groundwater receives treatment for the removal of various contaminants. Due to increasing levels of unregulated contaminants in the remediation wells serving the facility, this water is being sent to the reclaimed water system, and intermittent flows will be sent to the Santa Cruz River.



TARP ADVANCED OXIDATION PROCESS (AOP) FACILITY

Tucson Airport Remediation Project facility.

Water Quality

Tucson Water operates approximately 230 drinking water wells throughout its service area. Tucson Water measures more than 150 water quality parameters at 266 permanent water sampling taps located throughout its distribution systems. Tucson Water's Sentry Program has monitored unregulated and emerging contaminants for over a decade and helps Tucson Water track and proactively manage contaminants that may be regulated in the future. This extensive water quality testing verifies that Tucson Water provides high quality water supplies to customers throughout its service area. Tucson Water's robust monitoring system is well positioned to detect and manage contaminants. Additional information about Tucson Water's water quality monitoring and management can be found in the March 2022 TM, *One Water 2100 Water Quality Management* which is included in Appendix E.



WATER QUALITY MONITORING

Tucson Water employees monitor water quality at Hayden Udall Treatment Plant.

Groundwater Remediation

Per- and polyfluoroalkyl substances (PFAS) are a group of man-made chemicals that are manufactured and used in a variety of industries, most notably for foams used in fighting aircraft fires, stain-and water-repellent fabrics, and nonstick products. The United States no longer manufactures certain PFAS; however, the historic use of these compounds continues to threaten Tucson's drinking water supply. Tucson Water is committed to ensuring the quality of water for Tucson's water resources and is taking steps to maintain that quality. Out of an abundance of caution, Tucson Water has removed twenty-two drinking water production wells from service due to the presence of PFAS, and an additional six wells have been placed in active-emergency status. In March 2023, the EPA announced a proposed National Primary Drinking Water Regulation for six PFAS in drinking water:

- Proposed maximum contaminant level goals (MCLG) and maximum contaminant levels (MCLs) for perfluorooctanoic acid (PFOA) and perfluorooctyl sulfonate (PFOS), as individual contaminants.
- Proposed MCLGs and MCLs for perfluorononanoic acid (PFNA), hexafluoropropylene oxide dimer acid (HFPO-DA, commonly known as GenX Chemicals), perfluorohexane sulfonic acid (PFHxS), and perfluorobutane sulfonic acid (PFBS), as a PFAS mixture called Hazard Index (HI).

The proposed MCLs, when finalized, will supersede the previously published Health Advisory levels for PFAS (2016 and 2022). Tucson Water's operational targets are more conservative than the proposed MCLs for PFAS. Additional drinking water production wells in Tucson Water's Central Wellfield are at risk from PFAS, and Tucson Water is collaborating with the Arizona Department of Environmental Quality (ADEQ) and other agencies to protect the Central Wellfield and eventually treat affected wells. Protecting the Central Wellfield from PFAS contamination is critical for supply reliability.

RECYCLED WATER

Recycled water refers to the beneficial use of wastewater after treatment at a water reclamation facility. Within the umbrella of recycled water are multiple types of water treatment levels for various end-uses, aka fit-for-purpose water. These include:

- **Reclaimed water (aka non-potable reuse or NPR)** is the portion of recycled water that has been treated to high quality standards for non-potable uses such as irrigation.
- **Indirect potable reuse (IPR)** is recycled water that passes through additional advanced purification processes and an environmental buffer (such as a groundwater aquifer or surface water reservoir) before being used to supplement drinking water supply sources. Advanced treatment can occur before or after water passes through the environmental buffer.
- **Direct potable reuse (DPR)** involves introducing advanced purified recycled water into potable water system without the use of an environmental buffer.
- **Gray water** is water previously used in sinks (other than kitchen sinks), showers, baths and/or laundry washing machines that is reused for outdoor irrigation. This is commonly known as "showers-to-flowers" or "laundry-to-landscape" and can be implemented on a household or building size scale.
- **Black water** is gray water with the inclusion of water previously used in kitchen sinks and toilet flushing.

Of the types of recycled water, the City only uses reclaimed water through the Reclaimed Water System while gray water is used at the residential level. IPR and DPR represent opportunities for expanding the use of recycled water. Additional discussion of IPR and DPR is included later in this chapter.



SIGNAGE FOR THE RECLAIMED WATER SYSTEM

Reclaimed Water System

In 1984, Tucson was one of the first cities in the country to begin recycling water by intentionally treating wastewater for irrigation and other non-potable water uses to offset historic potable demands. The first reclaimed water customer was a golf course, but now the reclaimed system serves the vast majority of parks, schools, municipal properties, and golf courses throughout the region in addition to some residential customers. Tucson's Reclaimed Water System delivers between 11,000 and 14,000 AFY of reclaimed water to more than 900 sites via a network including approximately 200 miles of "purple pipe" distribution systems. Tucson Water also wheels approximately 3,000 AFY of reclaimed water to neighboring service areas. Purple coloring is used as an industry standard to identify non-potable water pipelines, pumps, and other fixtures, aimed at avoiding accidental cross-connections between potable and reclaimed water systems.

The Reclaimed Water System provides a range of benefits to residents and businesses within the Tucson region. Utilizing this resource reduces the demand for the potable water supply system. It is also a reliable and locally controlled water source that can be used to offset traditional water potable water demands. The availability of this water source helps support the destination golf sector in Tucson which provides economic value to the region.

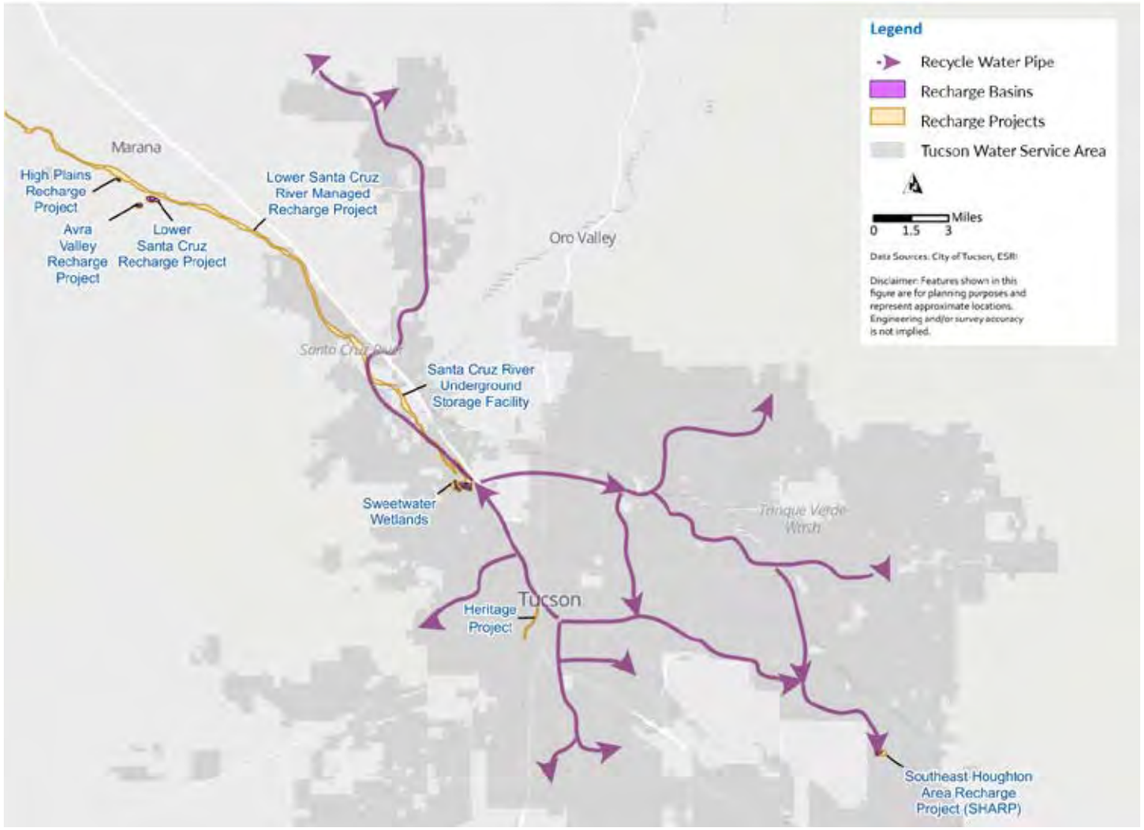
Since most parks, schools, municipal properties, and golf courses located near the existing Reclaimed Water System are already served by reclaimed water, there are minimal opportunities for additional irrigation customers. Additionally, there is declining demand for recycled water to be used for irrigation due to outdoor water conservation practices, as well as the reduction of non-functional turf due to concerns about water waste. To help respond to decreases in non-potable water demands, new potential reclaimed water customers and end uses can be explored. Examples include the use of reclaimed water for cooling towers and toilet flushing in commercial and industrial buildings.

The supply scenarios in the Plan include only the potable water supply portfolio. Future uses of the Reclaimed Water System are captured as offsetting potable water supplies and therefore reducing the potable per capita water use.



"PURPLE PIPES" IN THE RECLAIMED WATER SYSTEM

Per industry standards, Reclaimed Water Systems are constructed with "purple pipes" to avoid cross connections and clearly communicate the conveyance of non-potable water.



TUCSON WATER RECLAIMED WATER SYSTEM

Tucson's Reclaimed Water System delivers reclaimed water to more than 900 sites via the "purple pipe" distribution system. Reclaimed water is also used for groundwater recharge through numerous recharge projects.

Groundwater Recharge

Demand for reclaimed water increases during the hotter months, due to increased evapotranspiration and irrigation needs, while there is excess reclaimed water supply capacity during the cooler winter months. Reclaimed water produced during the off-peak period is directed to storage and recovery at the Sweetwater Recharge Facility and Wetlands. This strategy allows Tucson Water to "recharge" reclaimed water in the aquifer and "recover" it later through groundwater wells for use in the reclaimed system. Recycled water that isn't being used in the reclaimed system is also used to replenish the aquifer through the Southeast Houghton Area Recharge Project and the Santa Cruz River Heritage Project. Water "stored" in the groundwater aquifer at these sites earns LTSCs. A portion of the City's wastewater entitlement is discharged to Santa Cruz River where much of this resource leaves the basin without earning LTSCs. This water is available to be used by Tucson Water through new recycled water projects.



AERIAL VIEW OF THE SWEETWATER RECHARGE FACILITY AND WETLANDS

Multi-Benefit Sites

Tucson Water's Reclaimed Water System also provides ecosystem and social "quality-of-life" benefits for the region. In addition to recharge and recovery operations, the Sweetwater Wetlands, Santa Cruz River Heritage Project, and Southeast Houghton Area Recharge Project (SHARP) are key examples of sites providing multiple benefits for the community. These projects provide high quality recreational, aesthetic, educational, cultural, wildlife, and ecosystem restoration values to the community. This is discussed further in the May 2022 TM, *One Water 2100 Benefits and Costs of the Reclaimed System* which is included in Appendix F.

Santa Cruz River Heritage Project

The Santa Cruz River Heritage Project is an excellent example of how Tucson Water is committed to provide "fit-for-purpose" water resources for community and ecosystem benefits. The project, which launched in 2019, adds approximately 3,150 AFY of treated recycled water to the Santa Cruz River at a point south of downtown near the heart of the City. The added water brings perennial flow to this portion of the river after 80 years of no surface flow and fosters abundant native vegetation and wildlife along with recreational and economic opportunities. The flowing stretch of the river runs alongside the Chuck Huckelberry "Loop" trail, a popular bike and walking trail. The restored river is not only vital to the environment, but also to Tucson's history, culture, and identity.

Sweetwater Wetlands and Recharge Facilities

The Sweetwater Wetlands function as an urban wildlife habitat and an outdoor classroom at the same time. The wetland was originally constructed in 1996 to handle backwash filter water from the reclaimed water plant. The wetlands now use reclaimed water exclusively. Groundwater recharge is accomplished through the direct use of reclaimed water to supplement groundwater banking through net positive recharge that occurs in recharge basins next to the Sweetwater Wetlands.

The site contains paved and unpaved paths open to the public. Self-guided educational tours are offered through Tucson Water and Arizona Project WET (APW) where community members can use a QR code reader app to view information about the wetland. The Audubon Society holds weekly bird watching tours.

Southeast Houghton Area Recharge Project

SHARP is a 40-acre recycled water recharge project comprised of three recharge basins. This water soaks into an area of the aquifer that has seen continued decline in water levels due to historical groundwater pumping. In 2022, nearly 3,400 ac-ft of recycled water was delivered to SHARP, which is permitted for up to 4,000 AFY. SHARP is open to the public and provides green space for walking, running, and biking. This facility also provides educational opportunities for students through a partnership with APW.



The Santa Cruz Heritage Project releases treated recycled water to the Santa Cruz River at a point south of downtown near the heart of the city.



The Sweetwater Wetlands is an urban wildlife habitat and an outdoor classroom.



The Sweetwater Wetlands contains paved and unpaved paths open to the public.



The Southeast Houghton Area Recharge Project includes three recharge basins and is open to the public as a green space for walking and biking.

Gray Water

The City's Gray Water Ordinance, passed in 2008, requires that all new single-family homes and duplexes be built with gray water system hookup capabilities. Separate plumbing or diverts are required on washing machine hook-ups and for showers and bathtubs. In 2011, the City implemented the Gray Water Rebate to incentivize the installation of gray water systems for landscape irrigation on residential properties but participation in the program is low. Of the gray water systems that are being installed, most are "laundry-to-landscape" systems which allow for the recycling of 12 to 16 percent of household water use from clothes washers for outdoor irrigation purposes.

Onsite Reuse

Onsite reuse of recycled water refers to the practice of treating and reusing wastewater generated within a building or property for non-potable purposes, such as irrigation, toilet flushing, and cooling. Generally, onsite reuse of recycled water is most commonly used in industrial settings for uses such as cooling towers or toilet flushing within office buildings. Further development of opportunities for onsite reuse would involve new policies to address public health risks and would depend on public acceptance of onsite reuse for certain uses, such as residential developments.

Indirect and Direct Potable Reuse

Both IPR and DPR could expand the use of recycled water beyond just non-potable uses, such as outdoor irrigation. In Arizona, potable reuse is allowed under the rules of the ADEQ but additional state regulations for direct potable reuse are currently under development. Participating in state regulatory discussions, developing a public education campaign, and developing a demonstration project could all be potential steps toward implementing indirect or direct potable reuse. Both IPR and DPR are local water supply options that are drought proof, reliable, and not subject to the uncertainties of the Colorado River 2026 reconsultation process that may result in a change of Tucson Water's annual CAP allocation.

Positive public perception of recycled water is crucial for the continued utilization of this drought proof water resource. It is well known that a strong community engagement program is critical to moving these programs forward. As demonstrated in San Diego, Los Angeles, and Texas, extensive community engagement and education programs can shift public perception and help accelerate implementation of potable reuse, particularly in light of severe drought conditions. To maximize the use of recycled water in the future with either IPR or DPR, Tucson Water must also be proactive with respect to the water quality expectations of the community.

STORMWATER

The City has been a national leader in desert rain and stormwater harvesting. This resource is a small but growing component of Tucson's water supply. Tucson's summer monsoons provide a renewable source of water that can be used on landscapes to reduce reliance on potable water for landscape irrigation demands. In Tucson, rain and stormwater harvesting, including green stormwater infrastructure (GSI) programs can include a combination of the following additional benefits:

- Reducing stormwater pollution.
- Shading and cooling streets, sidewalks, bikeways, and parking areas.
- Mitigating minor flooding.
- Creating wildlife habitat and supporting biodiversity.
- Beautifying the urban environment.
- Providing a nature-based complement to gray infrastructure.

Rain and stormwater harvesting falls into two general categories: active and passive. Active harvesting refers to a tank or cistern storing rainwater collected from roofs, which provides a means to store the rainwater for later use. Passive harvesting typically refers to directing and retaining water in the landscape using site appropriate practices such as basins, berms, terraces, swales, and infiltration trenches. Rainwater harvesting typically refers to residential scale projects while stormwater harvesting is done in a municipal right of way.

Historically, traditional infrastructure such as gutters and pipes are used to transport stormwater away from a location. GSI helps collect and infiltrate stormwater near where it falls. GSI can also incorporate both passive and active stormwater harvesting techniques. These projects can range from an individual homeowner installing a cistern to the neighborhood scale where vegetated areas and curb cuts are designed along roadways to create areas for stormwater to be diverted, collected, and infiltrated.



RAINWATER HARVESTING

Cisterns or tanks at Tucson Water East Side Service Center, a form of active rainwater harvesting, can be used to store rainwater collected from roofs for use at a later date.



CURB CUTS

Green stormwater infrastructure, such as curb cuts, can reduce flooding on streets and, often diverts that water into basins to irrigate vegetation that can shade streets and sidewalks, cooling neighborhood temperatures and creating more desirable places for biking and walking.

One of the main challenges of stormwater as a water supply is its variability in water quantity and water quality. Unlike surface or groundwater, stormwater is unpredictable in timing, quantity, and water quality. These factors have contributed to the underutilization of stormwater and are often cost-prohibitive in arid regions when just considering water supply benefits. While there are some existing guidelines, there is currently a lack of consistency in installation and maintenance practices for GSI used in the city. The absence of a unified approach to GSI contributes to the difficulty in quantifying the saving and benefits derived from these types of projects. Water quality concerns can also arise from the lack of defined project standards and regulations, as well as the wide range types and concentrations of potential contaminants. This is specifically the case for urban runoff in high density and industrial areas where stormwater may be polluted with trash, heavy metals, motor oils, and bacteria to name a few. There are many types of small scale and GSI type stormwater treatment options available, but these systems do require additional operations and maintenance (O&M) staff to keep these treatment systems functioning properly.

Stormwater could further offset the use of potable water and reduce flooding in larger GSI projects. Tucson Water has been working closely with the Pima County Regional Flood Control District to take on the maintenance of larger GSI projects that the District designs and builds within the City limits. Tucson Water currently has an intergovernmental agreement (IGA) with Pima County Flood Control District to develop and fund the implementation of large-scale stormwater projects. Additional areas of expansion could include integrating and standardizing policies and practices for GSI across the City. New standards, and updated strategies for stormwater use would help facilitate the implementation of large-scale stormwater projects with multiple benefits and these opportunities would help expand Tucson's stormwater harvesting resource. Another step in expanding the use of stormwater may be the creation of a comprehensive stormwater utility for planning, design, construction, operation, and maintenance of stormwater facilities that include large scale stormwater harvesting. As stormwater is difficult to quantify, the expansion of stormwater resources is included in the supply assumptions in the Plan as an approach to reducing the long-term per capita water by offsetting potable water supplies for irrigation.



GREEN STORMWATER INFRASTRUCTURE (GSI)

The Rincon Heights neighborhood GSI project after a rain event

Residential Rainwater Harvesting Rebate Programs

Tucson Water has been investing in residential water harvesting since 2012. The rain harvesting rebate program covers both simple, passive harvesting systems as well as more complex, active harvesting systems that can include the use of a cistern or tank. In the past five years, Tucson Water has launched programs to:

- Provide funding for street-scale stormwater harvesting projects.
- Facilitate and install community-driven GSI projects.
- Increase the focus on maintaining projects built, community outreach, and equity.

To date, over 3,500 customers have installed water harvesting systems on their properties, including nearly 500 subsidized systems for low-income households.



RAINWATER HARVESTING

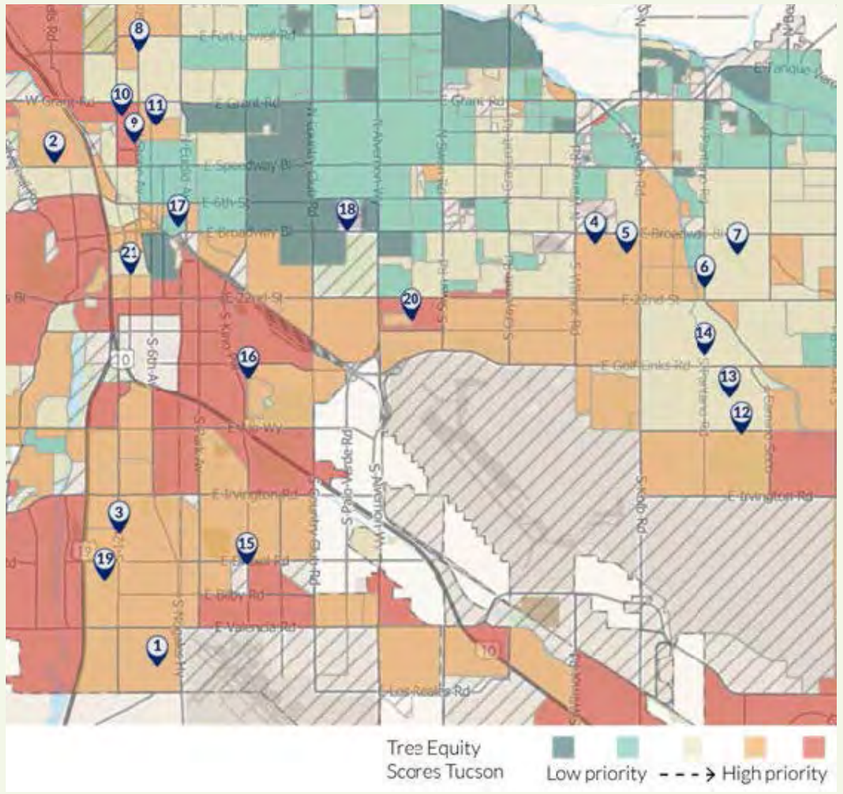
Cistern at the Ward 5 Council Office

Storm to Shade Program

The Storm to Shade (S2S) program was established in 2019 with the aim of installing and maintaining GSI features on public property, such as parks, roadways, and rights-of-ways, with a focus on the use of passive water harvesting features. The Tucson S2S program is funded by a GSI fee, which is assessed on customers based on their water consumption. The revenues generated from the fee are dedicated to fund the construction and maintenance of GSI projects citywide. The GSI Fee was initially established as a pilot program and has since been authorized as a permanent program of the City. The program has had success with leveraging other grant programs and voter-approved bonds for park and connection improvement projects.

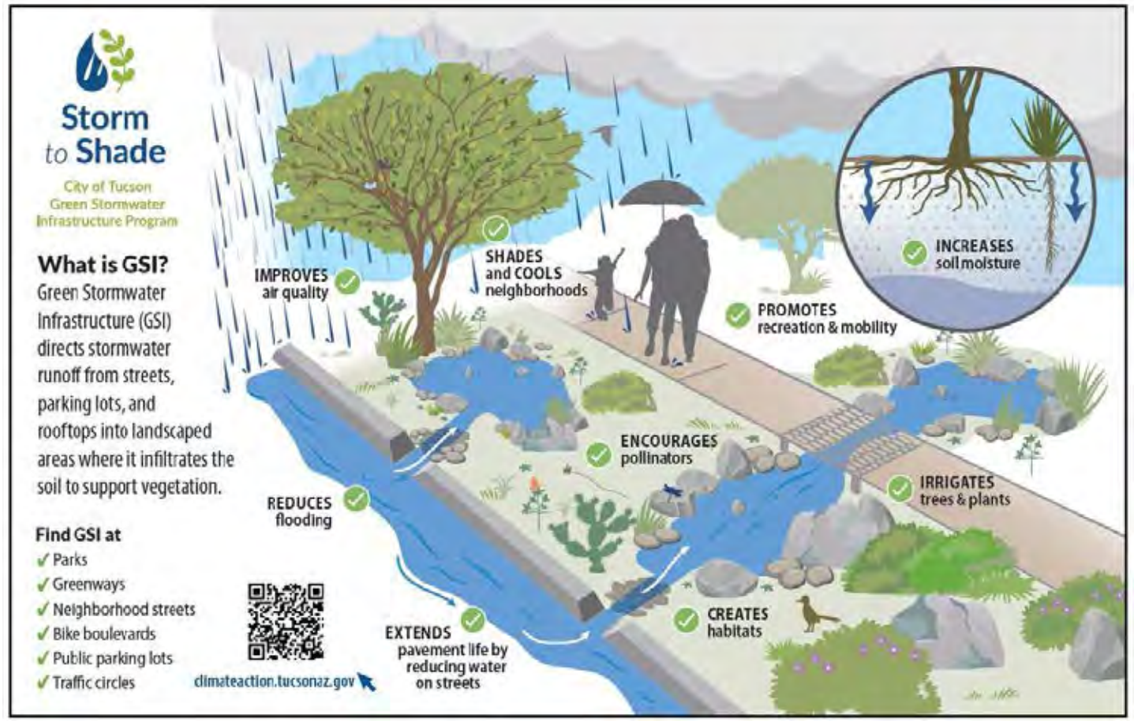
S2S has funded 22 projects to date (April 2023), with a variety of projects that divert stormwater from flowing directly into storm drains and infiltrate this water in harvesting basins that support greenways and parklets that irrigate trees and native vegetation without the need for water intensive turf. S2S utilizes a Tree Equity Score to prioritize projects in areas of Tucson that have historically received low levels of investment, are generally hotter, have less tree canopy, and house a more vulnerable population. A map of Tree Equity Scores and project locations through 2022 is shown in the following figure.

S2S has also published guidelines around GSI maintenance as well as general site design guidance. The maintenance guidelines include information about common GSI features, why GSI is important, as well as tools and general maintenance steps for site upkeep including plant care. The general site design guidance document covers current best practices for the planning, design, and construction of GSI. These documents are the first steps in creating integrated and consistent policies and standards for GSI projects in the City.



GSI PROJECTS AND TREE EQUITY SCORES

To maximize the benefits of GSI for communities most in need of additional tree canopy and green space, S2S developed a process for identifying potential projects as well as an accompanying set of selection criteria.



DESCRIPTION OF GREEN STORMWATER INFRASTRUCTURE

Green stormwater infrastructure directs stormwater from streets and parking lots into landscaped areas that provide multiple benefits to the area.

FUTURE WATER SUPPLY VULNERABILITIES

The scenario planning process, described in more detail in Chapter 2, identified key water supply vulnerabilities such as the over-reliance on supply from the Colorado River, the potential for the reduction of available water within each of the existing water supplies from drought, climate change, changes in water quality, and new regulations. These key vulnerabilities informed the development of the water supply strategies that are presented in Chapter 5.

FUTURE WATER SUPPLY OPPORTUNITIES

The scenario planning process also identified key opportunities associated with Tucson Water's water supply portfolio. Broadly summarized, the process included recommendations to further diversify the supply portfolio through more use of locally controlled and distributed sources. This includes increased development of recycled water, including onsite reuse, potential development of IPR and DPR, as well as rainwater and stormwater harvesting to help offset the use of potable water. The scenario planning process also created recommendations to protect the existing allocation of Colorado River water by actively participating in regulatory discussions while continuing to maximize water savings by reducing demand. Finally, stakeholders recommended protecting groundwater resources by addressing issues of water quality. These recommendations informed the development of the water supply strategies that are presented in Chapter 5.

CHAPTER 4

WATER DEMANDS



WATER DEMANDS

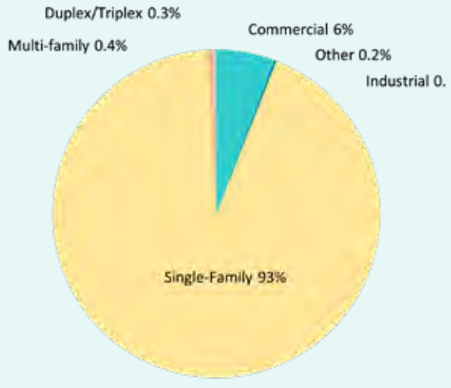
TODAY'S WATER USES

Today, Tucson Water serves close to 750,000 people through about 242,300 potable and reclaimed water accounts. Over 90 percent of Tucson Water's potable water accounts are residential, which includes both single and multi-family homes.

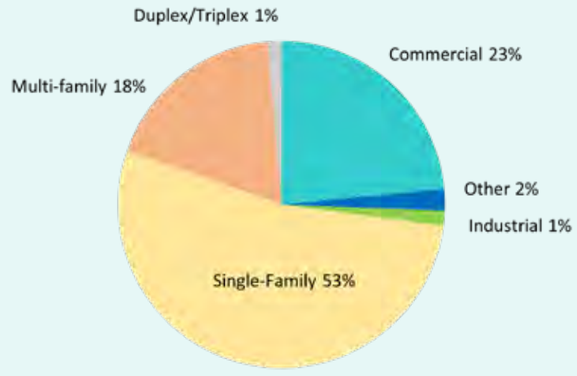
Although the vast majority of customer accounts are residential, single family residential customers only consume 70 percent of the water Tucson Water serves. The remaining non-residential demand includes classifications such as industrial customers, commercial customers, homeowner associations (HOAs), and institutional users such as school districts. The average annual non-residential consumption reflects approximately 30 percent of the total demand as shown in the following figure.

Tucson Water also has several wheeling agreements with regional water providers which allow them to transport a portion of their renewable water supply through Tucson Water's distribution system. These agreements do not impact Tucson Water's water supply needs but are accounted for in facility planning to confirm that the distribution system can convey these flows. Tucson Water also provides water for fire suppression and maintains the ability to provide water to emergency responders when it is needed.

TUCSON WATER 2022
CUSTOMER CLASSES BY ACCOUNT TYPE

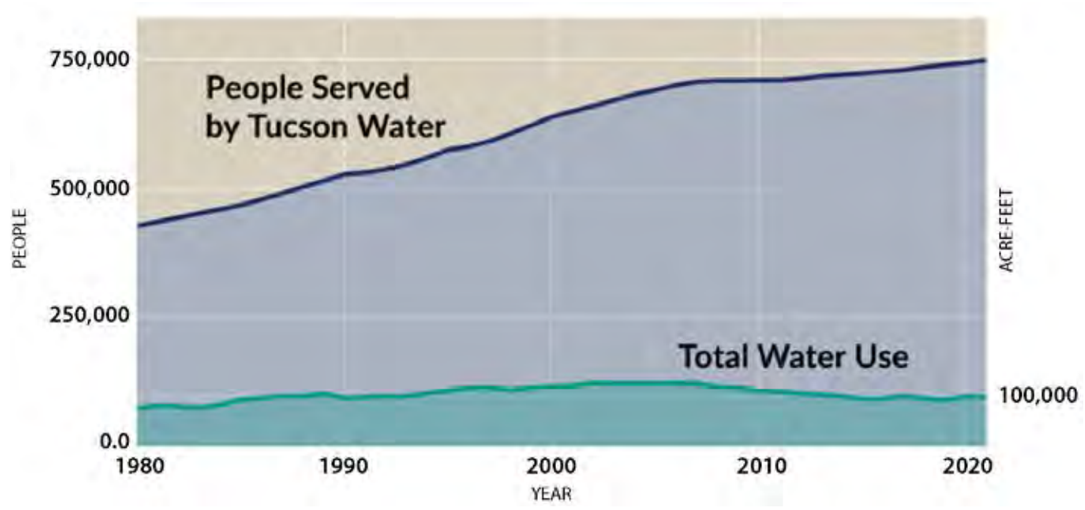


TUCSON WATER 2022
POTABLE METERED WATER USE BY ACCOUNT TYPE



Per Capita Water Use Trends

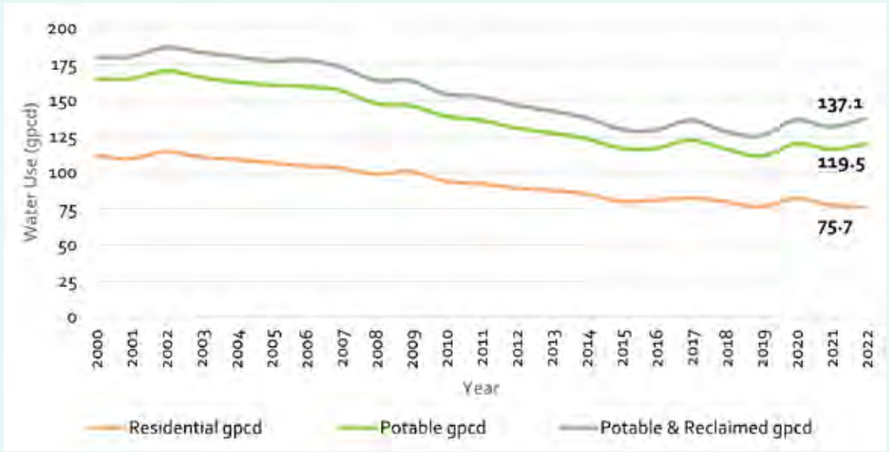
Tucson Water has been tracking per capita water consumption for decades. As shown in the following figure, a slight downward trend in water use has occurred since 2005, reducing the total per capita water use from roughly 180 gallons per capita per day (gpcd) to roughly 130 gpcd, with residential water use declining to about 75 gpcd. Since 2008, Tucson Water's total annual water usage has declined even though the population served has increased. This phenomenon is known as "decoupling," meaning water demand is no longer increasing along with population growth. Three factors key to "decoupling" have been improvements to the building code that have made new buildings more water efficient, the ongoing water conservation programs, and the community's strong conservation ethic. Projections for new development assume that this trend will continue.



TUCSON POPULATION GROWTH VS WATER USAGE

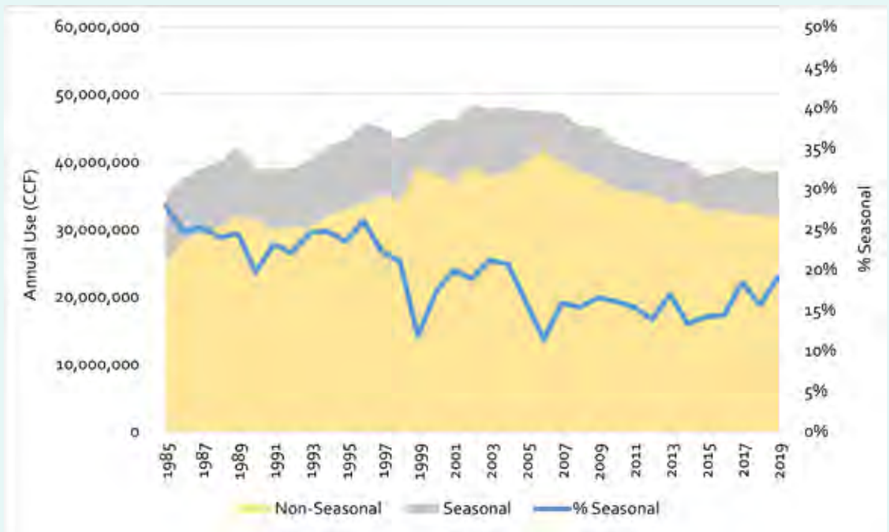
Since 2005, Tucson Water's total annual water usage has declined even though the population served has increased.

Robust conservation programs and a strong conservation ethic among the community have made decoupling possible. Today, Tucson Water customers are using the same total volume of water as they were in the mid-1980s, despite the service area population increasing by over 200,000 residents over that same timeframe. Tucson has among the lowest per capita water use of the cities in the southwestern U.S.



WATER SERVICE AREA WATER USE TRENDS

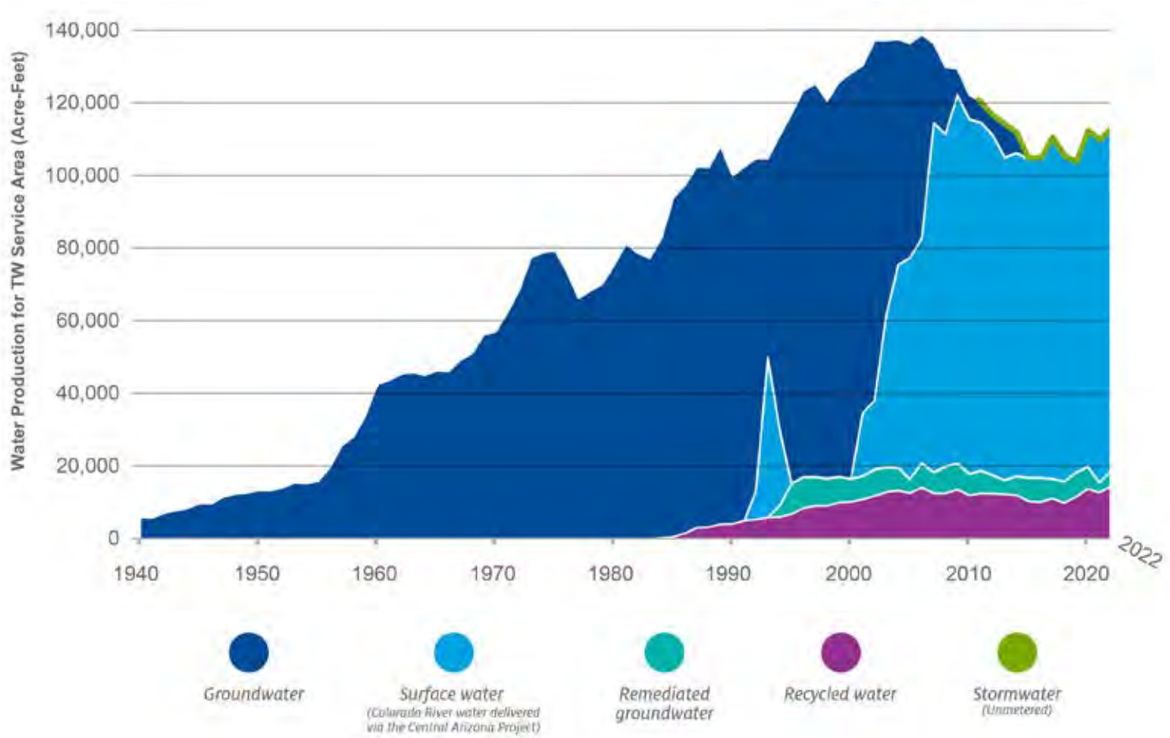
A historic analysis of Tucson's seasonal and non-seasonal demands was done in the August 2021 TM, *One Water 2100 Conservation Projections* which is included in Appendix G. Non-seasonal demands relate to indoor water use while seasonal demands correspond to outdoor or other temperature driven water demands. The following figure shows the annual potable season and non-seasonal water use and the percentage of water use that was considered seasonal demands. From 1985 to 2019, there has been a long-term trend of declining seasonal water use.



TUCSON'S ANNUAL POTABLE SEASONAL AND NON-SEASONAL USE AND % SEASONAL IN CCF FROM 1985-2019

Historical Water Use

The evolution of Tucson Water's supply diversification history can be seen in the following figure. Since the 2000s there has been a dramatic transition from a reliance on groundwater resource to renewable Colorado River supplies delivered via the CAP. There has also been a continued decline in total water use despite a growing population in Tucson Water's service area. By further reducing water use through demand management efforts, Tucson Water has the opportunity to reduce its reliance on the Colorado River, mitigating the risk of relying on finite groundwater resources during periods of shortages. In addition, further development of non-potable supplies such as recycled water and harvesting stormwater reduces potable demands, reducing reliance on the Colorado River and protecting groundwater resources for future generations.



WATER PRODUCTION IN ACRE-FEET, 1940-2022

Since the 2000s, Tucson has transitioned dramatically from a reliance on groundwater resources to Colorado River supplies delivered via the Central Arizona Project.

WATER CONSERVATION

Water conservation is vital to Tucson Water's long-term strategy to provide reliable water into the future. Tucson Water has one of the longest running conservation programs in the nation and the Tucson community has long embraced an ethic of water conservation. Water conservation has been one of the core components of Tucson Water's water resource planning efforts since the 1970s. Since that time, a Water Conservation Office was established within Tucson Water and a comprehensive Xeriscape Landscaping Ordinance has required the use of drought-tolerant plants in new multifamily, commercial, and industrial developments. The City also implemented a Water Waste Ordinance, plumbing code modifications, and rebates for encouraging the replacement of high-water use toilets and clothes washers.

Tucson's conservation program includes several financial incentives as well as a suite of public information and educational outreach projects. The conservation program has partnered with various organizations to inform customers about conservation programs and methods and techniques to use water more efficiently. Coupled with conservation-oriented water pricing, national plumbing codes, and the Environmental Protection Agency (EPA) WaterSense program, these programs support Tucson Water's commitment to establishing and maintaining a strong water conservation ethic in the community. Together, these incentive programs, tiered water rates, more efficient technology, increased water scarcity awareness, and associated behavioral changes have lowered the potable water consumption, typically expressed in gpcd.

Based on a review of local and national water demand trends and Tucson's current water conservation program offerings, Tucson Water prepared recommendations to consider for future conservation programs, which are documented in the August 2021 TM, *One Water 2100 Conservation Projections*. This TM is included in Appendix G. These recommendations are included in this Plan to further enhance the overall effectiveness of the Tucson Water Conservation Program to lead to continued, sustained, and equitable demand reductions across all sectors of water customers.

Rebates and Incentives

For the past two decades, Tucson Water has offered a range of rebate programs for both commercial and residential water users that promote water saving practices. These programs continue to be updated as new water efficient technology becomes available. Conservation efforts can be seen in reducing indoor water use through high-efficiency appliances and in reducing outdoor water use by promoting water-efficient landscaping.

- **Single-Family Residential Programs** – For single-family customers, rebates are available for installing high efficiency toilets (HET), high-efficiency clothes washers, rainwater harvesting systems and gray water systems.
- **Multi-Family Programs** – Programs for multi-family customers include HET and customized rebates.
- **Commercial Programs** – Rebates for commercial customers include high-efficiency toilets, high-efficiency urinals, and a customized commercial rebate. The customized rebate for both multi-family and commercial properties usually involves an onsite water audit that analyzes current water use and provides customers with return-on-investment calculations.

By adjusting rebate levels and offering new rebate programs, Tucson Water can increase efficiency of fixtures and appliances for which rebates are offered and increase water savings opportunities. Another area for further program expansion is in the continued focus on reducing outdoor water use, with emphasis on resilient, desert-adapted landscaping in lieu of grass and other high-use plants.

Zanjero Program Water Audits

A team of Tucson Water conservation experts provides free water audits to residential and commercial customers upon request. These Zanjero Program water audits are usually requested by customers with a high bill. The onsite audit includes a download and review of hourly, 40-day water use data recorded at the meter when available, a review of all onsite water uses, identification of leaks and additional water efficiency opportunities at the property. Rebates and incentives are shared when appropriate.

Low-Income Conservation Services

Tucson Water also offers several low-income conservation services. Qualifying low-income homeowners can receive free high-efficiency toilet replacements, discounted clothes washers, rainwater harvesting and gray water grants and loans in addition to the regular rebates and free emergency plumbing repairs.



This is an example of a water conserving landscape.

Advanced Metering Infrastructure

Tucson Water recently undertook an updated analysis of the possible benefits from implementing Advanced Metering Infrastructure (AMI), an approach to "smart metering" that provides real time water consumption data to the consumer and to the utility. This analysis is documented in the January 2022 TM, *One Water 2100 Smart Metering*. This TM is included in Appendix H. AMI can detect leaks in a timely manner and automatic leak detection can promptly inform customers of a leak. This information allows customers to change behavior and/or address and resolve leaks quickly, resulting in significant cost savings for the customer and reduces water waste. Also, the use of AMI meters and the consumption data it would provide would allow Tucson Water to better understand conservation measures' effectiveness and target conservation programs with customer-specific water budgets.

Community Education and Outreach Programs

Along with numerous rebates and conservation programs, community outreach and education are crucial to demand management. Investment in water education programs increases the awareness of water scarcity and changes community behavior around water use. Tucson Water continues to contract with several partners that provide outreach, conservation activities, and educational services throughout the service area. These include youth education programs and Smartscape, which offers adult education for landscape professionals and residents. Tucson Water partners with Arizona Project WET (APW) and Environmental Education Exchange (EEExchange) to offer these youth education programs. All programming meets Arizona Department of Education K-12 Standards.



SWEETWATER WETLANDS

Students participate in outdoor water education at the Sweetwater Wetlands.

Infill Development

One way to achieve conservation in new development is to pursue policies that support infill development. Infill development involves building within existing urban areas, which makes better use of existing infrastructure, and limits sprawl. This type of development has several environmental benefits, including reduced irrigation needs for smaller landscaped areas. *Tucson Resilient Together* includes action steps for how the City of Tucson can support infill development.

Non-Revenue Water Management Program

Non-revenue or unaccounted-for-water (aka water loss) is the difference between potable water production and customer consumption. Leaks at any point in the distribution system can contribute to the non-revenue water volume. Metering inaccuracies can also contribute to apparent levels of non-revenue water. On an annual basis, non-revenue water losses vary from 6 - 9 percent. Reducing non-revenue water is an important water conservation step for Tucson Water.

Focusing on leaks, breaks, and metering replacements helps account for and reduce non-revenue water. Tucson Water's assessment of AMI ties into its ongoing efforts to identify and implement strategies to reduce water loss as it travels through the distribution system to customers. Over the past decade, Tucson Water has been implementing programs targeted at reducing non-revenue water. This includes a reservoir rehabilitation program where tanks are inspected for leaks and upgraded as needed. There have also been pilot programs implementing leak detection testing on portions of the distribution system. To-date, these programs have only focused on portions of the Tucson Water distribution system; however, system-wide audits and repairs will become increasingly more important moving forward.

In 2021, Tucson Water started work on a system wide non-revenue water management program. This program is in the development stage and aims to significantly reduce the percentage of water lost each year. By creating and maintaining this comprehensive program, Tucson Water can work to reduce leaks throughout the system with the long-term goal of significantly reducing the yearly non-revenue percentage. These existing and latest programs highlight Tucson Water's continued commitment to internal water conservation practices.

Drought Preparedness and Response Plan

Following the 2020 update to the *Drought Preparedness and Response Plan*, Tucson Water prepared for current and future drought declarations on the Colorado River. The plan outlines four drought tiers, Tiers 0 through 3, which are declared based on the water levels in Lake Mead. However, it should be noted that shortages on the Colorado River do not immediately translate to shortages for Tucson's water supply as discussed in Chapter 3. Once each tier is declared, Tucson Water is required to take specific response measures, as follows:

- **Drought Tier 0** – Tier 0 is triggered when Lake Mead water levels are between elevation 1,090 and 1,075 feet above mean sea level (msl). Tucson Water is required to develop water use guidelines. Water use guidelines or water budgets are the amount of water required for indoor and outdoor use. These guidelines are developed for residential, commercial, and reclaimed water customers based on historic consumption data.
- **Drought Tier 1** – Tier 1 is triggered when Lake Mead water levels are between elevation 1,075 and 1,045 feet msl. Tier 1 involves providing targeted conservation information to customers who are exceeding the established water use guidelines. As a part of the Tier 1 Drought Plan measures, Tucson Water is working on a landscape water budget application that will identify commercial customers exceeding water budget targets. Educational outreach will be developed for these specific customers.



- **Drought Tier 2** – Tier 2 is triggered when Lake Mead water levels are between elevation 1,045 and 1,025 feet msl. Audits are required for customers whose consumption exceeds the established water use guidelines.
- **Drought Tier 3** – Tier 3 is triggered when Lake Mead water levels are below elevation 1,025 feet, or the volume of water delivered by the CAP to Tucson Water is less than annual demand. The City's Mayor and Council may consider water restrictions specific to customers who are not implementing audit recommendations or reducing water consumption within the provided guidelines.

As of 2023, the Lower Colorado River Basin is in a Tier 2a shortage. This level of shortage represents a 592,000 ac-ft reduction to Arizona's Colorado River supply, constituting 34 percent of CAP's normal supply in an average year. Tucson Water is implementing the Tier 2 response measures described above, including targeted conservation program information for customers whose consumption exceeds their specific water use guidelines, and water audit assistance for customers whose consumption continues to exceed water use guidelines.

Drought Policy Responses

In October 2022, the Mayor and Council directed staff to research several water conservation management approaches, code changes, and ordinances in response to the drought emergency on the Colorado River.

- **EPA WaterSense Fixture Building Code Requirement** – This would update the current building code to require EPA WaterSense Certified fixtures in new developments. Benefits would include both water and energy savings. These fixtures and their equivalents have been tested and certified by the EPA.
- **Irrigation meter requirements for new Commercial/ Industrial customers over a specific size** – Meter requirements for new commercial and industrial customers would help provide outdoor water use data that can be useful in managing peak demands and enacting drought measures.
- **Low Impact Development (LID) Ordinance** – This proposed ordinance would mandate the use of GSI in new housing developments. LID can greatly reduce the potable water demands for urban landscapes and the inclusion of GSI can create healthy green spaces full of native and drought tolerant plants.
- **Prohibition of non-functional ("ornamental") turf** – This policy would ban new ornamental turf from being approved for installation in new multifamily and commercial development projects. A complimentary rebate program could be developed to incentivize customers to remove existing turf, whether non-functional or not.

Additional policies to conserve water for new development and in the built environment are expected to emerge as conditions continue to change on the Colorado River. Research is also being conducted on Net Zero Water, an approach where all water demands for new developments are met through different offset measures. The goal of this approach is to avoid additional demands when new developments are created.

In June 2023, the Mayor and Council approved the EPA WaterSense Fixture Building Code Requirement and Unified Development Code amendments to prohibit non-functional or ornamental turf in new commercial, industrial, and institutional developments. Both amendments went into effect July 6, 2023. Research by Tucson Water staff into the LID Ordinance and irrigation meter requirements for new commercial/ industrial customers over a specific size is still ongoing.

FUTURE WATER DEMAND VULNERABILITIES

Key vulnerabilities identified through the scenario planning process include significant and unplanned population growth along with land use, economic, and other behavioral changes that would result in water demand increasing along with population growth.

FUTURE WATER DEMAND OPPORTUNITIES

The scenario planning process also identified that continuing to prioritize water conservation can be key to moving towards future sustainability and resilience. This includes developing and implementing a consistent and effective public outreach and education campaign to build on Tucson Water's strong existing water conservation and local water management strategies.



THE AVERAGE TUCSON CUSTOMER USES 80 GALLONS OF WATER PER DAY.

PROJECTED WATER USE

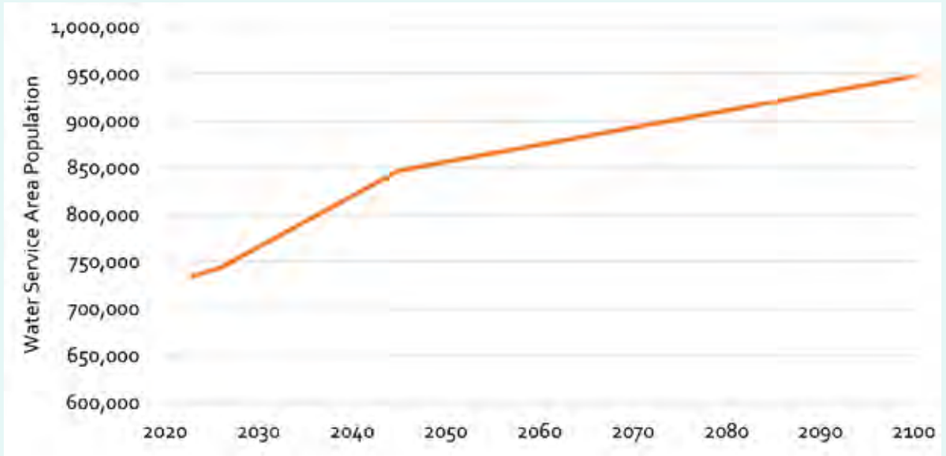
The scenario planning process identified that while understanding current water supply vulnerabilities and opportunities is crucial to the planning process, water supply is only one part of the equation for long-term resilience and sustainability. Understanding current demands and projecting future water demands is another key consideration in achieving Tucson's One Water vision. Future demands in the Plan are estimated using a combination of Tucson Water's projected population growth and recent historical potable water use accounting for climate change impacts and future conservation.

Population Projections

The region's population grew rapidly in the early 20th century with the arrival of the railroad and the establishment of the University of Arizona. The City's population has continued to expand in the decades since, driven in part by a strong economy, which is anchored by industries such as aerospace, defense, and healthcare. Since 2010, the Tucson Water service area has grown by around 30,000 people or an annual growth rate of 0.3 percent. While Tucson is not growing as quickly as it has in the past, steady population growth is still expected in the future.

To project population out through 2100, the Plan was supported by a future growth analysis. These population projections were used for the scenario planning process and informed the final population projection shown below. The analysis considered information on residential and non-residential growth provided by the Pima Association of Governments (PAG), Arizona's Office of Economic Opportunity, and the U.S. Census Bureau, as well as current zoning and planned and potential annexations of the Tucson Water Obligated Service Area.

Within the Tucson Water service area, the population is expected to increase by 29 percent, or about 213,000 people, to an estimated total of 947,000 by the year 2100. This equates to an average annual growth rate of 0.3 percent. The population projection in the graph below is the basis for the water demand analysis in the Plan. This projection is based on the medium growth projection by PAG. The full range of growth projections are included in the April 2020 TM, *One Water 2100 Population Projections* which is included in Appendix I. Information about potential expansions of the Tucson Water Obligated Service Area and other growth areas can be found in the February 2022 TM, *One Water 2100 Land Use Planning* included in Appendix J.



POPULATION PROJECTIONS IN THE TUCSON WATER SERVICE AREA

Supply and Demand Projections

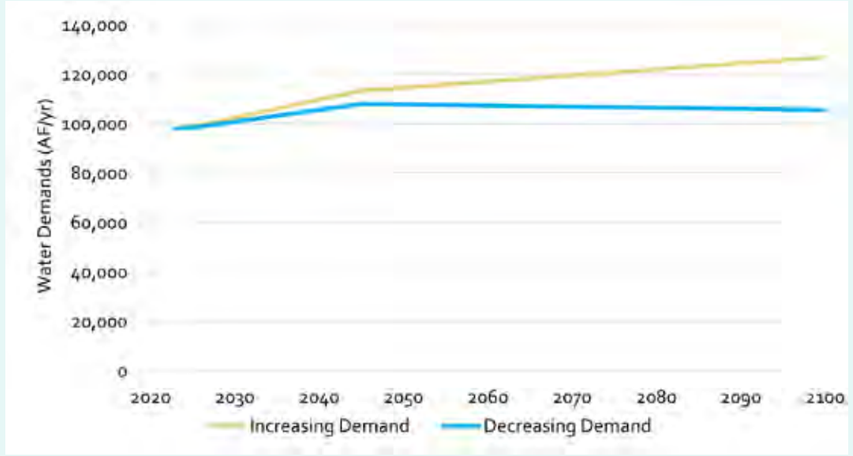
A comparison of supply and demand changes through the year 2100 was completed for the four scenarios created during the stakeholder workshops. These scenario projections attempt to characterize the uncertainty related to changes in water supplies and demand. The four scenarios created with stakeholder input are the *Sustainable Oasis*, *Desert Oasis*, *Counting Buckets*, and *Thirsty Desert* scenarios. Each scenario considers a different combination of projected water demand (as measured by GPCD) and water supplies (measured in acre feet). The water use projections include two plausible scenarios of future water use through 2100. Descriptions of these two scenarios and the projected water demand associated with each scenario are defined below.

- **Increasing Demand:** This scenario assumes that water demand will continue to increase into the future. It is based on an increasing population with a potable per capita water use that is held constant at the recent average value of 120 gpcd. Under the increasing demand scenario, potable water use is expected to increase by 29 percent, or just under 29,000 AFY to an estimated total of 127,000 AFY by 2100.
- **Decreasing Demand:** This scenario assumes that water demand will remain relatively flat into the future. It is based on an increasing population with a potable per capita water use that reduces by 20 gpcd to 100 gpcd by year 2100. A gradual long-term reduction of gpcd was assumed. Under the decreasing demand scenario, potable water use is expected to increase by 8 percent, or just under 8,000 AFY, to an estimated total of just under 106,000 AFY by 2100.

The supply assumptions in the Plan test Tucson Water's resilience against long-term shortage conditions for the City's Colorado River allocation. Two scenarios looking at Tucson Water's future supply availability under different estimated reductions to Tucson Water's CAP allocation were considered and are defined below:

- **Increasing Supply Availability:** This scenario assumes that the shortages to Tucson Water's CAP allocation will be no greater than existing shortage sharing agreements on the Colorado River. It is based on a long-term Tier 3 drought declaration under the Lower Basin DCP. Under this scenario, it is estimated that the City's CAP allocation would be cut to 124,000 AFY.
- **Decreasing Supply Availability:** This scenario assumes that the shortages to Tucson Water's CAP allocation will be significantly greater than existing shortage sharing agreements on the Colorado River. It assumes a long-term 50 percent reduction in Colorado River water supplied by the CAP starting in 2026. Under this scenario, it is estimated that the City's CAP allocation would be cut to 72,000 AFY.

Beyond its CAP allocation, Tucson Water has access to several other classes of water. These include Colorado River water and effluent stored by Tucson Water as underground LTSCs, as well as additional institutional safeguards such as CAP firming of LTSCs stored by the AWBA and CAGRD. Tucson Water also has access to over 54,000 AFY of groundwater resources identified in the City's 2023 application to modify its DAWS.



PROJECTED WATER DEMAND

Comparing Scenario Projections

A comparison of supply and demand projections through the year 2100 was completed for four scenarios to characterize the uncertainty related to the current water supply portfolio. The four scenarios considered are the *Sustainable Oasis*, *Desert Oasis*, *Counting Buckets*, and *Thirsty Desert* scenarios. Each scenario considers a different combination of water demand and water supply portfolio scenarios. The key assumptions and resulting annual demand-supply balance for each of these scenarios are described in the following sections.

There are inherent limitations in the planning process due to the need to make assumptions to address factors that are dynamic and to some extent, beyond Tucson Water's control. The decreasing supply availability scenario assumes a significant reduction in the available CAP allocation. Existing contracts are likely to be revisited as a part of the federal reconsultation process and may result in a change to Tucson Water's allocation. While some reductions can be expected in the future, the exact amount is unknown, and it is unlikely that the outcome will be as severe as a permanent 50 percent cut. Within the federal reconsultation process, Tucson Water is advocating for equitable sharing of the proposed cuts to Colorado River water across the basin states. Additionally, CAP is currently exploring options to augment its supplies.

Increased Portfolio Diversification

Supply

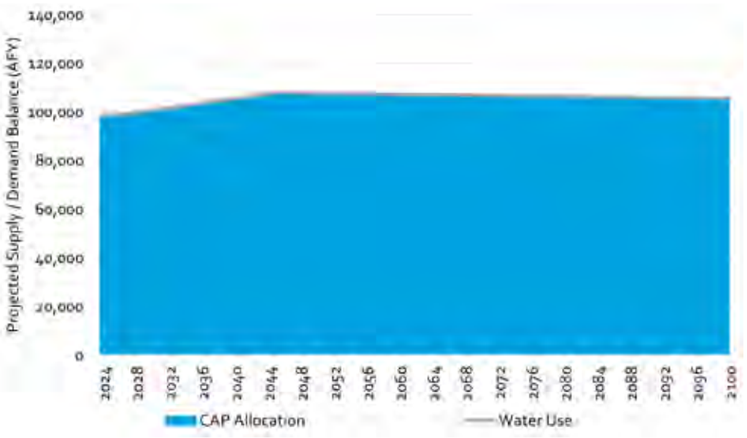
Decreased Demand

Demand

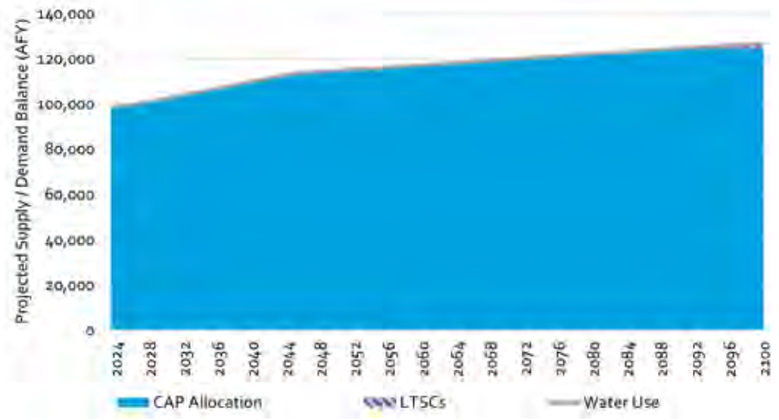
Increased Demand

Decreased Portfolio Diversification

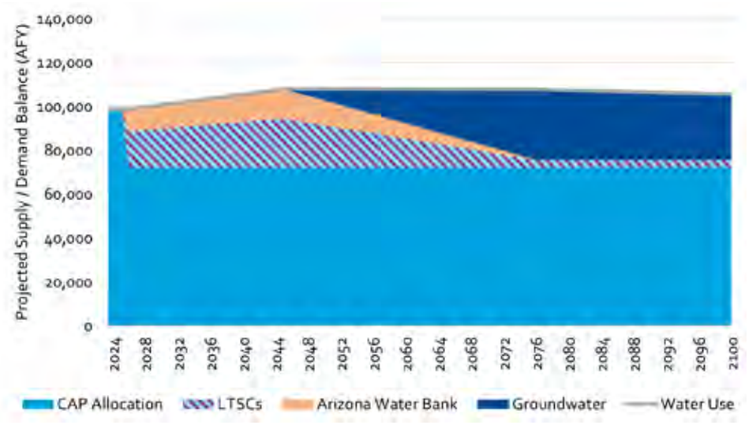
Sustainable Oasis



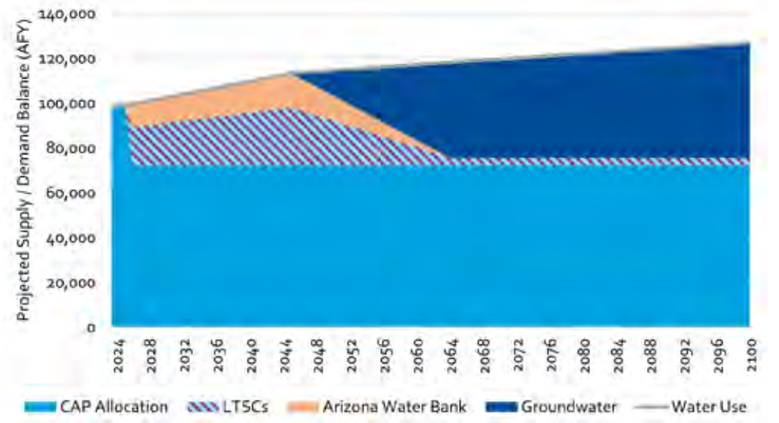
Desert Oasis



Counting Buckets



Thirsty Desert



Sustainable Oasis

In this scenario, renewable Colorado River water exceeds projected potable demands and Tucson Water can continue saving that water as LTSCs. If projected demands decrease and supply availability increases, Tucson Water's potable demand is within the CAP allocation through 2100. The total available CAP allocation (124,000 AFY) is estimated to exceed the projected water demand (106,000 AFY) by approximately 18,000 AFY in the year 2100. The figure shows the supplies used to meet the water use through the year 2100.

Desert Oasis

In this scenario, Colorado River water exceeds projected potable demands well into the future and Tucson Water can continue saving that water as LTSCs, until those supplies are used to meet customer demands from the 2080s to year 2100. If both demand and supply availability increase, the total projected potable water demand (127,000 AFY) is estimated to exceed the City's CAP allocation (124,000 AFY) by approximately 3,000 AFY in year 2100. The figure shows the supplies used to meet the annual water demand.

Counting Buckets

In this scenario, potable demands exceed the available Colorado River water and Tucson Water relies on LTSCs and other groundwater accounts to meet customer demands. If projected demands and supplies both decrease, potable water demand exceeds the available CAP allocation in year 2026. The projected potable water demand (106,000 AFY) exceeds the CAP allocation (72,000 AFY) by approximately 34,000 AFY in the year 2100. Tucson Water has sufficient available groundwater supplies through LTSCs, CAP firming by the AWBA, and other groundwater resources to meet the demands through the year 2100. The figure shows the supplies used to meet the water use through the year 2100.

Thirsty Desert

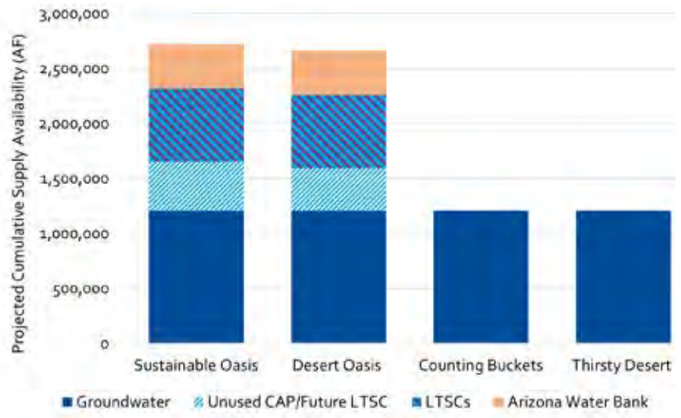
In this scenario, potable demands exceed Colorado River water and Tucson Water relies heavily on LTSCs and other groundwater accounts to meet customer demands. If demands increase while supply availability decreases, Tucson Water's potable demand exceeds the CAP allocation in 2026. The total projected water demand (127,000 AFY) exceeds the CAP allocation (72,000 AFY) by approximately 55,000 AFY in the year 2100. Tucson Water has sufficient available groundwater supplies through LTSCs, CAP firming by the AWBA, and other groundwater resources to meet the demands through the year 2100. The figure shows the projected annual water use and the supplies used to meet that water use through the year 2100.

Scenario Summary

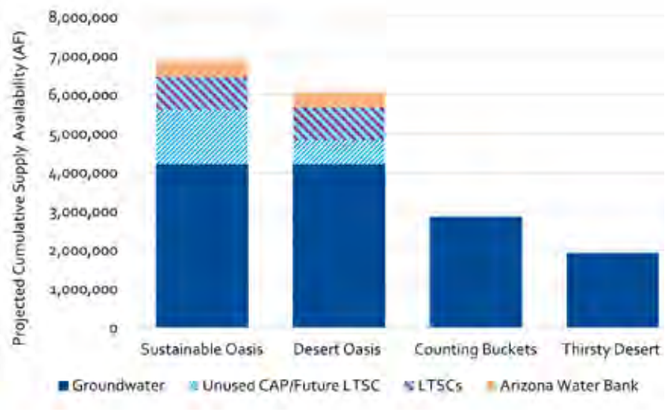
Tucson Water's projected cumulative supply availability for 2045 is summarized in the first figure. In the *Sustainable Oasis* and *Desert Oasis* scenarios, unused Colorado River water is stored to accrue additional LTSCs, bolstering Tucson's LTSC accounts. In the *Counting Buckets* and *Thirsty Desert* scenarios, renewable sources including stored LTSCs are committed to meet customer demands. These scenarios both assume that Tucson Water begins pulling from the groundwater resources in the Avra Valley aquifer in 2045. The groundwater shown accounts for the unused portion of the 54,000 AFY of available groundwater resources through 2045. In all four scenarios, Tucson Water has sufficient supplies to address the difference between supply and demand through the year 2045.

The projected cumulative supply availability as of 2100 is summarized in the second figure. In the *Sustainable Oasis* and *Desert Oasis* scenarios, unused Colorado River water continues to be stored to accrue an increase in LTSCs. In the *Counting Buckets* and *Thirsty Desert* scenarios, renewable sources, including stored LTSCs are used to meet customer demands and Tucson Water pulls from non-renewable groundwater stored in the Avra Valley aquifer. The groundwater shown accounts for the unused portion of the 54,000 AFY of groundwater resources through 2100. Even in these scenarios, Tucson Water has sufficient supplies to address the difference between supply and demand through the year 2100.

As the uncertainties and vulnerabilities around supply and demand conditions evolve over time, Tucson Water has the opportunity to take actions to mitigate the risks of the *Thirsty Desert* scenario and plan for a *Sustainable Oasis* where the water supply portfolio is increasingly diversified and water demands are well managed.



PROJECTED CUMULATIVE SUPPLY AVAILABILITY AS OF 2045



PROJECTED CUMULATIVE SUPPLY AVAILABILITY AS OF 2100

CHAPTER 5
TUCSON'S ONE WATER FUTURE

TUCSON'S ONE WATER FUTURE

INTRODUCTION

This chapter describes the potential and proposed water management strategies crafted to achieve the vision and five guiding principles outlined in Chapter 2 of the Plan. Here, the first guiding principle focusing on water reliability, is divided into two parts – one for managing water supply and the other for managing water demand. These were identified as the two areas of greatest concern in the scenario planning process. The water supply strategies are further divided into four water supply categories: surface water, groundwater, recycled water, and stormwater. The water demand strategies are further divided into three categories: incentives, monitoring and mandates, and education. The remaining four guiding principles and associated strategies are covered at the end of this chapter.

An example of a stormwater strategy under Guiding Principle 1, Water Reliability, is provided below. The strategy is numbered S-1 to indicate that it was ranked the highest in the stormwater category. An example implementation action is also included below the strategy. The strategies include the responses from the statistically valid survey and an associated priority level – "High," "Medium," or "Low" determined by the survey results.

Community feedback from the statistically valid survey and the online survey are both discussed in this chapter. A full summary of the results from the statistically valid survey is included in Appendix L while the online survey summary can be found in Appendix M. The results from the statistically valid survey are used to rank and prioritize the list of strategies as this survey is demographically representative of the Tucson community and was conducted by an independent third party. In the statistically valid survey, respondents were presented with a list of strategies and were asked to select which strategies were most important to them. Since a different number of strategies were shown for each question, the thresholds used to determine priority levels also varied by question.

The recommended strategies in Chapter 6 include the highest priority strategies, as well as additional strategies identified as priorities at different stages throughout the Plan development, including the scenario planning process and stakeholder workshops. These also include strategies identified by Tucson Water as having the greatest potential to increase supplies, diversify the supply portfolio, and reduce water demands.

Within the statistically valid survey, respondents also had the ability to provide written comments after each question. These comments are briefly summarized in each section. It should also be noted that some strategies developed by Tucson Water based on stakeholder and community feedback were not included in the statistically valid survey but are included in this chapter. These strategies do not have a survey response or an associated priority level.

The Plan also includes several climate-related strategies developed separately as part of *Tucson Resilient Together.* These strategies are also included in the Plan to provide consistency and alignment of these planning efforts and to reaffirm the City's commitment to improve Tucson's resilience in the face of changing climate conditions. The climate adaptation strategies included were selected to complement the vision and guiding principles of the Plan. Strategies from *Tucson Resilient Together* are shown in green tables to make them easily distinguishable from the strategies developed for this Plan.

EXAMPLE STORMWATER STRATEGY

Strategy #	Strategy	Survey Response	Priority Level
S-1	Explore opportunities for large scale stormwater projects with multiple benefits ***Example: Design detention basins to control flooding, harvest stormwater, and support native landscaping.***	69%	High

Community Priorities

Tucson Water involved the community at each stage of the development of the Plan strategies, with feedback obtained at community events, the public town hall, stakeholder workshops, and through the surveys. The strategies presented in this chapter were initially informed by the scenario planning process where stakeholders identified risks, vulnerabilities, and opportunities. These strategies are intended to lead Tucson Water towards the *"Sustainable Oasis"* future where the region's water supply portfolio is diverse, locally controlled supplies are increased, and water demands are well managed. The strategies also mitigate the risks associated with the *"Thirsty Desert"* future in which Tucson's water resources are more limited, and demands are growing.

Three strategy workshops were hosted by Tucson Water to develop strategies and actions related to the areas of greatest concern. At these workshops, stakeholders were given the opportunity to suggest strategy language, offer feedback, and propose additional strategies. An example of some of the feedback received within a workshop for Guiding Principle 5, Safe, High-Quality Water Supplies, is shown on the next page.



STAKEHOLDER WORKSHOP

Feedback from stakeholders on water demand management strategies.



FEEDBACK FROM STAKEHOLDERS ON GUIDING PRINCIPLE 5 – SAFE, HIGH-QUALITY WATER SUPPLIES

Sticky notes were used to gather input from stakeholders.

The strategies described in this chapter are based on Tucson Water's ongoing adaptive planning efforts and feedback obtained from stakeholders at community events and workshops. By utilizing this collaborative approach, the Plan reflects the community's priorities and is poised to effectively meet the needs of the community while achieving the One Water vision to manage Tucson's finite water resources to promote long-term resilience, equity, stewardship, and quality of life.



STAKEHOLDER WORKSHOP

Discussion of Plan strategies with stakeholders at one of the workshop events.

WATER SUPPLY STRATEGIES

The water supply strategies will guide Tucson Water in its efforts to provide a reliable and sustainable water supply in the face of a changing climate and ongoing drought conditions on the Colorado River. The strategies presented for water supply recognize the importance and interconnectedness of each source. Going forward, water supply development will require significant investments. Regional collaboration and partnerships will also be essential for success.

To maximize the use of existing resources, the strategies proposed look to protect surface water supplies and groundwater quality, manage groundwater basins, maximize the use of recycled water, and promote the development of stormwater as a key water source. As a main aspect of supply management, many of these strategies aim to increase the amount of locally developed and controlled water supplies that make up Tucson Water's supply portfolio. Through careful planning and execution, these strategies aim to address the challenges presented by changing and uncertain conditions while also developing a reliable and sustainable water supply for future generations.

GUIDING PRINCIPLE 1

Deliver reliability through water supply diversification, conservation, and innovative improvements to infrastructure.

Surface Water

The strategies under Tucson Water's surface water resources are aimed at maximizing the beneficial use of Tucson's Colorado River water allocation while taking cooperative actions to promote the long-term viability of this resource for future generations. These are complex water management challenges that require institutional collaboration with a broad range of federal, state, and local partners.

In the statistically valid survey, respondents were shown four surface water strategies and were asked to select the two that were the most important to them. Strategies to maximize the benefits of our current Colorado River water and to explore additional water supplies for the CAP were ranked as the highest priority strategies. This ranking was consistent across both the online and statistically valid surveys. Advocating for Tucson's allocation of Colorado River water followed closely behind these strategies. Although this strategy is ranked as medium priority, it is included in Chapter 6, as Tucson Water continues to prioritize protecting its allocation of Colorado River water through the federal reconsultation process and beyond.

Within the statistically valid survey, some respondents also submitted comments about additional surface water strategies. Support for rainwater capture and storage were the most dominant themes from these comments. Water conservation, desalination, reducing water use in new development, and purchasing agricultural land and retiring it were also common themes in the written responses.

Guiding Principle 1 – Surface Water Strategies

Strategy #	Strategy	Survey Response	Priority Level
SW-1	Maximize the benefits of our current Colorado River water ***Example: Continuing to store this water underground for future use.***	59%	High
SW-2	Work with the State of Arizona to explore additional water supplies for the Central Arizona Project ***Example: Treat brackish water near the canal to drinking water standards so that it can be delivered to cities.***	47%	High
SW-3	Advocate for Tucson's allocation of Colorado River water through the Central Arizona Project in state and federal negotiations ***Example: Tucson Water is actively participating in negotiations about how Colorado River water will be shared.***	46%	Medium
SW-4	Explore water exchanges with other water providers ***Example: Las Vegas has offered to invest in a treatment plant in Southern California in exchange for additional Colorado River water.***	26%	Medium
The following strategies were not included in the statistically valid or online survey.			
SW-5	Work with Arizona State Land Department to provide Central Arizona Project allocations to development of Trust Lands ***Example: Arizona State Land Department can assign a portion of their Municipal and Industrial subcontract to the City of Tucson.***		
SW-6	Support water supply firming and recharged water recovery efforts ***Example: Tucson Water is actively recharging portions of the City of Phoenix's CAP allocation for recovery during droughts.***		

Groundwater Strategies

Groundwater continues to be a vital part of Tucson's water resource portfolio. The strategies under Tucson Water's groundwater resources include steps to maintain water quality, address emerging contaminants, and practice sustainable groundwater management to address areas in the region where groundwater levels have continued to decline. Actions for these strategies include investments in treatment technologies, regional pipeline infrastructure, and collaboration and agreements with regional partners such as Tucson Water's ongoing partnership with the Santa Cruz Watershed Collaborative. These and other actions will help safeguard Tucson's groundwater supplies while providing the public with confidence in groundwater quality.

Respondents to the statistically valid survey were shown four groundwater strategies and were asked to select the two that were most important to them. Strategies aimed at protecting the aquifer and accelerating groundwater cleanup were ranked as the top priority strategies. Notably, respondents in the online survey ranked investing in new treatment technologies to address unregulated, emerging water quality issues as one of the top two strategies. This strategy was identified as a priority throughout the planning process and is also included as a recommended strategy in Chapter 6.

TUCSON'S ONE WATER FUTURE

A small number of respondents also wrote in additional strategy suggestions. Conservation and rainwater capture and storage remained high priorities among respondents to support groundwater sustainability. Some comments referred to the need to protect groundwater from pollutants and a need for ongoing education about protecting local groundwater. Additionally, agriculture, new development, and mining were the most mentioned threats to groundwater sustainability. There is no large scale agriculture in the Tucson Water service area and Tucson Water does not have any mining customers.

Guiding Principle 1 – Groundwater Strategies

Strategy #	Strategy	Survey Response	Priority Level
GW-1	Partner with regional water organizations to protect the aquifer ***Example: Work with other organizations to clean up contamination and ensure that the groundwater levels are balanced.***	59%	High
GW-2	Accelerate groundwater cleanup efforts to make local supplies more available ***Example: Some wells have been closed until the water can be treated to safe standards.***	44%	High
GW-3	Explore and invest in new treatment technologies to address unregulated, emerging water quality issues ***Example: Two examples of unregulated contaminants are pharmaceuticals and personal care products.***	42%	Medium
GW-4	Bolster sustainable groundwater management ***Example: Build pipelines to bring recovered Colorado River water to the southeast side of Tucson and reduce groundwater pumping in that area.***	38%	Medium
The following strategies were not included in the statistically valid or online survey.			
GW-5	Expand wheeling agreements that reduce groundwater pumping ***Example: Tucson Water has agreements with other regional water providers to deliver their CAP allocations through Tucson Water's distribution system.***		

Recycled Water

The recycled water strategies aim to maximize the use of this renewable water resource. These strategies address the onsite reuse of recycled water for non-potable purposes, such as irrigation, toilet flushing, and cooling. Strategies also include options for purifying recycled water to drinking standards, such as DPR.

Tucsonans overwhelmingly supported expanding uses for recycled water. The statistically valid survey respondents were presented with three strategies and were asked to select the single strategy they felt was most important. Adopting new policies for water reuse in buildings and purifying recycled water to drinking water standards were ranked as the highest priority strategies. Investing in new treatment technologies to address unregulated, emerging water quality issues in recycled water was identified as a priority throughout the planning process and is also included as a recommended strategy in Chapter 6.

Written in comments from the statistically valid survey generally supported expanded the use of recycled water, as well as the use of gray water (also known as "laundry-to-landscape" or "showers-to-flower") for landscaping, and the use of native plants in place of turf.



SWEETWATER WETLANDS

Reclaimed water is used to maintain the Sweetwater Wetlands

Guiding Principle 1 – Recycled Water Strategies

Strategy #	Strategy	Survey Response	Priority Level
RW-1	Adopt new policies for water reuse in buildings ***Example: Using rainwater, recycled water, and air conditioning condensate for toilet flushing.***	39%	High
RW-2	Begin purifying recycled water to drinking water standards ***Example: San Diego has begun using purified recycled water to augment their drinking water supply.***	31%	High
RW-3	Further treat recycled water for custom uses ***Example: Recycled water could be used in cooling towers for large buildings.***	23%	Medium
The following strategies were not included in the statistically valid or online survey.			
RW-4	Implement projects to retain all recycled water within the Tucson AMA ***Example: Recycled water can be stored underground for future use or purified for drinking water.***		
RW-5	Partner with regional organizations to enhance wastewater treatment ***Example: Collaborate with regional partners on decentralized water reclamation facilities.***		
RW-6	Implement treatment technologies to address unregulated, emerging water quality issues ***Example: Implement advanced water treatment to address unregulated emerging water quality issues.***		
RW-7	Acquire other recycled water entitlements ***Example: Purchase recycled water entitlements from regional partners.***		

Stormwater

Stormwater is a relatively new component of Tucson's water supply portfolio and there is growing interest in expanding the use of this supply. These stormwater strategies aim to integrate stormwater management into the built environment in a socially, economically, and environmentally beneficial way. This includes the areas of community education, development of additional institutional standards and practices, and support and funding. These strategies will require ongoing collaboration with other City and Pima County departments with responsibilities for flood control and management.

Four strategies were shown in the statistically valid survey and respondents were asked to select two as the most important. Strategies to explore opportunities for large scale stormwater projects, and to integrate and align stormwater standards were ranked as the highest priority. These results were consistent across both surveys. The medium priority strategies also continue to be ongoing considerations for Tucson Water. For example, the funding for the S2S program has been recently authorized as a permanent program. The continued success of this program would provide a basis for the development of a comprehensive stormwater utility. Additionally, Tucson Water will continue to offer multiple programs focused on education covering rain and stormwater uses for landscaping.

Written in comments from the statistically valid survey also indicated a strong interest in stormwater harvesting solutions. Comments included expanding stormwater capture solutions to existing homes and businesses and multiple comments expressed interest in mandating onsite capture and storage of stormwater for new businesses and developments.

Guiding Principle 1 – Stormwater Strategies

Strategy #	Strategy	Survey Response	Priority Level
S-1	Explore opportunities for large scale stormwater projects with multiple benefits ***Example: Design detention basins to control flooding, harvest stormwater, and support native landscaping.***	69%	High
S-2	Integrate and align stormwater standards, policies, and practices across the region ***Example: Stormwater harvesting sites are not always designed and built using best practices. Creating a shared set of standards and policies would help ensure the performance of these sites.***	42%	High
S-3	Educate the community about using rain and stormwater for landscaping ***Example: Community outreach that teaches the public about how to support native plants and trees with rain and stormwater harvesting.***	40%	Medium
S-4	Establish a comprehensive stormwater utility ***Example: Expand the City's existing stormwater fee to fund more green stromwater infrastructure projects.***	34%	Medium



GREEN STORMWATER INFRASTRUCTURE

Green stormwater infrastructure can reduce flooding on streets and often diverts that water into basins to irrigate vegetation that can shade streets and sidewalks.

DEMAND MANAGEMENT STRATEGIES

Tucsonans have long embraced a culture of conservation and Tucson Water continues to be a national leader in implementing water conservation policies and programs. Through decades of conservation initiatives, the Tucson Water service area has successfully reduced its overall water usage despite a growing population. As a result, the per capita water use has steadily decreased from 170 gpcd in 2002 to 130 gpcd in 2022.

Through this Plan and its supporting strategies, Tucson Water aims to assess existing conservation programs and identify opportunities for improvement while also continuing to protect vulnerable communities. By leveraging the expertise and experience gained through its past conservation efforts, and by staying committed to ongoing innovations and improvements, Tucson Water is well positioned to continue leading the way in water use efficiency measures and success.

Incentive Strategies

Incentive-based water management strategies aim to encourage water users to conserve and use water resources more efficiently. This could include both financial incentives, such as rebates, as well as non-financial incentives like certifications for landscape professionals or community awards. Participation in incentive programs often requires an up-front expense for customers, resulting in higher participation from higher income groups. As a result, these strategies also include a focus on low-income assistance to encourage equitable participation in these programs. Similarly, changes to water rates can have unintended consequences for some water users. That being said, the residential base water rate will be developed with affordability in mind.

In the statistically valid survey, three strategies were provided, and respondents were asked to pick which single strategy is most important. Through the statistically valid survey results, Tucsonans made it clear that water conservation is a community-wide effort and strategies should include all customers where possible. This includes a focus on assistance to low-income community members, programs targeted to renters, and increasing water saving opportunities for residential and commercial customers.

In the online survey results, respondents selected modifying the tiered rate structure as the most important strategy while increasing water saving opportunities for residential and commercial customers was ranked the lowest. Some initial work is already underway looking at the existing rate structure. The Citizens' Water Advisory Committee (CWAC) and Tucson Water staff are currently in the process of developing progressive rates for commercial customers, which is a step in working towards implementing that strategy.

Guiding Principle 1 – Demand Management - Incentives Strategies

Strategy #	Strategy	Survey Response	Priority Level
I-1	Improve outreach for low-income assistance programs for homeowners and renters ***Example: Community outreach that informs the public about low-income assistance such as free toilet replacement or emergency plumbing repairs.***	36%	High
I-2	Increase water savings opportunities through incentive programs for residential and commercial customers ***Example: Expand rebates to include retrofits and create online applications that better target commercial customers.***	33%	High
I-3	Modify tiered rate structure to make it more progressive ***Example: Currently, the more water customers use, the more they pay per unit of water. This tiered rate structure could be made more progressive, making it more expensive the more water you use.***	24%	Medium

Monitoring and Mandates

Monitoring and mandates are effective tools for water demand management particularly in response to drought conditions. Examples of monitoring range from "smart metering" via AMI that provides real-time water consumption data to quickly detect leaks and to provide customers with water use information such as guidelines on efficient water use, and water audits to identify areas where water is being wasted. Mandates can also be used to regulate water usage, such as implementing water conservation budgets or requiring the use of water-efficient appliances and fixtures. The effectiveness of these strategies depends on which combination of measures are being implemented and enforcement practices.

Five strategies were included in the statistically valid survey and respondents were asked to select a single strategy as the most important. As shown in the following table, statistically valid survey results indicate that Tucsonans widely favor implementing "smart meters".

Medium priority strategies relate to ongoing Tucson Water programs. For example, the ongoing implementation of the *Drought Preparedness and Response Plan* includes the development of water use guidelines for residential, commercial, and reclaimed water customers based on historic consumption data.



Guiding Principle 1 – Demand Management - Monitoring and Mandates Strategies

Strategy #	Strategy	Survey Response	Priority Level
MM-1	Install "smart meters" that monitor water use in real time, provide leak alerts, and inform water use habits ***Example: A website or application that notifies you when unusual water use is occurring.***	43%	High
MM-2	Create water use guidelines that provide an efficiency reference point specific to each customer type ***Example: For commercial customers, an application could be created to provide water use guidelines from parcel-based characteristics.***	13%	Medium
MM-3	Establish mandated water conservation rules ***Example: Restrictions on how often you can water your landscape***	13%	Medium
MM-4	Expand enforcement of water waste rules for public and city-wide operations ***Example: City employees contact people that allow water to run off their property and into the road.***	11%	Medium
MM-5	Expand opportunities for water audits ***Example: Online guides for a step-by-step analysis of indoor and outdoor water uses.***	8%	Low

Education Strategies

Education-based strategies refer to programs and initiatives aimed at promoting awareness and knowledge about water management and conservation. These strategies aim to provide information and education to help people understand the importance of water resources and the steps they can take to conserve and protect water resources. It should be noted that education and outreach are incorporated into numerous strategies. The strategies listed in the education category shown below focus specifically on education efforts related to demand management.

Four education strategies were included in the statistically valid survey and respondents were asked to select a single strategy as most important. As shown in the following table, the statistically valid survey results indicate that support was spread across multiple strategies with the highest level of support for conducting research on new technologies and approaches. In the online survey, landscape training received the highest percentage of responses. This strategy was identified as a priority throughout the planning process and is also included in Chapter 6.

Tucson Water continues to focus on improving its existing programs. Smartscape offers adult education for landscape professionals and Tucson residents. Tucson Water partners with APW and Exchange to offer youth education programs. Additional information about current community education and outreach programs is included in Chapter 4.

Guiding Principle 1 – Demand Management - Education Strategies

Strategy #	Strategy	Survey Response	Priority Level
E-1	Conduct research on new technologies and approaches ***Example: Landscape efficiency technology solutions that are more water efficient.***	30%	High
E-2	Provide landscape training to reduce outdoor water use, with emphasis on resilient, desert-adapted landscapes ***Example: Classes for homeowners and landscape professionals about water efficiency and native plants.***	28%	Medium
E-3	Continue to invest in classroom programs for children's education on conservation ***Example: Presentations about water conservation, our water supplies, and the water cycles for grade schools.***	25%	Medium
E-4	Expand community outreach programs ***Example: Digital advertising campaigns and websites.***	12%	Medium

CLIMATE RESILIENCE STRATEGIES

Tucson Water is focused on building resilience by planning for climate change and leading mitigation efforts. The strategies associated with this principle aim to promote sustainable management of water resources by prioritizing the need to reduce greenhouse gas emissions and promote energy efficiency. By adopting these strategies, water resource managers can help build resilience in their communities, reduce the vulnerability of their water systems to climate impacts, and promote a reliable and sustainable water supply for future generations.

In the last decade, Tucson has been moving towards including climate actions into the City's decision-making process. The Climate Action and Adaptation Plan also referred to as *Tucson Resilient Together*, outlines the City's roadmap to reducing greenhouse gas emissions and building community-wide resilience to climate change. There is considerable overlap between the Plan's guiding principles and *Tucson Resilient Together*. To avoid duplicating efforts and to make community outreach clearer, many strategies from *Tucson Resilient Together* are included in this Plan. *Tucson Resilient Together* has strategies organized into the following categories:

- Climate Leadership and Governance,
- Energy,
- Transportation and Land Use,
- Resource Recovery and Management, and
- Community Resilience.



THE CITY OF TUCSON IS PROUD TO LEAD BY EXAMPLE WITH SOLAR ENERGY

GUIDING PRINCIPLE 2

Reinforce resiliency by planning for climate change, leading mitigation efforts, and implementing collaborative and adaptive strategies.

City staff working on these two plans have coordinated to include public feedback in recommendations within both plans. While the plans were developed individually, implementation efforts will be done in tandem after the adoption of both plans. For the following sections, *Tucson Resilient Together* strategies are shown in green. See *Tucson Resilient Together* for additional details about the various strategies and the City's plans to reduce greenhouse gas emissions and adapt to climate change. Visit the City's Climate Action Hub to see what the City is doing to respond to climate change.



Several strategies from *Tucson Resilient Together* align with the Plan's vision and Guiding Principle 2. These six strategies are listed below. Some of these strategies discuss ongoing efforts. For example, the City currently has 64 active solar installations with many of these on Tucson Water properties.

Scan to go to the Tucson Resilient Together

Scan to visit the City's Climate Action Hub

Guiding Principle 2 – Strategies from Tucson Resilient Together

Category	Tucson Resilient Together Strategies
Energy	Decarbonize City owned and operated buildings and facilities (Energy strategy #1)
	Procure zero-emission electricity and decarbonize City and community power supply (Energy strategy #3)
	Install and promote distributed energy resources such as rooftop solar to provide local renewable energy and enhance energy resilience (Energy strategy #4)
Governance	Monitor and report emissions performance to adapt decarbonization strategies (Governance strategy #4)
Transportation	Transition public agency fleets to zero-emission and near-zero-emission vehicles (Transportation strategy #5)
	Encourage City employees to reduce the carbon footprint of their commuting and work-related travel (Transportation strategy #6)

QUALITY OF LIFE STRATEGIES

Water resources management is essential to maintaining a high quality of life for communities. This principle recognizes the importance of balancing environmental, social, and economic needs for sustainable development. Policy tools that separate economic growth and water demand can also be used to support the quality of life guiding principle. For example, Mayor and Council have directed City staff to research a Net Zero Water policy, or water offsets for new development, similar to polices currently enacted in other regions.

Several strategies from *Tucson Resilient Together* support this guiding principle and are shown on the next page. As an example, the Tucson Million Trees initiative launched in 2020 will plant one million trees by 2030 to increase the City's tree canopy and help mitigate the effects of climate change. The program utilizes stormwater harvesting infrastructure whenever possible to capture, retain, and filter stormwater to irrigate and sustain desert shade trees.

GUIDING PRINCIPLE 3

Enhance the community's quality of life by preserving and restoring riparian areas, increasing urban tree canopy, and supporting economic growth.



SONORAN DESERT GARDEN

Guiding Principle 3 – Quality of Life Strategies

Strategy #	Strategy
GP3-1	Research and implement policy tools that separate economic growth and water demand ***Example: Net Zero Water is an approach where all water demands for new developments are met through different offset measures.***

Category	Tucson Resilient Together Strategies
Resource Recovery	Encourage green infrastructure **(Resource Recovery strategy #5)**
Community Resilience	Deploy and maintain equitable nature-based solutions that reduce or sequester emissions, improve ecosystem health, and bolster climate resilience **(Community Resilience strategy #3)**
	Bolster the City's heat mitigation resources to reduce the urban heat island effect and protect vulnerable individuals and communities **(Community Resilience strategy #2)**
Governance	Accelerate climate action, adaptation, and resilience strategies through community and regional partnerships **(Governance strategy #2)**

AFFORDABILITY, ACCESSIBILITY, AND SOCIAL JUSTICE STRATEGIES

This guiding principle shows Tucson Water's commitment to prioritizing equitable and affordable service for all community members. Throughout the community outreach process for the Plan, Tucson Water received consistent feedback from its customers that affordability should be a key consideration. Community members prioritized equitable projects and programs, as well as improved access to low-income assistance. Addressing income-related barriers to participating in rebate programs is just one step in increasing accessibility for all customers.

Along with three *Tucson Resilient Together* strategies, two new strategies have been developed for this Plan. These strategies focus on increasing affordability and working to safeguard vulnerable populations. One strategy involves expanding the existing Community Assistance Relief Eligibility Program and taking actions to increase community awareness of this resource which could include developing new promotional materials for the program. The second strategy includes safeguards for vulnerable customers during drought responses through low-income assistance or other policies.

GUIDING PRINCIPLE 4

Achieve affordability, accessibility, and social justice by committing to fiscal responsibility and prioritizing equitable projects and programs.

Guiding Principle 4 – Affordability, Accessibility, and Social Justice Strategies

Strategy #	Strategy
GP4-1	Increase awareness and accessibility of the Community Assistance Relief Eligibility Program ***Example: Create promotional material for the program and advocate for program participation during community events.***
GP4-2	Adopt policies to safeguard vulnerable customers from drought responses ***Example: Provide low-income assistance to customers whose consumption exceeds their specific water use guidelines.***

Category	Tucson Resilient Together Strategies
Community Resilience	Bolster the City's heat mitigation resources to reduce the urban heat island effect and protect vulnerable individuals and communities **(Community Resilience strategy #4)**
Governance	Formalize climate action and resilience priorities in City operations, budgeting, processes, performance monitoring, and investments **(Governance strategy #1)**
	Accelerate climate action, adaptation, and resilience strategies through community and regional partnerships **(Governance strategy #2)**

SAFE, HIGH-QUALITY WATER SUPPLY STRATEGIES

This guiding principle emphasizes Tucson Water's commitment to providing safe, high-quality water supplies to all its customers. The importance of water quality was identified as a priority during the stakeholder workshops, with many community members supporting additional information and transparency regarding water quality monitoring. Water quality monitoring and communication practices are essential to promote safe and healthy drinking water for the community. Tucson Water's water quality monitoring program includes regular sampling and testing at source wells and throughout the distribution system. Tucson Water also employs a continuous online monitoring program for its primary sources of water to identify potential water quality issues quickly. Tucson also has programs to address ongoing maintenance for existing infrastructure and monitoring and addressing water quality. Tucson Water has an ongoing main line replacement program that renews infrastructure based on geographic area, infrastructure age, and observed issues. As these projects are completed, overall system reliability improves and the level of service in the area improves. To facilitate effective communication with the public, the City utilizes various channels, including social media, email, and the City website, to provide updates on water quality and any potential issues that may arise.

GUIDING PRINCIPLE 5

Ensure public confidence with safe, high-quality water supplies and exceptional customer service that includes transparency and responsiveness.

Along with one *Tucson Resilient Together* strategy, three new strategies have been developed as part of this Plan to support this guiding principle. As shown in the following table, these include long-term strategies to monitor emerging contaminants and continuously improve emergency preparedness and security all while providing exceptional customer service.

These strategies represent programs that will be ongoing initiatives throughout the planning period and beyond. These Plan strategies all build upon existing City and Tucson Water programs. Updates to the City customer service center and how Tucson Water communicates with the public will help Tucson Water continue to provide exceptional customer service.

Guiding Principle 5 – Safe, High-Quality Water Supply Strategies

Strategy #	Strategy
GP5-1	Provide exceptional customer service ***Example: Update the City website to improve information sharing to customers and provide outreach materials on the billing process.***
GP5-2	Continue monitoring for emerging contaminants ***Example: Improve communication to customers and the public on ongoing monitoring efforts and changes in water quality.***
GP5-3	Continuously improve emergency preparedness and security ***Example: Maintain up to date risk and resilience assessments and emergency response plans and develop educational material for the public about emergency response measures.***

Category	Tucson Resilient Together Strategies
Community Resilience	Bolster the City's heat mitigation resources to reduce the urban heat island effect and protect vulnerable individuals and communities **(Community Resilience strategy #4)** ***Actions: Conduct trainings with neighborhood and homeowners associations, resident and tenant associations, and other local groups to share information about the City's climate resiliency programs and form community emergency response teams (Community Resilience Action 4.1)*** ***Actions: Work with business organizations, retailers, and small stores to build capacity to sustain neighborhoods and ensure continued operations during and after an extreme climate event or natural disaster (Community Resilience Action 4.2)***



TUCSON WATER IS COMMITTED TO PROVIDING EXCEPTIONAL CUSTOMER SERVICE

CHAPTER 6

PLAN IMPLEMENTATION

PLAN IMPLEMENTATION

The Plan serves as an ambitious and informative guide to achieving a sustainable water future for the Tucson area. The City and Tucson Water are setting a course for a One Water future by proactively managing their water resources. Through the community engagement process, Tucsonans have identified water supply and demand changes as the areas of greatest concern. Through two separate public surveys, community members have shown the greatest support for water supply strategies that maximize the beneficial use of our existing water supplies and provide opportunities to expand the amount of locally controlled supplies in Tucson's supply portfolio, and demand strategies that expand conservation opportunities through innovation and technology, while promoting equitable solutions.

As the community was key in informing the Plan, it will be vital to the implementation process as well. Staff from the City and Tucson Water, CWAC, and Mayor and Council will work in partnership with state agencies and the community to implement the strategies and actions identified within the Plan. Additionally, this Plan, and the strategies discussed, will be incorporated into the City's upcoming general plan update, *Plan Tucson*.

Implementation Actions

Implementation actions are the specific projects, programs, policies, and/or tools that the City and Tucson Water will use to implement each of the recommended strategies. The implementation actions in the Plan were developed based on community feedback and through the stakeholder engagement process. They were refined by Tucson Water to include multiple steps and approaches to implementing each strategy. Implementation actions are included for each of the highest priority strategies identified through statically valid survey, as well as additional strategies identified as priorities at different stages through Plan development.

In total, the Plan identifies 16 high priority strategies and 66 implementation actions across the water supply and demand management categories. Each of the implementation actions takes time to undertake and adaptive management may be needed to refine the next steps as appropriate.

Each strategy is accompanied by a relative expense and a relative level of effort. Each implementation action has an implementation timeline. These are defined as follows:

- **Relative Expense:** $ (low) to $$$ (high)
- **Relative Level of Effort**: 1 (low) to 3 (high)
- **Implementation Timeline:** Ongoing (0-26+years), Near Term (1–10 years), Mid-Term (11–25 years), Long Term (26+ years)

The relative expense category is a scale from low to high and does not correspond to specific dollar amounts. This metric includes the anticipated cost of the strategy, which might include potential capital cost, O&M costs, as well as the cost-of-service costs, and costs paid by customers. Implementing new policies is considered a low relative expense, while strategies requiring large capital infrastructure or investments are considered a high relative expense. The relative level of effort considers factors such as additional work force needs to complete the strategy, possible partnerships or coordination required with other agencies, difficult negotiations, and the overall time and effort required by Tucson Water staff. Finally, the prioritized Plan strategies cannot all be implemented immediately nor concurrently. Multiple implementation actions were developed for each strategy and an approximate timeline has been established for each action. Some actions are already being taken by Tucson Water and these are considered ongoing. To further refine these estimates, next steps for implementing the recommended Plan actions may include a cost-benefit analysis, feasibility analysis, summary of resources needed, barriers to success, and a detailed implementation timeline.

Water Supply Implementation Actions

The recommended strategies for each water supply type and their associated implementation actions are presented in the following table. These strategies along with the others shown in Chapter 5, will help Tucson Water continue to provide reliable and sustainable water supplies while adapting to future uncertainties. The timeline for the actions needed to implement these high priority strategies ranges from ongoing to long-term, and the strategies include the full range of relative expenses and levels of effort. An example of an ongoing action is when the City entered a program to leave a large portion of its Colorado River water allocation in Lake Mead, in exchange for federal compensation. This specifically addresses the action to work collaboratively to reduce the risk of Lake Mead falling to critical levels. Many of these strategies involve complex water management challenges that require institutional collaboration and a broad range of federal, state, and/or local partners. Strategies to develop standards, policies, and practices for stormwater onsite reuse will require support and investments from industry stakeholders and would require ongoing outreach from Tucson Water. Purifying recycled water to drinking water will require large capital expenses, but would also provide the largest new water supply resource of locally-controlled water supplies.

Surface Water Implementation Actions

Strategy	Actions
SW-1 Maximize the benefits of our current Colorado River water. **Priority: High** **Relative Expense: $$** **Level of Effort: 2**	A. Continue to fully utilize Colorado River water with the use of CAVSARP, SAVSARP, Pima Mine Road Recharge Project, and groundwater savings facilities. (Ongoing) B. Annually update projected balance of groundwater storage credits to inform the adaptive management of Plan strategies. (Ongoing) C. Maintain and renew/replace infrastructure for storage and delivery of full CAP allocation. (Ongoing) D. Utilize groundwater storage credits as short-term transitional supplies during CAP allocation shortages while additional supplies are acquired, restored, and/or developed. (Near & Mid-Term) E. Develop implementation triggers for alternative supplies and enhanced conservation measures to prepare for extended CAP allocation shortages. (Near & Mid-Term)
SW-2 Work with the State of Arizona to explore additional water supplies for the Central Arizona Project. **Priority: High** **Relative Expense: $** **Level of Effort: 1**	A. Collaborate with CAP, ADWR, and other Arizona utilities to improve regional cooperation on water issues. (Ongoing) B. Work proactively with CAP, ADWR, and other Arizona utilities to explore the availability, water quality, accessibility, and cost of alternative water resource options. (Ongoing)

Strategy	Actions
SW-3 Advocate for Tucson's allocation of Colorado River water through the Central Arizona Project in state and federal negotiations. **Priority: High** **Relative Expense: $** **Level of Effort: 2**	A. Actively participate in negotiations about how Colorado River water will be shared. (Ongoing) B. Participate in collaborative efforts to reduce the risk of Lake Mead falling to critical levels. (Ongoing)

Groundwater Implementation Actions

Strategy	Actions
GW-1 Partner with regional water organizations to protect the aquifer. **Priority: High** **Relative Expense: $** **Level of Effort: 2**	A. Partner with ADEQ and other regional utilities to characterize groundwater contamination. (Ongoing) B. Participate in regional efforts to achieve and maintain safe yield for the Tucson AMA. (Ongoing) C. Consider regional solutions to address groundwater quality restoration where feasible. (Near-Term) D. Expand groundwater monitoring network to support groundwater management activities and decision-making. (Near-Term)
GW-2 Accelerate groundwater cleanup efforts to make local supplies more available. **Priority: High** **Relative Expense: $$** **Level of Effort: 2**	A. Implement water treatment solutions to address water quality issues from emerging contaminants. (Near-Term) B. Prioritize and address areas of contamination and restore availability of groundwater wells. (Near & Mid-Term) C. Fully remediate contaminated groundwater. (Long-Term)
GW-3 Explore and invest in new treatment technologies to address unregulated, emerging water quality issues. **Priority: Medium** **Relative Expense: $** **Level of Effort: 1**	A. Monitor the development of new Federal and State water quality regulations that could affect Tucson's future groundwater utilization potential. (Ongoing) B. Continue the Tucson Water Sentry Program to monitor unregulated and emerging contaminants in groundwater supplies. (Ongoing) C. Monitor the relative risk of emerging contaminants by comparing concentrations in groundwater supplies against Drinking Water Health Advisory levels and contamination risk for additional wells. (Ongoing) D. Participate in research projects to test novel treatment technologies for emerging contaminants. (Mid-Term) E. Implement advanced water treatment to address high priority emerging water quality issues. (Mid & Long-Term)

Recycled Water Implementation Actions

Strategy	Actions
RW-1 Adopt new policies for water reuse in buildings. **Priority: High** **Relative Expense: $** **Level of Effort: 2**	A. Research what other cities have done to promote, incentivize, and regulate onsite reuse for industrial, commercial, and large residential developments. (Near-Term) B. Provide regulatory and technical guidance for implementation of onsite reuse systems. (Near-Term) C. Create incentives for onsite reuse in commercial and industrial properties. (Near-Term) D. Develop a targeted outreach campaign to garner interest from commercial, industrial, and multi-family residential customers to participate in a pilot program. (Near-Term) E. Implement pilot programs for commercial and industrial customers. (Near-Term) F. Develop training programs for the operation and maintenance of onsite reuse. (Near-Term) G. Develop ordinance for onsite non-potable water programs, including design criteria, permitting, reporting, and enforcement. (Mid-Term) H. Develop criteria to require onsite reuse for certain water uses in commercial and industrial properties. (Mid & Long-Term)
RW-2 Begin purifying recycled water to drinking water standards. **Priority: High** **Relative Expense: $$$** **Level of Effort: 3**	A. Participate in the ADEQ regulation development process for direct potable reuse. (Near-Term) B. Evaluate benefits and costs for direct potable use of recycled water. (Near-Term) C. Conduct a survey to identify barriers to direct use of recycled water. (Near-Term) D. Develop a public outreach program to build public confidence and support. (Near-Term) E. Implement demonstration-scale projects to address potential customer or stakeholder concerns. (Mid-Term) F. Implement a full-scale direct potable reuse project to fully utilize effluent recycled water as a water supply. (Mid-Term) G. Beneficially use all recycled water within the Tucson AMA. (Mid-Term)
RW-6 Implement treatment technologies to address unregulated, emerging water quality issues. **Priority: Medium** **Relative Expense: $** **Level of Effort: 1**	A. Continue the Tucson Water Sentry Program to monitor emerging contaminants in recycled water. (Near-Term) B. Monitor the relative risk of emerging contaminants considering the end use. (Near-Term) C. Participate in research projects to test novel treatment technologies for emerging contaminants. (Mid-Term) D. Implement advanced water treatment to address unregulated emerging water quality issues considering the end use. (Mid-Term)

Stormwater Implementation Actions

Strategy	Actions
S-1 Explore opportunities for large scale stormwater projects with multiple benefits. **Priority: High** **Relative Expense: $$$** **Level of Effort: 3**	A. Use the intergovernmental agreement with Pima County Flood Control to implement large scale stormwater projects. (Ongoing) B. Establish additional governance and funding structures and strategies necessary to implement large scale stormwater projects. (Near-Term) C. Conduct a study to identify areas that have the greatest potential for implementing large scale stormwater projects with multiple benefits. (Near-Term) D. Prioritize and implement large scale stormwater projects. (Mid-Term)
S-2 Integrate and align stormwater standards, policies, and practices across the region. **Priority: High** **Relative Expense: $** **Level of Effort: 2**	A. Develop standardized measures of water savings. (Near-Term) B. Establish a regional task force or working group consisting of representatives from local governments, water management entities, and relevant stakeholders. (Near-Term) C. Conduct an inventory and analysis of existing stormwater standards and policies across the region. (Near-Term) D. Develop a toolkit or guidance document to support local governments in adopting and implementing consistent stormwater standards and policies. (Near-Term)

Demand Management Implementation Actions

The high priority demand management strategies and associated implementation actions are included in the following tables. Through these strategies and the additional demand management strategies discussed in Chapter 5, Tucson Water aims to assess and expand existing conservation programs while protecting vulnerable communities and continuing to lead the way in water use efficiency measures. The timeline for these high priority strategies ranges from ongoing to near-term, the relative expense ranges from $ to $$, and the relative level of effort ranges from 1 and 2. Strategies include targeted outreach, education, and training programs, adjustments to incentive levels, and researching new technologies and approaches. The implementation of a city wide "smart metering" system in strategy will require large investments in new technologies and additional staffing for customer support. Increasing investments in water conservation incentive programs will require significant investment in staff and resources to administer.

Demand Management - Incentive Implementation Actions

Strategy	Actions
I-1 Improve outreach for low-income assistance programs for homeowners and renters. **Priority: High** **Relative Expense: $** **Level of Effort: 1**	A. Continue to monitor participation in low-income assistance programs. (Ongoing) B. Conduct targeted outreach to increase low-income assistance program utilization. (Near-Term) C. Simplify the application processes for low-income assistance programs and provide customers with assistance in completing applications. (Near-Term)
I-2 Increase water savings opportunities through incentive programs for residential and commercial customers. **Priority: High** **Relative Expense: $** **Level of Effort: 1**	A. Continue to monitor participation rates, water savings, and return-on-investment for existing incentive programs. (Ongoing) B. Conduct targeted outreach to increase incentive program participation for high-demand customers such as multifamily complexes, HOAs, commercial properties, schools, and other institutional customers. (Ongoing) C. Adjust incentives, including rebates, focusing on high water use customers and customers with significant discretionary and/or outdoor water uses. (Near-Term)

Demand Management - Monitoring and Mandates Implementation Actions

Strategy	Actions
MM-1 Install "smart meters" that monitor water use in real time, provide leak alerts, and inform water use habits. **Priority: High** **Relative Expense: $$** **Level of Effort: 2**	A. Conduct pilot programs to evaluate how using smart meters will affect customer consumption. (Near-Term) B. Evaluate options and recommend a systems integration approach to best leverage smart meter data. (Near-Term) C. Implement utility wide smart meter communication technology. (Near Term) D. Develop a public education campaign to inform customers of the benefits of smart meters and how to use real-time data to monitor and manage their water use. (Near-Term) E. Use smart meter data to improve conservation measure effectiveness tracking. (Near-Term) F. Use smart meter data to create standards against which residential customers can measure their own usage. (Near-Term)

Demand Management - Education Implementation Actions

Strategy	Actions
E-1 Conduct research on new technologies and approaches. **Priority: High** **Relative Expense: $** **Level of Effort: 1**	A. Regularly research new technology and approaches used in conservation programs in other cities with similar climates. (Near-Term) B. Collaborate with research institutions, including universities and other industry organizations, to advance knowledge and develop new water conservation measures. (Near-Term) C. Develop a process for piloting new conservation technologies and evaluating their effectiveness. (Near-Term) D. Conduct a conservation program review on a fixed frequency that includes a review of all existing programs and an evaluation process for new conservation ideas and suggestions. (Near-Term)
E-2 Provide landscape training to reduce outdoor water use, with emphasis on resilient, desert-adapted landscapes. **Priority: Medium** **Relative Expense: $** **Level of Effort: 1**	A. Continue to update and promote desert-adapted landscaping manual and landscape watering guidelines with digital distribution on City's website, brochures at landscaping stores, and in-person outreach at public events. (Ongoing) B. Provide landscape training to landscapers and green industry professionals who design, install, and manage landscapes. (Ongoing) C. Partner with homeowner associations to promote water-efficient landscaping practices in common areas. (Ongoing) D. Conduct residential landscaping retrofit workshops to educate homeowners on desert adaptive landscaping practices. (Near-Term)



TUCSON WATER STAFF AT WORK

Monitoring and Evaluation

Tracking implementation progress and evaluating the effectiveness of recent programs and actions will be crucial to achieving the goals of the Plan. The metrics shown in the following table were developed to help evaluate progress toward achieving the implementation priorities. The historic water production chart will continue to be updated throughout the Plan implementation process to show the total volume produced by new water supply projects, and any changes in water production over time. The gpcd metric will also be a key indicator of whether demand is being reduced. Gathering data for each of these metrics to track trends and update graphs and figures promotes transparency to the general public.

Gathering data for each of these implementation metrics over time aims to provide a comprehensive view on the Plan implementation progress and provide concrete ways to evaluate that progress. By keeping track of the Plan progress over time, Tucson Water can proactively identify needs to accelerate, reprioritize or adapt any of the strategies identified in this Plan.

Implementation Metrics for the Plan

Metric	Metric Description
Annual Potable Production	Amount of recovered water produced and served to customers.
Annual Reclaimed Production	Amount of reclaimed water served to customers and the end uses of reclaimed water.
Annual Volume of Harvested Stormwater	The S2S program is developing a method for measuring the capacity of green stormwater infrastructure projects.
Annual Groundwater Savings	The annual volume of groundwater stored by Tucson Water, CAGRD, and AWBA.
Historic Production Chart	Total volume of water produced by the utility annually broken down by the source of the water (surface water, groundwater, recycled water, and stormwater) as well as relative proportions of each water source.
Gallons per Capita per Day	Annual gpcd, a common metric for comparing annual water use and water conservation effectiveness, is derived by dividing the number of people served by the amount of water produced.
Conservation Program Rebates and Incentives	Number of customers who take advantage of water efficiency programs (e.g., annual number of rebates or audits) and the level of water savings achieved through those programs.
Affordability	Number of low-income customers who receive assistance annually and the associated assistance funding and customer demographics.
Agency Collaboration	Number and type of collaborative efforts with other agencies and organizations, such as the number of meetings held, the level of participation, and the quantitative outcomes of the collaborations, such as number of multi-benefit projects, number of new collaboratively developed water policies.
Community Engagement	One Water 2100 feedback, presentations, and public events.
Greenhouse Gas Emissions	Tucson Water's Greenhouse Gas Emissions inventory will be shared with the team that implements *Tucson Resilient Together* (the City's Climate Adaptation and Action Plan).

ADAPTIVE MANAGEMENT

The implementation of Plan recommendations must adapt to changing conditions, such as ongoing drought conditions, population growth, climate change, regulatory changes, economic environments, and other factors that may continue to impact regional water availability. While near-term policies can be implemented now to address immediate needs, the mid-term and long-term strategies will be regularly reevaluated as conditions change and new information becomes available and as community priorities evolve. This approach allows for flexibility and agility in response to evolving conditions, while still maintaining a long-term vision for a resilient and sustainable water supply.

For example, changes in the long-term management of the Colorado River through the federal reconsultation process may impact many of the water supply management strategies. The outcome of this process may require Tucson Water to pivot to different water supply programs or prioritize conservation efforts. New statewide policies around potable reuse may act as a trigger for the implementation and public acceptance of wider adoption of potable reuse projects. This adaptive approach means that future community outreach regarding updated strategies will be needed as future updates to the Plan are made.

Adaptive Management Approach for Water Supply Portfolio

Increasing supply portfolio diversification and reducing reliance on Colorado River water delivered via the CAP is key to moving towards a resilient future and creating conditions that foster the *Sustainable Oasis* future. Quantitative triggers were developed that will be used to identify if significant long-term reductions are made to the City's Colorado River water supply, or if there are reductions within each of Tucson Water's locally controlled supplies from drought, infrastructure constraints, climate change, or other factors. If these quantitative triggers are met, the Plan implementation process will be reevaluated, and adaptive measures aimed at increasing supply diversification will be taken. Some of the metrics defined previously in this chapter will be used to support the adaptive management approach to the water supply portfolio. Metrics, quantitative triggers, and adaptive measures related to the supply portfolio are shown in the following table.

Metric	Adaptive Management Approach
Metrics	• Annual potable production. • Annual reclaimed production. • Annual volume of harvested stormwater. • Annual groundwater savings.
Quantitative Triggers	• Projected dependance on groundwater savings accounts due to the annual allocation of Colorado River water being less than potable demand. • Declining supply portfolio diversification, including reductions in the share of recycled water, groundwater, and stormwater resources within the portfolio.
Adaptive Measures	• Advocate for Tucson's allocation of Colorado River water and support the acceleration of new water supplies for the CAP. • Identify large water supply projects that can be accelerated. • Implement treatment technologies to address water quality limitations on the supply portfolio. • Adopt innovative standards, policies, and practices in stormwater harvesting and for reuse projects in buildings.

PLAN IMPLEMENTATION

Adaptive Management Approach for Water Demand Management

Water use efficiency (typically expressed in per capita water use or gpcd) and conservation program participation are key metrics for measuring the effectiveness of demand management strategies and programs. The supply and demand scenarios discussed in Chapter 4 assume either a constant gpcd over time or that the gpcd continues to decline by an additional 20 percent. Achieving these long-term reductions in gpcd are key to achieving a *Sustainable Oasis* future for Tucson Water and mitigating the risks of the *Thirsty Desert* future. Moving towards a lower gpcd will require continued water savings realized from Tucson Water's conservation program. Program innovation as well as engagement and investment throughout the community will be needed to see these continued water savings. Specific quantitative triggers related to demand management have been identified and if these quantitative triggers are met, adaptive measures aimed at increasing demand management will be taken. Additionally, some of the metrics defined previously in this chapter will be used to support the adaptive management approach for demand management. Metrics, quantitative triggers, and adaptive measures related to demand management are shown in the following table.

Metric	Adaptive Management Approach
Metrics	• Gallons per capita per day. • Conservation program rebates and incentives. • Annual groundwater savings.
Quantitative Triggers	• Per capita water use exceeds gpcd targets over a multiple year period. • Declining participation rates in conservation programs over multiple years. • Declining water savings from conservation programs over multiple years. • Declining groundwater stored by Tucson Water, CAGRD, and AWBA.
Adaptive Measures	• Enhance targeted outreach, education, and training programs. • Adjust incentive levels through increased funding. • Use smart meter data to drive additional conservation savings through innovative technologies. • Implement new outdoor landscape technologies and approaches in conservation programs.



TUCSON WATER STAFF AT WORK

REPORTING

As a long-term water resource planning document, many of the actions described in the Plan will involve projects spanning multiple years that will take time to fully implement. Additionally, many strategies identify actions that will become ongoing initiatives. To inform the public about the progress made towards implementing the strategies and actions within the Plan, several different approaches will be used to document and report steps taken.

Tucson Water communications, such as bill inserts, the One Water website (TucsonOneWater.com), City social media, and mailing lists from the community engagement process will all be used to communicate progress on the implementation of Plan strategies to community members. These updates will focus on progress made towards Plan goals and will provide information about upcoming events as well as new and existing resources regarding Plan actions. Opportunities for engagement with Tucson Water staff around the Plan implementation will also be highlighted.

A concise One Water 2100 Plan progress report will be produced every year and shared with the public to provide a progress update on the implementation of the Plan recommendations. These annual reports will summarize progress on the metrics described above, as well as any other Plan related activities including the completion of new projects, adoption of new policies, and community engagement activities. Actions related to the expansion and creation of incentives, rebates, and water conservation programs will also be covered in the annual Water Conservation Report by Tucson Water.







TUCSON WATER WILL INFORM THE PUBLIC ON PROGRESS MADE TOWARDS IMPLEMENTING THE STRATEGIES AND ACTION IN THE PLAN

CAPITAL IMPROVEMENT PROGRAM

Tucson Water has an ongoing CIP that covers a 5-year planning horizon, with short- and medium-term lists of specific projects that Tucson Water will pursue. This data-driven program is used to vet capital projects, meet budget constraints, and promote delivery of high-quality water to Tucson Water customers. With its longer implementation timeline, this Plan will provide long-term guidance for future CIP updates. This includes incorporating specific Plan strategies and actions as well as feedback from the community engagement process into recommendations for CIP projects.

Tucson Water uses hydraulic models of its entire potable and recycled water distribution systems across its service area that include supplies, customer demands, and facilities such as booster pumps and distribution pipelines. Water system modeling helps identify infrastructure and operational needs in areas where growth is already occurring or planned to occur. The modeling results translate into recommendations and improvements to maintain sufficient pressures throughout the City's water system under a variety of demand conditions, enhance system reliability and redundancy, and improve system operations. The water demand and supply projections used in the Plan are being incorporated into ongoing CIP planning efforts. Systems operations under different scenarios such as projected future demand conditions can also be simulated using these water system models.

Short-term gaps and improvement areas have been identified through this hydraulic analysis include conveyance system improvements, central well field rehabilitation, and reclaimed water application strategies. Conveyance system improvements include rehabilitation of existing and construction of new transmission mains. This includes new transmission mains and supporting facilities to convey water to areas in the southeastern portion of the service area where much of the area's growth is occurring.

While reliance on the central well field to meet water supply needs has decreased with the implementation of additional renewable supplies, the well field is still often used to meet peak demand in the summer months or when the CAP canal and assets are temporarily out of service. This infrastructure remains a valuable asset, and Tucson Water is considering implementing a comprehensive asset management program aimed at sustaining and enhancing the pumping capacity of the central well field.

Finally, the CIP includes evaluating Tucson Water's reclaimed water supplies to determine the best and highest use for the supply. This would include evaluating recharge capacities, aquifer recovery well locations, expansion of the reclaimed water distribution system, and preparation for indirect or direct potable reuse.

CHAPTER 7

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REFERENCES

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CITY OF TUCSON | TUCSON WATER

CASE STUDY: NEVADA IRRIGATION DISTRICT PLAN FOR WATER

Nevada Irrigation District

Plan for Water

Plan for Water

Final Technical Memorandum

7/17/2024

NID

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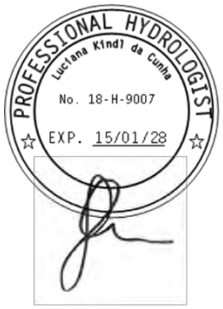
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Nevada Irrigation District *Plan for Water*

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APPENDICES

Appendix A: Chapter 2 Supplemental Information

Appendix B: Chapter 4 Supplemental Information

Appendix C: Chapter 5 Supplemental Information

Abbreviations

AF	acre-feet
ATI	antecedent temperature index
BOD	Board of Directors
CDEC	California Data Exchange Center
CFS	cubic feet per second
CIMIS	California Irrigation Management Information System
CMIP	Coupled Model Intercomparison Project
COA	Coordinated Operating Agreement
CSL	Central Sierra Snow Lab
CWC	California Water Commission
DEM	Digital Elevation Model
DSS	Data Storage System
DWR	Department of Water Resources
EM	Engineering Manual
FAO	Food and Agriculture Organization
FERC	Federal Energy Regulatory Commission
GCM	Global Climate Model
GIS	Geographic Information System
gSSURGO	Gridded Soil Survey Geographic Database
HEC	Hydrologic Engineering Center
HMS	Hydrologic Modeling System
HUC	Hydrologic Unit Code
IPCC	Intergovernmental Panel on Climate Change
ITRC	Irrigation Training and Research Center
IWFM	Integrated Water Flow Model

LOCA	Localized Constructed Analogs
MAD	management allowable depletion
MMC	Modeling, Mapping and Consequences
NAD 83	North American Datum of 1983
NAVD 88	North American Vertical Datum of 1988
NCAR	National Center for Atmospheric Research
NCSS	National Cooperative Soil Survey
NED	National Elevation Dataset
NID	Nevada Irrigation District
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
NSE	Nash-Sutcliffe Efficiency
NWIS	National Water Information System
NWS	National Weather Service
PBIAS	Percent Bias
PCWA	Placer County Water Agency
PFW	Plan for Water
PG&E	Pacific Gas & Electric
PRISM	Parameter-Elevation Regressions on Independent Slopes Model
RAS	River Analysis System
ResSim	Reservoir System Simulation
RMSE	Root Mean Square Error
RSR	Ratio of the Root Mean Square Error to the Standard Deviation
RWMP	Raw Water Master Plan
SCS	Soil Conservation Service

SHG	Standard Hydrologic Grid
SNODAS	Snow Data Assimilation System
SNOTEL	Snow Telemetry
SSURGO	Soil Survey Geographic Database
SWE	Snow Water Equivalent
SWRCB	State Water Resources Control Board
TAF	thousand acre-feet
UH	unit hydrograph
UNEP	United Nations Environment Programme
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
WMO	World Meteorological Organization
WPLM	Weighted Palmer Drought Severity Index
WRCC	Western Regional Climate Center
WRF	Weather Research and Forecasting
WY	water year

Executive Summary

The Nevada Irrigation District (NID) is committed to meeting the community's demand for water over the coming decades. To achieve this goal, NID is currently implementing the Plan for Water (PFW), a collaborative process to review NID's historical and projected available water supply and demands. The PFW will support NID's decisions about future investments and changes in water management practices to ensure the community enjoys the same high-quality water and reliable water system it has now and for the coming years. For more information on PFW follow the link: https://www.nidwater.com/plan-for-water#page-content.

Three numerical models were developed to collectively represent how NID's water delivery system works: a hydrology model to represent watershed performance, a demand model to estimate how much water is required to meet customer and regulatory needs, and an operations model to simulate the functions of NID's system of water storage and conveyance. Together, the models were used to evaluate a range of alternative operating strategies and their ability to meet the future needs of NID customers.

Hydrological Model Development

A physically based hydrological model (Chapter 2) was developed to best represent runoff conditions in NID watershed. Runoff scenarios were developed using the hydrological model with precipitation and temperature projections as input. Projections were generated based on global climate models known to best represent California's climate. (Chapter 3) From these projections, three scenarios were chosen for further analysis: bookend projections that represent the plausible extreme dry and wet climate conditions, plus a median condition.

Demand Model Development

"Demand" refers to the total volume of water required to meet NID's water users' needs. A well-known demand model (Chapter 4) was configured and applied to estimate projected demands for a 50-year horizon. The demand model provides a means of estimating NID customer demand under different potential future scenarios by physically simulating the processes that drive water use. The demand model leverages available local data, standard technical approaches, and best practices to account for the relative effects of estimated future changes in climate, land use, irrigation practices, soil properties, and other factors that impact demand. Results of the demand model were used to estimate the outflows required from NID's reservoirs to meet potential demands over the next 50 years.

Operations Model Development

A reservoir operations model (Chapter 5) was developed that simulates how NID operates its current storage, conveyance, and delivery system. The operations model used inflows from the hydrology model, current operating rules, and regulations to assess how well customer demands are met.

NID operations were simulated using a wide range of conditions, including historical conditions, current baseline operations, demands (low, median, and high), and climate (dry, median, and wet). Three future scenarios were selected for evaluation of potential PFW strategies.

- Dry Future Climate with High Demands
- Median Future Climate with Baseline Demands
- Wet Future Climate with Low Demands

These scenarios provide dry and wet bookends with a median climate scenario to represent a plausible mid-point. Use of these scenarios provides a wide range of hydrologic conditions and consumptive demands; the scenarios are suitable for testing the strategic alternatives.

Strategic Alternatives

Seven strategic alternatives (Chapter 6) were investigated to assess their potential to improve water security under projected climate conditions estimated by the Plan for Water HEC-ResSim model. These alternatives included:

- An extended irrigation season, assuming two additional weeks in October.
- A Rollins Reservoir storage increase of 10,000 acre-feet (AF), equivalent to an increase of 18 percent of existing storage capacity.
- A Rollins Reservoir storage increase of 50,000 AF, equivalent to an increase of 91 percent of existing storage capacity.
- The addition of Centennial Reservoir, a new reservoir on the Bear River downstream of Rollins Reservoir with a storage capacity of 96,660 AF
- A reduction in reservoir carryover storage targets in NID reservoirs at the end of the irrigation season totaling 50,000 ac-ft, equivalent to 38% of the current carryover storage target.
- Additional water purchases from PG&E based on the existing 2018 Coordinated operating Agreement (COA) between NID and PG&E.
- A combination of revised carryover storage targets (50,000 ac-ft) plus additional water purchases from PG&E based on the existing 2018 COA.

These seven alternatives were individually simulated by the HEC-ResSim operations model. Results of each strategic alternative simulation were compared against the baseline climate change scenario. Changes in average annual delivery, average annual unmet demand, and average annual carryover storage were calculated relative to the baseline to assess the relative benefit of each strategic alternative. This analysis was performed for all three climate change baseline scenarios: Dry Climate with High Demands, Median Climate with Baseline Demands, and Wet Climate with Low Demands.

The relative increase in average annual water delivery for each climate scenario is summarized in Figure 1 and annual average unmet demand (ac-ft) is shown in Table 1. Across all three climate scenarios, the Rollins Reservoir 50,000 AF storage increase alternative resulted in the largest relative increase in average annual deliveries, with similar reductions in average annual unmet demand. The Centennial Reservoir scenario and the Revised Carryover Targets + Water Purchase from PG&E scenario also produced relatively high relative increases in average annual deliveries. Despite the larger storage capacity increase for the Centennial Reservoir (96,000 ac-ft) alternative versus Rollins Reservoir (50,000 ac-ft) alternative, the lower elevation location of Centennial Reservoir limits its potential benefit to the NID water delivery

system. An increase in storage capacity at Rollins has much greater potential benefit because it can be used to supply water to a much larger percentage of NID customers. Revised Carryover storage targets produced the least beneficial increase in average annual water delivery.

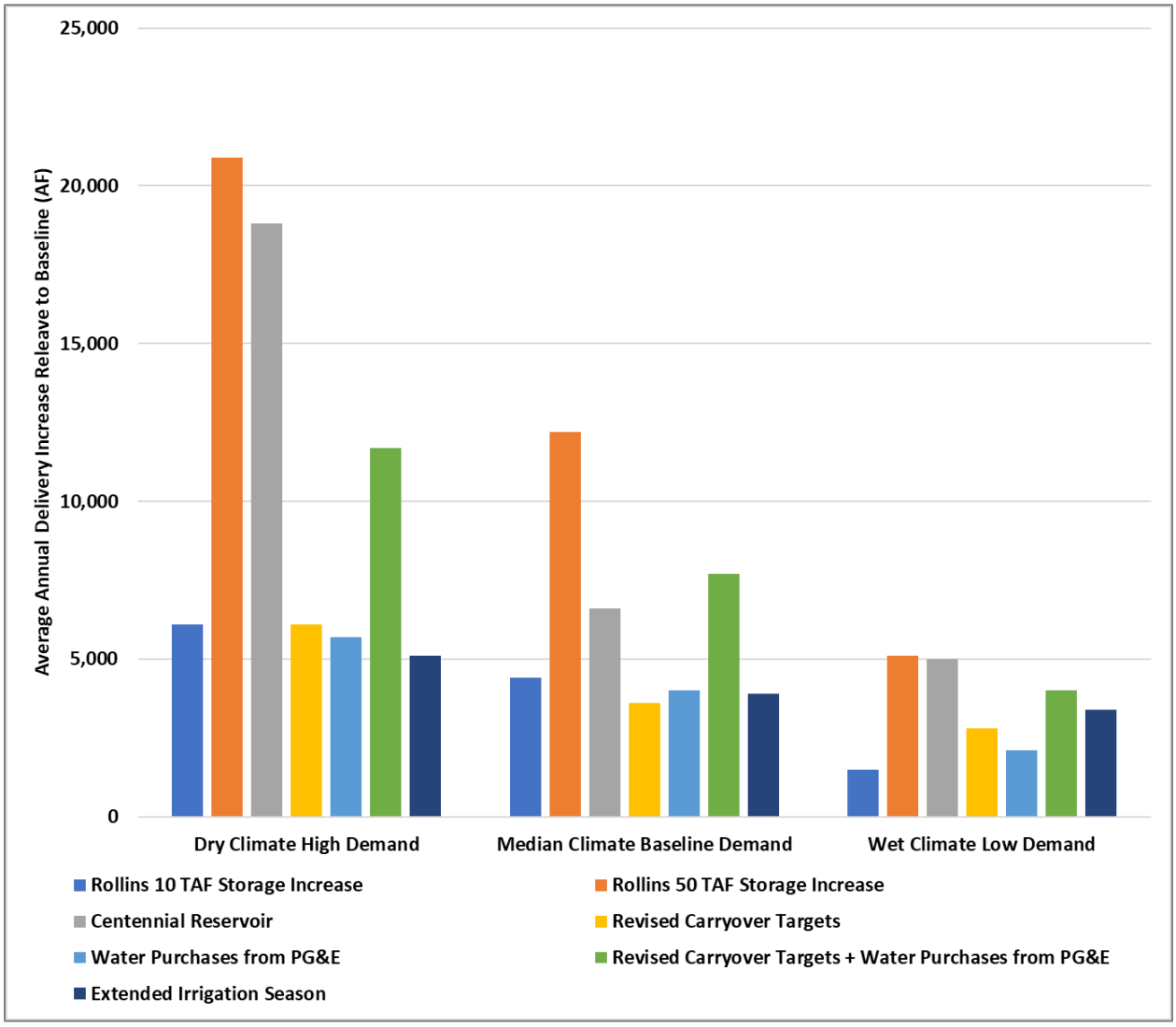


Figure 1. Relative Increase in Average Annual Water Delivery

Table 1. Annual Average Unmet Demand, Acre-Feet

Scenario	Dry Climate High Demand	Median Climate Baseline Demand	Wet Climate Low Demand
Baseline	35,000	13,900	5,900
Rollins 10 TAF Increase	28,900	9,500	4,400
Rollins 50 TAF Increase	14,100	1,700	800
Centennial Reservoir	16,200	7,300	900
Revised Carryover	28,900	10,300	3,100
Water Purchase	29,300	9,900	3,800
Revised Carryover + Water Purchase	23,300	6,200	1,900
Extended Irrigation Season	36,200	15,400	6,300

The relative change in average annual carryover storage for each climate scenario is summarized in Figure 2. Scenarios that added storage to the system, the two Rollins storage increase scenarios and the Centennial Reservoir scenario, increased the average annual carryover storage. The water purchases from PG&E scenario were relatively neutral, and the other scenarios result in a decrease in average annual carryover storage. Increased carryover storage provides additional protection against multi-year droughts. A decrease in carryover storage indicates a reduction in available NID water supply which increases risk.

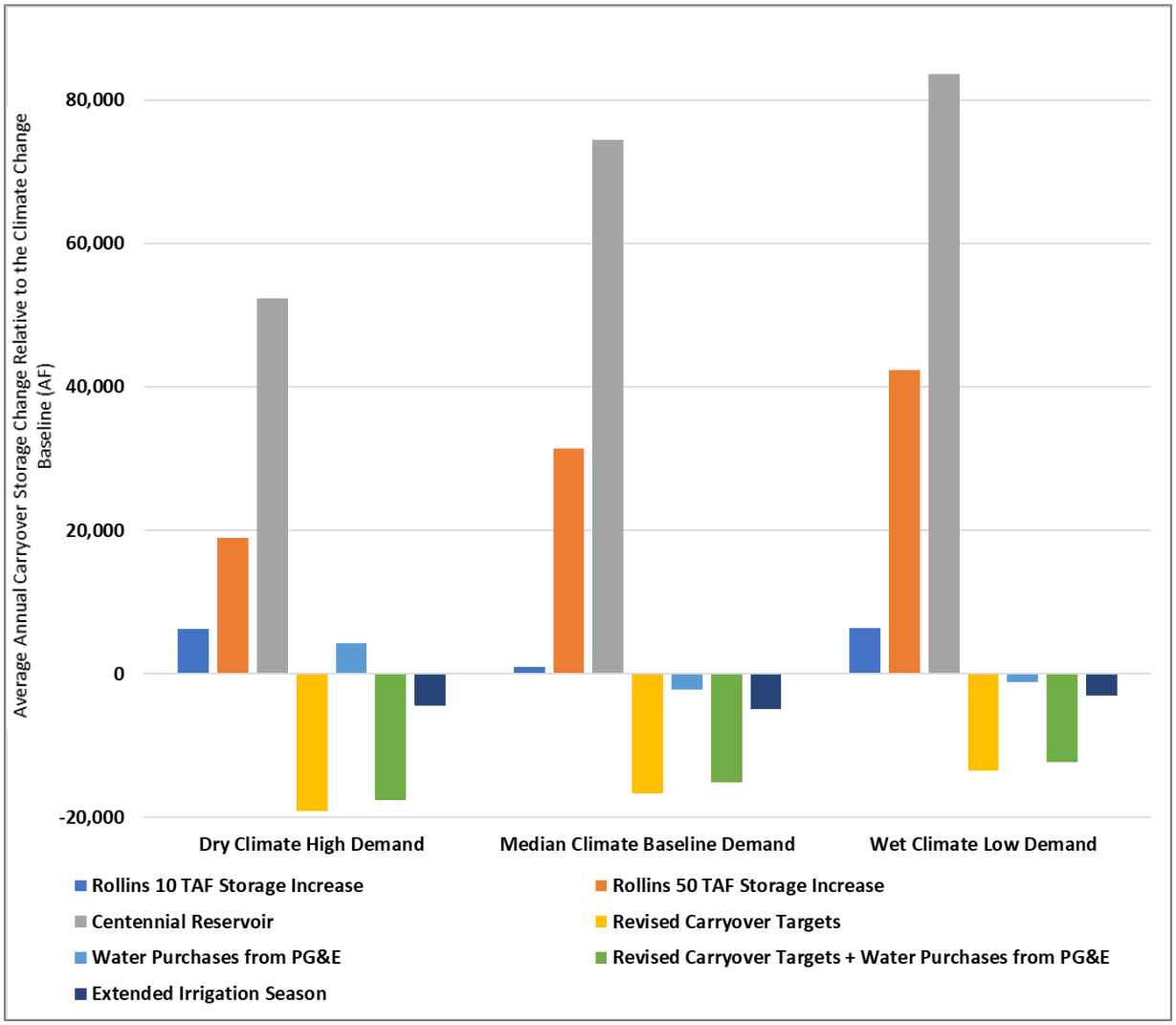


Figure 2. Relative Change in Average Annual Carryover Storage

Each of the strategic alternatives included in this analysis resulted in a net increase in water deliveries to NID customers under various projections of climate change. For some of these alternatives, the increase in deliveries comes with a negative impact on system storage, as measured by average annual carryover storage. Carryover storage is one of NID's four primary sources of water supply, which also includes natural runoff, contract water purchases, and recycled water. Alternatives that increase both water deliveries and carryover storage are much more valuable than those that increase water deliveries alone.

Chapter 1. Introduction

1.1. The Nevada Irrigation District

The Nevada Irrigation District (NID) is an independent public agency governed by a 5-member elected Board of Directors (BOD) and employs about 200 full- and part-time employees. NID supplies water to 25,000 homes, farms, and businesses in portions of Nevada, Placer, and Yuba Counties in the foothills of Northern California's Sierra Nevada Mountains. Water is collected from mountain watersheds and stored in a system of reservoirs. As water flows to NID customers, it generates more than 354 gigawatts of clean, hydroelectric energy per year while supporting environmental flows and serving public recreation. NID supplies both treated drinking water and crop irrigation water. Approximately 90% of NID's annual demand is for raw water/agricultural water during the irrigation season, April 15 to October 15.

In any given year, four primary sources supply NID's water:

1. Reservoir storage carried over from the previous year,
2. Natural runoff (including snowmelt) from the contributing watershed areas,
3. Contract water purchases, and
4. Recycled water.

NID regularly evaluates and updates its water supply availability projections. In the past, this was completed through the Raw Water Master Plan (RWMP), originally developed in 1985. The RWMP assessed the adequacy of the existing water storage and conveyance system to accommodate current and future water demand. Since 1985, the RWMP was updated in two phases: first in 2005 (Kleinschmidt et al. 2005), and then again in 2011 (Kleinschmidt Associates 2011).

Currently, NID's is evaluating and updating its water supply availability projects through the Plan for Water (PFW).

1.2. NID's Water Supply Network

NID's water supply system is a store-and-release system. Reservoirs store snowmelt and seasonal runoff for release during the typically dry summers. Water is delivered to customers via a network of channels, canals, flumes, and pipes. While there is natural runoff during the summer months, this water is generally used to meet regulatory requirements for environmental flows in the rivers. Irrigation demand is met primarily with withdrawals from storage reservoirs. Careful management and operation of storage reservoirs is essential to capture the maximum amount of runoff captured, minimize spillage from reservoirs, and ensure there is sufficient volume available in reservoirs to accommodate runoff during the spring snowmelt and storm events.

Water is stored and released from the high-elevation reservoirs based on NID's consumptive needs and reservoir carryover storage targets. Discretionary releases for water supply are made from Jackson Meadows Reservoir and Jackson, French, Faucherie, and Sawmill reservoirs during the spring runoff season through late fall. Releases from Jackson Meadows Reservoir are conveyed to Bowman Lake via the Milton-Bowman Tunnel. Releases from Jackson, French, Faucherie, and Sawmill lakes are stored and released by Bowman Dam through Bowman Powerhouse into the Bowman-Spaulding Conduit Diversion

Impoundment. Five small diversions along creeks that run perpendicular to the Bowman-Spaulding Conduit augment flows in the conduit up to its capacity and spill the remainder into their respective natural drainages downstream of the conduit.

Flows from the Bowman-Spaulding Conduit pass through PG&E's Lake Spaulding into PG&E's Drum Canal and the South Yuba Canal. Water transported into the South Yuba Canal is diverted into South Fork Deer Creek to supply NID customers in the Nevada City-Grass Valley area. This water is largely diverted at the Cascade Canal Diversion Dam located immediately downstream but is also used to manage Scotts Flat Reservoir storage. Releases from Scotts Flat Reservoir provide water to four other downstream diversions downstream along Deer Creek.

Water transported into the Drum Canal is passed through PG&E's Drum Forebay into the Bear River at PG&E's Drum Afterbay. Water is diverted and returned several times along the Bear River reach upstream of Rollins Reservoir by NID and PG&E for power generation. Daily volumes are scheduled by NID and PG&E for downstream consumptive demand.

Rollins Reservoir is NID's major low-elevation storage reservoir on the Bear River. Rollins Reservoir is a multipurpose facility that meets municipal, irrigation, domestic water supply, recreation, and power generation needs. From Rollins, water supplies NID customers in southern Nevada County and Placer County.

1.3. The Plan for Water

The PFW is a long-range decision tool to guide NID's future water management. The PFW process is an open and comprehensive look at available water resources affected by new regulations, changes in land use, varying climate, and community aspirations. The PFW offers a range of potential scenarios for NID's BOD to consider when assessing ways to best meet customer demands for water over the next 50 years. While 50 years is a sufficient time horizon for major water infrastructure planning, shorter term changes in water supply, water demand, regulation, and technology dictate the need for PFW updates every five years. The NID board members approved a resolution to update the plan every 5 years (NID 2023).

NID's PFW contains 11 stages, the first 6 stages are predominantly planning stages while the last 5 stages are the active modeling and evaluating stages, the latter of which will be discussed further in the next section.

1. System Overview
2. Water Rights Overview
3. Watersheds
4. Risk
5. Strategic Planning
6. Basis for Plan Water
7. Hydrology and Hydrography
8. Demand

9. Supply Needs
10. Strategy Options
11. Evaluate Strategies

More information regarding these specific stages can be found on NID's website at: https://www.nidwater.com/the-11-stages-of-plan-for-water.

1.4. General Approach

As briefly discussed above, watershed, supply and demand, and operation modeling was conducted during Stages 7 through 10 of the PFW. The various models are heavily informed by each other, as shown in Figure 1-1.

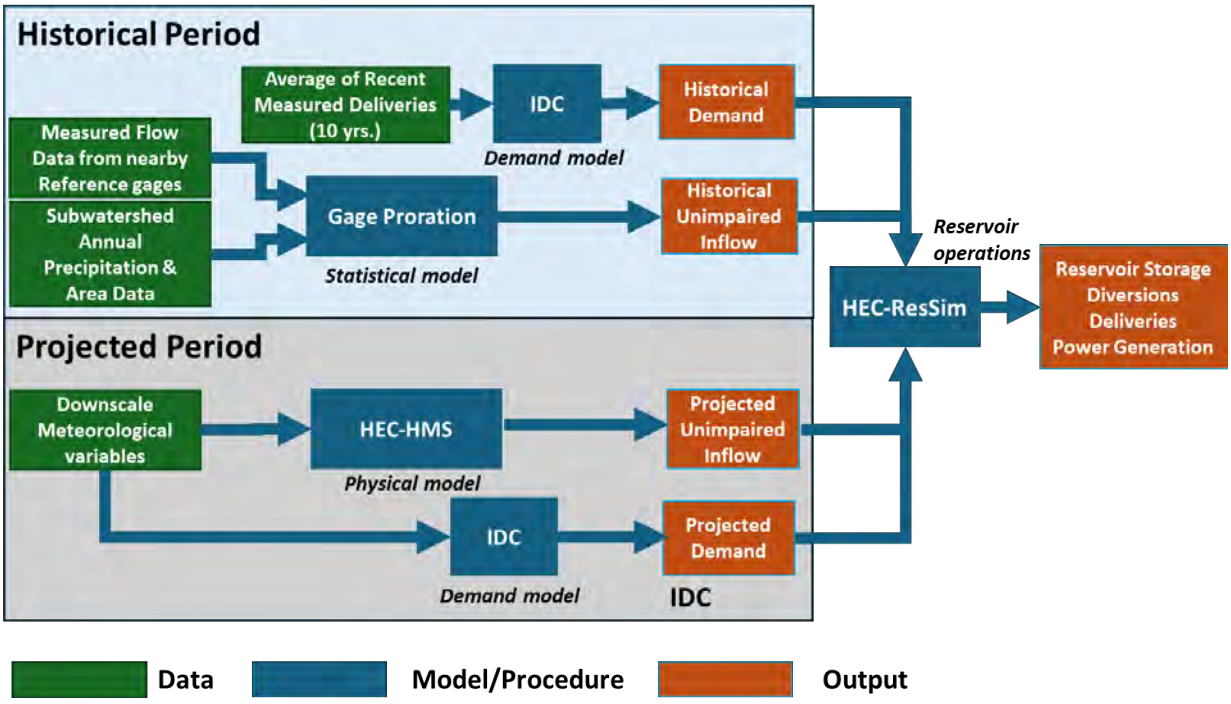


Figure 1-1. Modeling Schematic Demonstrating How Each Model Informs the Next

In the schematic in Figure 1-1, two modeling periods are highlighted: (1) historical and (2) projected. NID's snowpack-based supply and delivery strategy is affected by changing temperatures and precipitation associated with a warming climate. The PFW investigated potential impacts on supplies as temperature and precipitation patterns change. The analysis included projecting future temperatures and precipitation and their potential effect on watershed runoff and demand.

Historical and projected demands were estimated based on the California Department of Water Resources' Integrated Water Flow Model Demand Calculator (IDC model) built for NID's service area. Later chapters will describe the IDC model used for the PFW.

Unimpaired inflows were estimated based on two different methodologies for historical and projected data. For the historical period, the gage proration statistical method was used to estimate historical unimpaired

inflow based on measured flow data from nearby reference gages, annual precipitation, and watershed drainage area.

For the projected period, the PFW incorporates hydrologic data representative of projected climate conditions for the next 50 years. Projected climate data cover a range of plausible outcomes based on different scenarios of greenhouse gas emissions. Since observed data are not available for the projected period, a physically based hydrological is required to estimate projected unimpaired flows based on projected precipitation and temperature. The U.S. Army Corps of Engineers' Hydrologic Engineering Center (HEC) – Hydrologic Modeling System (HMS) was used to simulate projected unimpaired flows. Historical flow data were used to calibrate HEC-HMS. Recent studies have shown that HMS is technically and scientifically defensible as it can adequately simulate streamflow from precipitation, temperature and other hydrometeorological data (Li et al. 2022, Mahato et al. 2022, Moothedan et al. 2022). Later chapters will describe the HMS model development, calibration, and validation for the PFW.

Unimpaired inflows need to be converted into impaired flows based in the influence of reservoirs and other manmade hydraulic structures. The flow impairments that are modeled for the PFW include how the various reservoirs in the watershed hold or divert the unimpaired flows and consumptive, hydroelectric, environmental, and other state-mandated demands. The effects of flow impairments are added using the HEC – Reservoir System Simulation (ResSim) model.

HEC-ResSim is widely used for water supply and flood management in planning studies. The model features rule-based operations that attempts to reproduce the decision-making process that reservoir operators use in reservoir management. The software is Java-based and has the ability for the user to write scripts in Jython, an implementation of the python programming language in Java, which augments the model's flexible rule structures. The HEC-ResSim modeling software is widely used throughout California to model hydropower and water supply projects. The software has all the features needed to model NID's system and previous models of NID's system have been built on HEC-ResSim making it easier to incorporate previous work done to refine the modeling of NID's system. Later chapters will describe the HEC-ResSim model development, calibration, and validation for the PFW.

The combinations of models and methods implemented for the PFW allow for large flexibility on updating the results of this project as situations change (e.g., additional storage or modified regulations) and more information (e.g., updated climate projections) becomes available.

1.5. Stakeholder Participation

Community stakeholders and the public have been involved in numerous workshops covering the 11 stages mentioned earlier in this chapter. NID asserts that the PFW benefits greatly from public outreach that increases the organization and the public's understanding of water resource challenges. It is integral that NID and the community's long-term plans and priorities align with each other.

From the onset of the PFW, NID has promised the community to: assess our water situation together; develop a deeper understanding of subsequent impacts to community interests and the community's future; provide a forum for community members to offer their input, as opposed to a closed process consisting only of technical experts; focus on overarching strategic policies and not on specific projects; understand what is

really important to the community; and pursue community solutions within NID's legal responsibilities to its process customers and landowners within its service area.

Examples of stakeholder organizations that were prioritized and engaged throughout this process include: California Department of Fish & Wildlife, South Yuba River Citizens League, Nevada County Contractors' Association, Foothills Water Network, California Sporting Protection Alliance, and community members.

Chapter 2. Hydrological Model

2.1. Watershed Description Development

The NID watersheds, draining 448 sq. mi., are located on the western slope of the Sierra Nevada Mountains and cover portions of three counties: Nevada, Placer, and Yuba (Figure 2-1). The NID watersheds include the upper reaches of the Yuba River, Bear River, and Deer Creek. The highest peak in the NID watershed is the 8,373-ft English Mountain. NID transports water from high elevation mountain reservoirs to the lower elevation foothills and into portions of the northern Sacramento Valley near the City of Lincoln. Summers are dry with mild to hot temperatures. Winters are wet, especially in the upper elevations around Nevada City and Grass Valley. Snow levels are usually around 3,500 ft, but occasionally drop as low as 1,000 ft. Based on the historical data obtained from the California Irrigation Management Information System (CIMIS) and the Western Regional Climate Center (WRCC), the NID service area experiences average monthly temperatures ranging from 26 to 92 ˚F.

Throughout the NID watershed, several water management projects have been built to serve multiple purposes including flood control, water supply, irrigation, and recreation. These projects include dams/reservoirs, local flood reduction systems, and diversions, among others. The major dams and reservoirs located in the NID watershed are listed within Table 2-1. Figure 2-2 shows the locations of the various major water management projects throughout the NID watershed.

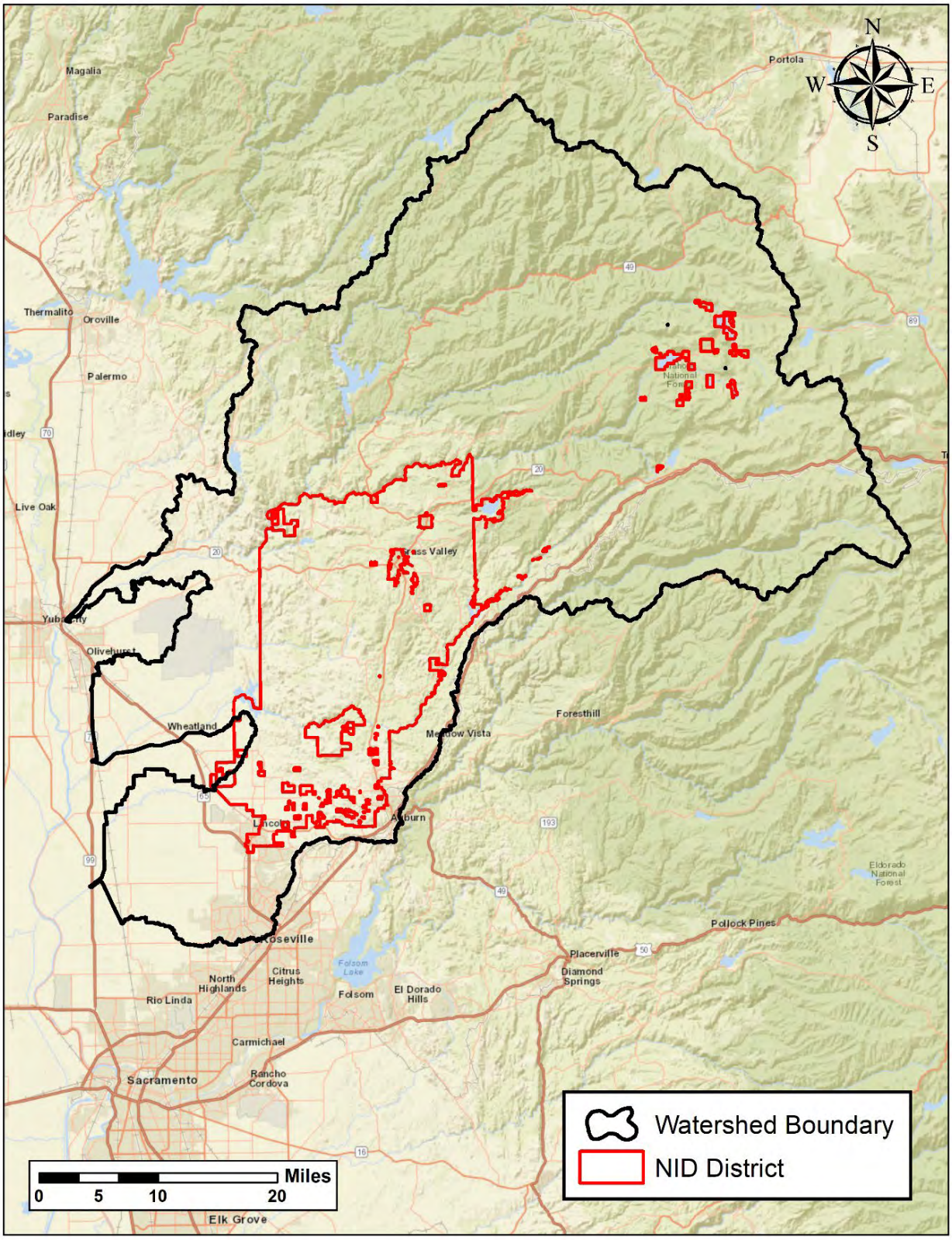


Figure 2-1. Nevada Irrigation District Map

Table 2-1. Major Dams and/or Reservoirs

Owner/Operating Agency	Dams and/or Reservoirs
Pacific Gas and Electric (PG&E)	Blue Lake Carr Lake Drum Afterbay Feeley Lake Fordyce Lake Fuller Lake Halsey Afterbay Kidd Lake Kelly Lake Lake Spaulding Lower Cascade Lake Lindsey Lakes Lake Valley Reservoir Lake Sterling Meadow Lake Rucker Lake Rock Creek Lake Upper Cascade Lake Upper Rock Lake White Rock Lake
USACE	Englebright Lake
PG&E and NID	Dutch Flat Afterbay
Camp Far West Irrigation District	Camp Far West Lake
South Feather Water and Power Agency	Slate Creek Reservoir
NID	Bowman Lake French Lake Faucherie Lake Jackson Meadow Reservoir Jackson Lake Milton Reservoir Lake Combie Sawmill Lake Scotts Flat Reservoir Rollins Reservoir
Placer County Water Agency	Lake Arthur Lake Theodore
Browns Valley Irrigation District	Collins Lake
Yuba Water Agency	New Bullards Bar Reservoir

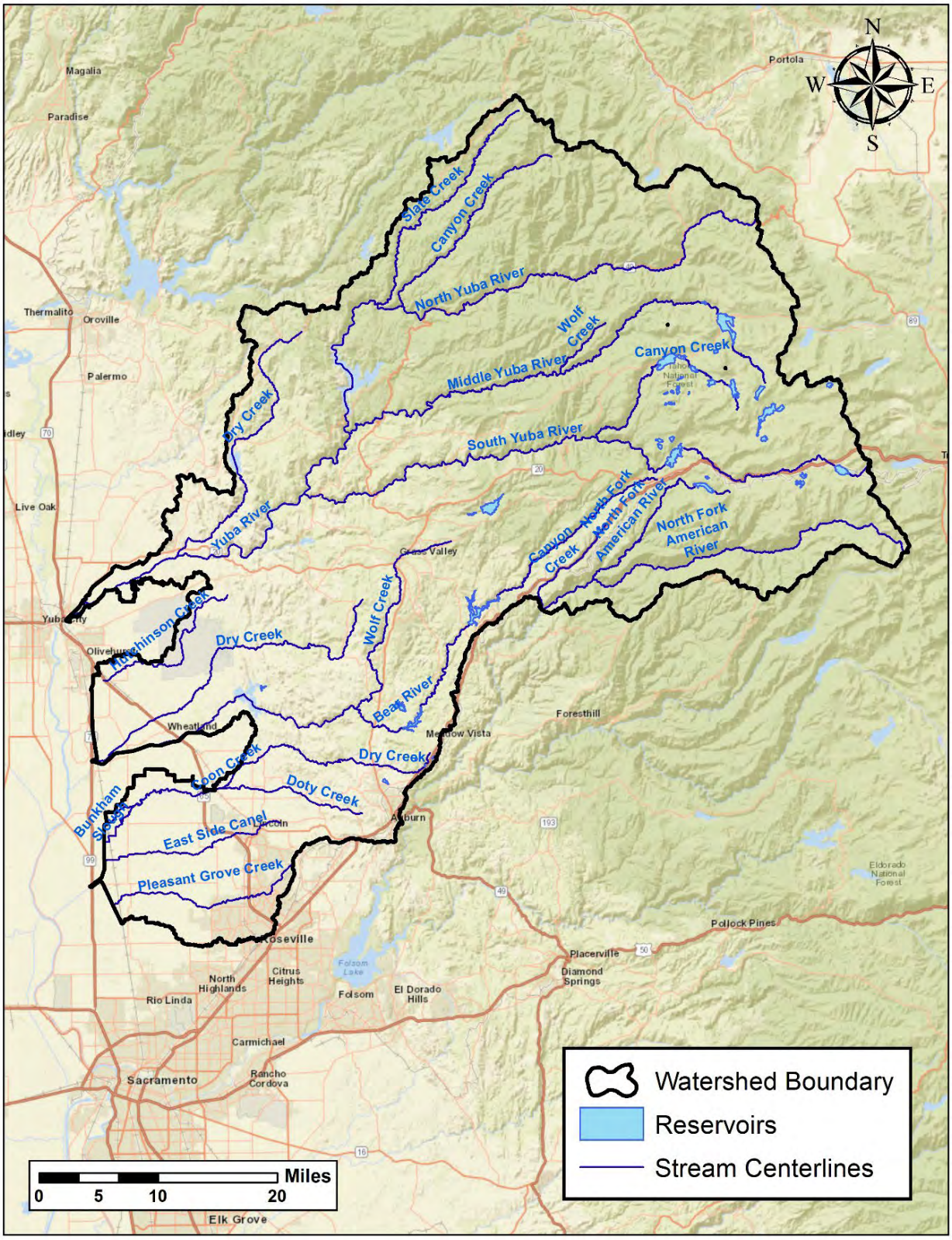


Figure 2-2. Major Tributaries and Reservoirs Within NID watersheds

2.2. Software

Table 2-2 provides a summary of the computer programs and their respective versions employed in development of the HEC-HMS model.

Table 2-2. Computer Programs Used

Program	Version	Capability	Developer
ArcGIS	10.7	Geographical Information System	ESRI
HEC-DSSVue	3.2.3	Plot, tabulate, edit, and manipulate data in HEC-DSS files	HEC
HEC-HMS	4.10	Catchment delineation and rainfall-runoff simulation	HEC
Vortex	0.10.20	Data Processing Utilities	HEC

2.3. Data Collection

The following sections discuss the data and tools used in the development of the HEC-HMS hydrologic model, which simulates NID's unimpaired hydrology.

2.3.1. Spatial Tools and Reference

To process and analyze the data necessary for hydrologic modeling and to generate the subbasin boundaries, ArcGIS and the HEC-HMS Geographic Information System (GIS) delineation tool were used.

The standard USGS map and projection parameters used for this study were:

- Horizontal Datum: North American Datum 1983 (NAD 83)- California State Plane Zone 2
- Projection: United States Contiguous Albers Equal Area Conic U.S. Geological Survey (USGS) version
- Vertical Datum: North American Vertical Datum, 1988 (NAVD 88)
- Linear units: U.S. ft.

2.3.2. GIS Data

The team used USGS web mapping services (USGS 2023) to download the Hydrologic Unit Code (HUC, a system used by USGS and other agencies to divide watersheds into smaller, more manageable units for hydrologic analysis and water resource management), soils, land cover, Federal agency gages, National Inventory of Dams locations, as well as the general base map layers. Additional GIS data were obtained from the ESRI database and used in figures prepared in this report.

2.3.3. Digital Elevation Model

The 10-m USGS National Elevation Dataset (NED, Gesch et al. 2002) was downloaded and merged to create a continuous Digital Elevation Model (DEM) that covers NID area of interest. That DEM was then used to delineate individual subbasins. (See Section 2.4.1).

2.3.4. Land Cover

Land cover data were obtained from the National Land Cover Database (NLCD 2019). The NLCD provides nationwide data on land cover and land cover change at a 30-m resolution with a 16-class legend based on a modified Anderson Level II classification system (Anderson 1976). NLCD 2019 is the latest evolution of NLCD land cover products focused on providing land cover and land cover change data for the United States. These datasets were used to estimate the subbasin-average percent impervious cover within the NID drainage basin. More discussion of land cover data and processing is provided in Section 2.4.2.

2.3.5. Soil Data

The USGS Gridded Soil Survey Geographic (gSSURGO, Soil Survey Staff 2022) for the NID basin were obtained from the Natural Resources Conservation Service (NRCS) for the State of California . The soil data were formatted and processed following instructions available in HEC-HMS Tutorials and Guides (USACE 2022a) to assign surface soil textures throughout the modeling domain and estimate initial soil loss parameters. The gSSURGO soils database includes information related to the available water storage depth as well as the hydrologic soil group classification. These datasets help estimate the initial values for the maximum soil moisture deficit and the initial values for the infiltration rates. More discussion about soils data is provided in Section 2.4.2.

2.3.6. Precipitation Data

Precipitation data used for the modeling effort were generated from Livneh Unsplit (Pierce et al. 2021) and Parameter-elevation Regressions on Independent Slopes Model (PRISM, PRISM Climate Group 2014). The continental-scale 4-km grid dataset was reprojected to the previously mentioned projection. Subsequently, the precipitation grids were delineated to the modeling domain's boundary and transformed into gridded data storage system (DSS) format using HEC-Vortex V0.10.20, accessible at (https://github.com/HydrologicEngineeringCenter/Vortex/releases/tag/v0.10.20). Since HEC-HMS 4.10 is unable to manage gridded DSS V7 produced by HEC-Vortex, the DSS Version 7 was converted to V6 using HEC-DSSVue 3.2.3.

2.3.7. Temperature Data

Temperature data used for the modeling effort were generated from Livneh Unsplit and PRISM dataset. The continental-scale 4-km gridded dataset was reprojected to the previously mentioned projection. Subsequently, the temperature grids were delineated to the modeling domain's boundary and transformed into gridded DSS format using HEC-Vortex V0.10.20. Given that HEC-HMS 4.10 is unable to manage gridded DSS V7 from HEC-Vortex, DSS V7 was converted to V6 using HEC-DSSVue 3.2.3.

2.3.8. Evapotranspiration

The Hamon Method (Hamon 1961) was used to simulate evapotranspiration (ET) losses throughout the modeling domain. Within the Hamon Method, ET losses are directly proportional to the daily average temperature and related to the location of interest and time of year. A modified, gridded version of the Hamon Method estimates potential ET losses using the daily average Livneh temperatures and a coefficient (Harwell 2012). The coefficient for NID watersheds was estimated as 0.0065.

2.3.9. Snow Data

Snow data are required to estimate the model parameters that control snow accumulation and melt. Snow data were obtained from the California Data Exchange Center (CDEC) managed by the Department of Water Resources (https://cdec.water.ca.gov/). The data available in CDEC are from the U.S. Department of Agriculture (USDA)-NRCS Snow Telemetry (SNOTEL) network and the California Cooperator Snow Sensors (https://www.wcc.nrcs.usda.gov/snow/). After analyzing the available data, four snow stations were chosen based on their diverse snowpack characteristics at elevations exceeding 5,000 ft and their data availability in time. The selected stations reflect different conditions present throughout the NID area of interest. The selected stations record key meteorological parameters, including precipitation, temperature, snow depth, and snow water equivalent (SWE). Table 2-3 identifies the snow stations and Figure 2-3 shows their locations within the NID basin.

Table 2-3. Snow Stations Used for Temperature Index Calibration

Source	Identifier	State	Site Name	Elevation (ft)	Latitude	Longitude
Cooperator Snow Sensors	BLC	CA	Blue Canyon	5,280	39.28	-120.71
	HYS	CA	Huysink	6,600	39.28	-120.53
	RCC	CA	Robinson Cow Camp	6,480	39.62	- 120.68
SNOTEL	CSS Lab (428)	CA	Central Sierra Snow Lab	6,894	39.33	-120.37

2.3.10. Streamflow and Reservoir Data

Daily average streamflow and reservoir data were obtained from the USGS National Water Information System (NWIS) (https://waterdata.usgs.gov/nwis) to support HEC-HMS model calibration. The stream flow and reservoir data observation sites are detailed in Table 2-4 and visualized in Figure 2-4.

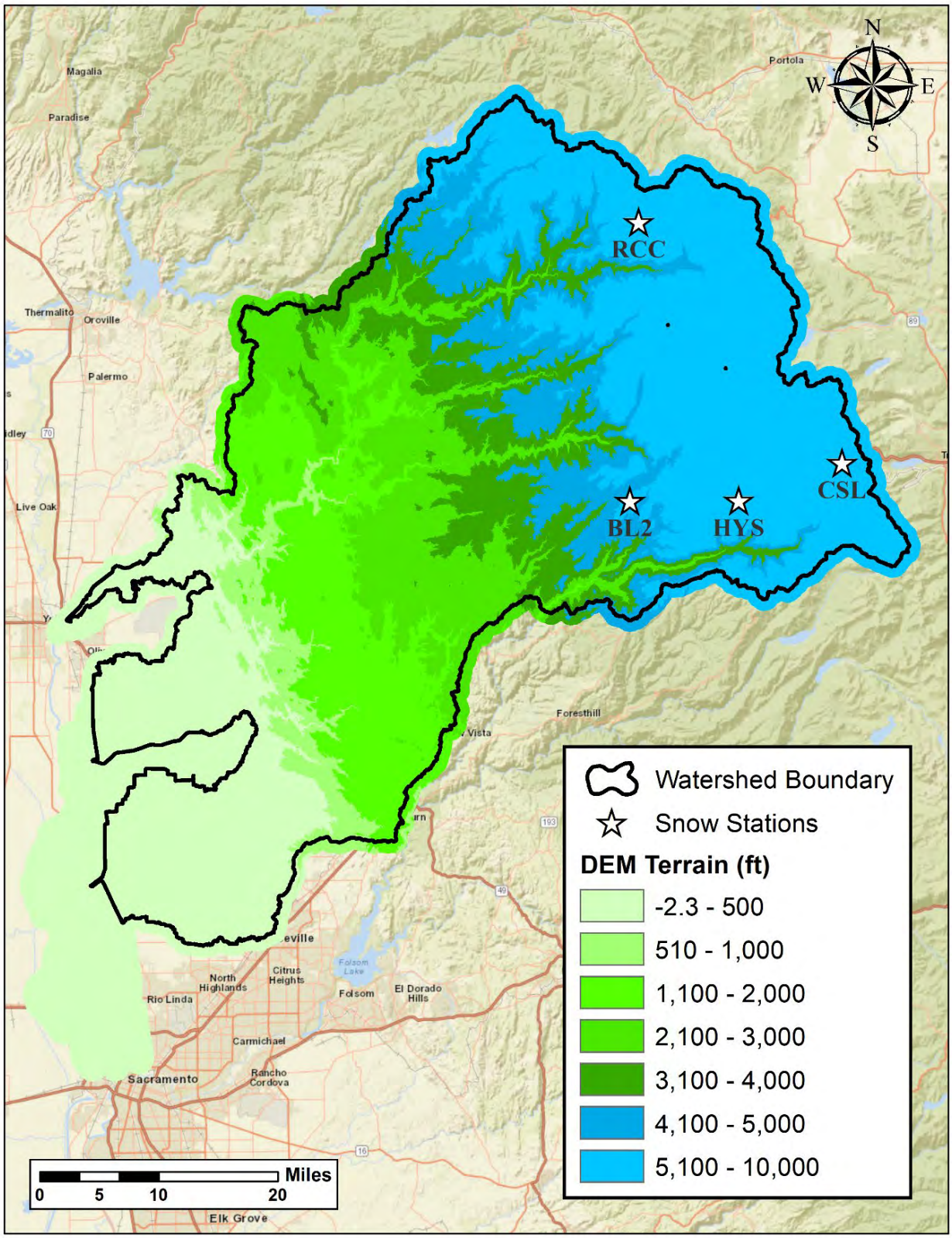


Figure 2-3. Snow Stations Used for Temperature Index Calibration

Table 2-4. Streamflow Gages for Model Calibration

Gage ID	Station Name	Latitude	Longitude
11408000	MILTON-BOWMAN TUNNEL OUTLET NR GRANITEVILLE CA	-120.611	39.46018
11408550	M YUBA R BL MILTON DAM CA	-120.584	39.52185
11408870	LOHMAN RIDGE TU A IT NR CAMPTONVILLE CA	-120.996	39.41239
11408880	M YUBA R BL OUR HOUSE DAM CA	-120.998	39.41156
11409350	CAMPTONVILLE TU A IT NR CAMPTONVILLE CA	-121.059	39.44017
11409400	OREGON C BL LOG CABIN DAM NR CAMPTONVILLE CA	-121.059	39.43934
11413000	N YUBA R BL GOODYEARS BAR CA	-120.938	39.52489
11413510	NEW COLGATE PH NR FRENCH CORRAL CA	-121.191	39.33073
11414100	FORDYCE C BL FORDYCE DAM NR CISCO CA	-120.499	39.3799
11414170	DRUM CN A TUNNEL OUTLET NR EMIGRANT GAP CA	-120.653	39.3174
11414194	DRUM NO 1 PH NR BLUE CYN CA	-120.766	39.25694
11414195	DRUM NO 2 PH NR BLUE CANYON CA	-120.767	39.25712
11414200	S YUBA CN NR EMIGRANT GAP CA	-120.663	39.31351
11414205	DEER C PH NR WASHINGTON CA	-120.844	39.29795
11414250	S YUBA R A LANGS CROSSING NR EMIGRANT GAP CA	-120.658	39.31851
11416000	BOWMAN-SPAULDING CN INTAKE NR GRANITEVILLE CA	-120.659	39.44046
11416100	BOWMAN-SPAULDING CN A JORDAN C SIPHON CA	-120.642	39.34212
11416500	CANYON C BL BOWMAN LK CA	-120.661	39.43962
11417500	S YUBA R A JONES BAR NR GRASS VALLEY CA	-121.105	39.29212
11418000	YUBA R BL ENGLEBRIGHT DAM NR SMARTSVILLE CA	-121.274	39.23517
11418500	DEER C NR SMARTSVILLE CA	-121.269	39.22434
11420750	BROWNS VALLEY IRR DITCH NR BROWNS VALLEY CA	-121.431	39.21711
11420760	BROPHY S YUBA CANAL NR MARYSVILLE CA	-121.45	39.16684
11420770	HALLWOOD-CORDUA ID CN NR MARYSVILLE CA	-121.458	39.20906
11421000	YUBA R NR MARYSVILLE CA	-121.525	39.17573
11421750	DUTCH FLAT NO 1 PH NR DUTCH FLAT CA	-120.835	39.21712
11421760	DUTCH FLAT NO 2 FLUME NR BLUE CANYON CA	-120.775	39.25434
11421770	BEAR R BL DRUM AFTERBAY NR BLUE CANYON CA	-120.775	39.25434
11421780	CHICAGO PARK FLUME NR DUTCH FLAT CA	-120.841	39.21518
11421790	BEAR R BL DUTCH FLAT AFTERBAY NR DUTCH FLAT CA	-120.845	39.21351
11422000	BEAR R CN NR COLFAX CA	-120.954	39.13267
11422500	BEAR R BL ROLLINS DAM NR COLFAX CA	-120.959	39.13129

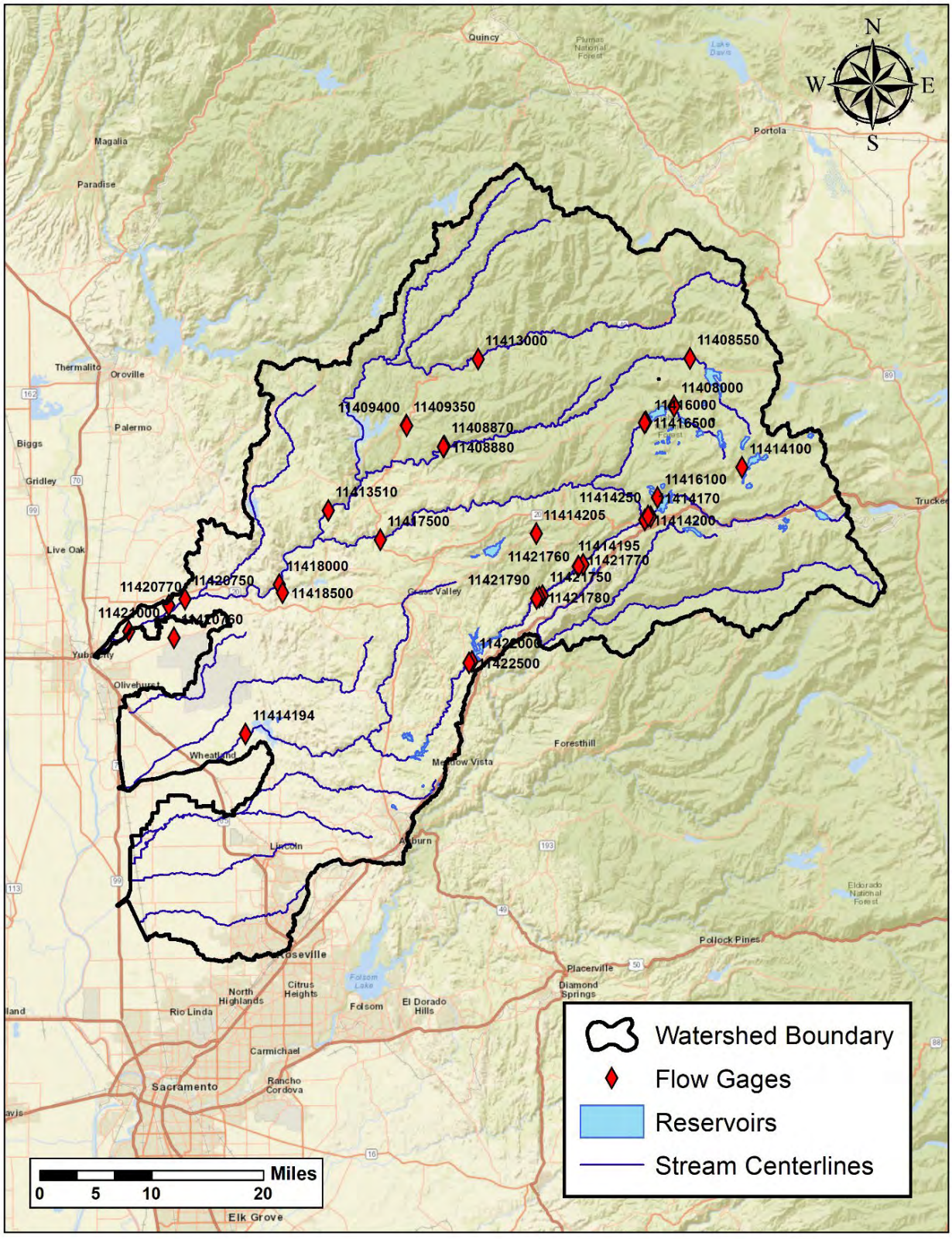


Figure 2-4. Streamflow Gages Used During Model Calibration

2.4. HEC-HMS Model Development

HEC-HMS is a hydrological model that simulates the physical processes that convert precipitation to runoff. An HEC-HMS model has three main components: a basin model, a meteorologic model, and control specifications. The basin model is the physical representation of the watershed. The meteorologic model describes watershed meteorological conditions that "drive" the basin model (i.e., the precipitation, evapotranspiration, and snowmelt data inputs). The control specifications define the length of the simulation period (e.g., years) and the temporal resolution of the simulated streamflow or reservoir storage (e.g., hours, days). HEC-HMS model development followed these steps:

- Collect relevant geographic, climatic, terrain, and time series data.
- Delineate the stream network and subbasins using the ArcGIS and HEC-HMS GIS processor.
- Develop the HEC-HMS basin model using the HEC-HMS GIS tools.
- Develop meteorological models for the calibration events.
- Select the physical models that best represent the dominant processes that control runoff generation in the area of interest. The selected physical models include, but are not limited to, snow, infiltration, baseflow, and routing models.
- Decide on the initial values for the hydrologic parameters required by the physical models chosen.
- Set the computational time step and simulation period in the HEC-HMS control specifications for each calibration event.

The following sections review the model-specific processes used in the NID HEC-HMS model.

2.4.1. Watershed Delineation

ESRI ArcGIS and the HEC-HMS GIS processor managed and analyzed spatial data such as topography and land cover for hydrologic modeling and to define subbasin boundaries. Shapefiles at the HUC-8 and HUC-12 levels were downloaded and reprojected for the delineation of the NID watershed boundary. Three HUC-8 and nine HUC-12 subbasins within the NID watershed are listed in Table 2-5 and shown in Figure 2-5. These selected subbasins were merged, and then buffered by 2 miles to create the watershed boundary. When individual subbasins are merged with the GIS tools, the boundaries might not match exactly, leaving small gaps with no elevation data along interior seams. Buffering mitigates edge effects and helps create a seamless terrain raster with no missing elevation data. The resulting rasters were thoroughly examined to ensure that the GIS tools could correctly process the files.

The resulting terrain raster was imported into a new HEC-HMS project and assigned to a basin model for subbasin delineation. The basin was delineated using the HEC-HMS GIS tool and the methods recommended in HEC-HMS Tutorials and Guides (USACE 2022a). Subbasins were sub-divided based on the inflow points of interest, which correspond to USGS gage and reservoir locations or locations with important hydraulic structures (diversions). The final HEC-HMS model has 146 subbasins encompassing approximately 2,329 sq. mi.

Table 2-5. HUC-8 and HUC-12 subbasins

HUC Level	Subbasin Name
HUC-8	Upper Yuba
	Upper Bear
	Upper Coon-Upper Auburn
HUC-12	Wabena Creek-North Fork American River (NFAR)
	Big Granite Creek
	Big Valley Canyon- NFAR
	East Fork North Fork- NFAR
	North Fork of NFAR
	Humbug Creek- NFAR
	Indian Creek- NFAR
	Upper Shirttail Canyon
	Lower Shirttail Canyon

Each model element—whether a subbasin, reach, or junction—was assigned a unique name. The first two letters of the element name represent an abbreviation for the major river associated with the element, followed by any pertinent secondary river name. The element name concludes with the symbol showing its type, “S” for subbasin, “R” for reach, or “J” for junction, followed by a unique identifying number. The identifying numbers were assigned in increments of 10, systematically increasing in the downstream direction. If an element linked to the main river did not have a secondary river, the secondary river name was designated as the same as the main river. In cases where more than one branch conveys flow into the main river, the element numbers (e.g., S10, S20) along one branch were labeled first. Then, succeeding element numbers (e.g., S30, S40) along the next branch were assigned, with the element numbering continuing after the confluence of the two branches (e.g., S50, S60). The major and secondary river names were determined using the National Hydrography Dataset (USGS 2016) flowlines. The final subbasin delineation is presented in Figure 2-6, and subbasin names, along with their respective drainage areas, are detailed in Appendix A.

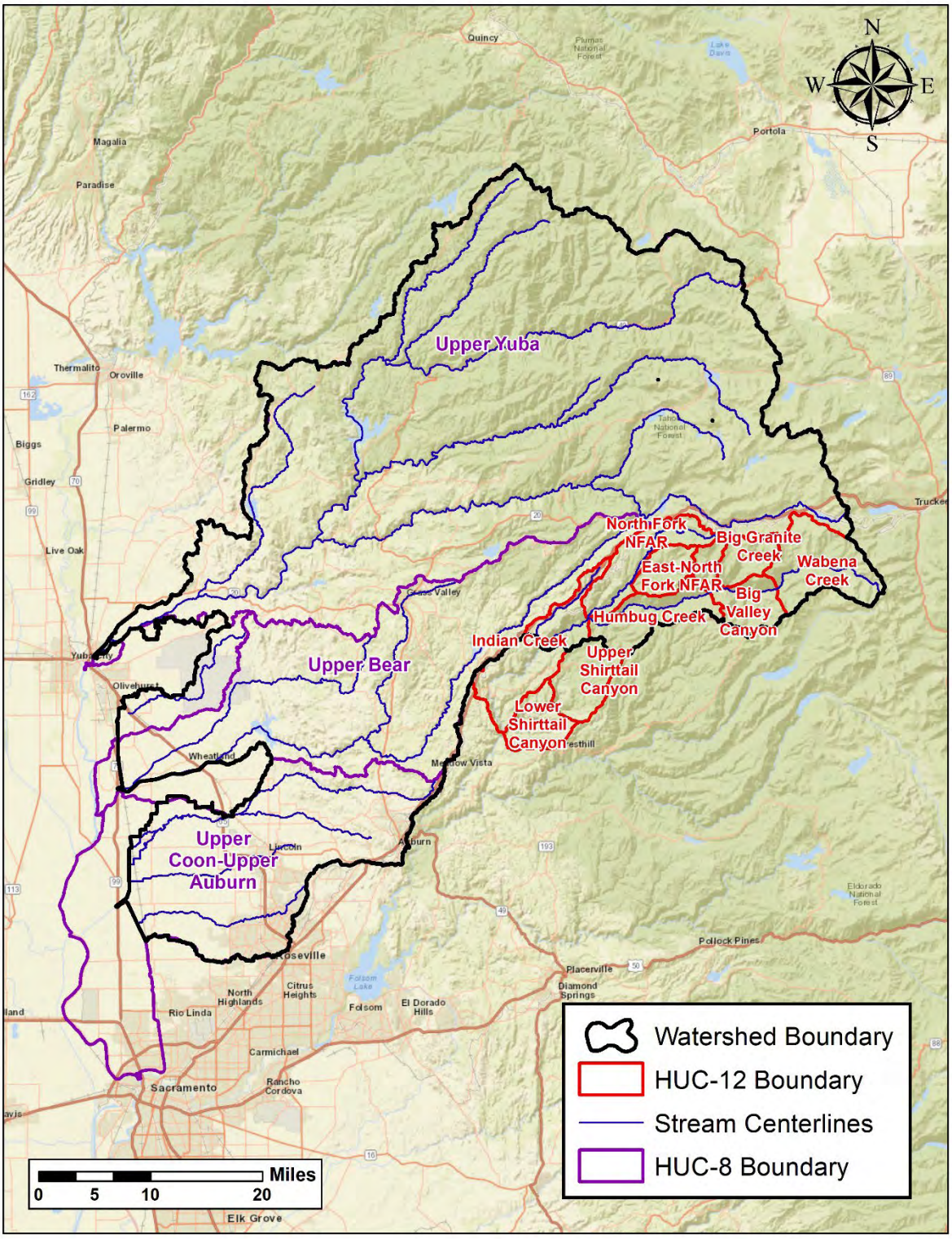


Figure 2-5. NID Watershed Delineation

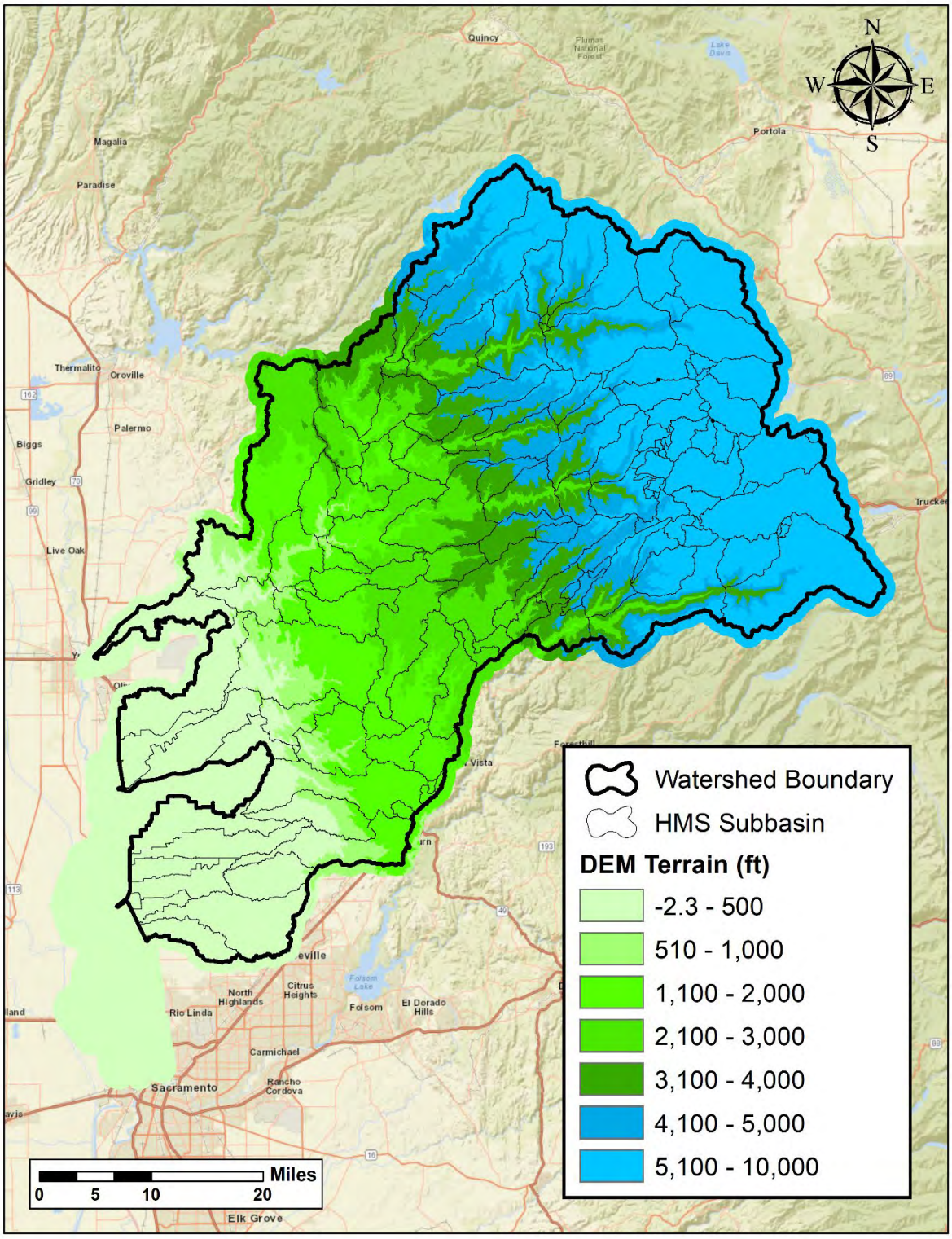


Figure 2-6. HEC-HMS Subbasins Delineation

2.4.2. Infiltration

Infiltration was estimated with the Deficit and Constant Loss Method. Required inputs for this method include initial soil moisture deficit, maximum soil moisture deficit, constant infiltration rate, and percent of directly connected impervious area. The first estimates for initial deficit, maximum deficit, and constant loss rate were based on surficial soil texture estimates. The soil texture was obtained from the NRCS gSSURGO soil coverages. Based on the soil gSSURGO datasets, the five dominant soil textures for the watershed were bedrock, sandy loam, loam, clay loam, and sandy clay loam.

Table 2-6, as listed in the Engineering Manual (EM) 1110-2-1417-Flood-Runoff Analysis (USACE 1994) and the HEC-HMS Technical Reference Manual (USACE 2022b), guided estimates of initial infiltration parameters. These parameters were based on effective porosity, wetting front suction head, saturated hydraulic conductivity, and wilting point. 'Note that the computed values are initial estimates subject to adjustment during model calibration.

The initial deficit parameter represents the initial soil moisture conditions for the soil layer. An initial deficit equal to zero indicates that the layer is fully saturated and that any precipitation falling at a rate exceeding the constant infiltration rate is transformed to runoff. The value used for the initial deficit was set to zero for all subbasins.

Table 2-6. Soil Textures and Effective Porosity, Wetting Front Suction Head, Saturated Hydraulic Conductivity, and Wilting Point (USACE 1994)

Soil Texture	Saturated Hydraulic Conductivity (in./hr)	Wetting Front Suction Head (in.)	Effective Porosity	Wilting Point
Clay	0.01	12.5	0.39	0.27
Clay Loam	0.04	8.2	0.31	0.2
Loam	0.1	3.5	0.43	0.12
Loamy Sand	1.2	2.4	0.4	0.06
Sand	4.6	1.9	0.42	0.03
Sandy Clay	0.02	9.4	0.32	0.2
Sandy Clay Loam	0.06	8.6	0.33	0.15
Sandy Loam	0.4	4.3	0.41	0.1
Silt Loam	0.3	6.6	0.49	0.13
Silty Clay	0.02	11.5	0.42	0.25
Silty Clay Loam	0.04	10.7	0.43	0.21
Bedrock	0	0	0	0

The maximum deficit parameter specifies the maximum depth of water held within the soil layer. This parameter is typically estimated as the difference between the saturation storage of the soil and the wilting point storage over an assumed active soil layer depth. In this study, an active soil layer depth of 24 in. was

assumed. Therefore, based on the soil texture, the average (i.e., representative) maximum deficit for the study area was estimated to be 2 in. over the active soil layer depth.

The constant loss rate parameter defines the rate at which water is percolated out of the soil layer. Typically, this parameter is equated with the saturated hydraulic conductivity of the soil, which is defined as the rate at which water moves through a unit area of saturated soil in a unit time under a unit hydraulic gradient. Based on the study area soil texture, the initial value used for constant loss was set to 0.1 in./hr for all subbasins.

Directly connected impervious area estimates for each subbasin were assigned using the NLCD 2019 coverage. Figure 2-7 displays the 2019 NLCD Land Cover Classifications for the study area. The percent impervious parameter denotes the percentage of impervious area within each subbasin that is directly hydraulically connected to the conveyance network. It is assumed that no infiltration occurs within directly connected impervious areas, and all rainfall in such areas becomes direct runoff. Table 2-7 outlines the percent impervious cover defined per land cover type (USACE 2022a) that was used in this study.

Table 2-7. Impervious Values Defined Per Land Cover Category (USACE 2022)

Land Cover Type	Percent Impervious
Open Water	100
Perennial Snow/Ice	100
Developed, Low Intensity	20
Developed, Medium Intensity	40
Developed, High Intensity	60
Woody Wetlands	50
Emergent Herbaceous Wetlands	75
Barren Land	0
Deciduous Forest	0
Evergreen Forest	0
Mixed Forest	0
Shrub/Scrub	0
Herbaceous	0
Hay/Pasture	0
Cultivated Crops	0
Developed, Open Space	0

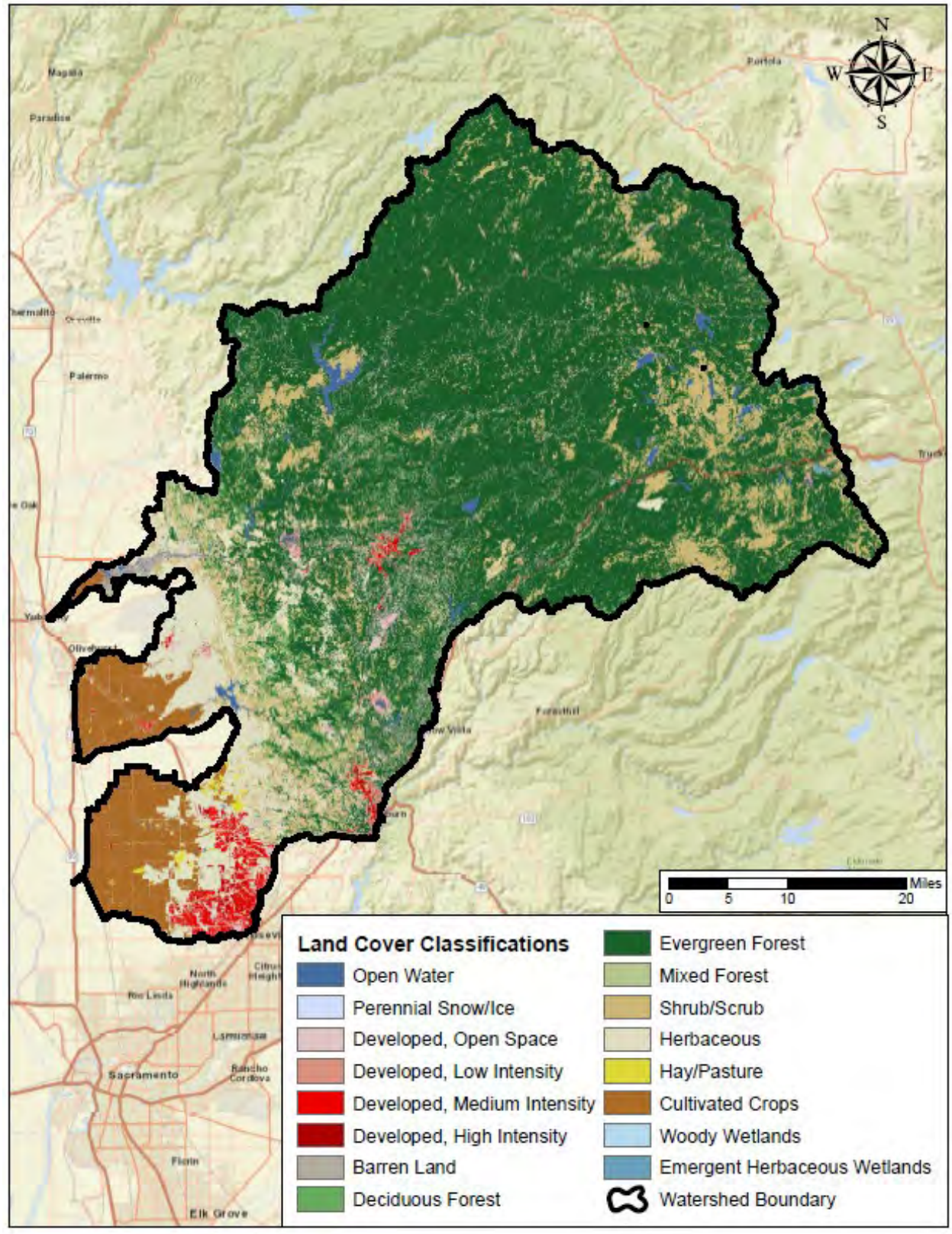


Figure 2-7. 2019 NLCD Land Cover Classifications for NID Basin

2.4.3. Canopy Losses

Canopy losses for this project were computed based on the simple canopy method, which requires five inputs: 1) initial storage percentage, 2) maximum storage, 3) crop coefficient, 4) evapotranspiration timing, and 5) uptake method.

The initial storage percentage was first set equal to 0, indicating a completely empty canopy, subject to adjustment during the calibration. Canopy storage depth depends on vegetation type or land cover. The 2019 NLCD land cover classification, shown in Figure 2-7, was applied to estimate the maximum canopy storage depths.

Canopy storage depths for each of the NLCD classes were recommended based on EM 1110-2-1417 (USACE 1994), HEC training materials, and engineering judgment. Table 2-8 lists the canopy storage values used for each NLCD land cover category.

The crop coefficient, used to adjust potential evapotranspiration, was set to 1.0 for all simulations. In HEC-HMS, evapotranspiration is set to take place either during periods without precipitation or throughout the entire simulation, regardless of whether precipitation is occurring. For this study, evapotranspiration is set to occur only during periods without precipitation ("Dry Periods"). Finally, the soil uptake method is defined as either simple or tension reduction. The tension reduction method only works when the soil moisture accounting method is selected as the soil infiltration loss method; therefore, the simple soil uptake method is used.

Table 2-8. Canopy Storage Depths for NLCD Land Cover Classifications (USACE 2022)

NLCD Code	NLCD Land Cover Classification	Canopy Storage (in)
11	Open Water	0.00
12	Perennial Snow/Ice	0.01
21	Developed, Open Space	0.05
22	Developed, Low Intensity	0.04
23	Developed, Medium Intensity	0.03
24	Developed, High Intensity	0.02
31	Barren Land	0.05
41	Deciduous Forest	0.08
42	Evergreen Forest	0.10
43	Mixed Forest	0.09
52	Shrub/Scrub	0.08
71	Grassland/Herbaceous	0.08
81	Hay/Pasture	0.08
82	Cultivated Crops	0.11
90	Woody Wetlands	0.10
95	Emergent Herbaceous Wetlands	0.09

2.4.4. Unit Hydrograph Transform

HEC-HMS offers a selection of eight transformation methods for modeling hydrologic processes. The ModClark unit hydrograph (UH) transform was used to route excess precipitation to the subbasin outlet within each subbasin. This linear, quasi-distributed transform method uses a grid of cells to depict travel times within a subbasin to the outlet point. It explicitly incorporates variations in travel time from all areas within a subbasin by employing a time travel index for each grid cell. These grid cells were laid out using the Standard Hydrologic Grid (SHG) system with a 2- x 2-km resolution (SHG 2000) and positioned across the modeling domain using tools provided within HEC-HMS.

Two essential parameters are needed for the ModClark method: the time of concentration for the basin, and the basin storage coefficient. USACE (2022a) suggests the following equations to estimate initial values of time of concentration and the basin storage coefficient:

$$T_c = 2.2\left(\frac{L * L_c}{\sqrt{S}}\right)^{0.3}$$

$$\frac{R}{T_c + R} = 0.65$$

Where Tc is Time of concentration (hr), R is storage coefficient (hr), L is longest flow path length (miles), L_c is centroidal flow path length in miles, and S is 10-85 slope (ft/mi). The estimated T_c and R values were adjusted, as necessary, during calibration . Those equations were applied in this project to obtain initial parameters for the ModClark method.

2.4.5. Baseflow

The Linear Reservoir method was used to transform infiltrated water into interflow and baseflow. This helps simulate the movement of water within the soil. In this project, the storage and movement of infiltrated water is simulated using two layers. Linear reservoirs are used because, for every time step, the outflow is modeled as a linear function of the average storage within that specific time step. As a result of employing the Deficit and Constant Loss Method, the infiltrated water volume is evenly distributed between the two layers. The resulting outflow from both layers is combined to compute the total baseflow for each subbasin. The conceptualization of the two baseflow layers helps distinguish between short and long baseflow responses. The upper layer is set to respond faster than the lower layer.

Each calibration simulation starts on October 1st, after the summer months, and before the rainy season; therefore, the basin is usually quite dry. Because of that, all initial baseflow was set to originate from the slower draining groundwater storage (the Groundwater (GW) 2 layer).

Since processes that affect storage, attenuation, and timing of surface water also impact the response of interflow and baseflow, a ratio of ModClark storage coefficient was used for the groundwater storage coefficients in both layers. This approach ensures a consistent representation of these hydrological factors across the entire modeling framework. Initially, the GW 1 storage coefficient was set at 1.5 times the subbasin ModClark storage coefficient, while the GW 2 coefficient was set at 50 times the subbasin ModClark storage coefficient. Also, GW fractions in both layers are initially set to 0.5. These values are adjusted during model calibration, as necessary.

2.4.6. Streamflow Routing

Six different options are available in HEC-HMS to route flow through channels. For the routing of reaches across the modeling domain, the Muskingum-Cunge routing method was selected. This choice was made due to its ability to closely mimic more detailed hydraulic routing. The Muskingum-Cunge method uses physically based reach characteristics to compute flow attenuation and timing through the reach. Input parameters for this method are based on measurable physical parameters, which helps to increase the confidence in the routing calculations for ungaged watersheds. These physical parameters are often developed using existing hydraulic models and/or detailed topographic and hydrographic data.

To estimate the necessary depth-discharge, depth-area, and depth-top width relationships for all routing reaches, eight-point cross sections were used. While hydraulic models for rivers within the NID drainage basin were not readily available, cross-sectional data for certain reaches had been obtained during a recent relicensing study (Technical Memorandum 3-2, Instream Flow - October 2011). For the remaining reaches not covered in the study), the 1-m USGS NED was used to generate the cross-sectional data. This approach allowed for a comprehensive representation of the hydraulic characteristics across the modeling domain.

Initial estimates of channel roughness were 0.035 and 0.07 for the main channel and left/right overbank areas, respectively. These estimates were based on channel characteristics and engineering judgment. The length and average slope of each routing reach were determined within HMS GIS tool. For the celerity index method, an index celerity of 5 ft/second, and automatic optimization of space and time steps were used for all routing reaches.

2.4.7. Reservoir Routing

In the HEC-HMS model, dams and reservoirs were incorporated after a thorough screening process. The selection criteria for inclusion involved multiple factors, such as the available storage capacity, the intended purposes of the dam and reservoir, and the upstream drainage area. This approach ensured that major dams and reservoirs were correctly accounted for in the model. Elevation-area-discharge and elevation-storage relationships for the reservoirs were available from previous studies (NID, 2020). All reservoirs with observed discharge data were set to use the specified release method within HEC-HMS. In that method, HEC-HMS uses the observed outflow from a reservoir as input to the next sub-watershed. The observed outflow is a time series that combines all the reservoir's outflow that are measured by gages, including diversions to other reservoirs, diversions to powerhouses, low flow outlet, spillway outlet, etc. If observed outflow discharge data were not available at a reservoir or for a specific year, the model uses the outflow curve method, which estimates reservoir outflow based on the relationship between storage and reservoir outflow discharge. Table 2-9 presents the list of reservoirs in the HEC-HMS model along with the corresponding routing methods.

Table 2-9. Inventory of Reservoirs in the Model and the Corresponding Routing Methods

Reservoirs	Routing Method		Reservoirs	Routing Method
JACKSON MEADOW RESERVOIR	Outflow Curve		SAWMILL LAKE	Outflow Curve
UPPER CASCADE LAKES	Outflow Curve		JACKSON LAKE	Outflow Curve
LOWER CASCADE LAKES	Outflow Curve		LAKE COMBIE	Outflow Curve
KIDD LAKE	Outflow Curve		ROCK CREEK LAKE	Outflow Curve
MEADOW LAKE	Outflow Curve		LAKE VALLEY RESERVOIR	Outflow Curve
WHITE ROCK LAKE	Outflow Curve		KELLY LAKE	Outflow Curve
LAKE STERLING	Outflow Curve		NEW BULLARDS BAR RESERVOIR	Specified Release
FULLER LAKE	Outflow Curve		MILTON RESERVOIR	Specified Release
BLUE LAKE	Outflow Curve		OUR HOUSE DAM	Specified Release
RUCKER LAKE	Outflow Curve		LOG CABIN DAM	Specified Release
UPPER LINDSEY LAKES	Outflow Curve		LAKE SPAULDING	Specified Release
LOWER LINDSEY LAKES	Outflow Curve		BOWMAN LAKE	Specified Release
CULBERTSON LAKE	Outflow Curve		ENGLEBRIGHT LAKE	Specified Release
UPPER ROCK LAKE	Outflow Curve		SCOTTS FLAT RESERVOIR	Specified Release
LOWER ROCK LAKE	Outflow Curve		DUTCH FLAT AFTERBAY	Specified Release
FEELEY LAKE	Outflow Curve		ROLLINS RESERVOIR	Specified Release
CARR LAKE	Outflow Curve		CAMP FAR WEST LAKE	Specified Release
FRENCH LAKE	Outflow Curve		FORDYCE LAKE	Specified Release (Outflow Curve for 1997)
FAUCHERIE LAKE	Outflow Curve			

2.4.8. Snowmelt

In this study, the gridded temperature index method was used for snowmelt modeling. The gridded temperature index method uses temperature and precipitation data to estimate snowpack melting and accumulation. When computing snowmelt runoff using the gridded temperature index method, multiple factors are considered, including the initial SWE, precipitation, air temperature, the form of precipitation (rain or snow), snowpack temperature, snowpack liquid water content, time of year, and the cumulative thawing degree-days. This comprehensive set of parameters supports a detailed and accurate representation of complex snow processes. The main assumption underlying this method is that the difference between air temperature and base temperature is directly proportional to the snowpack melt rate (USACE 1956). This implies that temperature, along with a melt rate coefficient, serves as the key factor in simulating snowmelt (USACE 1998). The gridded temperature index method requires 12 different parameters as inputs:

- PX Temperature: Distinguishes between precipitation falling as rain or snow.
- Base Temperature: Specifies the temperature at which snow melts.
- Wet Melt Rate: Defines the snow melt rate when rain is falling on the snowpack.
- Rain Rate Limit: Determines the difference between wet and dry melt rate.
- ATI-Melt Rate Coefficient: Adjusts the melt rate antecedent temperature index (ATI) calculated during the previous time step.
- ATI-Melt Rate Function: Allows the melt rate to change as the snowpack ages and the melting season progresses.
- Cold Limit Rate: Specifies the amount of snow that is required to accumulate before the snowpack temperature is reset to the base temperature.
- ATI-Cold Rate Coefficient: Adjusts the cold content of the snowpack based on the influence of the air temperature on the internal snowpack temperature.
- ATI-Cold Rate Function: Selects the cold rate based on the ATI for cold content.
- Water Capacity: Defines the maximum amount of melted water that can be held in the snowpack before the liquid water seeps into the soil or exits the snowpack as runoff.
- Ground Melt Rate: Specifies the rate at which the ground transfers heat to the snowpack, causing the snowpack to melt.

The parameters of the snowmelt meteorologic model were calibrated independently of the basin model by performing a multiyear daily simulation of SWE values. The calibration used observed SWE data from four stations located within the watershed boundary. A detailed discussion of the multiyear daily simulation calibration effort is presented in Section 2.5

2.5. Calibration of Snow Processes

Snow accumulation and melt depths are sensitive to topographical factors such as elevation and aspect. These factors influence the depth of snowfall and the extent of melting. The calibration efforts were concentrated on snow stations situated in higher elevation mountainous areas. Snow accumulation and melting at elevated locations tend to be more substantial compared to lower elevations. The following sections provide an overview of the calibration process, evaluate model performance, and presents results from multi-year snowmelt model calibration.

2.5.1. Approach

To accurately estimate flow rates when calibrating the HEC-HMS model, it is essential to initially calibrate the temperature index snowmelt and accumulation processes and parameters. The parameters calibrated are then used as the initial input to the HEC-HMS model. Parameters are further refined during calibration of the overall gridded HEC-HMS model. The methodology used to calibrate temperature index method parameters follows guidance in the USACE Modeling, Mapping and Consequences (MMC) Technical Manual for CWMS (USACE, 2016). The calibration steps include:

1. Perform data analysis on four SNOTEL and Cooperator Snow Sensors stations in the NID watershed, as previously illustrated in Figure 2-3 and listed in Table 2-3.
2. Create subbasins for each station, incorporating observed temperature, precipitation, and SWE data. The drainage area for each subbasin was set at 1 sq. mi. All the basin modeling methods are specified as "None" except for snow method. "Temperature Index" snow method was chosen for each subbasin, and a specific elevation band was assigned to each subbasin based on the elevation corresponding snow station. Table 2-10 lists the parameters that were used in the elevation band component for all the subbasin.

Table 2-10. Elevation Band Parameters

Elevation Band Parameter	Units	Value
Percent	%	100
Elevation	ft	Snow Station Elevation
Initial SWE	in.	0
Initial Cold Content	in.	0
Initial Liquid Water	in.	0
Initial Cold Content ATI	˚F	32
Initial Melt ATI	˚F-day	0

3. Set initial values for the parameters of the snow method (temperature index) for all subbasins (Table 2-11)

Table 2-11. Initial Temperature Index Method Parameters

Meteorologic Parameter	Units	Value
PX Temperature	˚F	34.5
Base Temperature	˚F	32
Wet Melt Rate	in./˚F-day	0.12
Rain Rate Limit	in./day	0.2
ATI-Melt Rate Coefficient	-	0.98
Cold Limit	in./day	0.8
ATI-Cold Rate Coefficient	-	0.84
Water Capacity	%	5
Ground Melt	in./day	0

4. Incorporate time series of observed precipitation, temperature, and SWE gages in the model.
5. Link the observed SWE at each snow station to the corresponding subbasins as observed SWE data.
6. Develop a meteorologic model using the specified hyetograph and thermograph methods for the observed precipitation and temperature components, respectively.

7. Assign precipitation and temperature gages to their corresponding subbasins in the meteorologic model.
8. Create paired data for ATI-Melt Rate Functions and ATI-Cold Rate Functions for all subbasins/stations and assign them to their respective subbasins/stations. The initial functions are in Table 2-12 and Table 2-13.

Table 2-12. Initial ATI-Melt Rate Function

ATI (˚F-day)	Melt Rate (in./˚F-day)
0.0	0.000
30.0	0.011
55.0	0.055
120.0	0.077
150.0	0.088
200.0	0.099
1000.0	0.110

Table 2-13. Initial ATI-Cold Rate Function

ATI (˚F-day)	Melt Rate (in./˚F-day)
-100.0	-2.00
-10.0	-0.20
-1.0	-0.02
1.0	0.02
10.0	0.20
100.0	2.00
1000.0	20.00

9. Create control specification using a daily time interval, spanning from January 1, 2017, to December 01, 2021. This 5-year time period was selected due to the availability of snow data for all four snow stations.
10. Create optimization trials and simulation runs to compare simulated and observed SWE at each snow station.
11. Conduct both automatic and manual calibration processes to find parameters that yield the best match to the observed SWE values at each station.

2.5.2. Performance

Model performance is measured using Nash-Sutcliffe Efficiency (NSE), the Ratio of the Root Mean Square Error (RMSE) to the Standard Deviation Ratio (RSR), and Percent Bias (PBIAS). Comparisons are also made for peak SWE, as well as the date of peak SWE.

NSE measures the relative magnitude of the residual variance compared to the measured data variance. NSE ranges between -∞ and 1, where NSE = 1 is optimal. A value of NSE ≤ 0 indicates the mean observed value is a better predictor than the simulated value. NSE is computed using the following equation:

$$NSE = 1 - \left[\frac{\Sigma_{i=1}^{n}(Y_i^{obs} - Y_i^{sim})^2}{\Sigma_{i=1}^{n}(Y_i^{obs} - \bar{Y}^{obs})^2}\right]$$

where n = number of observed values compared to computed over the duration of the simulation, Y_i^{obs} = observed values, Y_i^{sim} = computed values, $\bar{Y}^{obs}$ = average of observed values.

RSR normalizes the RMSE by using the standard deviation of the observations. By normalizing RMSE, that statistic can be directly compared among different stations. A lower RMSE-to-SDR ratio indicates that the model's predictions are relatively accurate compared to the variability in the observed data, which is desirable. Conversely, a higher RMSE-to-SDR ratio suggests that the model's predictions have lower accuracy relative to the variability in the observed data, which may indicate poor model performance. RSR is computed using the following equation:

$$RSR = \frac{RSME}{STDEV_{obs}} = \frac{\left[\sqrt{\Sigma_{i=1}^{n}(Y_i^{obs} - Y_i^{sim})^2}\right]}{\left[\sqrt{\Sigma_{i=1}^{n}(Y_i^{obs} - \bar{Y}_i^{sim})^2}\right]}$$

where RMSE = root mean square error, STDEVobs = standard deviation of the observations, and $\bar{Y}_i^{sim}$ = average of simulated values.

PBIAS measures the average tendency of the simulated data to be larger or smaller than the observed data. The optimal value for PBIAS is 0.0, with low absolute PBIAS indicating accurate model simulation. A negative PBIAS means the computed volume is low and a positive PBIAS means the computed volume is high, when compared to observed data. PBIAS is computed using the following equation:

$$PBIAS = \left[\frac{\Sigma_{i=1}^{n}(Y_i^{obs} - Y_i^{sim}) \times 100}{\Sigma_{i=1}^{n}(Y_i^{obs})}\right]$$

Summary statistic performance ratings are presented in Table 2-14. The ranges shown for each of the performance ratings are based on values found in the literature. An NSE of "Very Good" or "Good" might indicate an adequate fit to the magnitude and timing of the snowmelt; however, the simulated and observed hydrographs should be evaluated along with other metrics for a more complete picture of model performance.

Table 2-14. HEC-HMS Performance Ratings for Summary Statistics

Performance Rating	NSE	RSR	PBIAS
Very Good	$0.65<NSE\leq1.00$	$0.00<RSR\leq0.60$	$PBIAS< \pm10$
Good	$0.55<NSE\leq0.65$	$0.60<RSR\leq0.70$	$\pm10\leq PBIAS<\pm35$
Satisfactory	$0.40<NSE\leq0.55$	$0.70<RSR\leq0.80$	$\pm35\leq PBIAS<\pm50$
Unsatisfactory	$NSE\leq0.40$	$RSR>0.80$	$PBIAS\geq\pm50$

2.5.3. Results

A sensitivity analysis assessed how variations in the snow parameters influence the model's output. The analysis helped to identify which parameters have a significant impact on the model results. Based on the sensitivity analysis, snow melt and accumulation are extremely sensitive to the PX temperature, base temperature, and ATI-melt rate coefficient. Results were less sensitive to wet melt rate, rain rate limit, ATI-melt and cold rate functions, cold melt rate, ATI-cold rate coefficient, water capacity, and ground melt rate. Therefore, during calibration, attention was focused on the more sensitive parameters.

Figure 2-8 through Figure 2-11 show the precipitation, temperature, and simulated SWE versus observed SWE time series at the selected snow stations. Table 2-15 summarizes the performance statistics. The overall performance rating for all stations varies from Good to Very Good.

Table 2-15. Snow Model Calibration Results from January 1, 2017, through December 1, 2021

Stations	Peak SWE (in.)		NSE	RSR	PBIAS	Overall Performance Rating
	Model	Obs.				
BLC	26.00	31.08	0.91	0.3	-15.29	Good to Very Good
HYS	50.10	53.64	0.87	0.36	0.15	Very Good
RCC	71.06	77.32	0.92	0.28	-19.26	Good to Very Good
CSL	49.97	72.90	0.70	0.55	-29.20	Good to Very Good

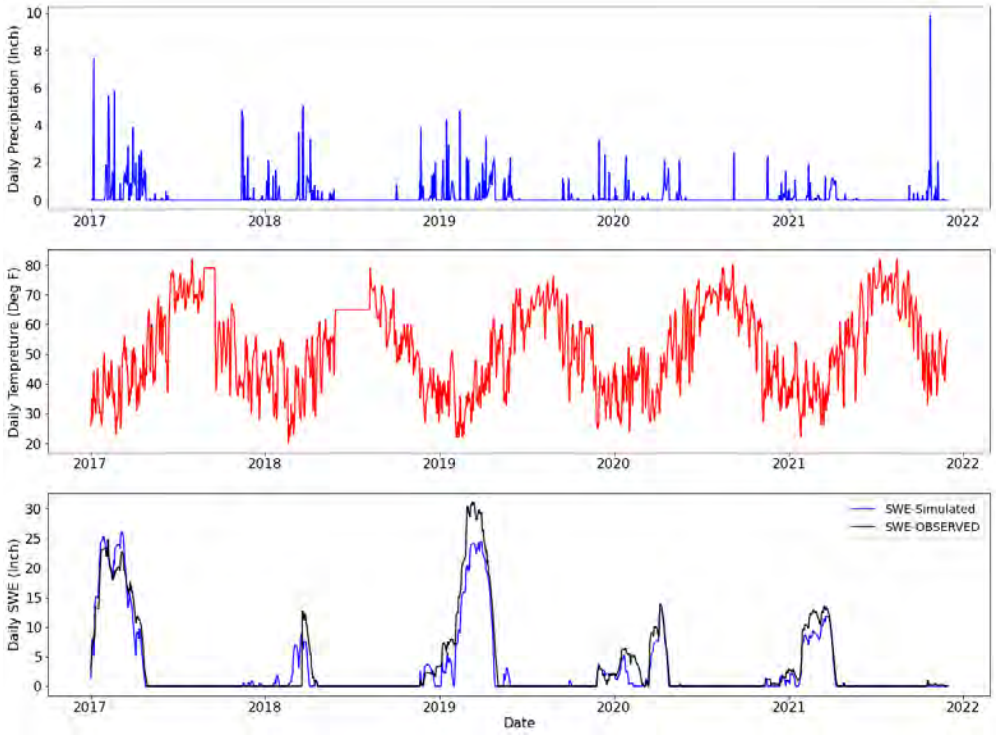


Figure 2-8. Precipitation, Temperature, and Modeled Versus Observed SWE Comparison at Blue Canyon Station (BLC)

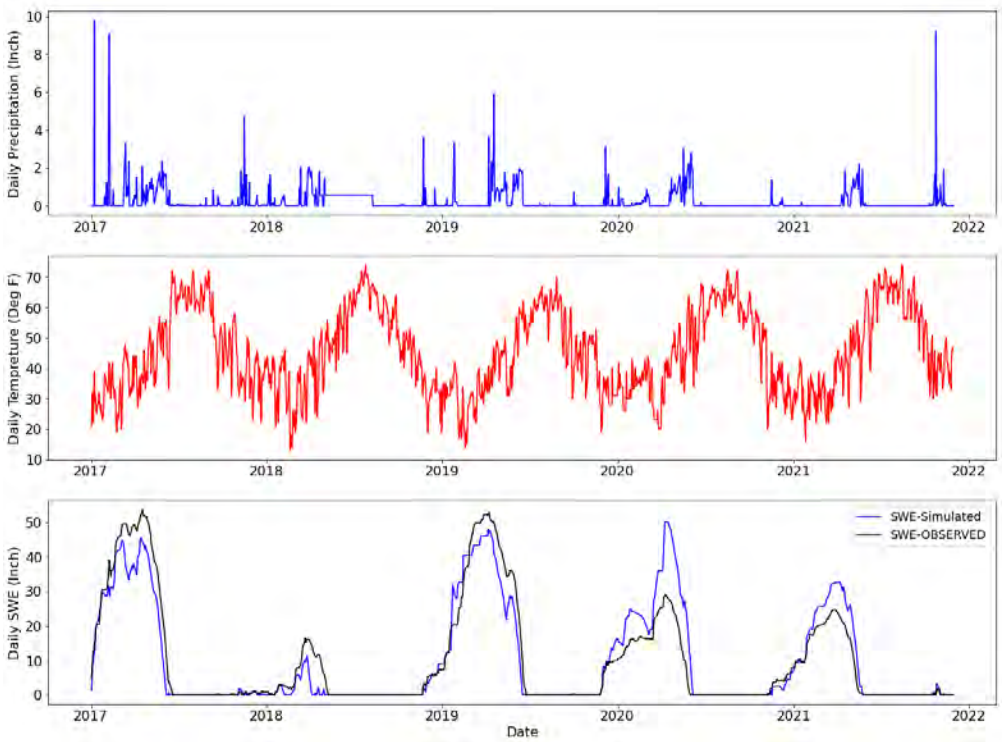


Figure 2-9. Precipitation, Temperature, and Modeled Versus Observed SWE Comparison at Huysink Station (HYS)

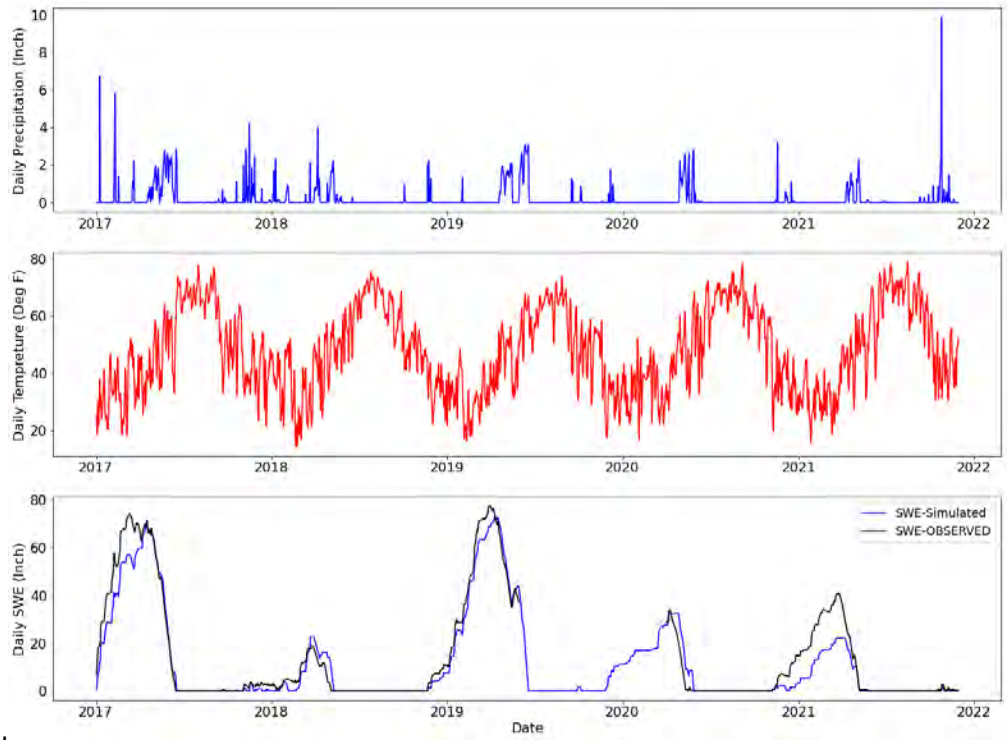


Figure 2-10. Precipitation, Temperature, and Modeled Versus Observed SWE Comparison at Robinson Cow Camp Station (RCC)

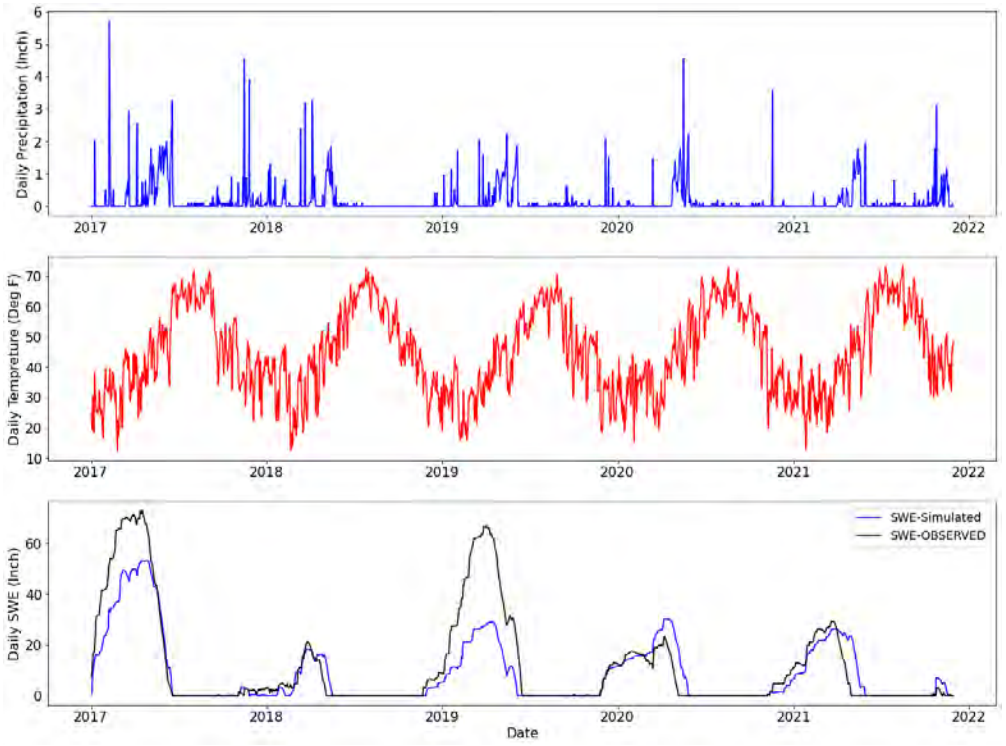


Figure 2-11. Precipitation, Temperature, and Modeled Versus Observed SWE Comparison at Central Sierra Snow Lab Station (CSL)

The calibrated snow parameters and ATI-melt and cold rate functions for each station are presented in Table 2-16 to Table 2-18. These parameters were used to define the initial parameters in the HEC-HMS model for the whole area of interest. Each subbasin in the model was assigned a specific set of snow parameters. The determination of these parameters for each subbasin was based on the nearest snow station in terms of elevation. Subbasin parameters were fine-tuned during HEC-HMS calibration as discussed in Section 2.6.

Table 2-16. Calibrated Temperature Index Parameters

Parameter	Unit	BLC	HYS	RCC	CSL
PX Temperature	°F	35	33.9	34.5	34.5
Base Temperature	°F	33	32.1	33.6	34.5
ATI - Meltrate Coefficient	-	0.8	0.98	0.94	0.9
Wet Meltrate	in./°F-day	0.13	0.099	0.11	0.17
Rain Rate Limit	in./day	0.1	0.1	0.1	0.5
Cold Limit (in./day)	in./day	0.1	0.1	0.1	0.1
ATI - Coldrate Coefficient	-	0.98	0.99	0.98	0.99
Water Capacity (%)	-	3	3	3	3
Groundmelt	in./day	0	0	0	0

Table 2-17. ATI-Meltrate Function

ATI (˚F-day)	BLC	HYS	RCC	CSL
0	0.000	0.0000	0.000	0.000
30	0.011	0.0075	0.010	0.012
55	0.055	0.0375	0.048	0.060
120	0.077	0.0525	0.067	0.084
150	0.088	0.0600	0.076	0.096
200	0.099	0.0675	0.086	0.108
1000	0.110	0.0750	0.095	0.120
2000	0.132	0.0900	0.105	0.132

Table 2-18. ATI-Coldrate Function

ATI (˚F – Day)	BLC	HYS	RCC	CSL
-100.0	-2.00	-1.800	-2.00	-2.00
-10.0	-0.20	-0.180	-0.20	-0.20
-1.0	-0.02	-0.018	-0.02	-0.02
1.0	0.02	0.018	0.02	0.02
10.0	0.20	0.180	0.20	0.20
100.0	2.00	1.800	2.00	2.00
1000.0	20.00	18.000	20.00	20.00

2.6. HEC-HMS Model Calibration

The previous section described the calibration of the snow model using observed SWE as reference. This section discusses the calibration of other important processes in HEC-HMS, including runoff generation, infiltration, and recharge. The calibration described in this section uses observed streamflow or reservoir inflow as reference.

The calibration procedure consists of adjusting several parameters to guarantee that the model accurately represents hydrological processes and outputs for selected historical events.

The following sections provide an overview of the HEC-HMS model calibration process and results.

2.6.1. Calibration Parameters and Approach

Like the calibration process for snow, the evaluation of model performance involved comparing computed results with observed results across the entire modeling domain. Model parameters were altered to minimize the differences between simulated and observed discharge volume and hydrograph shape at locations where they are available (Table 2-20). Since the focus on the hydrological model for this project is to simulate annual water availability, the calibration process was focused toward ensuring minimal bias in the model. Therefore, model performance evaluation was centered on PBIAS. For detailed explanation of PBIAS, Refer to Section 2.5.2. A second priority was the ability of the model to predict streamflow peak, since a large peak may result in water loss through the reservoir spillways. Differences less than or equal to 15% between computed and observed peak flow rates and flow volumes were desired.

Table 2-14 provides the summary statistic performance ratings for the NID HEC-HMS model calibration. Note that the PBIAS statistics at each location were mostly calculated using the complete water year for each calibration year. The exception was the USGS Station 11418500, between Scotts Flat Reservoir and USGS Station 11418500 on Deer Creek. Since the Deer Creek Diversion Dam is ungaged for flows moving down Deer Creek, the D-S Canal could not be incorporated into the unimpaired hydrology modeling efforts. The diversion predominantly affects the flow in Deer Creek from April through November. To mitigate these effects, the PBIAS statistics for USGS Station 11418500 were computed using the time series from

November through April. Schematics illustrating the complex systems of storage and diversions across the North, Middle, and South Yuba Rivers, along with the Bear River can be accessed on the USGS website and are included in Appendix A.

As described in more detail in the following sections, the calibration approach followed two main steps: (1) calibration based on 5 selected years with varying climatology, and (2) re-calibration based on extrapolation for the period of record.

2.6.1.1 Step 1: Calibration for Selected Years

Based on a first evaluation of the model results with initial model parameters (before calibration), it was concluded that the model captured streamflow peaks and timing reasonably well. For some of the events, disparities in the timing of snow accumulation and melting and in runoff volume were identified. The sensitivity analysis, calibration parameters, and general approach are summarized in Appendix A. To evaluate the model's performance under different hydrological conditions, including dry, normal, and wet conditions, five water years, spanning from October 1 to September 30, were chosen. The details of the calibration water years are provided in Table 2-19.

Table 2-19. Calibration Events

Wet Water-Year	Normal Water-Year	Dry Water-Year
Oct 1996–Sep 1997	Oct 2003–Sep 2004	Oct 2020–Sep 2021
Oct 2005–Sep 2006		Oct 2014–Sep 2015

2.6.1.2 Step 2: Re-Calibration Based on Extrapolation for Period of Record

Following model calibration for the five selected water years using the observed data, the next step was to use the same calibration parameters to simulate streamflow for other historical years (from 1975 to 2022 except WYs 1997, 2004, 2006, 2015, and 2021). A first step in this process was to develop a methodology for defining which of the five sets of calibrated parameters should be applied to simulate each historical year.

While evaluating the five sets of calibrated parameters for various climate conditions (dry, normal, and wet) within the NID basin, it was determined that the baseflow index is strongly correlated with watershed initial condition. Baseflow index in HEC-HMS represents the average percentage of water received as precipitation that is lost to recharge in each water year. In dry years, much of the received precipitation infiltrates in the dry soil and does not end up as runoff. For those years, the baseflow index is high. For years with high precipitation, the soil gets saturated, and a large percentage of the precipitation runs off to the river. Note that the baseflow recharge in HEC-HMS represents a percentage of total volume, not the actual recharge volume. In wet years, both recharge and runoff will present large volumes, with a smaller portion of the volume recharging the aquifer. The relationship between basin moisture condition and baseflow recharge was used to determine the most suitable set of parameters for each year in the historical period.

2.6.2. Results for Selected Water Years

Data for 16 locations for which streamflow data were available (USGS streamflow) or could be computed (reservoir inflow), were used for HEC-HMS model calibration. These locations are listed in Table 2-20 and shown in Figure 2-12. Data for Fordyce Lake were not fully available for the water year (WY) 1997. Therefore, the area delineated above Fordyce Lake for WY2004, WY2006, WY2015, and WY2021 is considered as part of the Lake Spaulding area for WY1997.

Table 2-20. Calibration Locations in NID Basin

River Basins	Number of Locations	Location Name/Stations
North Yuba River	2	USGS Gage 11413000; New Bullards Bar Reservoir
Middle Yuba River	3	Jackson Meadows and Milton Reservoirs jointly (Jackson Meadows-Milton); Our House Dam; Log Cabin Dam
South Yuba River	4	Fordyce Lake; Bowman Lake; Lake Spaulding; USGS Gage 11417500
Bear River	3	Dutch Flat Afterbay; Rollins Reservoir; Camp Far West Lake
Deer Creek	2	Scotts Flat Reservoir; USGS Gage 11418500
Yuba River (outlet)	2	Englebright Lake; USGS Gages 11421000, 11420750, 11420760, 11420770 jointly

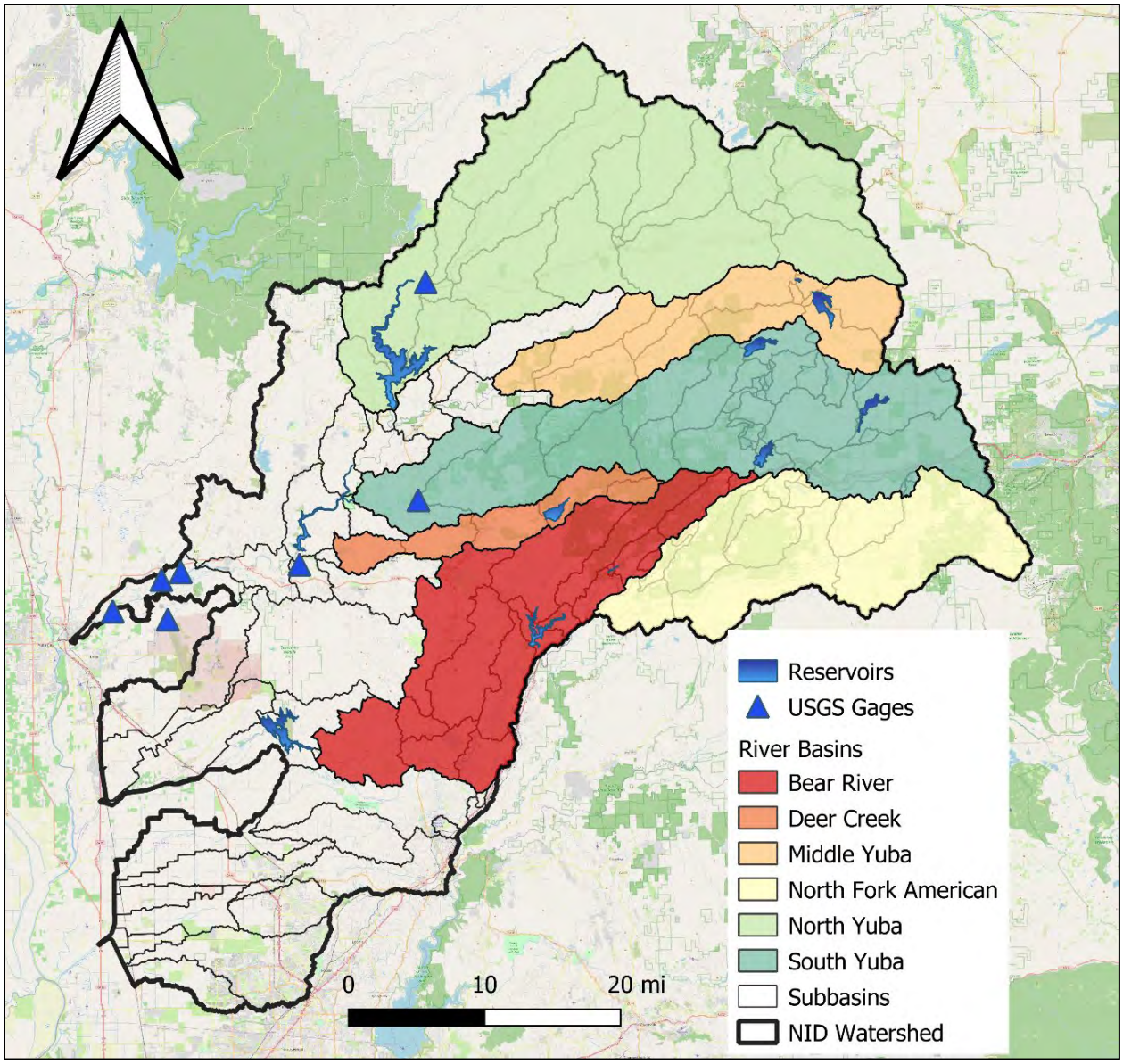


Figure 2-12. Calibration Locations for NID HEC-HMS Model (Described in Table 2-20)

The adjustments to the snowmelt parameters were made in the area upstream of Fordyce Lake, Bowman Lake, and Lake Spaulding. The Wet Meltrate and the ATI - Meltrate Function were adjusted for these subbasins by a factor of 1.1 to minimize differences in observed and simulated snowmelt. The adjusted parameters are listed in Table 2-21 and Table 2-22.

Table 2-21. Adjusted Calibrated Temperature Index Parameters

Parameter	Unit	BLC	HYS	RCC	CSL
Adjusted Wet Meltrate	in./°F-day	0.143	0.1089	0.121	0.187

Table 2-22. ATI-Meltrate Function

ATI (˚F-day)	BLC	HYS	RCC	CSL
0	0.0000	0.00000	0.0000	0.0000
30	0.0121	0.00825	0.0110	0.0132
55	0.0605	0.04125	0.0528	0.0660
120	0.0847	0.05775	0.0737	0.0924
150	0.0968	0.06600	0.0836	0.1056
200	0.1089	0.07425	0.0946	0.1188
1000	0.1210	0.08250	0.1045	0.1320
2000	0.1452	0.09900	0.1155	0.1452

The constant loss rate was first estimated to be 0.1 in./hr. Minor adjustments were made to ensure minimal to no excess precipitation was generated while maximizing runoff using the linear reservoir baseflow routine. The final values ranged between 0.06 and 0.13 in./hr.

Due to the high precipitation magnitudes necessary to generate excess precipitation runoff, most water was infiltrated and routed as baseflow. Therefore, adjustments to the baseflow recharge were implemented during the calibration process that provided the flexibility of varying the amount of water removed through the system based on deep groundwater recharging for different subbasins. To account for high positive/negative PBIAS across the NID watersheds, the fraction of GW 1 or GW 2 baseflow lost to aquifer recharge was adjusted iteratively to achieve Good to Very Good PBIAS.

2.6.2.1 Water Year 1997: Wet Year

This section describes the calibration results and statistics for WY1997. PBIAS statistics were calculated using the complete WY from 01 Oct 1996 through 30 Sep 1997 for all calibration locations except USGS Station 11418500, where the subsection of the WY from 01 Nov 1996 through 01 Apr 1997 was used. PBIAS maps and metrics are shown in Figure 2-13, comparing the computed results and observed time series of flow at each of the calibration locations. Tabular results summarizing the statistical metrics for the 15 previously mentioned calibration locations are shown in Table 2-23. Hydrographs comparing the computed and observed flow at the 15 calibration locations are shown in Appendix A.

Overall, calibration for this event was “Good” to “Very Good.” Unfortunately, the observed data at Fordyce Lake were not available for this WY. For WY1997, the observed runoff volume of the Yuba River at the Yuba River Outlet was approximately 3,475,200 AF.

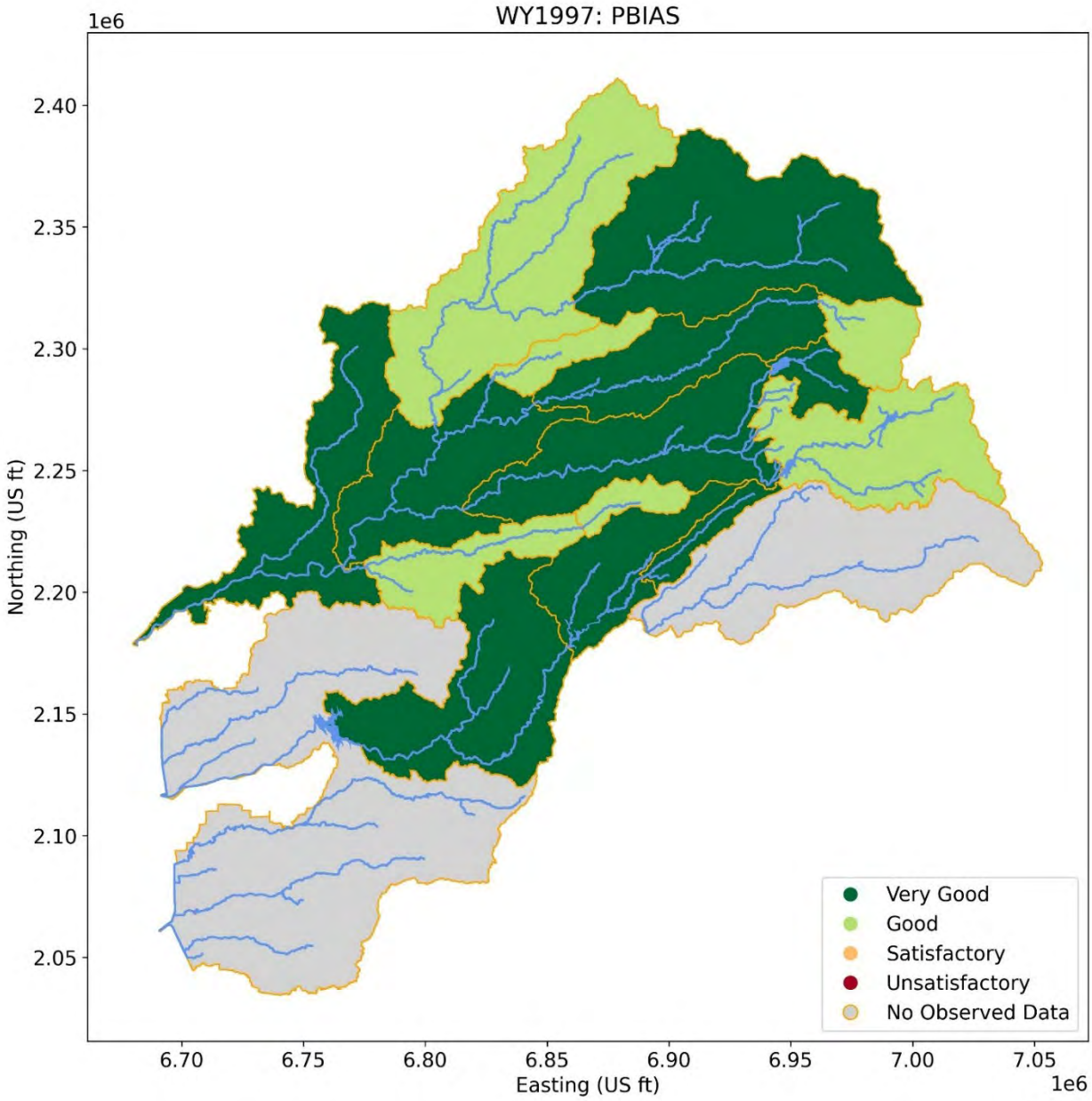


Figure 2-13. WY1997 PBIAS Results

Table 2-23. WY1997 Tabular Results for Primary Locations

Computation Point	PBIAS (%)	Volume Observed (TAF)	Volume Simulated (TAF)
USGS 11413000	-4.91	848.9	807.2
New Bullards Bar Reservoir	-19.55	1,834.6	1,476.0
Jackson Meadows – Milton Reservoirs	-19.71	137.5	110.4
Our House Dam	6.46	378.9	403.3
Log Cabin Dam	-21.25	170.2	134.0
Bowman Lake	-1.42	220.0	216.9
Lake Spaulding	11.26	694.0	772.1
USGS 11417500	9.15	676. 4	738.3
Scotts Flat Reservoir	26	108.2	136.3
USGS 11418500[1]	11.43	145.0	161.6
Englebright Lake	6.08	3,088.2	3,275.9
Yuba River Outlet	3.37	3,475.2	3,592.1
Dutch Flat Afterbay	-9.67	377.94	341.3
Rollins Reservoir	-2.85	709.4	689.2
Camp Far West Lake	-1.89	593.7	582.5

[1]Volume is considered only from 11/1/1996 to 4/1/1997.

2.6.2.2 Water Year 2004: Normal Year

This section describes the calibration results and statistics for WY2004. PBIAS statistics were calculated using the complete WY from 01 Oct 2003 through 30 Sep 2004 for all calibration locations except USGS Station 11418500, where the subsection of the WY from 01 Nov 2003 through 01 Apr 2004 was used. PBIAS maps and metrics are shown in Figure 2-14, comparing the computed results and observed time series of flow at each of the calibration locations. Tabular results summarizing the statistical metrics for the 16 previously mentioned calibration locations are shown in Table 2-24. Plots comparing the computed and observed flow at the 16 calibration locations are shown in Appendix A.

Overall, calibration for this event was “Good” to “Very Good.” For WY2004, the observed runoff volume of the Yuba River at the Yuba River Outlet was approximately 1,384,900 AF.

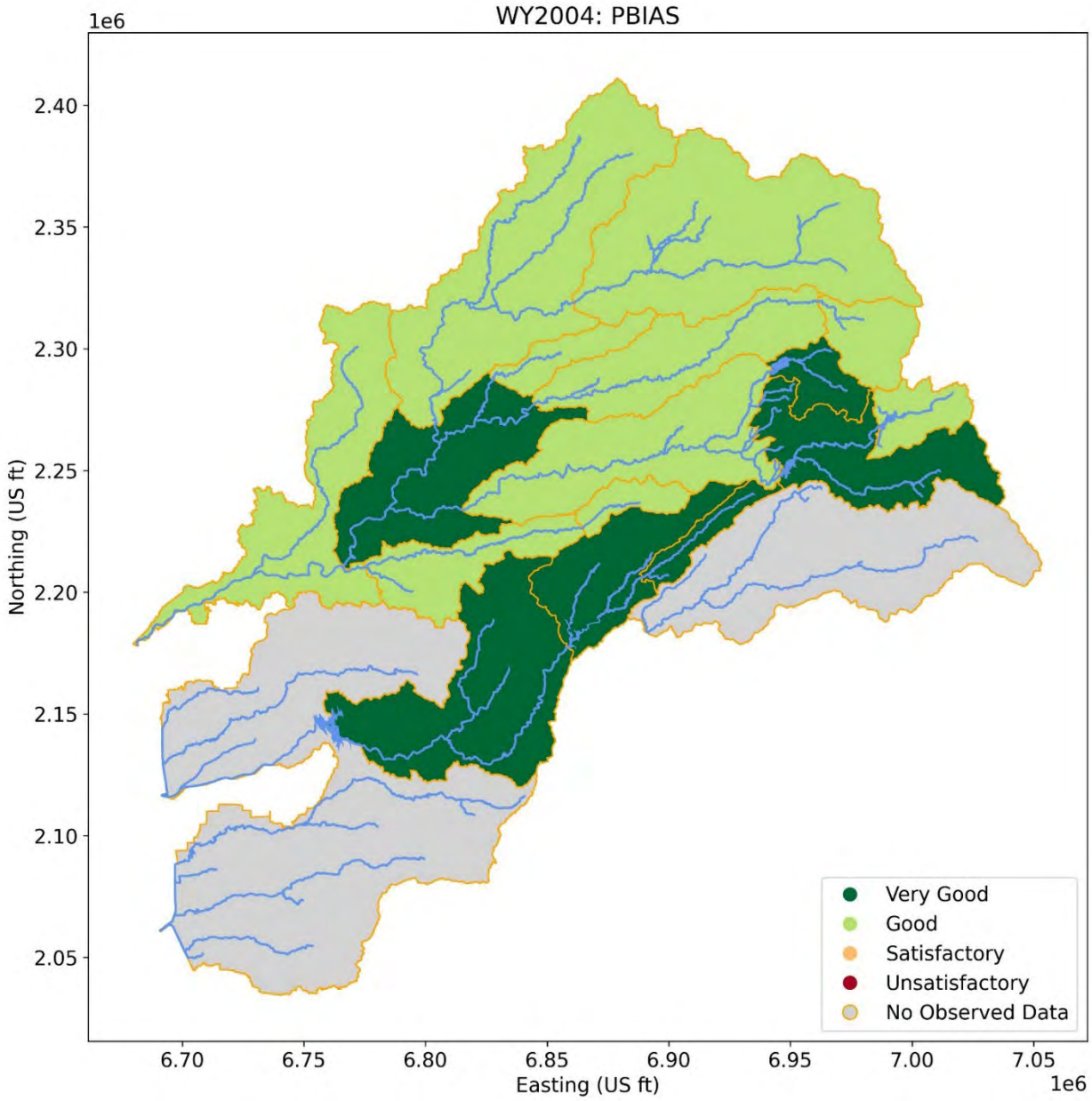


Figure 2-14. WY2004 PBIAS Results

Table 2-24. WY2004 Tabular Results for Primary Locations

Computation Point	PBIAS (%)	Volume Observed (TAF)	Volume Simulated (TAF)
USGS 11413000	-27.99	425.3	306.3
New Bullards Bar Reservoir	-28.29	861.8	617.9
Jackson Meadows – Milton Reservoirs	-23.00	66.5	51.2
Our House Dam	-19.87	141.7	113.5
Log Cabin Dam	-18.70	144.8	117.7
Fordyce Lake	-11.88	71.5	63.0
Bowman Lake	-0.40	128.6	128.1
Lake Spaulding	-2.60	425.1	414.0
USGS 11417500	-27.89	161.5	116.4
Scotts Flat Reservoir	11.99	53.9	60.4
USGS 11418500[1]	-26.39	41.5	30.5
Englebright Lake	-4.95	1,294.6	1,230.6
Yuba River Outlet	11.51	1,384.9	1,544.4
Dutch Flat Afterbay	-1.69	409.0	402.1
Rollins Reservoir	-9.64	510.6	461.4
Camp Far West Lake	0.44	273.6	274.8

[1]Volume is considered only from 11/1/2003 to 4/1/2004.

2.6.2.3 Water Year 2006: Wet Year

This section describes the calibration results and statistics for WY2006. PBIAS statistics were calculated using the complete WY from 01 Oct 2005 through 30 Sep 2006 for all calibration locations except USGS Station 11418500, where the subsection of the WY from 01 Nov 2005 through 01 Apr 2006 was used. PBIAS maps and metrics are shown in Figure 2-15, comparing the computed results and observed time series of flow at each of the calibration locations. Tabular results summarizing the statistical metrics for the 16 previously mentioned calibration locations are shown in Table 2-25. Plots comparing the computed and observed flow at the 16 calibration locations are shown in Appendix A.

Overall, calibration for this event was “Good” to “Very Good.” For WY2006, the observed runoff volume of the Yuba River at the Yuba River Outlet was approximately 4,161,200 AF.

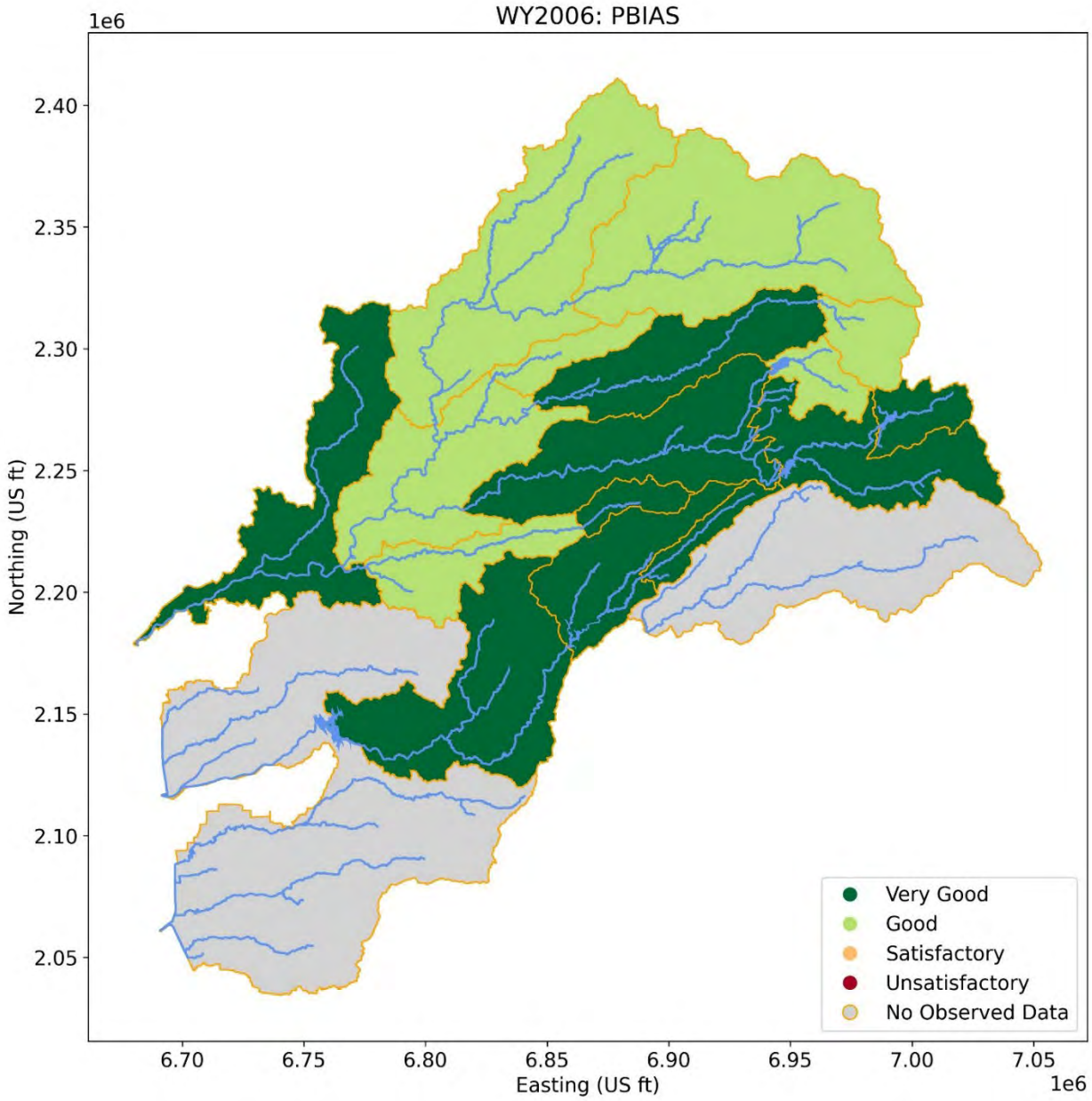


Figure 2-15. WY2006 PBIAS Results

Table 2-25. WY2006 Tabular Results for Primary Locations

Computation Point	PBIAS (%)	Volume Observed (TAF)	Volume Simulated (TAF)
USGS 11413000	-20.85	1,005.8	796.1
New Bullards Bar Reservoir	-23.39	2,152.6	1,649.1
Jackson Meadows – Milton Reservoirs	-19.07	149.2	120.8
Our House Dam	-0.92	510.3	505.7
Log Cabin Dam	-23.26	241.0	184.9
Fordyce Lake	-9.99	151.5	136.4
Bowman Lake	-10.3	239.3	214.6
Lake Spaulding	-4.06	780.8	749.1
USGS 11417500	8.83	788.0	857.6
Scotts Flat Reservoir	-8.85	104.5	95.2
USGS 11418500[1]	-14.61	121.4	103.6
Englebright Lake	13.75	3,340.9	3,800.3
Yuba River Outlet	-1.78	4,161.2	4,087.2
Dutch Flat Afterbay	-7.82	523.9	482.9
Rollins Reservoir	-6.28	864.0	809.7
Camp Far West Lake	-1.25	887.0	875.9

[1]Volume is considered only from 11/1/2005 to 4/1/2006.

2.6.2.4 Water Year 2015: Dry Year

This section describes the calibration results and statistics for WY2015. PBIAS statistics were calculated using the complete WY from 01 Oct 2014 through 30 Sep 2015 for all calibration locations except USGS Station 11418500, where the subsection of the WY from 01 Nov 2014 through 01 Apr 2015 was used. PBIAS maps and metrics are shown in Figure 2-16, comparing the computed results and observed time series of flow at each of the calibration locations. Tabular results summarizing the statistical metrics for the 16 previously mentioned calibration locations are shown in Table 2-26. Plots comparing the computed and observed flow at the 16 calibrations locations are shown in Appendix A.

Overall, calibration for this event was “Satisfactory” to “Very Good.” PBIAS statistics for most locations were within the “Good” range that was previously described, with several basins in the “Very Good” range and a few basins in the “Satisfactory” range. It is unsurprising that a couple of basins fell in the “Satisfactory” range for WY2015. WY2015 is the first of two dry year examples, and hydrological processes during dry years are highly non-linear, and those non-linearities are not always captured by the model. However, since volumes are smaller during dry periods, a relatively higher PBIAS in comparison to wet years still represents a small volume of flow. For example, during WY1997, the total volume difference at Jackson Meadows-Milton reservoirs was approximately 27,100 AF and yielded a -19.71% PBIAS. During WY2015, the total volume difference at Jackson Meadows-Milton reservoirs was approximately 13,900 AF, nearly

half of the volume difference from WY1997, and yielded a less desirable PBIAS of -39.07%. For WY2015, the observed runoff volume of the Yuba River at the Yuba River Outlet was approximately 633,800 AF.

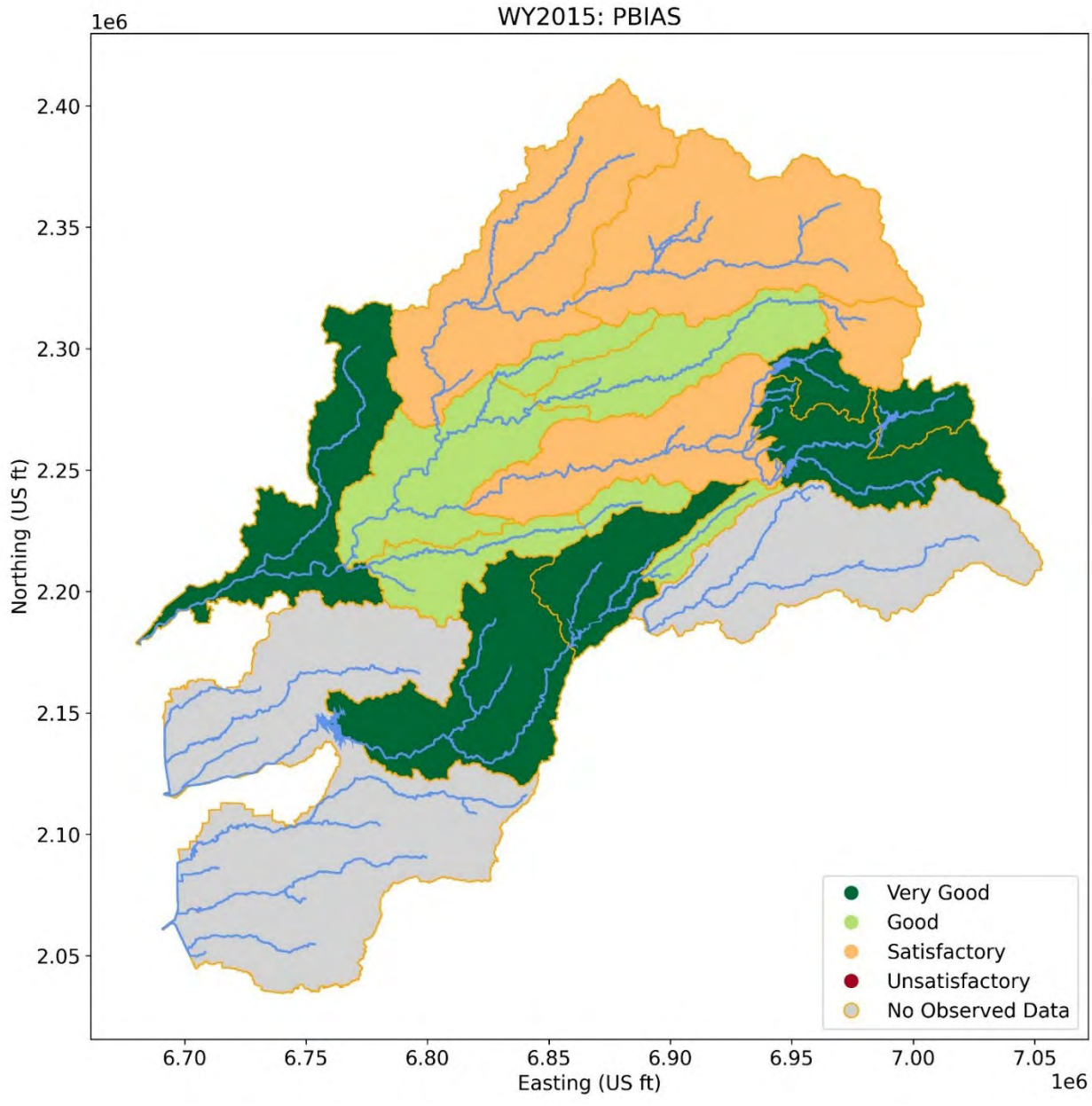


Figure 2-16. WY2015 PBIAS Results

Table 2-26. WY2015 Tabular Results for Primary Locations

Computation Point	PBIAS (%)	Volume Observed (TAF)	Volume Simulated (TAF)
USGS 11413000	-49.63	202.4	102.0
New Bullards Bar Reservoir	-47.18	432.3	228.4
Jackson Meadows – Milton Reservoirs	-39.07	35.5	21.6
Our House Dam	-31.92	72.7	49.5
Log Cabin Dam	-23.14	63.1	48.5
Fordyce Lake	-3.86	44.5	42.7
Bowman Lake	-3.20	75.1	72.7
Lake Spaulding	-0.50	256.6	255.3
USGS 11417500	-43.74	83.3	46.9
Scotts Flat Reservoir	21.46	43.6	53.0
USGS 11418500[1]	-31.00	18.3	12.6
Englebright Lake	-10.26	596.7	535.5
Yuba River Outlet	9.84	633.8	696.2
Dutch Flat Afterbay	10.07	196.6	216.4
Rollins Reservoir	-4.14	236.6	226.8
Camp Far West Lake	-8.71	116.4	106.2

[1]Volume is considered only from 11/1/2014 to 4/1/2015.

2.6.2.5 Water Year 2021: Dry Year

This section describes the calibration results and statistics for WY2021. PBIAS statistics were calculated using the complete WY from 01 Oct 2020 through 30 Sep 2021 for all calibration locations except USGS Station 11418500, where the subsection of the WY from 01 Nov 2020 through 01 Apr 2021 was used. PBIAS maps and metrics are shown in Figure 2-17, comparing the computed results and observed time series of flow at each of the calibration locations. Tabular results summarizing the statistical metrics for the 16 previously mentioned calibration locations are shown in Table 2-27. Plots comparing the computed and observed flow at the 16 calibration locations are shown in Appendix A.

Overall, calibration for this event was “Satisfactory” to “Very Good.” PBIAS statistics for most of the locations were within the “Very Good” range that was previously described, with several basins in the “Good” range and a few basins in the “Satisfactory” range. As with WY2015, it is unsurprising that a couple of basins fall in the “Satisfactory” range for WY2021, as the water year was a significantly dry year with the same highly non-linear effects mentioned in Section 2.6.2.4. For WY2021, the observed runoff volume of the Yuba River at the Yuba River Outlet was approximately 630,500 AF.

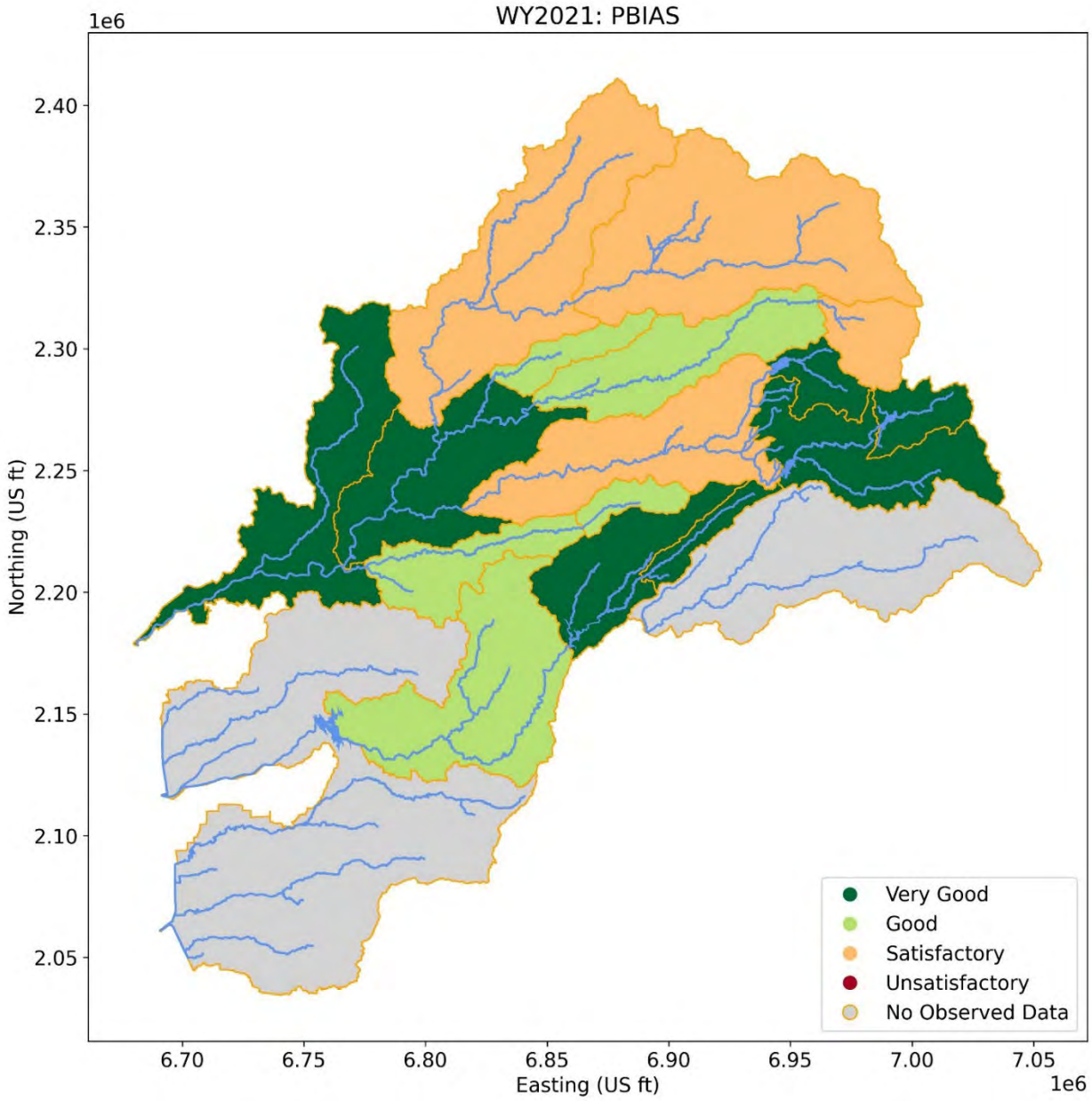


Figure 2-17. WY2021 PBIAS Results

Table 2-27. WY2021 Tabular Results for Primary Locations

Computation Point	PBIAS (%)	Volume Observed (TAF)	Volume Simulated (TAF)
USGS 11413000	-48.25	160.4	83.0
New Bullards Bar Reservoir	-42.13	317.0	183.4
Jackson Meadows – Milton Reservoirs	-37.78	25.1	15.6
Our House Dam	-32.81	51.7	34.7
Log Cabin Dam	-30.99	42.0	29.0
Fordyce Lake	-0.91	37.4	37.0
Bowman Lake	-1.31	65.1	64.3
Lake Spaulding	-0.40	275.7	274.6
USGS 11417500	-38.10	57.3	35.5
Scotts Flat Reservoir	21.75	42.8	52.1
USGS 11418500[1]	-13.64	7.4	6.4
Englebright Lake	-3.64	637.8	614.6
Yuba River Outlet	10.00	630.5	693.5
Dutch Flat Afterbay	4.29	182.6	190.4
Rollins Reservoir	-0.45	209.9	208.9
Camp Far West Lake	34.65	62.9	84.8

[1]Volume is considered only from 11/1/2020 to 4/1/2021.

2.6.3. Results for Other Water Years

The first step for simulating other water years was to identify an indicator that describes basin moisture condition. Multiple drought indicators were calculated for each river basin in the NID watershed (North Yuba River, Middle Yuba River, South Yuba River, Bear River, and Deer Creek) using a drought tool (Wells et al. 2004) developed by National Center for Atmospheric Research (NCAR). The input data for the tool include monthly basin-average temperature and precipitation data compiled from the daily Livneh dataset.

The correlation between multiple drought indicators and baseflow index were evaluated, and the indicator that presented the highest correlation was selected as a proxy to select the best parameter set. A different relationship was established for each region (North Yuba River, Middle Yuba River, South Yuba River, Bear River, and Deer Creek). Among all the relationships, it was observed that Weighted Palmer Drought Severity Index (WPLM) for July of each WY has the highest correlation with the weighted recharge for all the regions. The relationships for the multiple areas are shown in Figure 2-18.

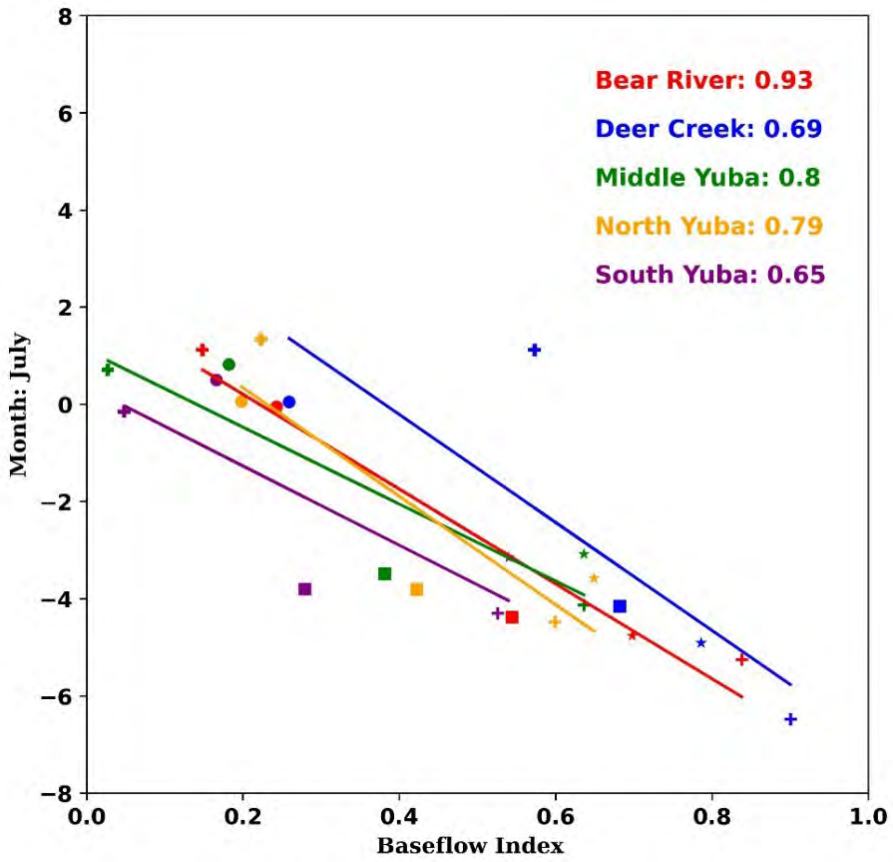


Figure 2-18. Scatter Plot of WPLM for July Versus Weighted Average Baseflow Index

The following procedure was used to define parameters for other water years for each river basin:

1. Identify the minimum monthly WPLM value within a WY.
2. Calculate the baseflow index value using the established relationship and the minimum WPLM value from Step 1.
3. Determine the closest weighted average recharge from the five calibrated parameter sets (WY1997, WY2004, WY2006, WY2015, and WY2021) to the one computed in Step 2. This identifies the calibrated parameter set suitable for that WY.
4. Adjust the GW 1 and GW 2 coefficients in the selected payment set (Step 3) to align with the weighted average recharge computed in Step 2. Other parameters remain unchanged.

The HEC-HMS model was run for the historical period using input daily precipitation and temperature data from the Livneh dataset (available from 1950 to 2018). The approach described above was used to define parameters for each water year. To evaluate the model, the cumulative simulated streamflow from 1975 to 2018 was compared with the one estimated based on the gage proration approach (HDR 2020) at various locations within the NID basin. The validation results revealed bias at six locations. Figure 2-19 presents the cumulative daily inflow (1975–2018) at Yuba at Smartsville (USGS gage 11419000) from the gage proration approach (red line) and HEC-HMS (blue line).

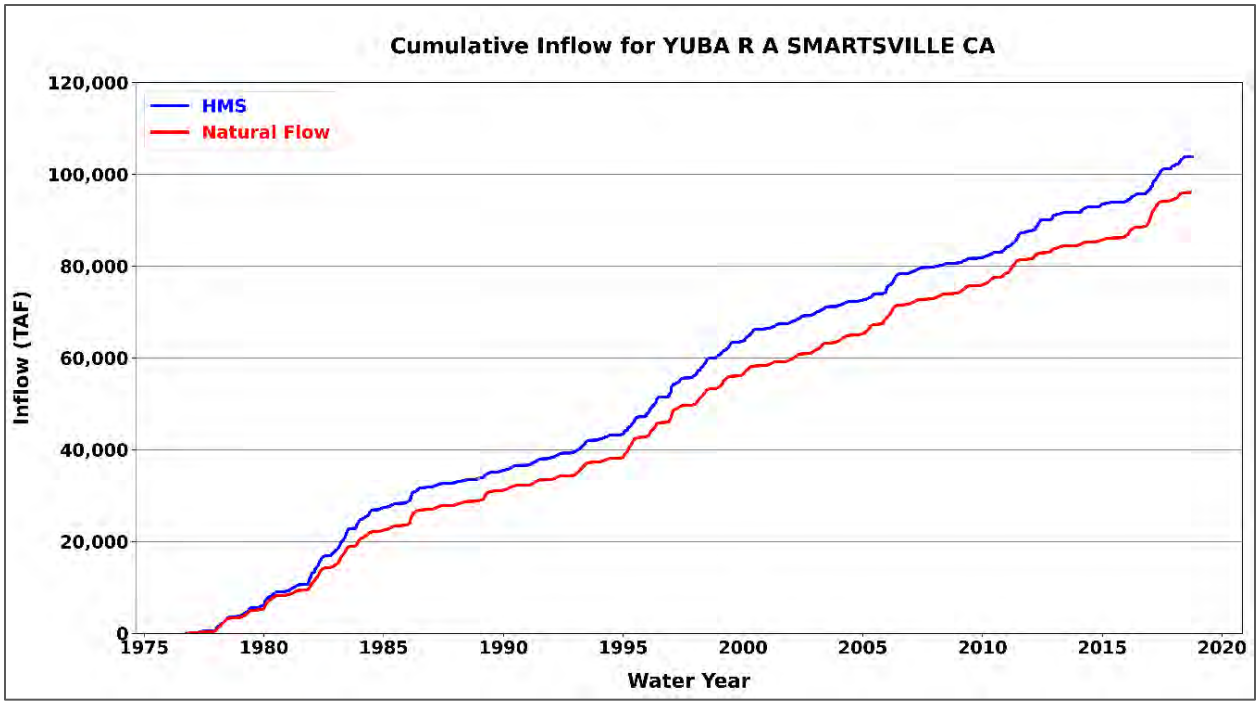


Figure 2-19. Cumulative Daily Inflow (1975–2018) for Yuba at Smartsville (USGS gage 11419000)—After Refinements

To address the bias in the model, calibration refinements were performed using gage proration flows as reference and accounting for all years between 1975 and 2018. In the refinement process, PX, base temperature, and baseflow recharge were adjusted to reduce the bias in the HEC-HMS model.

Figure 2-20 illustrates the cumulative daily inflow (1975–2018) at Yuba at Smartsville (USGS gage 11419000) using the gage proration approach (red line) and HEC-HMS (blue line) obtained after the calibration refinement procedure. Plots comparing the cumulative daily inflow using the gage proration approach and HEC-HMS for other locations are shown in Appendix A. The results for this location and others validate (the HEC-HMS model and demonstrate the mitigation of bias in the HEC-HMS model.

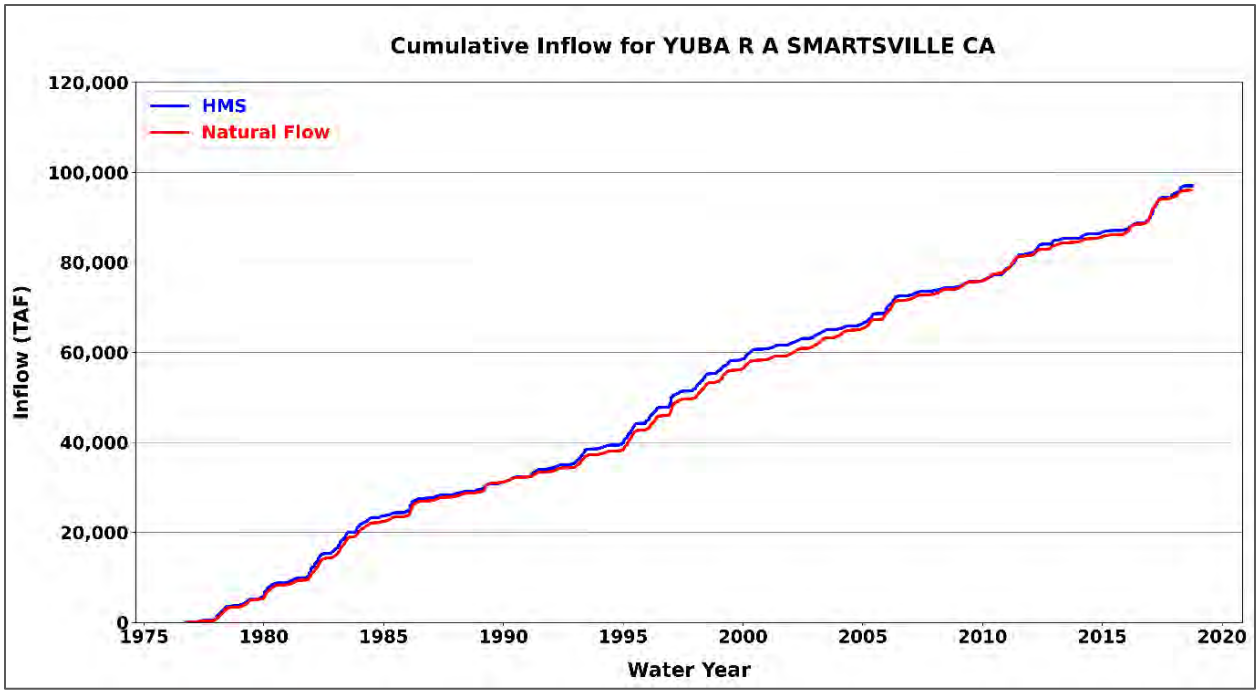


Figure 2-20. Cumulative Daily Inflow (1975–2018) for Yuba at Smartsville (USGS gage 11419000)—After Refinements

Chapter 3. Projected Hydrology

3.1. Introduction

This chapter discusses future unimpaired hydrology for the PFW. The goal of the unimpaired hydrology task is to update historical natural watershed runoff to the most recent available data as discussed in Chapter 2. This chapter discusses unimpaired hydrology anticipated under projected climate conditions. As shown in Figure 3-1, the generation of projected hydrology requires the development of three main datasets:

1. Global Climate Model (GCM) Projections: GCMs are mathematical representations of the Earth's climate system. GCMs are important tools for understanding the potential effects of climate variability and changes, providing climate projection data, including precipitation and temperature, at a resolution of 50–250 km for the period of 1950–2100. To understand the strengths and weaknesses of various GCMs, the Intergovernmental Panel on Climate Change (IPCC), established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP), manages the Coupled Model Intercomparison Project (CMIP). CMIP develops standards for model runs and collects, compares, analyzes, and shares the results of multiple GCMs from around the world. Because GCMs are constantly evolving and computational resources improving, model results and CMIP's protocols, standards, and data distribution mechanism are updated frequently. To reflect this, CMIP has been organized in different numbered phases (e.g., CMIP3, CMIP5, and CMIP6), with CMIP6 being the most recent phase to release its modeling output data.
2. Downscaled Global Climate Model Projections: The resolution of temperature and precipitation provided by current GCMs is too course for local and regional planning studies like the PFW. Data downscaling increases the resolution of GCM data to scales more appropriate for analyzing the hydrologic response of the complex terrain of NID watersheds, the variety of water demands across the NID service area, and the details of NID's water infrastructure.
3. Reservoir Inflow Projections: To obtain inflow to the reservoirs, hydrological or statistical methods are applied to convert meteorological forcing into projected inflows.

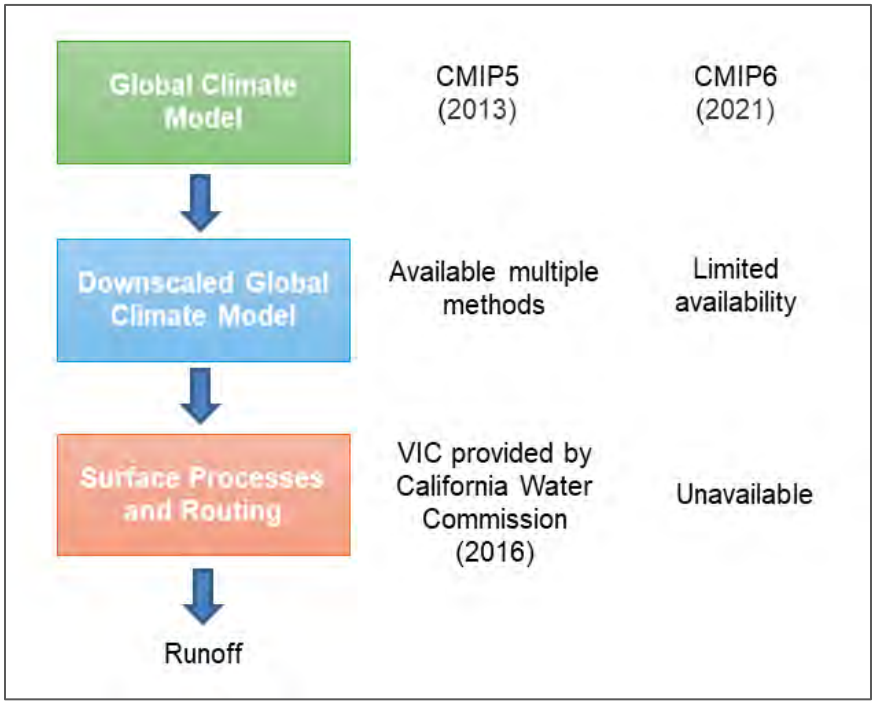


Figure 3-1. Required Datasets for the Generation of Projected Inflow and Their Current Availability for CMIP5 and CMIP6

The NID water plan developed in 2013 applied the projected hydrology the California Water Commission (CWC) developed and provided (2016). The CWC used CMIP5 and the Variable Infiltration Capacity hydrology model to generate projected inflow across multiple California regions. That information was used to generate local inflows to NID's service area. A full description of the hydrologic data and methods used to develop the 2070 projection of unimpaired hydrology are presented in the Hydrologic Analysis Technical Memorandum (HDR 2020).

3.1.1. Global Climate Model Projections

In 2021, a new, updated version of the GCM projections, CMIP6, was released (Li et al. 2021). CMIP6 continues the pattern of evolution and adaptation characteristics of previous CMIP phases, with the CMIP6 models generally having finer resolution with improved dynamical processes and emission scenarios based on the new Shared Socioeconomic Pathways (SSPs) for future climate change projections (Li et al. 2021, O'Neill et al. 2016). Therefore, CMIP6 data were selected for use in the PFW.

3.1.2. Downscaled Global Climate Model Projections

Since CMIP6 was only recently published, precipitation and temperature downscaled datasets were not widely available when the present project was being developed. Multiple groups were working to generate CMIP6 downscaled information using dynamical and statistical methods. In dynamical downscaling, the data from a GCM is used as input and boundary conditions for higher resolution Regional Climate Models. Statistical downscaling uses relationships between the large-scale climate patterns provided by GCMs and observed local climate responses. More details on these two methods are provided at this link.

A research group at the University of California, Los Angeles, is applying dynamical methods to downscale CMIP6 data. The researchers used the Weather Research and Forecasting (WRF) model to generate downscaled information for the period of 1980 through 2100 at a spatial resolution of 3 km and temporal resolution of 1 hr (Rahimi and Lei 2022). While publicly available, because the dataset was still under review, the UCLA researchers suggested not applying this dataset until the review process is complete (Rahimi 2022).

Krantz et al. (2021) is applying a combination of statistical and dynamical methods to downscale CMIP6 precipitation and temperature. The approach is new and combines physics-based simulations with an updated version of the Localized Constructed Analogs (LOCA) statistical downscaling method (Pierce et al. 2014). First, high-resolution physics-based simulations are applied to downscale a selection of GCMs. The simulations are then used to train a new version of LOCA based on statistics of the future climate. Finally, the method is applied to downscale a broader set of GCMs. The downscaled meteorological variables are publicly available and used in the PFW analysis to provide temperature and precipitation time series data at each location in the NID basin grid for 50 years of projected climate.

3.1.3. Reservoir Inflow Projections

The last step includes the application of downscaled temperature and precipitation to estimate runoff and inflow to the reservoirs.

Two types of approaches are commonly used to convert projected temperature and precipitation into inflows: 1) statistical methods (Freni et al. 2009, Xing et al. 2018, Yang and Yang 2011), and 2) hydrological models (Chiew et al. 2018, Islam et al. 2014, Shi et al. 2022). Statistical models are not recommended since they predict the future based on what has happened in the past. However, with climate change, that relationship might not be valid. Moreover, these types of models are usually inaccurate in predicting rare extreme dry or wet events. Hydrological models are preferable since they simulate the important physical processes affecting the rainfall-runoff conversion, including snow accumulation, snow melt, evapotranspiration, and soil dynamics including infiltration (Fowler et al. 2018, Li et al. 2022, Pechlivanidis et al. 2016, Shi et al. 2022). Recent studies (Li et al. 2022, Mahato et al. 2022, Moothedan et al. 2022) show that the HEC- HMS model can accurately simulate the range of inflow scenarios desired for the PFW. Therefore, the HEC-HMS model was selected for the PFW studies.

To obtain the projected inflows to the NID areas of interest, the downscaled precipitation and temperature data were used as inputs to the HEC-HMS hydrological model described in Chapter 2.

3.2. Climate Scenario Selection

To determine which GCMs perform better for the State of California climate, Krantz et al. (2021) evaluated the performance of CMIP5 and CMIP6 models. The results of the analysis are presented in Figure 3-2, reproduced from Krantz et al. (2021). The GCMs that perform best in California are shown in the green box. Additional well performing models are in the blue box. Seven downscaled climate models listed in Table 3-1 were chosen for the analysis from the red box in Figure 3-2.

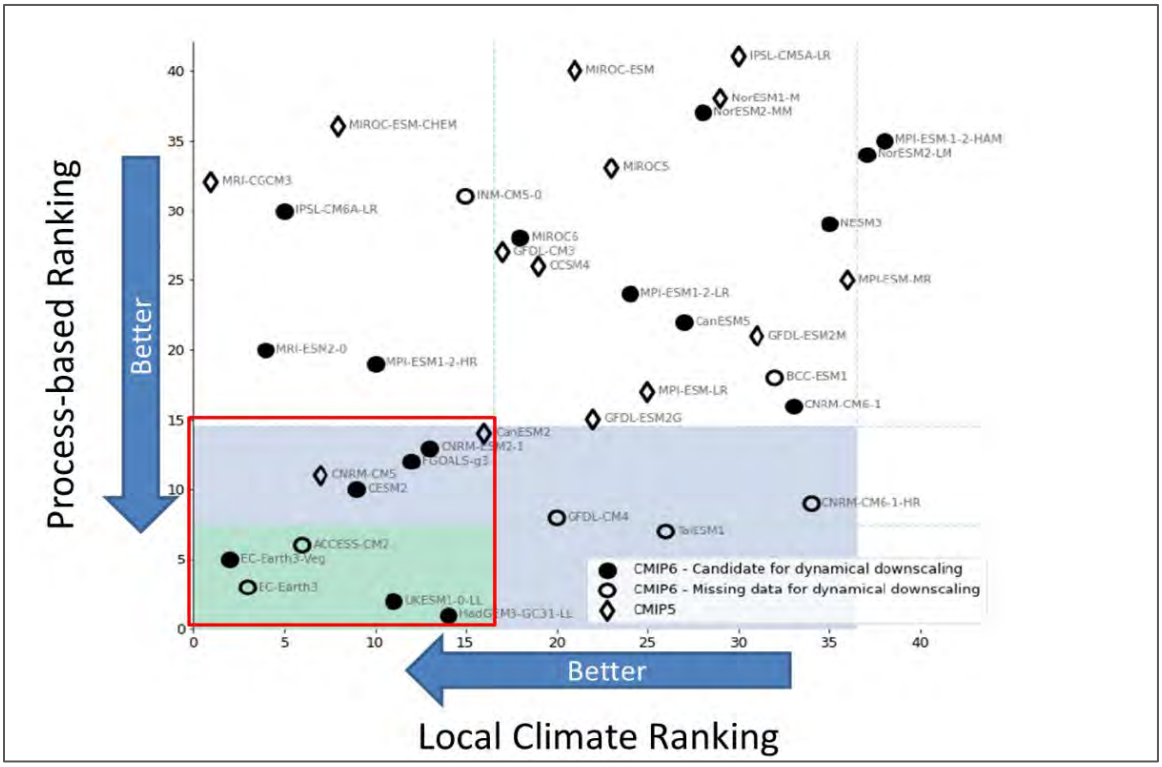


Figure 3-2. Comparison of the GCM Rankings by Local Climate Metric Performance and Process-Based Metric Performance (Source: Krantz et al. 2021).

GCMs use emission scenarios as input data to estimate the amount of CO_2 and other greenhouse gases launched to the atmosphere. Each GCM can use multiple emission scenarios to explore a range of potential future climate outcomes and their associated uncertainties. These scenarios, known as SSPs, outline various trajectories of energy production, land use, and greenhouse gas emissions implications. The SSPs are part of a new scenario framework established by the climate change research community to facilitate the integrated analysis of future climate impacts, vulnerabilities, adaptation, and mitigation. The SSPs do not predict the future, but rather provide a range of plausible scenarios that help researchers and policymakers explore the potential consequences of different pathways of human development. In this project, three SSPs were selected to represent endpoints and median scenarios for the analysis:

1. SSP245 (optimistic scenario): This scenario portrays a future characterized by relatively rapid and effective mitigation of environmental and societal challenges. This scenario envisions proactive efforts to address issues such as climate change, resource management, and social equity. Technological innovation, international cooperation, and sustainable development practices feature prominently in this optimistic narrative. Economic growth is balanced with environmental stewardship, leading to a world where human wellbeing is prioritized alongside ecological preservation.
2. SSP370 (median scenario expected to be exceeded): This scenario represents a middle-of-the-road projection in terms of societal and environmental trends. It anticipates moderate efforts to address global challenges, with progress occurring at a pace that may not be sufficient to prevent significant disruptions. While some measures are taken to address issues like climate change and

social inequality, they may fall short of what is necessary to avoid more severe consequences. This scenario reflects a world grappling with both opportunities and challenges, where progress is made but not at a pace that ensures long-term sustainability or resilience.

3. SSP585 (pessimistic scenario): This scenario presents a future marked by escalating environmental degradation, societal conflict, and economic inequality. In this pessimistic narrative, efforts to mitigate climate change and other global challenges are limited or ineffective. Technological progress may exacerbate rather than alleviate societal divisions and environmental pressures. Resource depletion, extreme weather events, and geopolitical tensions are prominent features of this scenario. It paints a picture of a world facing significant crises, with profound implications for human wellbeing, biodiversity, and the stability of global systems.

Table 3-1 shows the 7 selected downscaled GCMs with 3 emission scenarios (SSP245, SSP370, and SSP585) that were selected for this project. Out of the 21 climate scenarios (7 GCMs for each of 3 emissions scenarios), 18 scenarios with available downscaled temperature and precipitation (indicated with "√" in Table 3-1) were used for NID projected hydrology simulations.

Table 3-1. Climate Change Scenarios for HEC-HMS Simulations

GCMs	Emissions		
	SSP245	SSP370	SSP585
ACCESS-CM2	√	√	√
EC-Earth3	√	√	√
EC-Earth3-Veg	√	√	√
CNRM-ESM2-1	√	√	√
FGOALS-g3	√	√	√
HadGEM3-GC31-LL	√	-	√
CESM2-LENS	-	√	-

3.3. Historical Hydrology

Historical hydrology analysis was employed to assess the bias in both the calibrated NID HEC-HMS model (discussed in Chapter 2) and the selected climate models. Model bias refers to the presence of systematic errors in a model resulting in consistent deviations from observed or expected values, leading to inaccurate predictions. It indicates a tendency for the model to consistently overestimate or underestimate certain aspects of the system it is simulating. These errors can arise from many sources, among them, inaccuracies or limitations in the input datasets used for model calibration, the assumptions underlying the model's construction, and the algorithms employed in the modeling process. Climate models can also exhibit some systematic biases due to the limited spatial resolution, simplified physics and thermodynamic processes, numerical schemes, or incomplete knowledge of climate system processes.

To evaluate the bias in the calibrated NID' HEC-HMS model, a comparison was conducted for the average annual local inflow in the NID basin. This assessment focused on the historical period from 1976 to 2021 and involved three independent methods:

1. Gage Proration: The local inflows from the gage proration method from the unimpaired hydrology study by HDR (2020).
2. Water Balance: The average annual local inflow for the NID basin was estimated from the equation:

   Annual runoff = Streamflow at the basin outlet + Losses + Diversions

   Streamflow at the basin outlet = Sum (USGS gages at outlet)

Where:

USGS streamflow gages downstream at 11418000, 11424000, 11418500, and 11408880 were summed, and the streamflow at location 11413510 was subsequently subtracted.

The estimated annual losses and diversions (Western Hydrologics 2023):

- Evaporation: ~23,300 AF/year
- Diversions to the Bear River Canal: ~132,300 AF/year
- Diversions out of Lake Combie: ~62,000 AF/year
- Diversions: diversions off Deer Creek: ~53,000 AF/year

3. HEC-HMS: The calibrated NID HEC-HMS model using the Livneh precipitation and temperature data as input for simulating local inflows within the NID basin.

Figure 3-3 displays the average annual local inflows estimated from the three methods for the historical period (1976–2021), with the y-axis representing the average annual inflow in thousand acre-feet (TAF). Figure 3-3 shows that the three independent methods applied to estimate average annual inflow to the area of interest present very similar results, increasing confidence that the estimates are accurate (negligible bias). The annual average from the HEC-HMS model (1,547 TAF) closely aligns with the estimates from the gage proration method (1,509 TAF) and the water balance method (1,444 TAF).

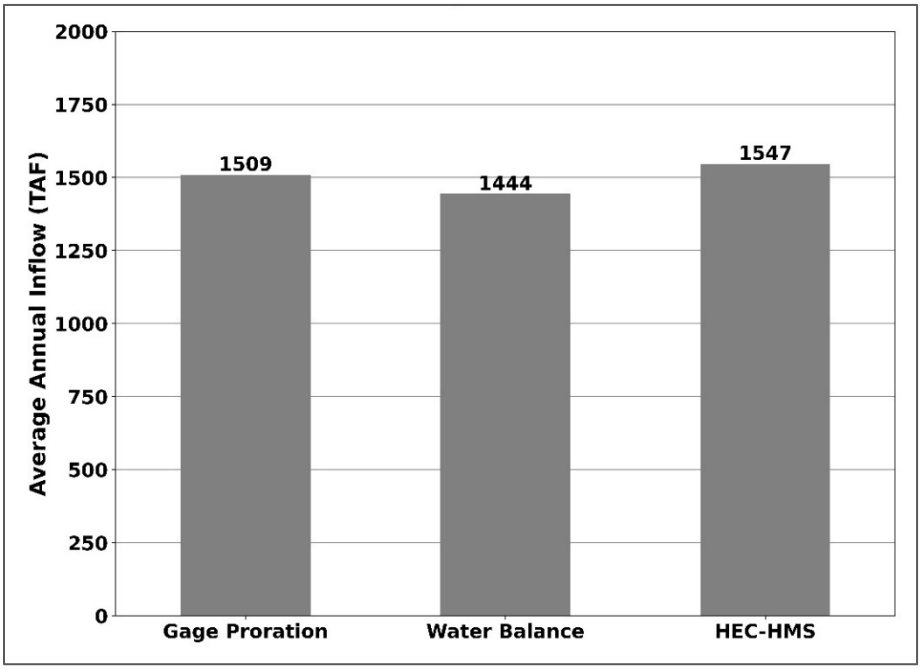


Figure 3-3. Comparison of Average Annual Inflow (1976–2021) for NID Basin

To assess bias in the climate models, the downscaled precipitation and temperature data from the selected climate models and scenarios (refer to Table 3-1) were used as inputs to the calibrated NID HEC-HMS model. This was done to generate local inflow simulations for the entire NID basin during the historical period 1976–2021.

Figure 3-4 visually presents a comparison between the average annual inflow for the NID basin from 1976–2021, as obtained from the HEC-HMS model using the climate model data as input. The average historical inflows derived from the gage proration method (indicated by the green dashed line) is used for validation. This graph contrasts the model's performance against historical inflow estimates, providing insights into any potential biases in the climate models. The x-axis of Figure 3-4 corresponds to a specific combination of a climate model and its associated emission scenario. For instance, the label "HadGEM3-GC31-LL_ssp585" signifies the HadGEM3-GC31-LL climate model paired with the SSP585 emission scenario. Some spread in the results is expected due to natural variability in climate, since the historical simulations represent just one realization of what could have happened in the past, and not exactly the observed historical climate for that period. Since the average annual inflow obtained from the climate models closely aligns with the average historical inflow, it indicates that the climate models are not biased, and are providing simulations that, on average, and considering the whole area of interest, are consistent with the historical data over the historical period.

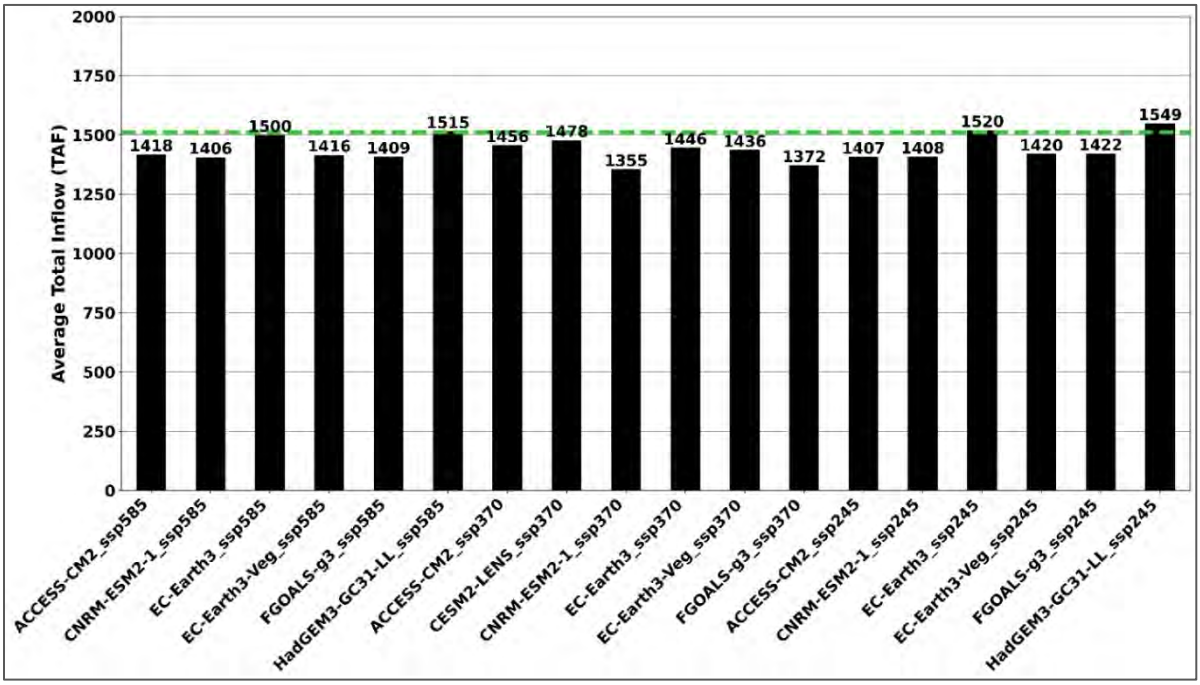


Figure 3-4. Comparison of Average Annual Inflow (1976–2021) for NID Basin

3.4. Projected Hydrology

The downscaled precipitation and temperature dataset from the selected climate models and scenarios (refer to Table 3-1) were used as inputs in the calibrated NID HEC-HMS model to obtain the local inflows for the entire NID basin for the projected period (2022–2071).

Figure 3-5 to Figure 3-7 illustrate the 50-year average total inflow for durations of 1, 5, and 10 years, while Figure 3-8 and Figure 3-9 depict the median of annual total inflow for the same durations using the 18 climate model scenarios. Based on the analysis, three representative hydrology scenarios were selected, and they are outlined as follows:

High Bookend (Wet) Scenario: This scenario implies conditions characterized by higher-than-average precipitation, increased temperature, and/or more frequent and intense rainfall events. The climate model EC-Earth3-Veg_ssp370 has been selected to represent the high bookend (wet) scenario. In this climate scenario, the 50-year average total inflow is highest for all durations along with the highest median annual inflow for 5- and 10-year durations. In Figure 3-5 through Figure 3-10, this scenario is visually presented by the blue bars, indicating a wet 50-year runoff pattern.

Median Scenario: This scenario typically reflects moderate changes or trends, neither excessively optimistic nor pessimistic. The climate model CNRM-ESM2-1_ssp245 has been chosen to represent the median scenario. In Figure 3-5 through Figure 3-10, this scenario is depicted by the green bar , indicating a median 50-year runoff pattern.

Low Bookend (Dry) Scenario: This scenario implies conditions characterized by lower-than-average precipitation, decreased humidity, and/or more prolonged periods of drought. The climate model CESM2-

LENS_ssp370 scenario has been chosen as the representative for low bookend (dry) scenario. In this climate scenario, the 50-year average total inflow is lowest for all durations. accompanied by a consistently low median annual inflow for all durations. This scenario is represented as the red bar in Figure 3-5 through Figure 3-10, indicating a dry 50-year runoff pattern.

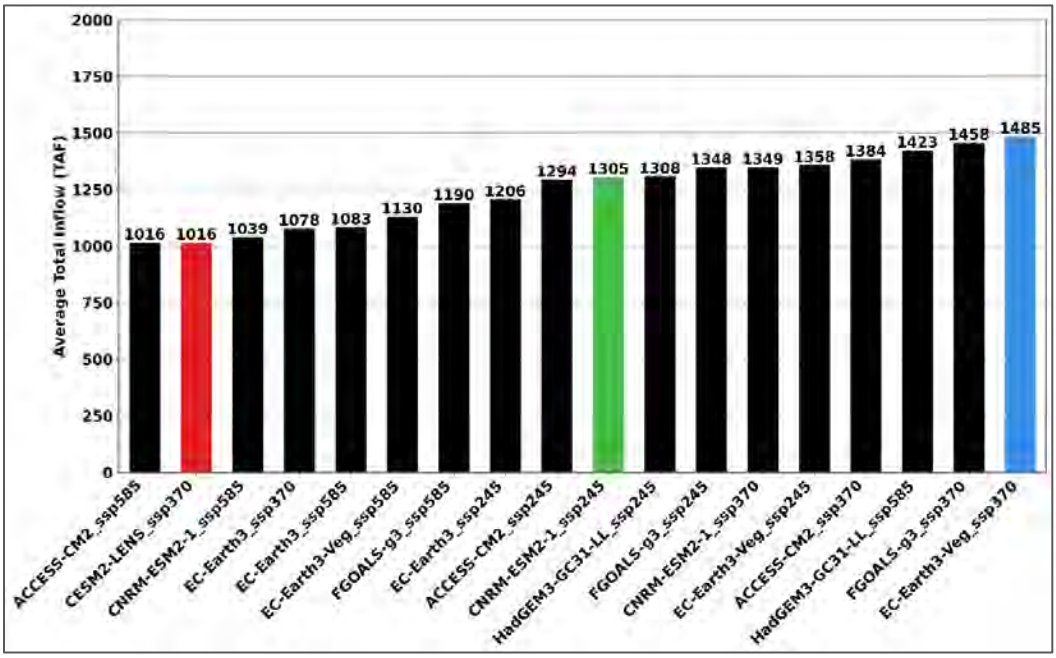


Figure 3-5. 50-Year Average Total Inflow for 1-Year Duration highlighting the dry (red), median (green) and wet (blue) scenarios

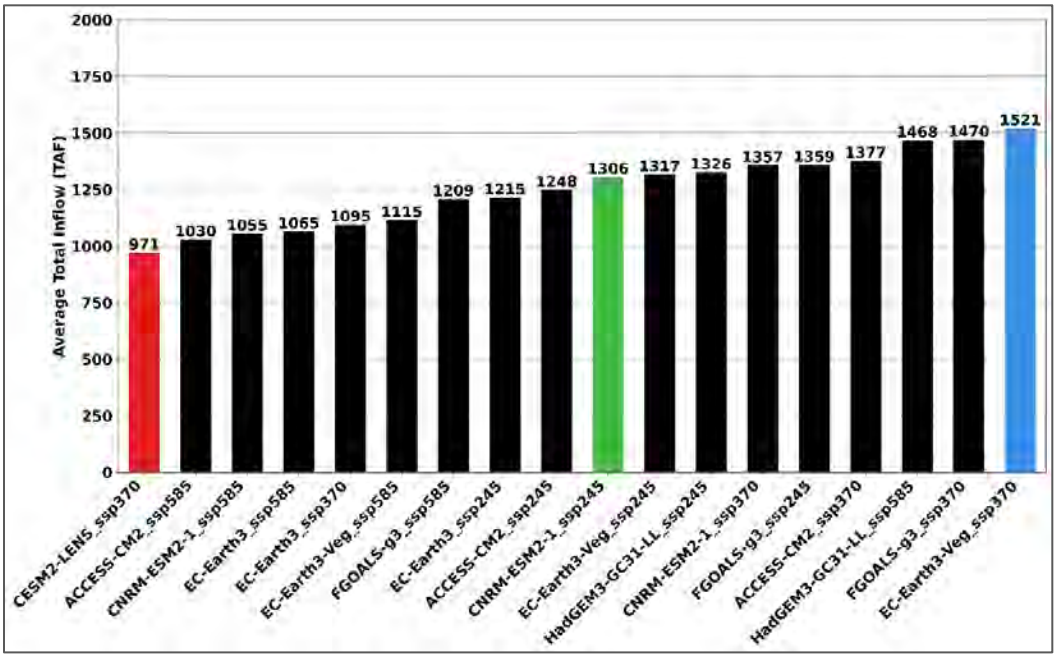


Figure 3-6. 50-Year Average Total Inflow for 5-Year Duration highlighting the dry (red), median (green) and wet (blue) scenarios

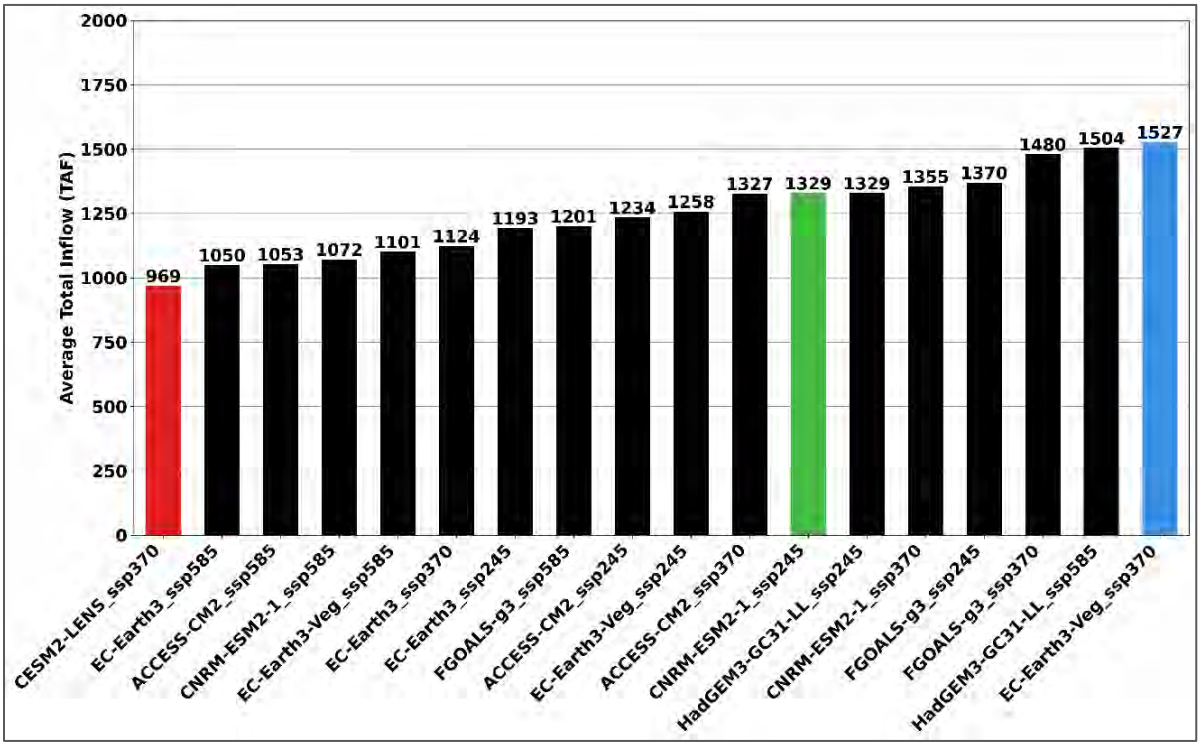


Figure 3-7. 50-Year Average Total Inflow for 10-Year Duration highlighting the dry (red), median (green) and wet (blue) scenarios

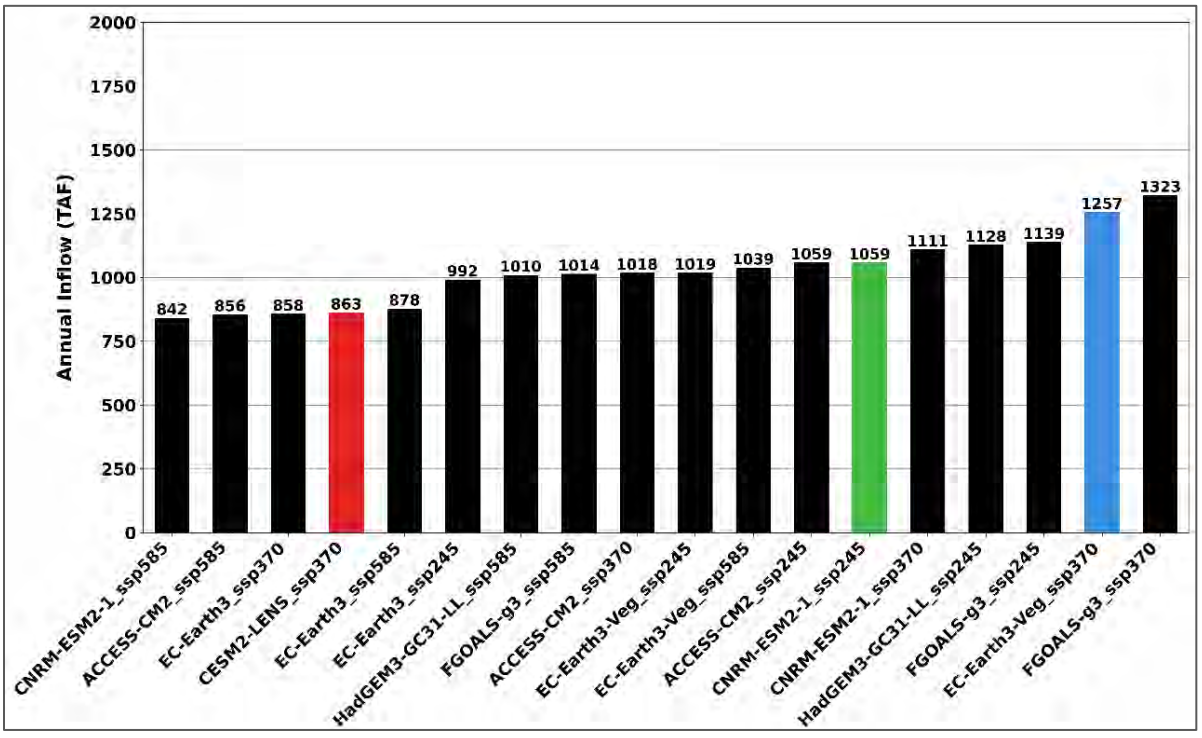


Figure 3-8. Median Annual Inflow for 1-Year Duration highlighting the dry (red), median (green) and wet (blue) scenarios

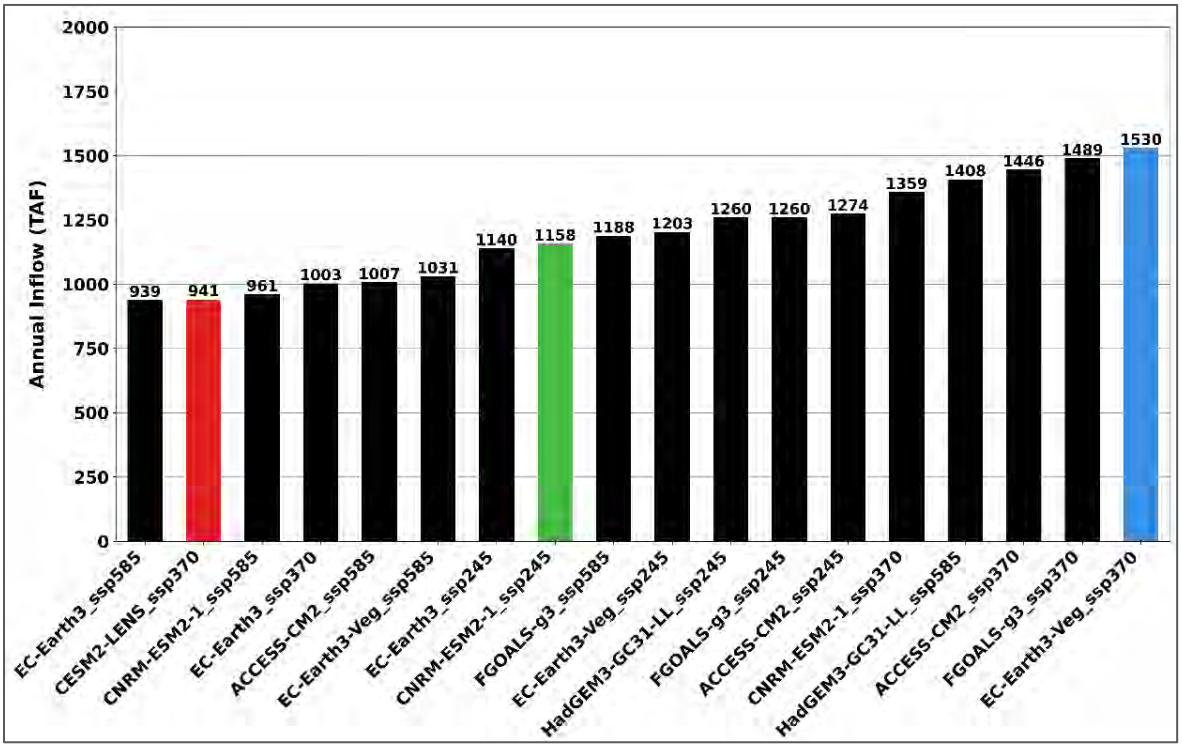


Figure 3-9. Median Annual Inflow for 5-Year Duration highlighting the dry (red), median (green) and wet (blue) scenarios

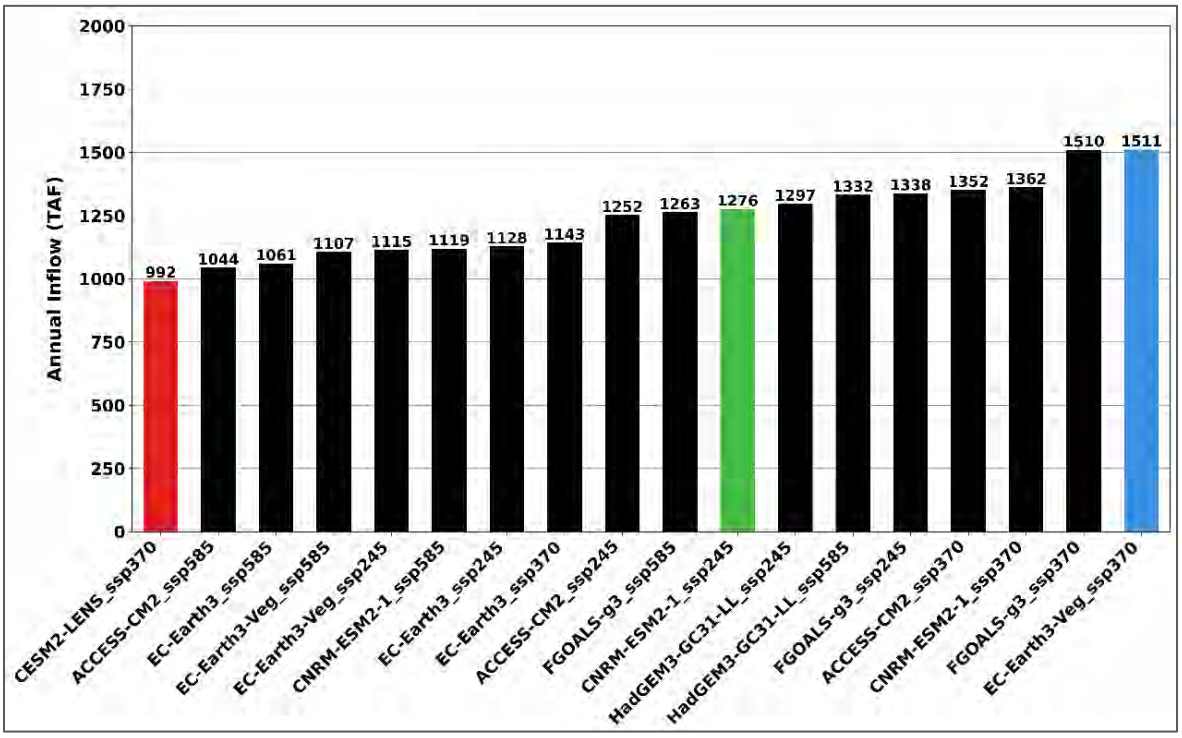


Figure 3-10. Median Annual Inflow for 10-Year Duration highlighting the dry (red), median (green) and wet (blue) scenarios

3.5. Representative Scenarios

Table 3-2 provides a summary of the three representative hydrologic scenarios. These scenarios encompass two extremes, serving as bookends, and a moderate, middle-of-the-road hydrologic scenario. The range of outcomes covered by these three scenarios reflects both low and high inflow possibilities. It is important to note that while the scenarios may not follow a normal distribution statistically, they are treated as having equal probabilities for analytical purposes. Actual future conditions inflow patterns are expected to be between the low and the high bookends, without preference for any scenario.

Table 3-2. Climate Change Scenarios for HEC-HMS Simulations

Scenarios	Models and Emissions
High Bookend (Wet)	EC-Earth3-Veg_ssp370
Median	CNRM-ESM2 1_ssp245
Low Bookend (Dry)	CESM2-LENS_ssp370

The total annual inflow simulated record from 2022–2071 for the entire NID basin for the three representative scenarios is illustrated in Figure 3-11. The wet bookend (blue line) has the greatest number of high inflow events, but also has occurrences of drought conditions. The dry bookend (red line) has the greatest number of drought conditions, but also has few occurrences of high inflow events. The median scenario (green line) has some high inflow events and some drought events, but not as significant as the bookends.

Figure 3-12 presents the 50 years (2022–2071) cumulative total annual inflow for the entire NID basin for the three representative scenarios. This graph demonstrates that over the 50-year projection of inflows, the cumulative values lie in the proper order. The wet has the highest cumulative total inflow for the 50-year projection, the dry has the lowest, and the median is in the middle. The black dashed line takes the average annual inflow value of 1,509 TAF from the historical dataset of 1976–2021 and creates a cumulative trend line using this average value. This line was included only for comparison. One takeaway is that the wet bookend has a very similar total inflow to historical values over the projected period.

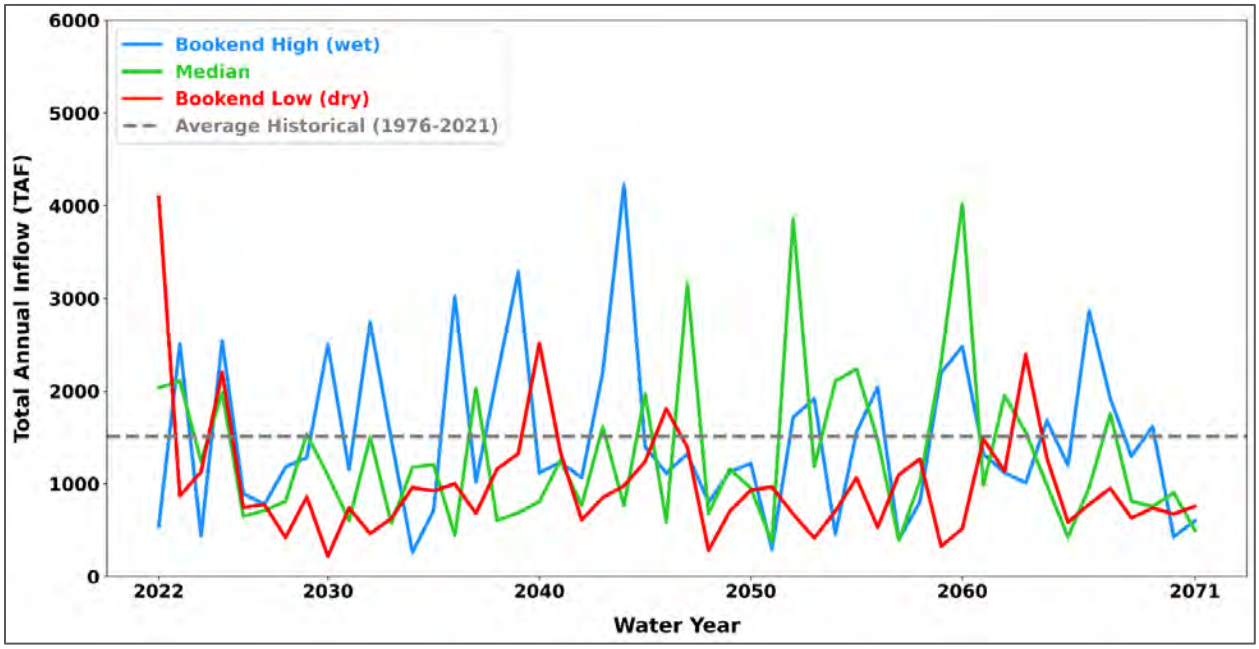


Figure 3-11. Total Annual Inflow Time Series for NID Basin, 2022–2071

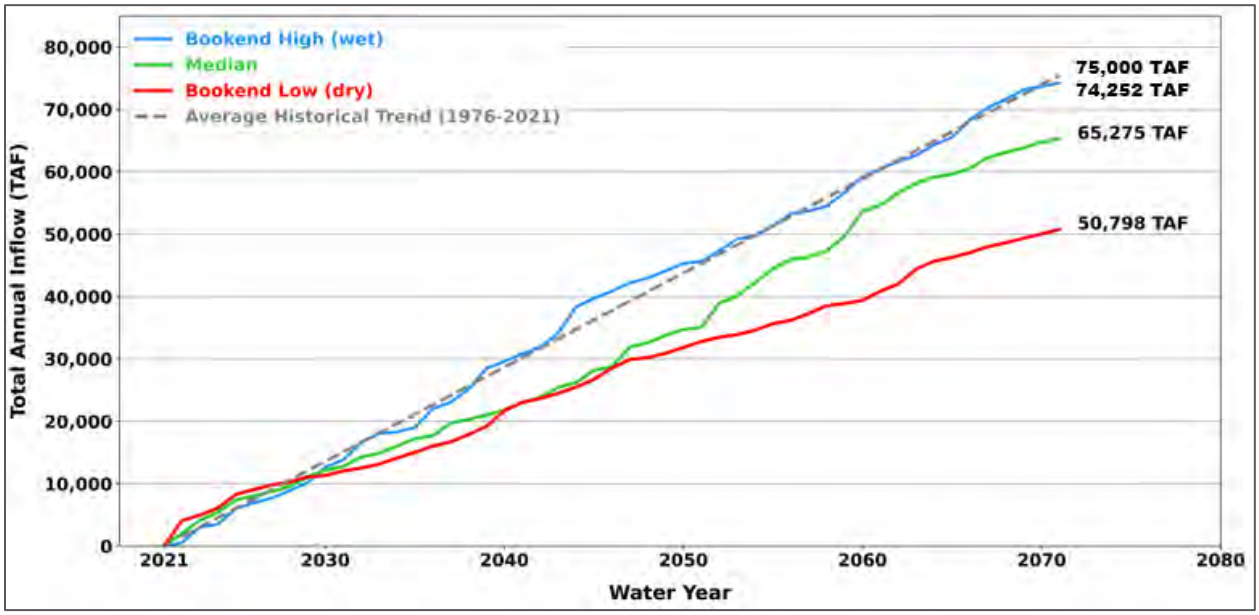


Figure 3-12. 50-Years Cumulative Total Annual Inflow for NID Basin

Chapter 4. Demand Model

4.1. Introduction

This section discusses the development and application of the demand model used to support the NID PFW process. In the context of the NID PFW process, demand generally refers to the total volume of water required to meet water users' needs. This includes water used by raw water customers, treated water customers, and municipal water suppliers that receive water from NID (collectively referred to as NID's customers), together with the system losses that occur delivering water to NID's customers and the regulatory-required environmental flows that NID provides.

The demand model discussed in this section was developed to estimate the demand, or outflows, from NID's reservoirs, required under various scenarios to supply the water needs of NID's customers, inclusive of system losses in NID's canals and distribution system downstream of NID's reservoirs. Regulatory-required environmental flows are included in the reservoir operations model discussed in Chapter 5.

The purpose of this demand model is to provide a means of estimating the demand of NID's customers under different potential projected (i.e., future) scenarios by physically simulating the processes that drive water use on the landscape under the effects of those scenarios. The demand model was thus developed to leverage available local data, standard technical approaches, and best practices to account for the relative effects of estimated future changes in climate, land use, irrigation practices, soil properties, and other factors that impact demand. Results of the demand model were then used to estimate the outflows required from NID's reservoirs to meet those demands, facilitating analyses of water supply versus demand and conditions of unmet demand under potential projected scenarios.

The subsections that follow describe in greater detail the structure and development of the demand model, the projected demand scenarios evaluated in the demand model, and the results of those scenarios.

4.2. Demand Model Development

4.2.1. Background and Major Drivers of Water Demand

Generally, the demand model was developed to create water budgets for the areas within NID where NID's customers receive and use water (e.g., parcels associated with raw and treated water customers). A water budget is a method of accounting for the water that flows into and out of, or is stored within, an area of interest (Healy et al. 2007). A water budget can be calculated for virtually any area of any size, ranging from local (e.g., particular parcels or canal reaches) to regional (e.g., NID service area or canal system) to global. Both the driving forces of water use and uncertainty around water use impact the estimates of water demand at each scale and influence the assumptions and decisions that are made for developing the water budget. The United Nations and other organizations recognize many important environmental, social, economic, and political factors that impact water demand at all scales, including land use change, population change, global climate change, and other technological and economic factors (United Nations 2018, Wada et al. 2016). While the net effects of each individual factor are difficult to quantify and carry significant uncertainty, the importance of considering these factors within the context of local and regional water planning is clear.

4.2.1.1 Major Drivers of Agricultural Water Demand

The majority of NID's raw water customers receive water deliveries from NID to support irrigation of agricultural lands. In general, agricultural water demand includes all water used to irrigate crops or otherwise meet agricultural production-related needs. Agricultural water demand can be divided into consumptive use and non-consumptive use:

- Consumptive Use: "That part of water withdrawn that is evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise removed from the immediate water environment" (ASCE-EWRI 2016). The vast majority of consumptive use occurs through evapotranspiration (ET) from plants and water surfaces. Consumptive use is often used interchangeably with ET (Allen et al. 1998).
- Non-consumptive Use: "That part of water withdrawn that is not evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise removed from the immediate water environment" (ASCE-EWRI 2016). Non-consumptive use encompasses other water uses that do not result in water being removed from the local environment, such as spillage, tailwater, and deep percolation of water into the groundwater system.

At the local level, cropping, soil management practices, land management practices, and irrigation practices all significantly impact both the consumptive and non-consumptive components of agricultural water demand and can also significantly affect water availability in surrounding landscapes (FAO 2011).

Consumptive use (primarily ET) is a major focus of long-term water management planning and irrigation demand projections. In total, projected ET is expected to be significantly impacted by future changes in land use and climate, the major parameters evaluated by the U.S. Bureau of Reclamation (USBR) when developing the irrigation demand projections as part of the "West-Wide Climate Risk Assessments: Irrigation Demand and Reservoir Evaporation Projections" (USBR 2015). Shifting land use toward or away from higher-demand crops and land uses will likewise shift agricultural water demand (Allen et al. 1998). Increasing temperatures in the future are also expected to increase ET demand across all land uses (USBR 2015). While non-consumptive use also impacts agricultural demand, there are opportunities for improving water use efficiency to reduce or strategically leverage those demands, for example through conservation, reuse, or conjunctive management efforts.

4.2.1.2 Major Drivers of Urban Water Demand

In addition to raw water customers, NID also supplies water to a substantial number of treated water customers and municipal water suppliers to support what may be referred to as urban water demand. In the context of water budget development for demand modeling, urban water demand typically includes water demand from municipal water suppliers, public water systems, and urban, commercial, industrial, or residential water users who either supply or directly use water to meet demands in urban or residential settings. Urban water demand can include water use for indoor uses (drinking, sanitation, etc.) and certain outdoor uses (household landscape irrigation, etc.). Like agricultural water demand, urban water demand can also be divided into consumptive use and non-consumptive use by the same definitions given above (ASCE-EWRI 2016).

Projected urban water demand is expected to be impacted by pressures associated with future changes in land use, climate, and population (USBR 2021). Pressures associated with land use change and climate change are similar to those anticipated for agricultural land use change (described above). In NID, pressures associated with population change are expected to include changes in the total population and changes in per capita water use of NID's treated water customer base and municipal suppliers served by NID. Because the net effect of these changes over the next 50 years is unknowable, a variety of potential projected demand scenarios were developed to evaluate possible future outcomes. However, it is worth noting that a retrospective analysis of total and per capita water use among multiple water suppliers in California between 2000–2015 found that shifts toward increased efficiency (i.e., lower per capita water use) were enough to offset increases in population and decrease the total urban water demand over the same period (Abraham et al. 2000).

4.2.2. Overview of the NID Demand Model Structure and Inputs

As described above, demand in the NID PFW process generally refers to the total volume of water required to meet water users' needs, including water used by NID's customers, the system losses that occur delivering water to customers, and the regulatory-required environmental flows that NID provides.

The demand model developed to support the NID PFW process was used to estimate the components of demand that are directly related to NID's operations to distribute water to NID's customers, including:

- Raw water demand
- Treated water demand
- Municipal water demand
- System losses (in NID's canals and distribution system downstream of NID's reservoirs)

Regulatory-required environmental flows are included in the reservoir operations model discussed in Chapter 5. An overview of the simulation approach for each demand component is shown in Table 4-1.

The demand model was developed to estimate these demands through two integrated model components:

- Integrated Water Flow Model Demand Calculator (IDC) model: The IDC model was used to estimate the raw water demand and treated water demand of NID's customers based on information about land use, irrigation practices, soil properties, population, per capita water use, and other factors that impact the water use of NID's customers. Results of the IDC model were linked to parcels within the NID service area to identify the location(s) in NID where demand occurs for raw water and treated water customers and to quantify the volume of demand in those locations (Table 4-1). The IDC model is discussed in detail later in this subsection.
- Canal system balance model: The canal system balance model was developed to link the results of the IDC model (by parcel) and the municipal water demand estimates to the conveyance system and canals that NID uses to distribute water to those customers. The canal system balance was then used to estimate the system losses and the inflows to those canal systems from NID's reservoirs that would occur to supply those demands (Table 4-1). The canal system balance model is also discussed in detail later in this subsection.

Table 4-1. Overview of Demand Component Simulation Approach

Demand Component	Model Component Where Demand is Simulated	Associated Section(s) Describing Model Component
Raw water demand	IDC model	Section 4.2.3
Treated water demand	IDC model	Section 4.2.3
Municipal water demand	Quantified outside IDC model, included in canal system balance model	Section 4.2.3
System losses	Canal system balance model	Section 4.2.4
Environmental flows	Reservoir operations model	Chapter 5
Total demand to supply the water needs of NID's customers. (excluding environmental flows)	Demand model	Chapter 5
Total demand (including environmental flows)	Reservoir operations model	Chapter 5

Various data sources and inputs were considered and incorporated into the demand model development, including (but not limited to) the following general information:

- GIS parcel information
- Land use
- Zoning
- Historical water delivery data
- Treatment plant data
- Canal flows
- Cropping and agricultural development
- Typical agricultural practices relating to water use and management
- Soil parameters
- Precipitation data
- Evaporative demand
- Population
- NID's service area, including existing customers
- Changes to NID's service area (e.g., soft service areas, "fill in" areas)
- Population changes stemming from COVID-19 and other factors

The data and assumptions used to develop the demand model and its inputs were documented and discussed through a stakeholder engagement process, leveraging information gained from available local data, technical standards, best practices, and outreach to local agencies, as needed. A comprehensive

summary of the data sources, inputs, and assumptions used to develop the demand model is provided in Appendix B.1.

The key data sources, inputs, and methods used to develop the IDC model and the canal system balance are described in the sections below.

4.2.3. IDC Model

The Integrated Water Flow Model Demand Calculator (IDC) model is a modeling tool developed, maintained, and supported by the California Department of Water Resources (DWR). As a tool, IDC is used for applications in estimating demand through simulation of the physical processes that occur on the land surface that drive demand. IDC is the demand-modeling module of DWR's broader Integrated Water Flow Model (IWFM), an integrated surface water-groundwater modeling platform that has been broadly used to support long-term strategic water planning in numerous Groundwater Sustainability Plans (GSPs), Agricultural Water Management Plans (AWMPs), and other long-term, often multi-decade planning documents developed by water managers throughout California. The IDC model used in the NID PFW process was built using DWR's IDC Version 2015.0.0140, the latest available as of early 2023 (DWR 2022a).

The IDC model uses data and information about climate, land use, soil properties, agricultural and irrigation practices, and urban and residential parameters to physically simulate inflows and outflows of water through the landscape over time (Figure 4-1). IDC estimates the amount of water required to meet the demands of water users under different conditions, whether for agricultural, urban, or residential use. The IDC model structure is designed to simulate these inflows and outflows through finite elements, or grids of simple three- or four-sided polygons. Functionally, IDC models (and IWFM models) are typically developed and operated with a relatively coarse grid, in which each element represents tens to hundreds of acres.

The IDC model used in the NID PFW process was developed as a unitized model (as compared to a spatial model) to simulate conditions for unique and representative combinations of land use, soil characteristics, and climate zones that are found throughout the NID service area within each finite element. In the unitized model structure, demand is simulated for each combination (i.e., each element) and represented on a unit basis (e.g., feet of water required per unit area, or AF/acre). Those unitized results are then linked directly to individual parcels matching one of the simulated land use/soil/climate combinations, permitting parcel-level spatial quantification of demand volumes outside the coarse grid and spatial constraints of a typical spatial IDC model (Figure 4-2).

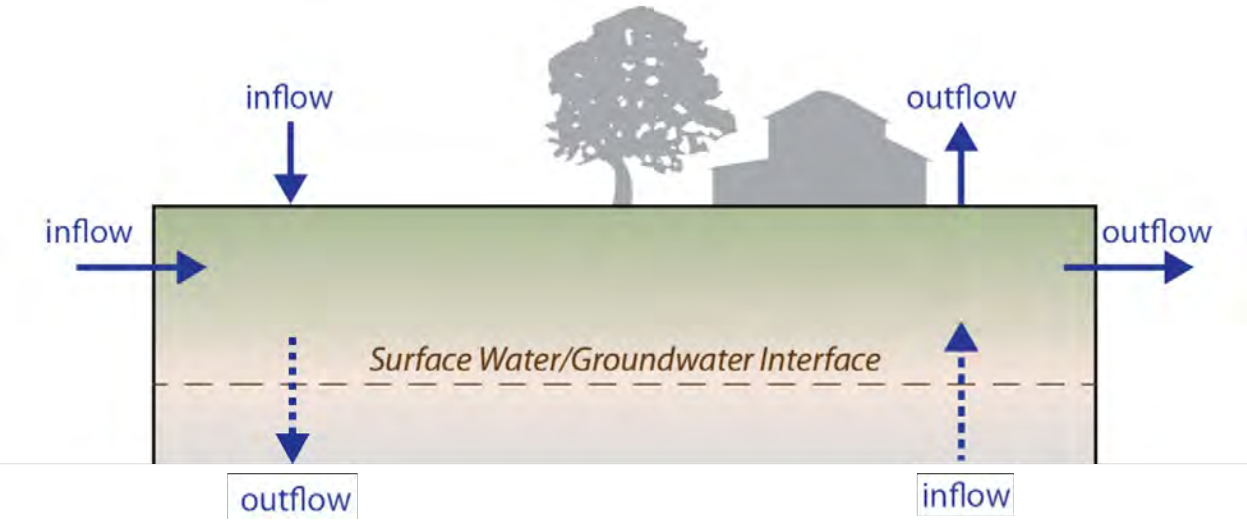


Figure 4-1. Conceptual Water Budget as Simulated in the IDC Model, Quantifying Inflows and Outflows of Water Through the Landscape (DWR 2016)

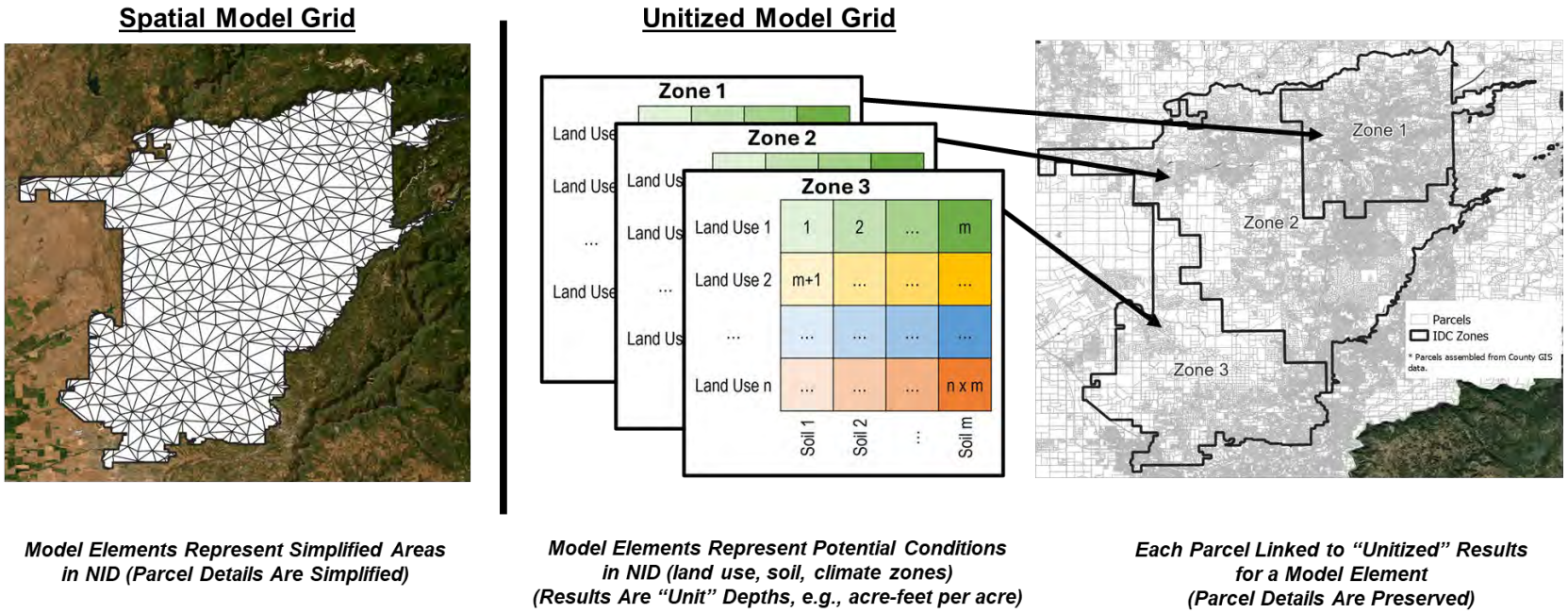


Figure 4-2. Overview of Structural Differences Between a Spatial IDC Model and a Unitized IDC Model

In total, 11 land use categories, 5 soil textures, and 3 climate zones were simulated in the IDC model used in the NID PFW process (Table 4-2). Altogether, these represent 165 unique combinations of land use, soil, and climate zones simulated within the NID service area. The land use categories and soil textures were developed through analyses described in Section 4.2.3.2. The representative climate zones were developed by assessing elevation profiles, precipitation, and reference evapotranspiration (ETo) within the NID service area (Section 4.2.3.1) to identify regions with similar climate characteristics.

Table 4-2. Combinations of Land Use Categories, Soil Textures, and Climate Zones Simulated in the IDC Model

Climate Zone	Soil Texture	Land Use Categories[1]
Zone 1 (Higher Elevation)	Clay Loam	Citrus and Subtropical
		Miscellaneous Deciduous
		Miscellaneous Truck and Nursery
		Pasture
		Vineyard
		Young Perennial
		Idle
		Native Vegetation
		Riparian Vegetation
		Water
		Urban and Residential
	Loam	*[All Land Use Categories Repeated]*
	Sandy Loam	*[All Land Use Categories Repeated]*
	Silt Loam	*[All Land Use Categories Repeated]*
	Sandy Clay Loam	*[All Land Use Categories Repeated]*
Zone 2 (Middle Elevation)	Clay Loam	*[All Land Use Categories Repeated]*
	Loam	*[All Land Use Categories Repeated]*
	Sandy Loam	*[All Land Use Categories Repeated]*
	Silt Loam	*[All Land Use Categories Repeated]*
	Sandy Clay Loam	*[All Land Use Categories Repeated]*
Zone 3 (Lower Elevation)	Clay Loam	*[All Land Use Categories Repeated]*
	Loam	*[All Land Use Categories Repeated]*
	Sandy Loam	*[All Land Use Categories Repeated]*
	Silt Loam	*[All Land Use Categories Repeated]*
	Sandy Clay Loam	*[All Land Use Categories Repeated]*

[1]Additional information about the land use categories is provided in Section 4.2.3.2.

In the NID PFW process, the IDC model was developed, refined, and operated to simulate NID customers' demand under different scenarios, in particular:

- Current demand scenario: developed to simulate recent historical demand in 2013–2021, for the purpose of serving as a baseline for comparison and interpretation of the projected demand scenarios.
- Projected demand scenarios: developed to simulate multiple baseline or bookend (low or high) scenarios in 2022–2071 under alternate future conditions with regard to climate, land use, agricultural and irrigation practices, population, and NID system operations.

This section summarizes the general data sources and inputs used to develop the IDC model.

The IDC model was developed using data sources and information that capture the unique, local conditions within the NID service area to the extent available. More details on the assumptions and results of the demand model scenarios—including the projected demand scenario assumptions and rationale—are described in Section 4.3.

4.2.3.1 Climate-Related Inputs

Climate-related inputs to the IDC model included ET and precipitation. Data sources used to develop these inputs are described below.

4.2.3.1.1. Evapotranspiration (ET)

ET, or consumptive water use, is the major driver of agricultural water use. Unlike recoverable water uses, such as surface runoff or infiltration of water into the groundwater system (whether through seepage, deep percolation, recharge, or other means), ET is water that cannot be recovered or directly reused in the NID service area. ET is impacted by: the types of crops or vegetation that are grown (reflecting the inherent differences in water needs of different crops and vegetation); the quality of crops, vegetation, or land use, including water availability, nutrient and pest management, and other factors; and environmental demand for evaporation related to weather and climate parameters, as a function of temperature, solar radiation, wind speed, and humidity. Each of these factors are accounted for in the methods used to quantify ET.

In the IDC model, ET time series information was quantified for different land uses and different climate zones in NID for each of the demand model scenarios using the best available local information and standard technical approaches (ASCE-EWRI 2016).

In the current demand scenario, ET was quantified based on an evaluation of satellite-based remote sensing analyses available from OpenET (described below):

- The ensemble mean ET from OpenET was used to quantify spatial ET on a monthly timestep from 2016 to 2022 for all areas within NID (with a spatial resolution of 30 m by 30 m, or approximately 0.22 acre/pixel).
- Spatial ET results were linked to land uses in NID based on parcel-level land use data (described in Section 4.2.3.2).
- Representative average ET curves (i.e., ET rates over time) were quantified from the spatial ET results for different land uses in the different climate zones within NID, generating monthly ET curves representing hundreds of parcels in NID over the period from 2016–2022. These monthly

ET curves were used to quantify ET for the corresponding land uses within the corresponding climate zones. Before the availability of OpenET data, ET was estimated for each land use based on the monthly ET curves for the same land use and climate zone in a hydrologically similar WY.

In the projected demand scenarios, ET was quantified following the standard crop coefficient approach described in the United Nations Food and Agriculture Organization (FAO) Irrigation and Drainage Paper 56 (Allen et al. 1998). In the crop coefficient approach, ET is calculated by multiplying a reference evapotranspiration (ETo) value by a crop coefficient (Kc) such that: ET = Kc × ETo. Reference evapotranspiration, crop coefficients, and the calculation of ET by this method are described below. Adjustments were made to these parameters, as appropriate, to reflect changes in climate and water needs for particular land uses over time following the assumptions of the projected demand scenarios (described in Section 4.3).

Data sources used to calculate ET, or the parameters comprising ET, are summarized in Table 4-3 and in the sections below.

Table 4-3. Evapotranspiration Data Sources

Parameter	Demand Scenario	Source	Description
ET	Current	OpenET	OpenET data used to generate representative average ET curves for different land uses in the different climate zones in NID
ET	Projected	Calculated	Based on ET = ETo x Kc
ETo	Projected	Calculated based on CMIP-6 results (hydrology scenarios)	Values calculated for the different climate zones in NID based on CMIP-6 results used in the hydrology scenarios (Chapter 3)
Kc	Projected	Calculated	Kc values estimated based on the ratio of recent historical ET (from OpenET) to recent historical ETo (from Spatial CIMIS) for different land uses in the different climate zones in NID

OpenET Data

OpenET is a multi-agency web-based geospatial utility that quantifies ET over time with a spatial resolution of 30 m x 30 m (approximately 0.22 acre). OpenET information is available in raster coverages of the NID service area on both a daily and monthly timestep from 2016 through present. While OpenET is a new utility, the underlying methodologies to quantify ET apply a variety of well-established modeling approaches that are widely used in local, state, and Federal Government and research applications. Additional information about the OpenET team, data sources, and methodologies is available at: https://openetdata.org/. For the NID demand model, OpenET data were used to observe recent historical ET trends and evaluate representative ET rates for land uses in NID (e.g., average ET and percentiles across tens to thousands of pixels in NID) (Figure 4-3). Importantly, OpenET data were not used to directly assign an ET value representing any single point within NID in the demand model.

The OpenET data in Figure 4-3 shows areas with generally higher ET in the upper elevation regions of the NID service area (e.g., climate zone 1) and areas with generally lower ET in the lower elevation regions of NID (e.g., climate zone 3). These differences are mainly attributed to water availability within the landscape and land use within NID. While NID supplies raw water for irrigation to approximately 30,000 acres, most land within the boundaries of NID is "native vegetation" (undeveloped natural vegetation, such as forest, meadows, and non-irrigated open spaces) that relies on precipitation, shallow groundwater, and other water supplies in the landscape. Greater water availability in the higher elevation regions of NID supports generally higher ET for native vegetation in those areas, while generally lower ET occurs in lower elevation regions where less water is available in the landscape. Open water surfaces, such as reservoirs, also show higher ET rates indicating evaporation that occurred.

For the current demand scenario, an analysis of OpenET data spatially across the land uses in NID was used to generate representative average ET curves (i.e., ET rates over time) for land uses in the different climate zones within NID (Figure 4-4). The ET curves from this analysis were compared to representative ET curves reported from other sources—including DWR's Cal-SIMETAW (DWR 2022b) and the Irrigation Training and Research Center (ITRC) at California Polytechnic State University, San Luis Obispo (ITRC 2023)—to verify their general consistency with the ET trends for each crop reported in technical literature. In contrast with OpenET, many ET approaches do not account for crop stress, which is caused by a variety of factors, and if present, will reduce ET; thus, many ET approaches overestimate ET. One benefit of the approach used for quantifying ET in the demand model is that the variability of ET is evaluated within NID for each crop group, allowing for identification and use of a representative ET curve that captures local conditions and agronomic practices. The ET curves from other sources (e.g., Cal-SIMETAW, ITRC) tended to be higher than the OpenET results, especially in the mid to late summer period when evaporative demand is highest and when crop stress, if present, will be most noticeable. Differences observed between other sources and OpenET are influenced by these factors.

For the projected demand scenarios, OpenET ET data were used together with ETo information to calculate Kc curves that represent the unique, local water use characteristics of land uses within NID. This was intended to provide a more accurate understanding of local water demands directly in NID, rather than relying on Kc values from technical literature that were developed in other areas of California or the United States. The evaluation of ET data and development of Kc curves are discussed further in Appendix B.2.

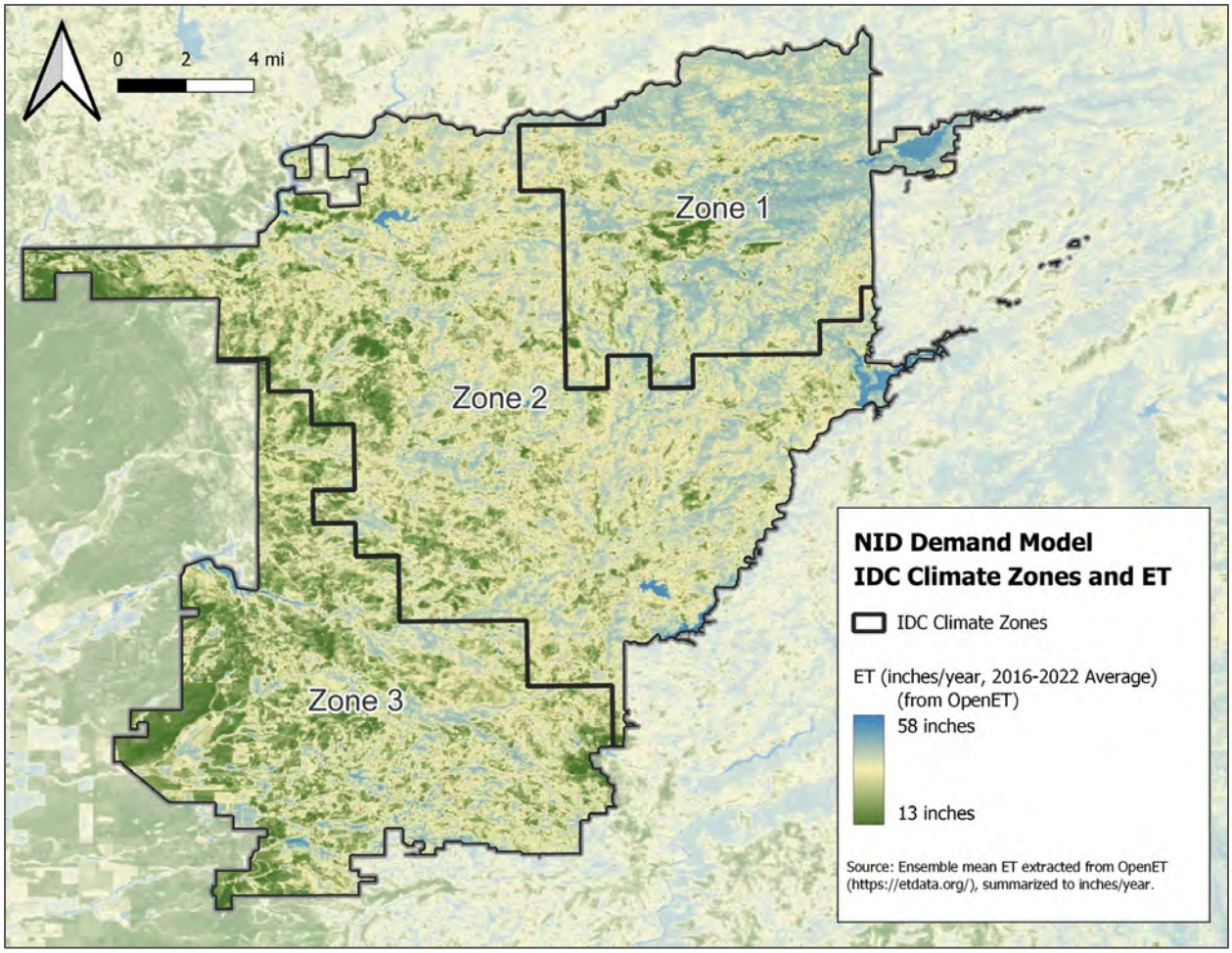


Figure 4-3. Average ET (2016–2022) from OpenET and Climate Zones

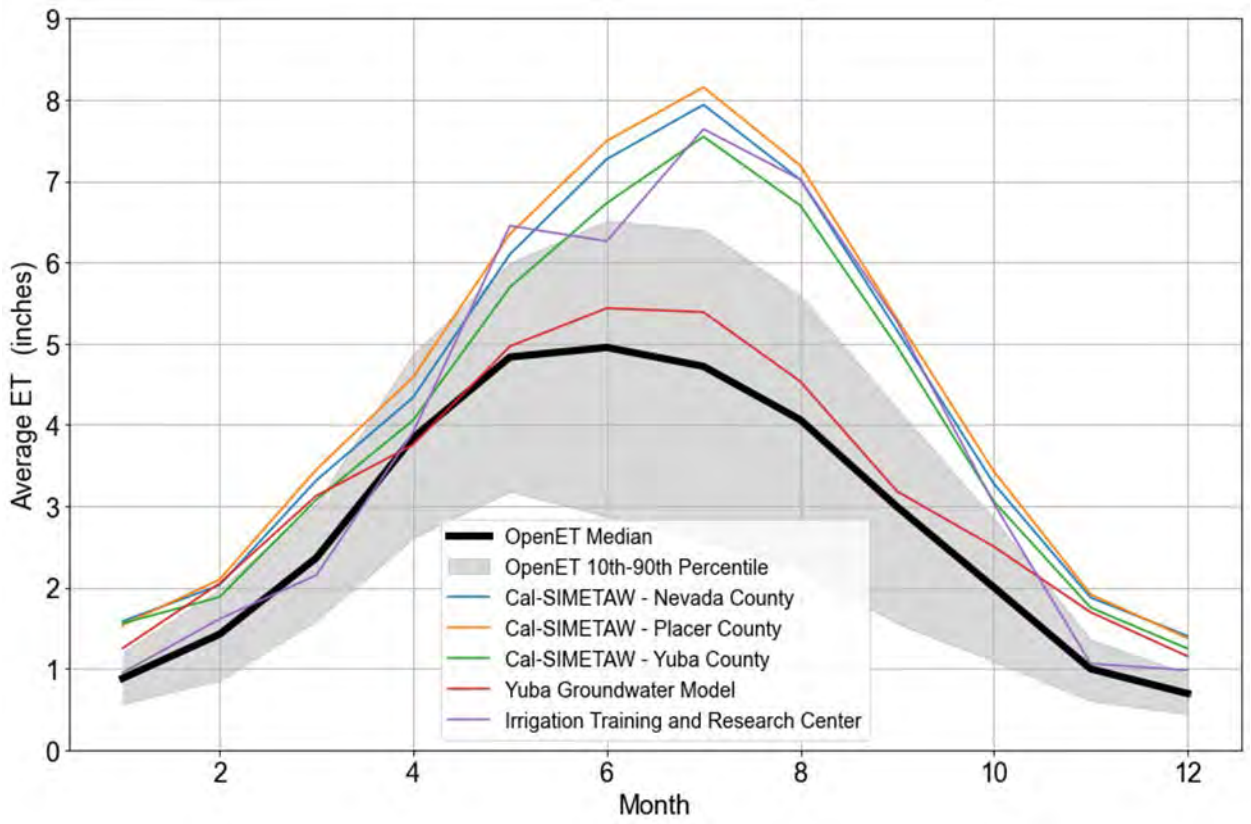


Figure 4-4. Sample ET Curve Summarized for all Parcels Categorized as Pasture in Climate Zone 3 (2021), with Comparisons to Other Representative ET Estimates for Pasture from Cal-SIMETAW (DWR 2022b), the Yuba Groundwater Model (YWA, 2019), and the Irrigation Training and Research Center ET Data for Water Budget Applications (ITRC 2023)

Reference Evapotranspiration (ETo)

Reference evapotranspiration represents the evapotranspiration rate from a reference surface. Throughout California, the standard reference surface used by the CIMIS is a well-watered, full-cover grass surface, commonly referred to as ETo (CIMIS 2023). ETo provides information about climatic parameters that affect ET and essentially quantifies the evaporative demand of the environment. Recent historical ETo estimates are available directly from CIMIS. Projected ETo can be calculated from projected climate parameters or can be scaled to reflect changes in climate parameters.

In the current demand scenario, ET was quantified primarily based on OpenET information (2016–2022), so ETo was not directly necessary for quantifying ET in those years. However, recent historical ETo was quantified to generate local Kc curves for different land uses in different climate zones of the NID service area that were then used to estimate ET in earlier years and projected ET in the future following the standard crop coefficient approach (Allen et al. 1998). The approach used to generate local Kc values is described below. Recent historical ETo used to generate local Kc values was summarized from spatial CIMIS data (Figure 4-5 and Figure 4-6). Spatial CIMIS data extracted for the NID service areas was calculated based on available quality controlled CIMIS station data and interpolation between stations with

reference to topography and other factors that impact climate conditions. Additional information about the spatial CIMIS data sources and methodologies is available at: https://cimis.water.ca.gov/SpatialData.aspx.

In the projected demand scenarios, ETo was quantified following the standard Hargreaves-Samani approach (Hargreaves and Samani 1985, Allen et al. 1998). In contrast with other more complex methodologies for quantifying ETo, the Hargreaves-Samani approach simplifies the estimation of ETo based on data and assumptions pertaining to air temperature and extraterrestrial radiation. Average daily ETo for each climate zone within the NID service area was quantified based on spatial projected temperature information derived from the CMIP-6 analyses used in the hydrology scenarios, as described in Chapter 3 and assumptions regarding extraterrestrial radiation based on the geographic location of the NID service area and the day of the year. In this way, projected ETo was calculated and scaled to reflect changes in climate parameters over time and under different projected demand scenarios that will impact ET.

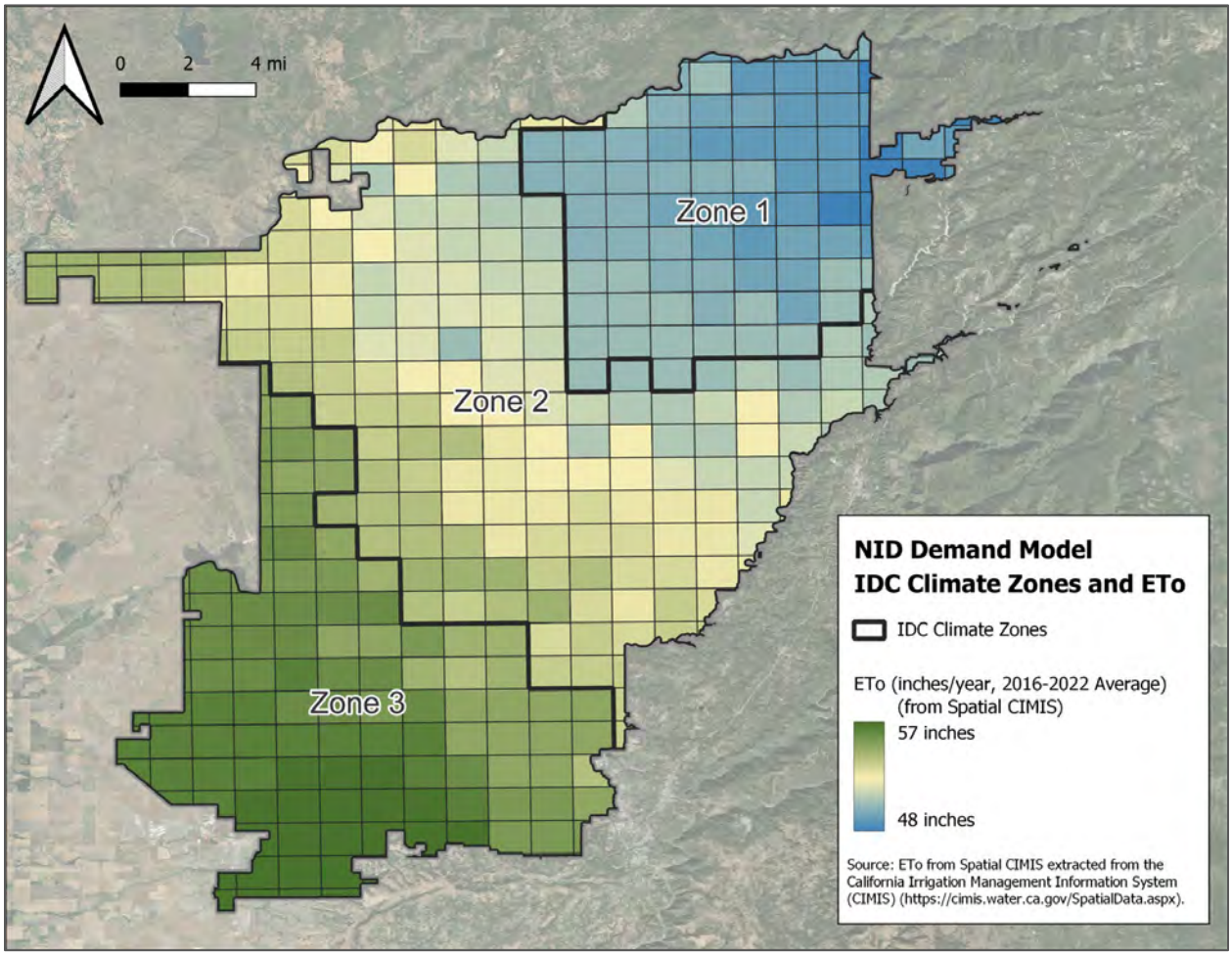


Figure 4-5. Average ETo (2016–2022) from Spatial CIMIS and Climate Zones

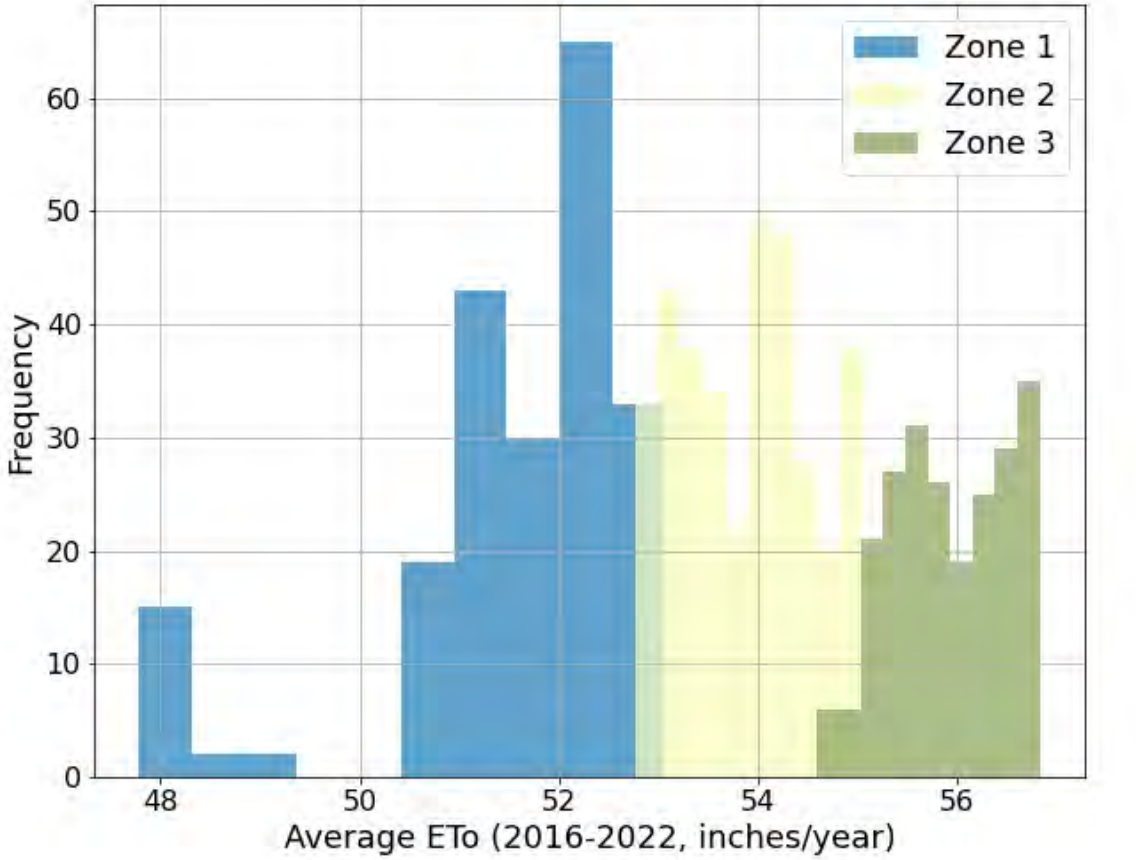


Figure 4-6. Distribution of ETo (2016–2022) from Spatial CIMIS Across the Climate Zones, Where Frequency Represents the Number of Pixels Within Each Zone

Crop Coefficients (Kc)

Kc is calculated based on the ratio of ET to ETo and represents the unique crop characteristics that distinguish a particular land use's water use needs from that of a reference grass surface. Different land uses and crops have different Kc values and curves, depending on their water use needs. In use, Kc is a scaling factor that adjusts the climate-related factors that affect ET (captured in ETo) to reflect the crop-related factors that affect ET as a land use or crop grows and matures.

Local Kc values were developed for land uses in the NID service area over the period from 2016–2022 based on the ratio of:

- ET values from OpenET, which were used to observe trends in consumptive water use and evaluate representative ET rates for specific land uses in NID.
- ETo values from spatial CIMIS, which were used to observe trends in climate and weather conditions that impact ET over the same time period.

Local Kc values were calculated through a geospatial analysis of ET (OpenET data at a 30 m x 30 m resolution) and ETo (spatial CIMIS data averaged over each of the three climate zones in NID, and then downscaled to the ET resolution) over time. From these two data sources, Kc values were calculated on a monthly timestep at a 30 m x 30 m resolution over the full spatial extent of the NID service area and were mapped to specific land uses in NID based on spatial land use information (described below). The end result was a distribution of monthly Kc curves from 2016–2022 that represent the water use needs of particular land uses in particular climate zones within NID calculated across tens to thousands of parcels in NID. Development of the Kc curves is discussed further in Appendix B.2. Evaluation of this range of Kc curves allowed simulation of a range of crop water use conditions across NID. The projected demand scenarios considered the 25th percentile, median, and 75th percentile Kc distribution (described in Section 4.3).

4.2.3.1.2. Precipitation

Precipitation is an important source of water on the landscape that is used to support ET and that results in runoff, percolation, and changes in soil moisture. For the IDC model, precipitation time series information was quantified for the different climate zones in NID for each of the demand model scenarios using the best available information (Table 4-4).

For the current demand scenario, spatial precipitation estimates were extracted from the PRISM developed by the PRISM Climate Group at Oregon State University (Figure 4-7). PRISM quantifies spatial precipitation estimates, among other climate parameters, based on available weather station data and modeled spatial relationships with topography and other factors influencing weather and climate. Additional information about the PRISM data and methodologies is available at: https://prism.oregonstate.edu. Monthly precipitation rasters were evaluated at a spatial resolution of 4 km x 4 km for the demand model.

For the projected demand scenarios, spatial projected precipitation estimates for each climate zone in the NID service area were summarized from the CMIP-6 analyses used in the hydrology scenarios, as described in Chapter 3. In each case, precipitation data were summarized into representative, average precipitation curves (i.e., precipitation rates over time) for the different climate zones within NID.

Table 4-4. Precipitation Data Sources

Scenario	Source	Description
Current	PRISM	PRISM data used to generate representative average precipitation curves for the different climate zones in NID.
Projected	CMIP-6 results (hydrology scenarios)	Values summarized for the different climate zones in NID based on CMIP-6 results used in the hydrology scenarios (Chapter 3)

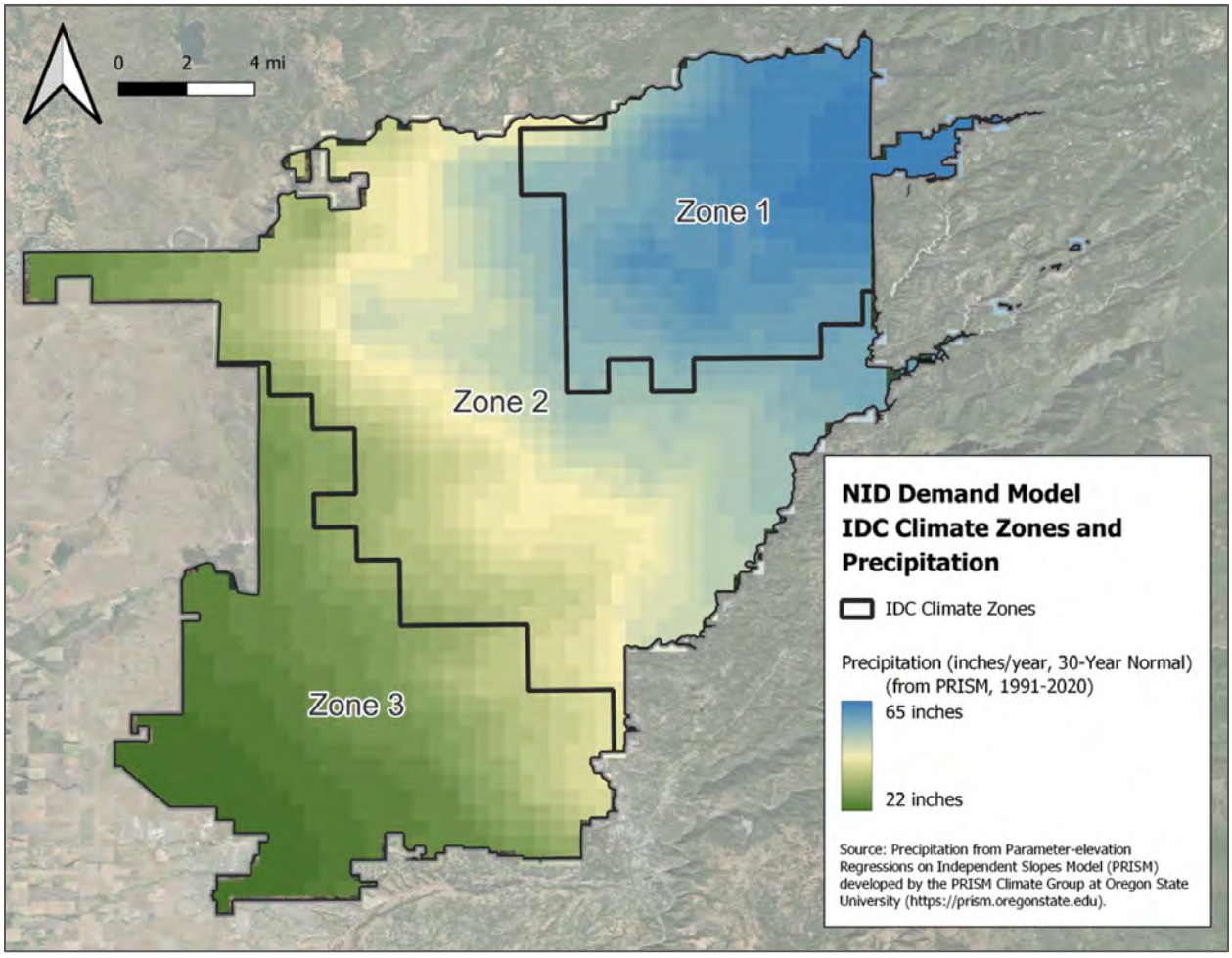


Figure 4-7. Average Precipitation from PRISM (30-Year Normal, 1991–2020) and IDC Climate Zones

4.2.3.2 Land Use and Soil-Related Inputs

Land use and soil-related inputs to the IDC model included parcel-level land use information, runoff characteristics, as well as soil textures and related parameters that influence soil moisture storage. Data sources used to develop these inputs are described below.

4.2.3.2.1. Land Use

Parcel-level land use data across the NID service area were identified using the most recent and reliable geospatial land use data for California, as well as available local information from Nevada, Placer, and Yuba Counties and their General Plans regarding zoning and anticipated land use changes over time. Land use and land cover (simplified to land use in this discussion) refers to both the vegetation and development of the landscape, ranging from developed urban or rural residential areas, to agricultural land, to undeveloped natural vegetation (referred to as native vegetation in the IDC model).

For the current demand scenario, spatial land use information was summarized through a land use analysis process based on:

1. Statewide land use mapping, available from the California DWR (DWR 2023).

2. CropScape Cropland Data Layer coverage, available from the USDA (USDA 2023).

To generate a complete land use map of the NID service area, land use data from these sources were compiled into 30 m x 30 m raster coverages of the NID service area for 2016–2022, according to the following order of preference:

- The statewide land use mapping from DWR was preferentially used to identify agricultural land (including irrigated and non-irrigated lands) and urban areas. These data include extensive ground-truthing and analytical review of results statewide and are considered the most accurate spatial land use data source available within the NID service area in recent years.
- The CropScape Cropland Data Layer coverage from the USDA was subsequently used to back-fill gaps of non-irrigated, idled, and non-developed (i.e., native vegetation) areas within the NID service area that were not captured in the DWR data.

The unique land uses within NID that were identified from these sources were then summarized and aggregated into predominant land use categories for simulation in the IDC model (Table 4-5 and Figure 4-8).

After generating a complete land use map of the NID service area, land use data were then linked to parcels within NID using parcel delineations gathered from Nevada, Placer, and Yuba County and parcel identification numbers from NID's customer and delivery records (described further in Section 4.2.3.5). This linkage allowed identification of the predominant land use that existed within each parcel in each year, and the fraction of the parcel area that was represented by that land use (based on an analysis of the 30 m x 30 m raster coverage within the parcel boundaries). Ultimately, the demand model was developed to estimate raw and treated water demand at the parcel level based on the developed area of each parcel—that is, the area of the parcel in which agricultural, urban, or residential water use occurs, excluding non-developed land (i.e., non-irrigated native vegetation, etc.). Thus, at this stage, the relative fraction of each parcel that was developed was also determined from the land use data based on the relative proportion of developed areas within that parcel. Results of this land use analysis process were then compared with NID crop report information to verify the general acreages and relative proportions of crops grown in NID. Additional discussion of the land use analysis process is available in Appendix B.3.

For the projected demand scenarios, the current demand scenario land use from 2022 was used as a baseline for land use changes over time, layering in information from the counties and their General Plans regarding parcel zoning, land use mapping, and areas where development may occur, as well as information from NID identifying NID's potential growth areas ("soft service areas"). This information was used to modify land use to reflect growth or contraction of customers in the NID service area over time following the assumptions of the projected demand scenarios (described in Section 4.3).

Table 4-5. Land Uses Simulated in the IDC Model

Land Use Sector	Land Use Category	Description
Agricultural	Citrus and Subtropical	Irrigated citrus and subtropical crops (e.g., citrus trees)
	Miscellaneous Deciduous	Irrigated orchard crops (e.g., fruit and nut orchard crops)
	Miscellaneous Truck and Nursery	Other miscellaneous irrigated truck and nursery crops (e.g., berries, tomatoes, cucurbits)
	Pasture	Irrigated pasture, turf, and alfalfa
	Vineyard	Irrigated vineyards and grapes
	Young Perennial	Irrigated young perennial crops (prior to maturation)
	Idle	Non-irrigated, non-cropped agricultural land
Urban	Urban and Residential	Land uses include urban and residential areas
Native and Riparian Vegetation	Native Vegetation	Undeveloped natural vegetation is referred to and simulated as native vegetation in the IDC model. While native vegetation is included in land use analyses and is simulated in the IDC model, demand from native vegetation is not included in the demand results.
	Riparian Vegetation	Undeveloped natural riparian vegetation is referred to and simulated as riparian vegetation in the IDC model. While riparian vegetation is included in land use analyses and is simulated in the IDC model, demand from riparian vegetation is not included in the demand results.
	Water	Reservoirs, ponds, waterways, and other water surfaces are simulated as water in the IDC model. While water is included in land use analyses and is simulated in the IDC model, demand from water is not included in the IDC results but would be included in the system losses.

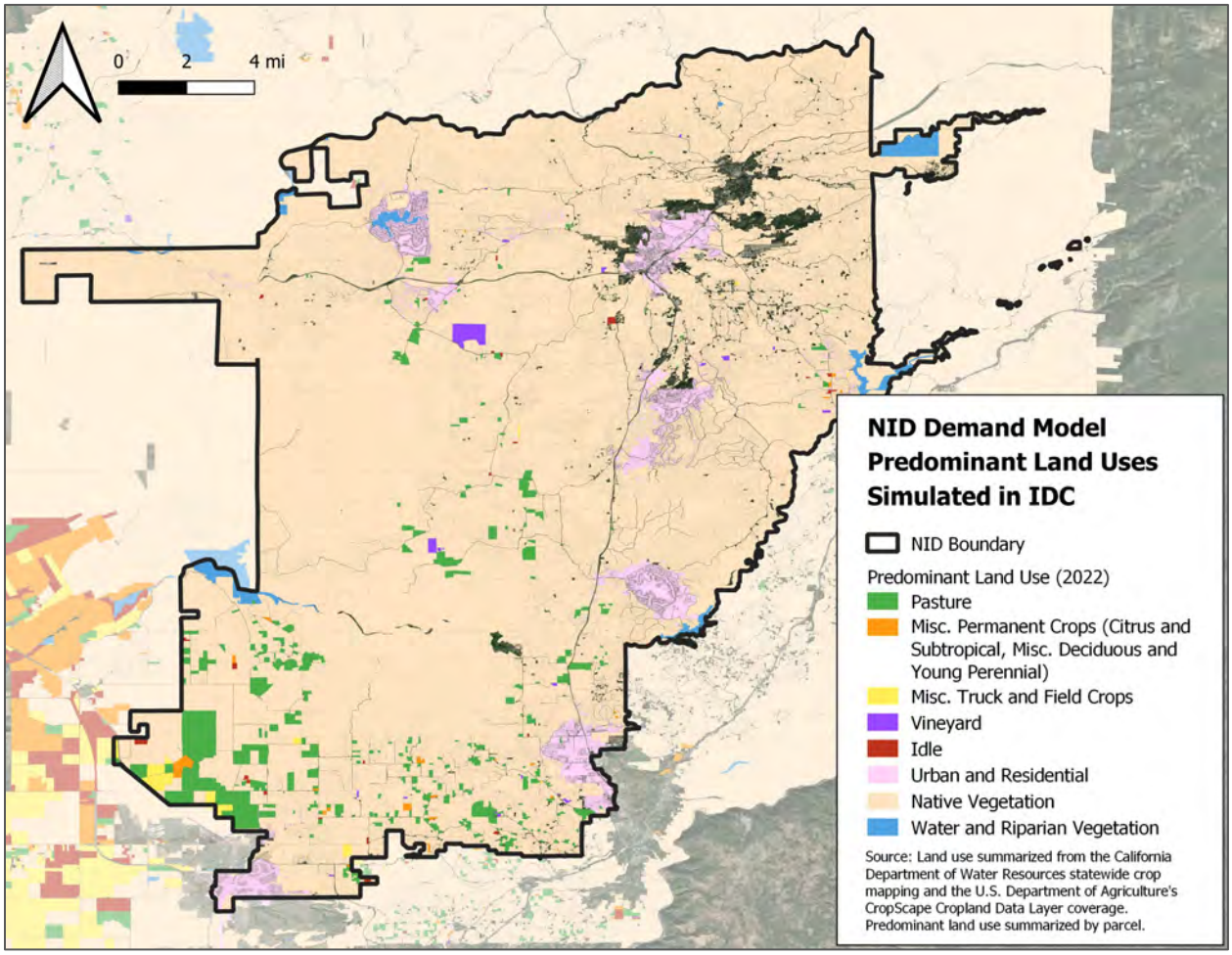


Figure 4-8. Land Uses Simulated in the IDC model, Summarized by Parcel (2022)

4.2.3.2.2. Soil Textures and Parameters

Soil textural classes and associated soil hydraulic parameters used in the IDC model were estimated from a compilation of the Soil Survey Geographic (SSURGO) and State Soil Geographic (STATSGO) datasets available from the California Soil Resource Lab at the University of California, Davis, and University of California – Agriculture and Natural Resources (UC-ANR) (Walkinshaw et al. 2022). The SSURGO and STATSGO datasets contain geospatial soil information collected by the National Cooperative Soil Survey (NCSS) regarding soil textures and soil properties in the United States. The USDA-NRCS organizes the NCSS and publishes soil surveys. The IDC model includes five soil textures representing the predominant soil texture classes found within the NID service area (Table 4-6 and Figure 4-9).

The following five soil parameters were provided as inputs to the IDC model and are summarized for each soil texture class in Table 4-6:

1. Permanent Wilting Point, dimensionless (ratio of volume/volume)
2. Field Capacity, dimensionless (ratio of volume/volume)
3. Total Porosity, dimensionless

4. Pore Size Distribution Index, dimensionless
5. Saturated Hydraulic Conductivity (K_{sat}), (ft/day)

An explanation of these soil parameters and their role in the IDC model is available from DWR in their IDC model documentation (DWR 2022a). Soil parameters were determined through a combination of area-weighted summaries of information in the SSURGO/STATSGO datasets, as well as a calibration process to refine the simulation of these soil parameters within the IDC model. For each soil texture class derived from SSURGO/STATSGO, initial soil parameters were estimated based on pedotransfer functions reported by Saxton and Rawls (2006) and refined to provide drainage from saturation to field capacity within a reasonable amount of time, as determined from the percentage of drainage after three days (generally exceeding 60–80%), and to predict minimal gravitational drainage once field capacity was reached.

Table 4-6. Predominant Soil Textures and Soil Parameters Simulated in the IDC Model

Soil Texture	Area (acres)	Field Capacity (-)	Wilting Point (-)	Total Porosity (-)	Pore Size Distribution Index (-)	Ksat (ft/d)
Clay Loam	100,175	0.31	0.17	0.42	0.150	1.200
Loam	107,757	0.28	0.15	0.40	0.173	1.625
Sandy Loam	45,051	0.19	0.09	0.38	0.322	8.350
Silt Loam	38,941	0.28	0.13	0.40	0.210	0.660
Sandy Clay Loam	11,833	0.24	0.14	0.39	0.195	5.800

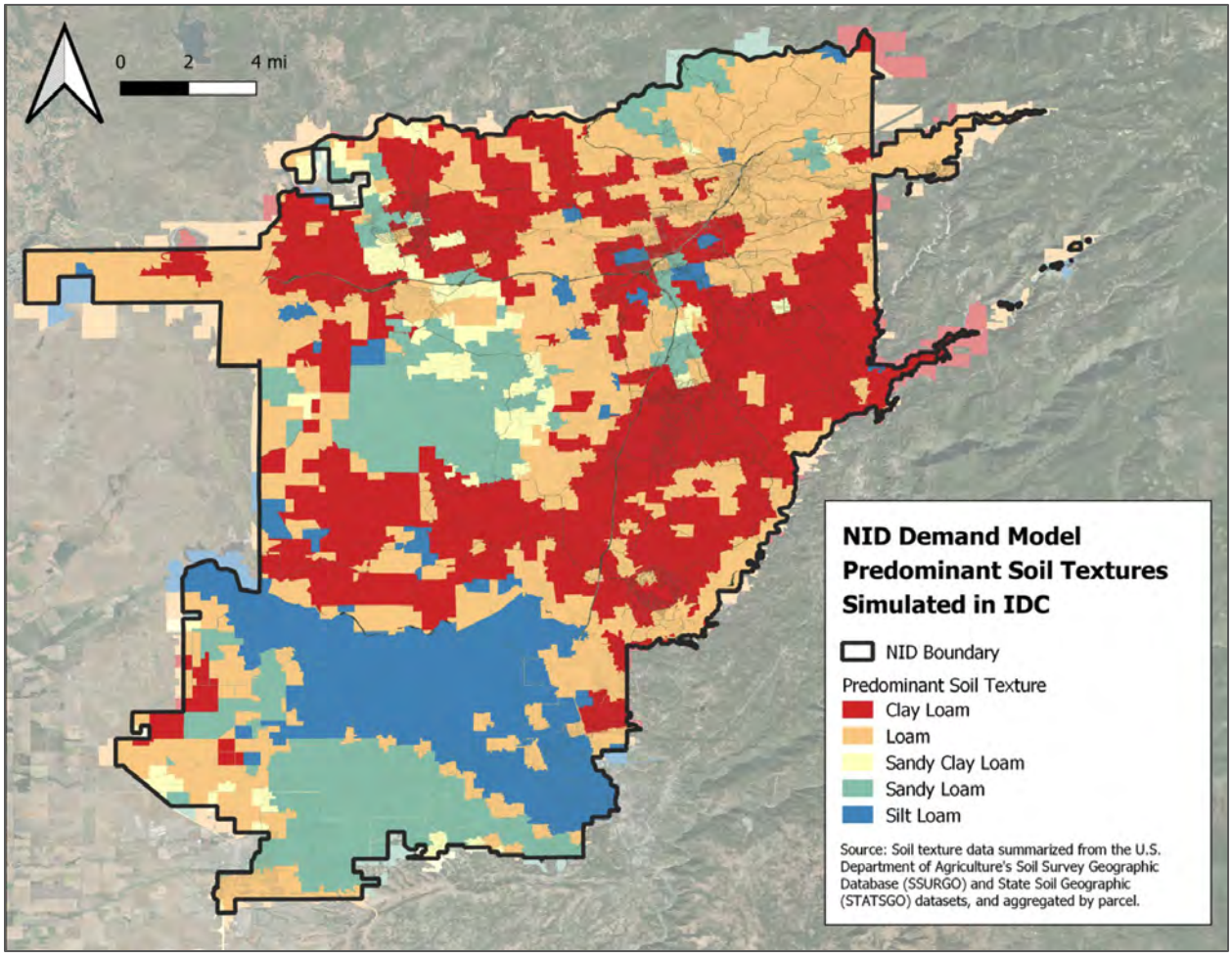


Figure 4-9. Predominant Soil Textures Simulated in the IDC Model

4.2.3.2.3. Runoff Curve Numbers

The IDC model uses a modified version of the SCS curve number (SCS-CN) method to compute runoff of precipitation, which uses curve numbers for each land use class and soil texture to simulate runoff. Curve numbers are used as described in the National Engineering Handbook Part 630 (USDA 2004, 2007) based on the land use or cover type, typical or representative treatment (straight rows, bare soil, etc.), hydrologic condition, and hydrologic soil group. An area-weighted average curve number for each land use-soil texture combination was calculated based on curve number values for each land use (SCS 1986) over the area in each hydrologic soil group, assuming generally good hydrologic conditions (Table 4-7).

Table 4-7. Curve Number Used to Represent Runoff Conditions in the IDC Model

Land Use Category	Soil Texture (Hydrologic Soil Group[1])				
	Clay Loam (D)	Loam (B)	Sandy Loam (A)	Silt Loam (B)	Sandy Clay Loam (C)
Citrus and Subtropical	82	65	44	65	77
Miscellaneous Deciduous	82	65	44	65	77
Miscellaneous Truck and Nursery	89	78	67	78	85
Pasture	78	58	30	58	71
Vineyard	82	65	44	65	77
Young Perennial	82	65	44	65	77
Idle	93	85	76	85	90
Urban and Residential	60	60	60	60	60
Native Vegetation	79	60	36	60	73
Riparian Vegetation	77	56	35	56	70
Water	100	100	100	100	100

[1]Hydrologic soil groups and curve numbers summarized from Appendix B.1 of the SCS Report "Urban Hydrology for Small Watersheds" (TR-55) (SCS 1986).

4.2.3.3 Agriculture and Irrigation Water Use Inputs

Other inputs to the IDC model pertaining to agricultural water use, irrigation, and operational practices are described below.

4.2.3.3.1. Root Depth

Root depths simulated in the IDC model for each of the agricultural land use categories were estimated primarily from ASCE-EWRI (2016) and Keller and Bliesner (1990) (Table 4-8).

Table 4-8. Root Depths Simulated in the IDC Model by Agricultural Land Use Category

Agricultural Land Use Category	Root Depth (ft)
Citrus and Subtropical	4.0
Miscellaneous Deciduous	4.0
Miscellaneous Truck and Nursery	2.5
Pasture	3.0
Vineyard	4.0
Idle	3.0

4.2.3.3.2. Irrigation Period

In the IDC model, the irrigation period determines the periods when each agricultural land use is irrigated. In the IDC model, the irrigation period was enabled, and demand was summarized between March and October for all irrigated agricultural land uses, roughly corresponding with the irrigation season in NID. For

idle land uses (and other non-irrigated, non-agricultural land uses), the irrigation period was disabled in all months.

4.2.3.3.3. Tailwater

In the IDC model, tailwater is simulated as a fraction of the total applied irrigation water that results in runoff. In the IDC model, tailwater for all irrigated agricultural land uses was estimated to be approximately 5% of applied water on average, recognizing that a small amount of runoff typically occurs even with high-efficiency irrigation methods. Apart from tailwater, the IDC model assumed that all water supplied to parcels for irrigation of agricultural land uses was available or used for irrigation.

4.2.3.3.4. Soil Moisture Parameters

The minimum soil moisture value for each agricultural land use corresponds to the moisture content at the management allowable depletion (MAD) specified for that land use, which is the desired soil water deficit at the time of irrigation and can vary with growth stage (ASABE 2007). During irrigation, the minimum soil moisture is often restricted to the percent of total available moisture that a crop can withstand without suffering stress or yield loss. Water stress is estimated within the IDC model when the percentage of total available moisture exceeds 50%. Thus, values for the minimum soil moisture were set to 50% for all irrigated land uses to prevent additional stress from occurring in the simulation. However, it is important to note that the ET and Kc values, as described previously, were developed using satellite-based remote sensing analyses of actual ET occurring on the landscape. Thus, in the current demand scenario the ET estimates already included observed ET reductions that may have occurred due to water stress or other factors. In the projected demand scenarios, ET reductions due to water stress were simulated by proxy through other assumptions (described Section 4.3).

The target soil moisture fraction corresponds to the fraction of available soil moisture that irrigation provides. In the IDC model, target soil moisture fractions were estimated between approximately 0.80–1.05 for all land use classes based on common irrigation methods and scheduling practices in which irrigators typically irrigate near field capacity.

4.2.3.4 Urban and Residential Water Use Inputs

In the IDC model, urban and residential water use was simulated based on population data, per capita water use requirements, typical fractions of indoor versus outdoor water use, and parameters used to estimate outdoor water use (ET, curve numbers, etc. described above). Urban and residential water use inputs were simulated for different urban regions within NID to facilitate refinement of IDC inputs to represent population, per capita water use, and other conditions in different areas (Table 4-9). In the IDC model, these urban regions were used primarily to estimate the treated water demand of NID customers located within those regions. The data and information sources used to estimate population and treated water use are described below.

Table 4-9. Urban Regions Simulated in the IDC Model, With Average Per Capita Water Use

Urban Region	Simulated in Climate Zone(s)	Average Per Capita Water Use 2014–2021 (Gallons Per Person Per Day)
City of Grass Valley	Zone 1	150
City of Nevada City	Zone 1	150
City of Lincoln	Zone 3	130
Other Urban Areas (Rural Communities and Residential Areas, Unincorporated Areas, etc.)	Zone 1-3	150–180
Urban Soft Service Areas	Zone 1-3	150

4.2.3.4.1. Population

For the IDC model, annual population information was quantified for the different urban regions within NID for each of the demand model scenarios using the best available information. For the current demand scenario, annual population data were obtained from the California Department of Finance and from the United States Census Bureau American Community Survey for cities, census designated places, and unincorporated areas in Nevada, Placer, and Yuba Counties. Available population data were summarized for simulated urban and residential areas within the NID service area as unitized IDC inputs (i.e., average population per unit area). For the projected demand scenarios, population changes in NID's service area and customer base were evaluated based on analyses of population projections from the California Department of Finance and from Nevada, Placer, and Yuba County General Plan information (summarized in Section 4.3).

4.2.3.4.2. Treated Water Use

Monthly per capita water use and other parameters used to simulate indoor and outdoor water use were also quantified for the different urban regions within NID for each of the demand model scenarios using the best available information.

Per capita water use (as a volume per capita) is used in the IDC model to simulate the amount of treated water that is used within each urban and residential area, on average, across the population. In the current demand scenario, average monthly per capita water use rates were quantified from available historical water production data in 2014–2021 extracted from the California State Water Resources Control Board (SWRCB) and from NID water treatment plant data, with reference to population information available in the SWRCB records and population estimates quantified independently for the IDC model (above). The average daily per capita water use in each urban demand region is summarized in Table 4-9. In the projected demand scenarios, per capita water use in all years was estimated to be similar to the per capita water use in 2022 across all simulations, as changes to treated water demand were simulated through changes to population and other inputs (see Section 4.3). In all scenarios, the fraction of water used indoors versus outdoors was estimated based on the average monthly distribution of per capita water use from available data in 2014–2021, estimating that the water use in February (typically the minimum monthly use) is used primarily for indoor uses. The IDC model simulated all indoor use based on per capita water

use requirements, while outdoor use was also simulated with respect to ET demands and available precipitation, similar to irrigated land uses (described above).

4.2.3.4.3. Municipal Water Use (Raw Water)

In addition to serving raw and treated water customers, NID also supplies raw water to municipal water suppliers. NID's municipal water supplies ("municipal water use") are not directly simulated in the IDC model, which simulates direct water use on the landscape for irrigation and urban or residential use. However, municipal water use is quantified outside the IDC model using the best available information. Municipal water use is incorporated into the demand estimates in the canal system balance and is included in the overall results of the demand model.

In the current demand scenario, municipal water use was quantified directly from NID's records of raw water deliveries to municipal water customers in 2013–2022. In the projected demand scenarios, changes to municipal water use were estimated based on five-year projected changes to municipal water use (2020–2040) from NID's Urban Water Management Plan, with interpolation or extrapolation in the intervening and following years through the end of the projected period.

4.2.3.5 Parcel Linkages to IDC and the Canal System Balance

Alongside development of the IDC model, geospatial parcel information was evaluated and summarized for all parcels within the NID service area. Historical parcel maps, parcel areas, and identifying information were gathered from Nevada, Placer, and Yuba Counties. Parcel data were then linked to other geospatial data and summarized to determine the predominant characteristics of each parcel (by area), including:

- Predominant land use within the parcel, based on the land use analysis described in Section 4.2.3.2.1.
- Predominant soil texture within the parcel, based on the soil analysis described in Section 4.2.3.2.2.
- Representative climate zone, based on delineations of climate zones through an assessment of elevation profiles, precipitation (Section 4.2.3.1.2), and ETo (Section 4.2.3.1.1).

The parcel linkages to a predominant land use, soil texture, and climate zone allowed the unitized IDC model results (e.g., AF/acre) to be linked directly to parcels matching the same combination of primary characteristics, with an associated area over which those IDC results are applied (e.g., acre). The IDC-parcel linkages thus permitted spatial representation of demand volumes (AF) across the NID service area over time under the different scenarios.

Parcels were also linked to information about the NID service area and NID customer base, identifying existing NID customers and providing the ability to add or remove NID customers spatially over time in the projected demand scenarios depending on their location within the NID soft service areas and proximity to NID canals. Additionally, parcels were linked to information from the Nevada, Placer, and Yuba County General Plans related to parcel zoning, land use mapping, and planning to identify areas where development may occur over the next 50 years.

In combination, these parcel linkages allowed for:

- Quantification of demand volumes from the IDC model, and connection of those demand volumes spatially within the NID service area and canal system through the canal system balance (Section 4.2.4).
- Verification of the historical demand model results compared to historical NID delivery records (Appendix B.4).
- Simulation of future changes to NID's customers and service area at the parcel-level in the projected demand scenarios (scenarios described in Section 4.3).

4.2.4. Canal System Balance

The canal system balance component of the demand model takes the results of the IDC model that are linked to parcels in NID and connects those results to specific NID reservoirs, incorporating estimates of the canal system losses incurred in the process of delivering water from the reservoirs to NID's customers. The canal system balance thus quantifies the demand, or outflows from NID's reservoirs, which would be required to supply the water needs of NID's customers, inclusive of system losses in NID's canals and distribution system downstream of NID's reservoirs. These demand volumes are incorporated and simulated within the reservoir operations model (Chapter 5. Operations Model), along with regulatory-required environmental flows. This section briefly describes the process and assumptions of the canal system balance.

4.2.4.1 Demand Zones

Parcels and municipal water suppliers within the NID service areas were associated with specific demand zones that identify the specific NID reservoir ("demand node") from which NID's customers receive water deliveries. Through development of the demand zones, linkages were made between:

- Parcels representing raw and treated water customers served by NID, either currently or in projected demand scenarios and the canals that deliver—or would deliver—water to those parcels.
- Municipal water suppliers that receive raw water from NID and the canals that deliver water to those suppliers.
- Canals within the overarching NID canal system and the upstream NID reservoir that supplies water to those canals within the canal system.

A map of NID's service area, the delineation of demand zones, and connection of demand zones to particular NID reservoirs (i.e., demand nodes) is shown in Figure 4-10. Demands within each demand zone are aggregated to the demand node and represent the outflows from the NID reservoir supplying water to that demand zone.

4.2.4.2 System Losses

As water is released from NID's reservoirs into the canal system, some water is lost to seepage, evaporation, and other downstream outflows. In the canal system balance, system losses were estimated to be approximately 15% of the canal inflows, based on findings from NID's RWMP and associated analyses by NID of water that is released into NID canals that is not delivered to NID customers. Opportunities exist for further refinement of these system loss estimates through further data collection and

analysis. The system loss estimate is understood to include seepage (i.e., infiltration of water into the groundwater system) from the canal system, evaporation from open water surfaces, and downstream outflows not delivered to NID customers. The system loss estimate does not include losses from NID reservoirs simulated in the reservoir operations model or other upper system losses above those reservoirs. Losses from NID's reservoirs are accounted for in the reservoir operations model.

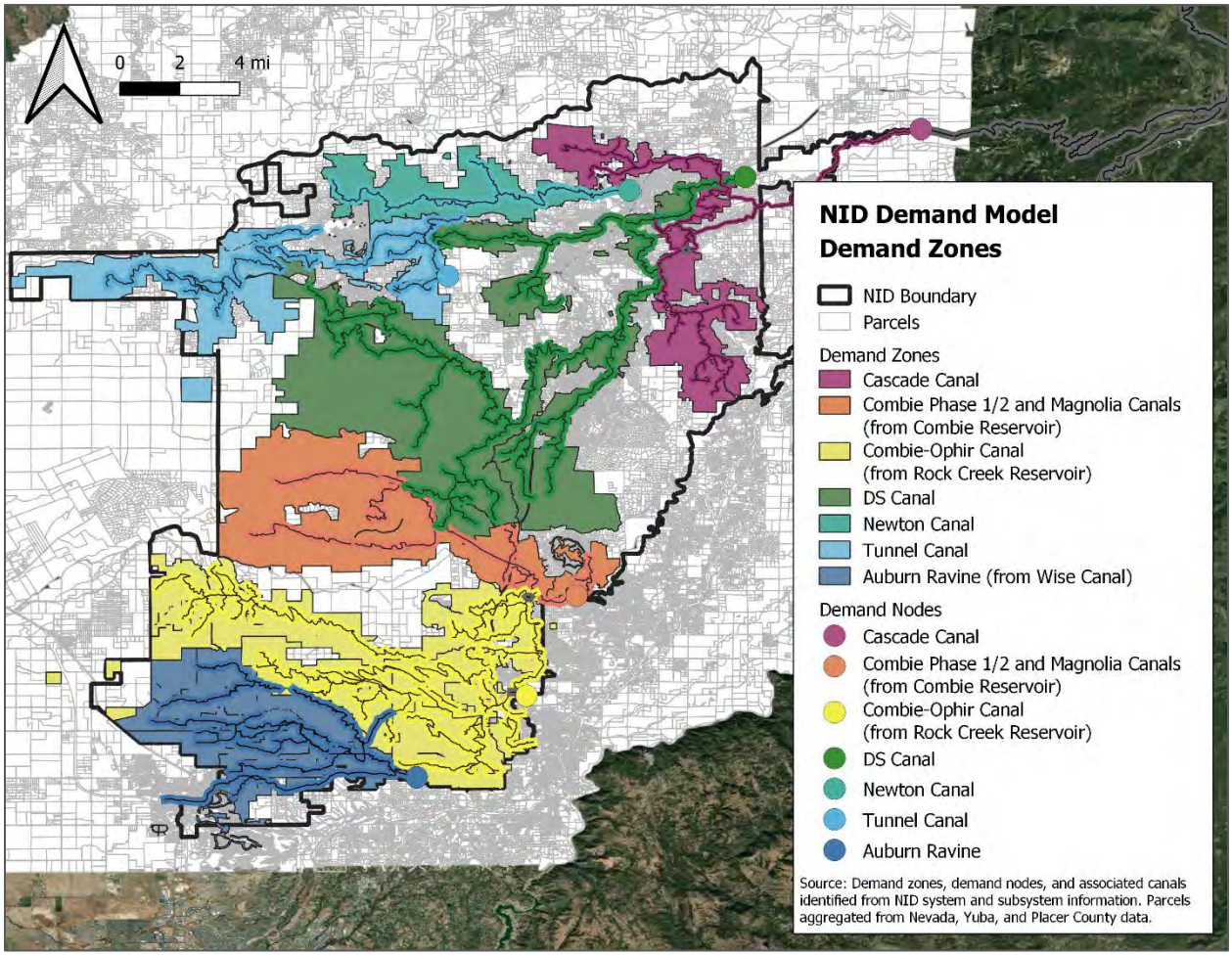


Figure 4-10. Demand Zones and Demand Nodes Simulated in the Demand Model

4.2.5. Demands from NID Reservoirs

As described previously, the demand (or outflows) from each of NID's reservoirs are summarized from the aggregated demands of NID's raw water customers, NID's treated water customers, municipal water customers, and system losses in the demand zones that are supplied from each respective NID reservoir (i.e., demand nodes).

The demand requirements at each demand node include the sum of:

- Demand results from the IDC model, representing the demand of NID's raw and treated water customers. Results are summarized for parcels within the demand zones supplied from the demand node.

- Municipal water use estimates, representing the demand of municipal water suppliers that receive raw water from NID.
- System losses, representing the loss of water from NID's canals downstream of NID's reservoirs that is not supplied to NID customers.

Regulatory-required environmental flows are not included in these demand model results but are included in the reservoir operations model.

The demand requirements from each of NID's reservoir (i.e., from each demand node) serve as an input and the primary point of connection between the reservoir operations model and the demand model. Additional information about how demands are incorporated into the reservoir operations model are described in Chapter 5. Operations Model.

4.3. Demand Model Scenarios

4.3.1. Summary of Scenarios

The demand model was developed and used to estimate demands for a total of 11 scenarios:

- One current demand scenario representing recent historical demand conditions in 2013–2021, as a baseline for comparison and interpretation of the projected demand scenarios.
- Ten projected demand scenarios, representing a range of potential future demand conditions in 2022–2071, including:
  - Nine scenarios representing the combinations of three potential demand scenarios and three potential climate scenarios.
  - One current demand constant baseline scenario, considering current demand (2022) and median hydrologic conditions for 2022–2071.

Assumptions and information used to develop the scenarios are summarized in Table 4-10.

The current demand scenario was developed using recent historical data for the NID service area based on the data sources and methodologies described in Section 4.2. The projected demand scenarios were developed based on the assumptions described in Section 4.3.2. Average results of the current and projected demand scenarios are summarized in Section 4.4.

Table 4-10. Summary of Demand Model Scenarios with Information about Underlying Assumptions and Data Sources

Demand Model Scenario			Climate-Related Conditions		Demand-Related Conditions		
Period	Demand Scenario	Hydrology Scenario (CMIP-6)	Precipitation	Evapotranspiration	Raw Water Demand	Treated Water Demand	System Losses
Current (2013–2021)	Recent historical	N/A	Recent historical data (Section 4.2.3.1)	Recent historical data (Section 4.2.3.1)	Recent historical customers and demand conditions (Sections 4.2.3 and 4.2.4)	Recent historical customers and demand conditions (Sections 4.2.3 and 4.2.4)	Historical canal losses (15%, from NID RWMP, Section 4.2.4)
Projected (2022–2071)	Low	Dry (CESM2-LENS_ssp370)	Climate change analysis (Dry hydrology scenario)	Calculated based on temperature-adjusted ETo (Dry hydrology scenario) and 25th percentile Kc curve (by land use, from 2022)	20% demand reduction from baseline	Population decline to lowest since 2000	10%
	Low	Median (CNRM-ESM2 1_ssp245)	Climate change analysis (Median hydrology scenario)	Calculated based on temperature-adjusted ETo (Median hydrology scenario) and 25th percentile Kc curve (by land use, from 2022)	20% demand reduction from baseline	Population decline to lowest since 2000	10%
	Low	Wet (EC-Earth3-Veg_ssp370)	Climate change analysis (Wet hydrology scenario)	Calculated based on temperature-adjusted ETo (Wet hydrology scenario) and 25th percentile Kc curve (by land use, from 2022)	20% demand reduction from baseline	Population decline to lowest since 2000	10%

Demand Model Scenario			Climate-Related Conditions		Demand-Related Conditions		
Period	Demand Scenario	Hydrology Scenario (CMIP-6)	Precipitation	Evapotranspiration	Raw Water Demand	Treated Water Demand	System Losses
Projected (2022–2071)	Baseline	Dry (CESM2-LENS_ssp370)	Climate change analysis (Dry hydrology scenario)	Calculated based on temperature-adjusted ETo (Dry hydrology scenario) and 50th percentile Kc curve (by land use, from 2022)	Expansion to soft service areas similar to historical rate (~20 acres/year developed land)	Expansion to soft service areas similar to historical rate (~50 customers/year)	15%
	Baseline	Median (CNRM-ESM2 1_ssp245)	Climate change analysis (Median hydrology scenario)	Calculated based on temperature-adjusted ETo (Median hydrology scenario) and 50th percentile Kc curve (by land use, from 2022)	Expansion to soft service areas similar to historical rate (~20 acres/year developed land)	Expansion to soft service areas similar to historical rate (~50 customers/year)	15%
	Baseline	Wet (EC-Earth3-Veg_ssp370)	Climate change analysis (Wet hydrology scenario)	Calculated based on temperature-adjusted ETo (Wet hydrology scenario) and 50th percentile Kc curve (by land use, from 2022)	Expansion to soft service areas similar to historical rate (~20 acres/year developed land)	Expansion to soft service areas similar to historical rate (~50 customers/year)	15%

Demand Model Scenario			Climate-Related Conditions		Demand-Related Conditions		
Period	Demand Scenario	Hydrology Scenario (CMIP-6)	Precipitation	Evapotranspiration	Raw Water Demand	Treated Water Demand	System Losses
Projected (2022–2071)	High	Dry (CESM2-LENS_ssp370)	Climate change analysis (Dry hydrology scenario)	Calculated based on temperature-adjusted ETo (Dry hydrology scenario) and 75th percentile Kc curve (by land use, from 2022)	Greater expansion to soft service areas at 150% baseline rate (~30 acres/year developed land)	Greater expansion to soft service areas at 150% baseline rate (~75 customers/year)	20%
	High	Median (CNRM-ESM2 1_ssp245)	Climate change analysis (Median hydrology scenario)	Calculated based on temperature-adjusted ETo (Median hydrology scenario) and 75th percentile Kc curve (by land use, from 2022)	Greater expansion to soft service areas at 150% baseline rate (~30 acres/year developed land)	Greater expansion to soft service areas at 150% baseline rate (~75 customers/year)	20%
	High	Wet (EC-Earth3-Veg_ssp370)	Climate change analysis (Wet hydrology scenario)	Calculated based on temperature-adjusted ETo (Wet hydrology scenario) and 75th percentile Kc curve (by land use, from 2022)	Greater expansion to soft service areas at 150% baseline rate (~30 acres/year developed land)	Greater expansion to soft service areas at 150% baseline rate (~75 customers/year)	20%
Current Demand Constant Baseline (2022–2071)	Recent historical (2022)	Median (CNRM-ESM2 1_ssp245)	Climate change analysis (Median hydrology scenario)	Calculated based on temperature-adjusted ETo (Median hydrology scenario) and 50th percentile Kc curve (by land use, from 2022)	Recent historical customers and demand conditions (2022)	Recent historical customers and demand conditions (2022)	Historical canal losses (15%, from NID RWMP, Section 4.2.4)

4.3.2. Projected Demand Scenario Assumptions

The 10 projected demand scenarios were developed using available estimates of future climate conditions from the projected hydrology scenarios, as well as assumptions about future changes to NID's raw water and treated water customer base over a range of potential system losses. The purpose of these projected demand scenarios was to develop a range of potential future demand conditions that could occur—as baseline or bookend conditions—from 2022 through 2071.

The primary data sources and assumptions used to develop the 10 projected demand scenarios are summarized in Table 4-10. Nine of the projected demand scenarios were developed as the combinations of:

- Three potential demand scenarios, corresponding to baseline or bookend (low or high) demand-related conditions with respect to raw water customer demand, treated water customer demand, and system losses.
- Three potential climate scenarios, corresponding to the climate change analyses (CMIP-6 results) used in the three projected hydrology scenarios (wet, median, and dry hydrologic conditions). The climate-related conditions were factored into estimates of precipitation and crop water use, as manifested through temperature-related impacts on ET. Precipitation and temperature information from the corresponding projected hydrology scenario were summarized for each of the IDC climate zones before their inclusion in the demand model.

Through these combinations, these nine projected demand scenarios resulted in:

- Three baseline demand scenarios, representing a baseline projection of demand conditions in 2022–2071 that follows the current trajectory and/or best information about expected projected changes to NID's customers and their demands. One scenario each accounted for wet, median, and dry hydrologic conditions.
- Three low demand scenarios, representing a lower bookend of low demand conditions in 2022–2071. These demand scenarios represented the lowest simulated projection of demand conditions, based on assumptions of potential raw water demand reductions, potential population decline, and potential reductions in system loss. One scenario each accounted for wet, median, and dry hydrologic conditions.
- Three high demand scenarios, representing an upper bookend of high demand conditions in 2022–2071. These demand scenarios represented the highest simulated projection of demand conditions, based on assumptions of potential raw water and treated water demand increases, associated with potential expansions of the NID service area, and potential increases in system loss. One scenario each accounted for wet, median, and dry hydrologic conditions.

The 10th projected demand scenario was developed to simulate a current demand constant baseline, considering current demand conditions in 2022 and median hydrologic conditions in 2022–2071. Current demand conditions were summarized from recent historical data for the NID service area based on the data sources and methodologies in Section 4.2. Median hydrologic conditions were summarized using the same data sources and methodologies used for summarizing the climate-related conditions in the other projected demand scenarios, described below.

The parameters and assumptions used to develop the projected demand scenarios are summarized below.

4.3.2.1 Climate-Related Conditions

Climate-related conditions that were considered in the projected demand scenarios include precipitation and evapotranspiration (also described in Section 4.2.3.1).

Precipitation was summarized directly from results of the climate change analyses (CMIP-6 results) used in the three projected hydrology scenarios (wet, median, and dry hydrologic conditions). Average precipitation from the corresponding projected hydrology scenario was summarized across each of the IDC climate zones and was then included in the IDC model component of the demand model. Additional information is provided in Section 4.2.3.1.2.

Evapotranspiration was calculated following the standard crop coefficient approach described in FAO Irrigation and Drainage Paper 56 (Allen et al. 1998), based on:

- Temperature-adjusted ETo, quantified following the standard Hargreaves-Samani approach using temperature information from the climate change analyses (CMIP-6 results) used in the three projected hydrology scenarios (wet, median, and dry hydrologic conditions). Average temperature from the corresponding projected hydrology scenario was summarized across each of the IDC climate zones.
- Kc curves for each land use, representing either the:
  - 25th percentile Kc curve (for the low demand scenario),
  - Median (50th percentile) Kc curve (for the baseline demand scenario), or the
  - 75th percentile Kc curve (for the high demand scenario).

Additional information is provided in Section 4.2.3.1.1 and Appendix B.2. The selection of the 25th percentile and 75th percentile Kc curve for the low and high demand scenarios was informed by comparison of ET differences from the baseline demand scenario to typical differences in ET under reasonable changes in cultivation and irrigation practices where ET is reduced (in the low bookend scenario) or ET is increased (in the high bookend scenario). Typical ranges of ET variability are +/-15% or more, depending on conditions, and are consistent with the ET variability from the baseline scenarios resulting from the 25th and 75th percentile Kc curves (Appendix B.2).

4.3.2.2 Demand-Related Conditions

Demand-related conditions considered in the projected demand scenarios include raw water demand, treated water demand, and system losses (described in Section 4.2.3.1).

Raw water demand was estimated for each of the projected demand scenarios as follows:

- For the low demand scenario: A 20% reduction in raw water demand from baseline conditions. These potential demand reductions are not explicitly tied to any specific future conditions within the NID service area but are considered to be within the range of potential changes due to agronomic practices, future impacts due to regulatory constraints, land use changes, or other constraints.

- For the baseline demand scenario: Expansion of NID's customer base into soft service areas at an average rate similar to the historical average growth of NID's raw water customers (approximately 20 acre/year of developed land). The historical average growth of NID's raw water customers was determined based on an analysis of NID delivery records from 2013–2022, in relation to the total areas (and developed areas) of parcels that received raw water deliveries from NID over time.
- For the high demand scenario: Expansion of NID's customer base into soft service areas at an average rate that is approximately 150% (1.5X) of the historical average growth of NID's raw water customers (approximately 30 acre/year of developed land). This potential growth of NID's raw water customer base was determined to be a high estimate, considering the total area of parcels potentially suitable for raw water customers within the soft service areas (based primarily on land use analyses).

Treated water demand was estimated for each of the projected demand scenarios as follows:

- For the low demand scenario: Estimated based on population decline to the lowest population identified in the NID service area since 2000, based on evaluation of available historical population data (Section 4.2.3.4.1). The potential population decline is not explicitly tied to any specific future conditions within the NID service area but is considered to be within the range of potential changes over the next 50 years.
- For the baseline demand scenario: Expansion of NID's customer base into soft service areas at an average rate similar to the historical average growth of NID's treated water customers (approximately 50 customers/year). The historical average growth of NID's treated water customers was determined based on an analysis of NID delivery records from 2013–2022.
- For the high demand scenario: Expansion of NID's customer base into soft service areas at an average rate that is approximately 150% (1.5X) of the historical average growth of NID's treated water customers (approximately 75 customers/year). This potential growth of NID's treated water customers was determined considering the parcels potentially suitable for treated water customers within the soft service areas (based primarily on land use analyses).

System losses in NID's canals and distribution system downstream of NID's reservoirs were estimated for each projected demand scenario as either:

- 10% of canal inflows (for the low demand scenario),
- 15% of canal inflows (for the baseline demand scenario), or
- 20% of canal inflows (for the high demand scenario).

The baseline demand scenario system losses were estimated as equal to historical canal losses, based on findings from NID's RWMP and associated analyses by NID of water that is released into NID canals that is not delivered to NID customers (Section 4.2.4.2). The low and high demand scenario system losses were estimated as a +/- 5% range around the baseline demand scenario system losses and are considered within the range of typical losses of canal systems in California.

4.4. Results

Average annual results of the current and projected demand scenarios are summarized in Table 4-11. Results of the projected scenarios are also shown in Figure 4-11 through Figure 4-14. The average annual demand estimates in the baseline demand scenarios were approximately 2,500 to 5,300 AF/year greater than the current demand scenario (2–3% greater), with higher demands experienced in the median and wet hydrology scenarios. In contrast, the average annual demand estimates in the low demand scenarios were approximately 39,000 to 41,000 AF/year lower (26–27% lower) than the current demand scenario, while the high demand scenarios were approximately 35,000 to 39,000 AF/year higher (23–25% higher) than the current demand scenario. Some variability was observed between the hydrology scenarios, although that was less than the differences between demand scenarios. The current demand constant baseline scenario resulted in approximately 156,000 AF/year of total demand.

Overall, the demand scenarios resulted in greater changes in total demand estimates versus the hydrology scenarios, pointing toward greater impacts between scenarios due to demand-related conditions rather than climate-related conditions. In total, average annual demand for the high and low demand scenarios ranged approximately +/- 40,000 AF/year around the current demand scenario, and with a similar range around the current demand constant baseline scenario. The wide range of potential demand conditions is reflective of the bookend nature of the high and low demand scenarios; although neither scenario is anticipated to occur with a high degree of certainty, these scenarios do provide useful bounds on the extremes that could strain NID's operations in the future. In reality, changes in demand conditions (either decreases or increases) would be expected to be less pronounced than those presented in the bookend scenarios.

Although climate-related conditions did result in some differences between scenarios—as observed in Table 4-11 and Figure 4-11 through Figure 4-14—the changes between scenarios resulted in less extreme changes. It is noted that the hydrology scenarios (dry, median, and wet) were developed and defined to be reflective of unimpaired inflows to NID's reservoirs, on average, over the projected period. The hydrology scenario naming conventions are not strictly indicative of hydrologic conditions with respect to average precipitation and temperature within the NID service area. For instance, higher average annual ETo is experienced in both the dry and wet hydrology scenarios, as compared to the median scenario, and is tied to higher temperatures in both the dry and wet scenarios. Additionally, while the wet hydrology scenario features the highest average annual precipitation of all scenarios, the timing of that precipitation occurs more during the winter months, whereas the highest precipitation during the irrigation season months occurs in the dry hydrology scenario. Nevertheless, demand estimates for all combinations of climate-related and demand-related conditions are useful for simulating potential future baseline and bookend conditions in the reservoir operations model to analyze water supply versus demand and conditions of unmet demand.

Table 4-11. Average Annual Results of the Current and Projected Demand Scenarios

Scenario			Years in Demand Model	Average Annual Demand (AF/year)	Difference from Current (AF/year)	Difference from Current (%)	Difference from Baseline Median (AF/year)	Difference from Baseline Median (%)
Period	Demand	Hydrology						
Current			2013-2021	153,000	0	0%	-4,000	-3%
Projected	Low	Dry	2022-2071	111,000	-42,000	-27%	-46,000	-29%
	Low	Median	2022-2071	113,000	-40,000	-26%	-44,000	-28%
	Low	Wet	2022-2071	113,000	-40,000	-26%	-44,000	-28%
	Baseline	Dry	2022-2071	155,000	2,000	1%	-2,000	-1%
	Baseline	Median	2022-2071	157,000	4,000	3%	0	0%
	Baseline	Wet	2022-2071	158,000	5,000	3%	1,000	1%
	High	Dry	2022-2071	188,000	35,000	23%	31,000	20%
	High	Median	2022-2071	190,000	37,000	24%	33,000	21%
	High	Wet	2022-2071	191,000	38,000	25%	34,000	22%
Current Demand Constant Baseline	Recent historical (2022)	Median	2022-2071	156,000	3,000	2%	-1,000	-1%

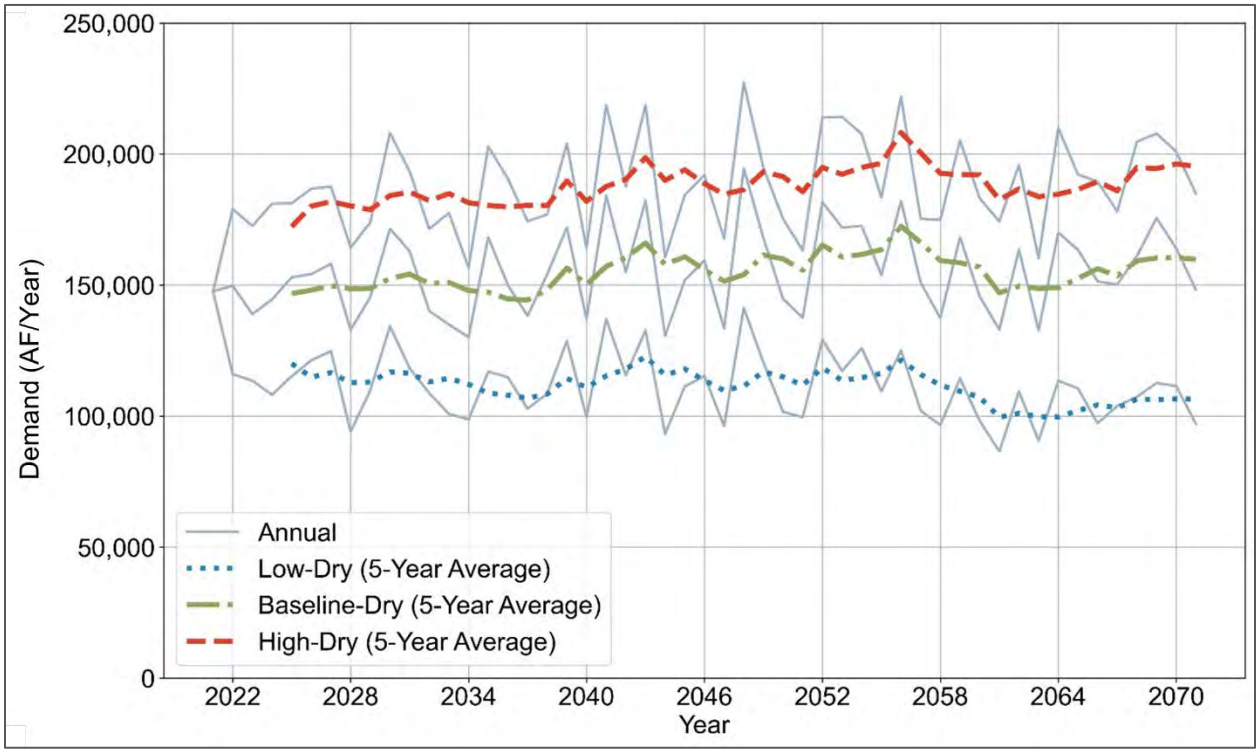


Figure 4-11. Annual Results of the Low, Baseline, and High Demand Scenarios, for Dry Hydrologic Conditions (2022–2071)

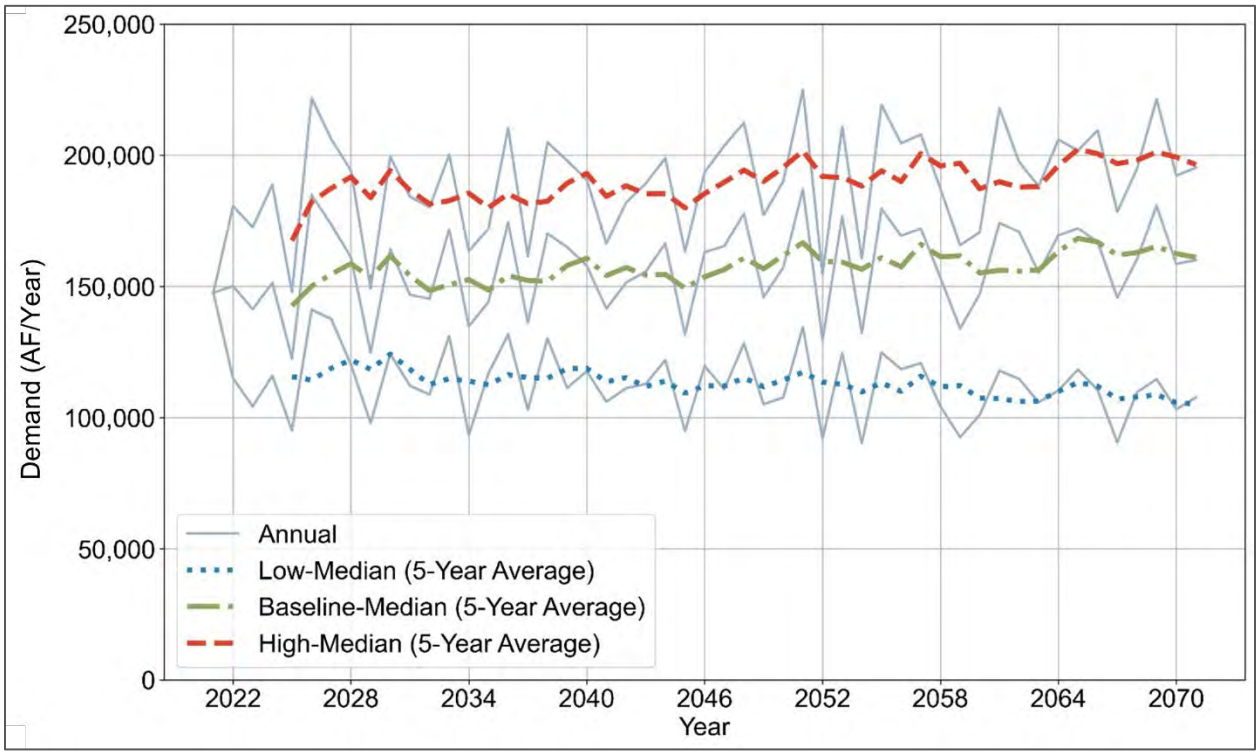


Figure 4-12. Annual Results of the Low, Baseline, and High Demand Scenarios, for Median Hydrologic Conditions (2022–2071)

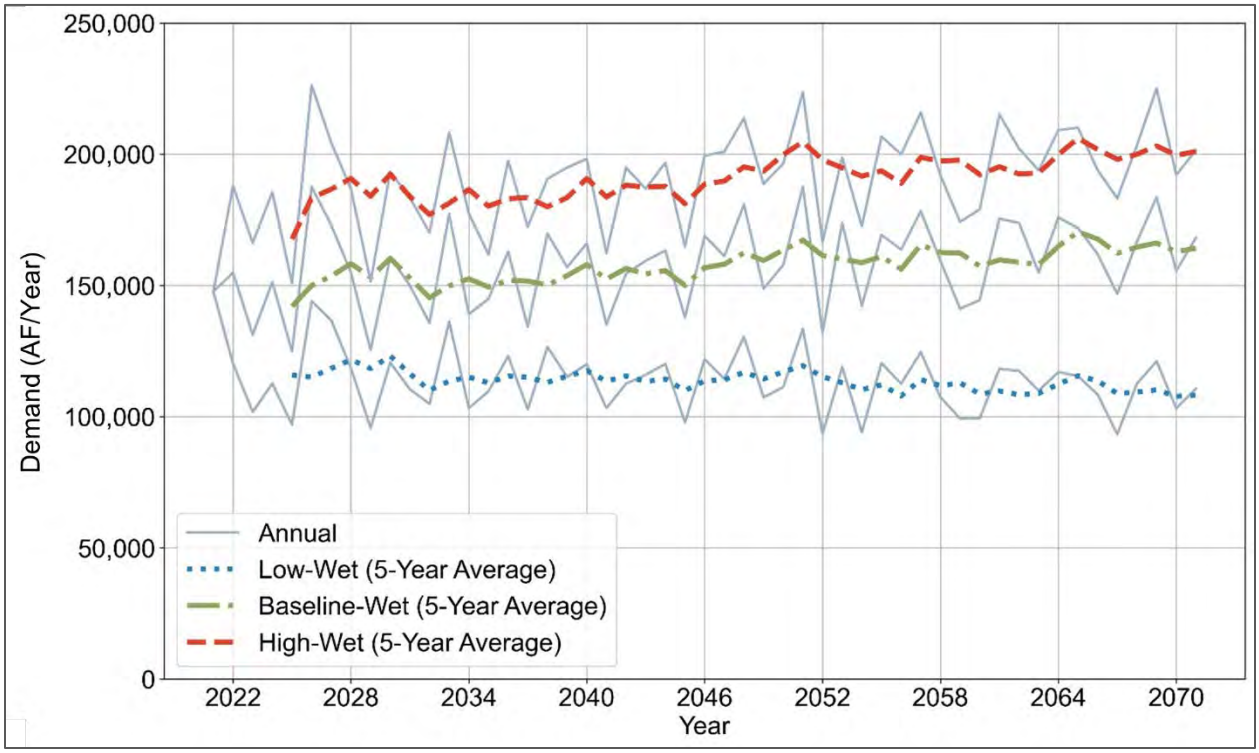


Figure 4-13. Annual Results of the Low, Baseline, and High Demand Scenarios, for Wet Hydrologic Conditions (2022–2071)

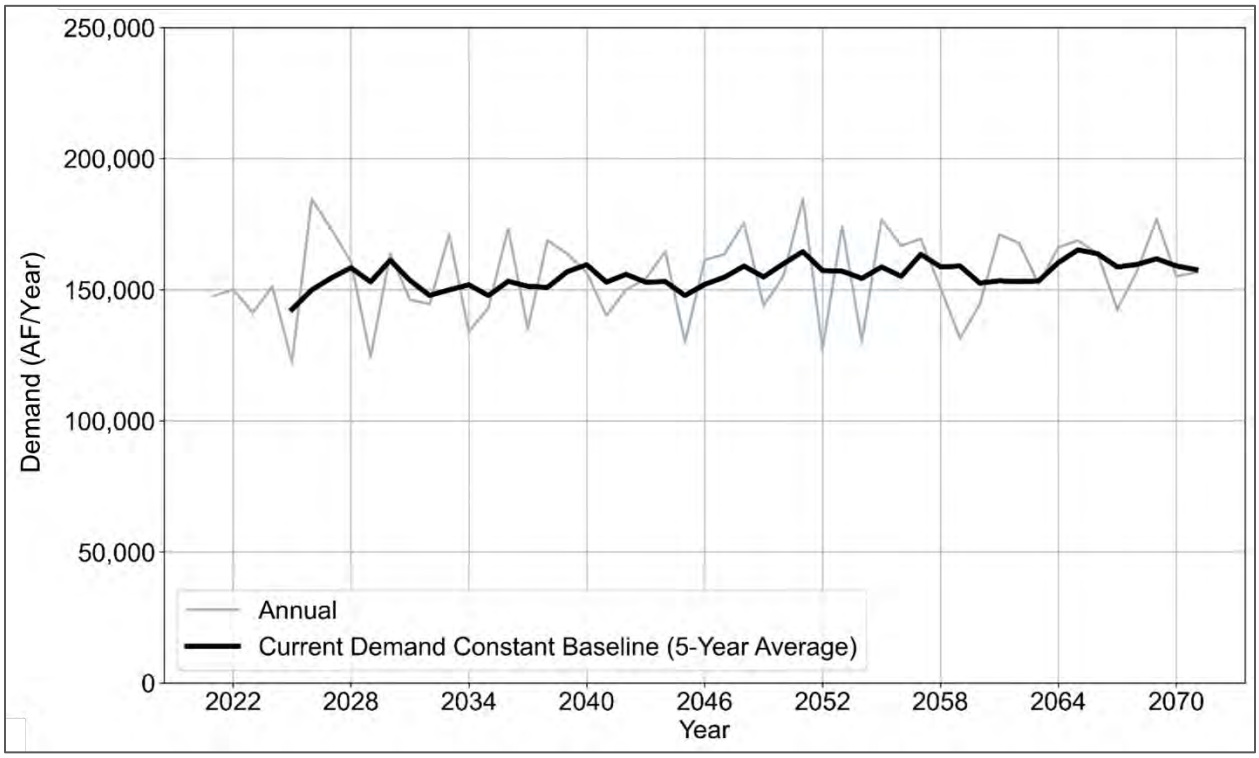


Figure 4-14. Annual Results of the Current Demand Constant Baseline Scenario (2022–2071)

Chapter 5. Operations Model

A reservoir operations model was developed that simulates how NID operates its current storage, conveyance, and delivery system. The operations model uses inflows from the hydrology model, current operating rules, and regulations to assess how well customer demands are met.

NID operations were simulated using a wide range of conditions, including historical conditions, current baseline operations, demands (low, median, and high), and climate (dry, median, and wet). Three future scenarios were selected for evaluation of potential PFW strategies.

- Dry Future Climate with High Demands
- Median Future Climate with Baseline Demands
- Wet Future Climate with Low Demands

These scenarios provide dry and wet bookends with a median climate scenario to represent a plausible mid-point. Use of these scenarios provides a wide range of hydrologic conditions and consumptive demands; the scenarios are suitable for testing the strategic alternatives.

5.1. Historical Inflow Hydrology

Historical inflow hydrology is needed for the calibration of the reservoir operations model and for the development of modeling studies that simulate current facilities and operations over historical inflow hydrology. No facilities in the project area have directly gaged inflows, so inflows need to be calculated or estimated using established hydrologic methods.

5.1.1. Methods

Most reservoirs in the project area do not have sufficient gaging to perform a mass balance calculation to determine inflows. Historical watershed inflows in the project area are estimated using a paired-basin approach, and these estimated inflows are compared to mass balance calculations where available to validate the paired-basin method.

The paired-basin approach used for these historical inflows is the same as that developed for the Yuba-Bear Drum-Spaulding Federal Energy Regulatory Commission (FERC) relicensing process and further refined for additional efforts since the relicensing. The approach is described in detail in NID's 2020 Raw Water Master Plan Hydrological Analysis Technical Memorandum, Appendix B (NID 2020).

5.1.2. Validation

The estimated historical inflow hydrology developed with the paired-basin approach is compared to mass balance calculations for reservoirs where sufficient data exist over a time when gage periods of record overlap. Average annual unimpaired flow is shown in Table 5-1. The comparison for Jackson Meadows Reservoir is shown in Figure 5-1. The comparison for Bowman Reservoir is shown in Figure 5-2. The comparison for Lake Spaulding is shown in Figure 5-3. The comparison for Scotts Flat Reservoir is shown in Figure 5-4.

Table 5-1. Average Annual Unimpaired Flow Comparisons for Historical Hydrology

Watershed	Paired-Basin Estimate (AF)	Mass Balance Calculation (AF)
Jackson Meadows Reservoir	78,477	78,847
Bowman Reservoir	84,705	90,827
Lake Spaulding	340,966	316,177
Scotts Flat Reservoir	19,394	20,537

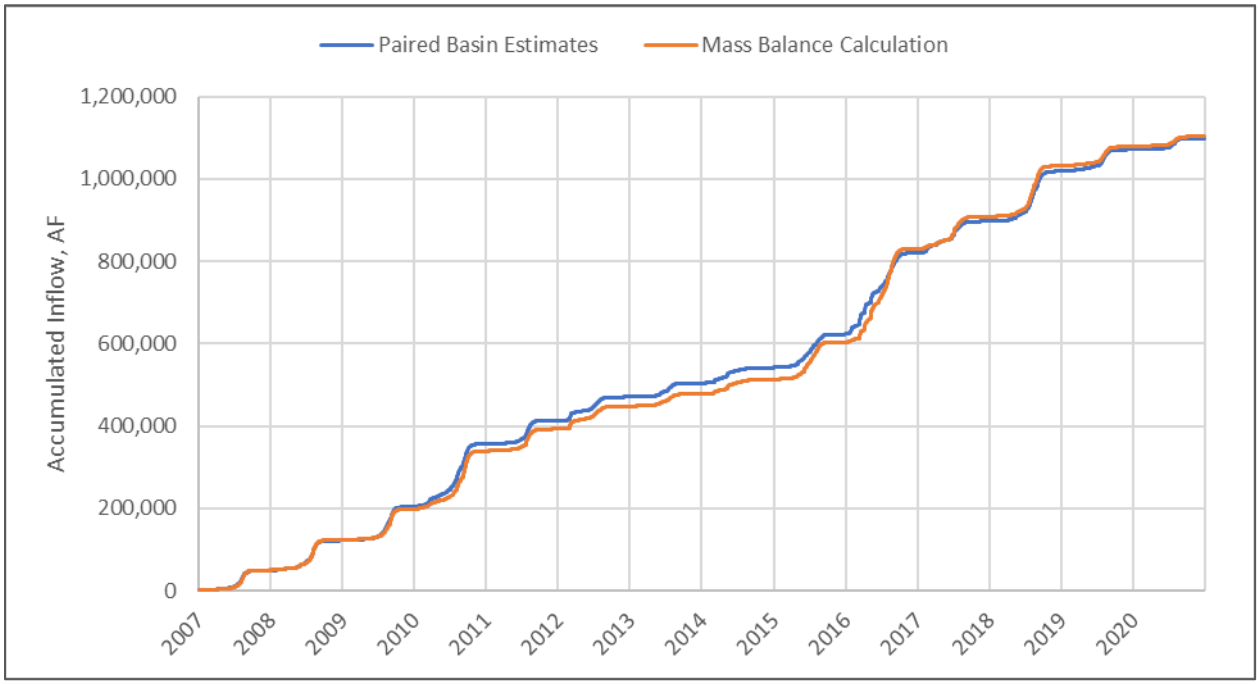


Figure 5-1. Accumulated Inflow Calculations, Jackson Meadows Reservoir, WYs 2008–2021

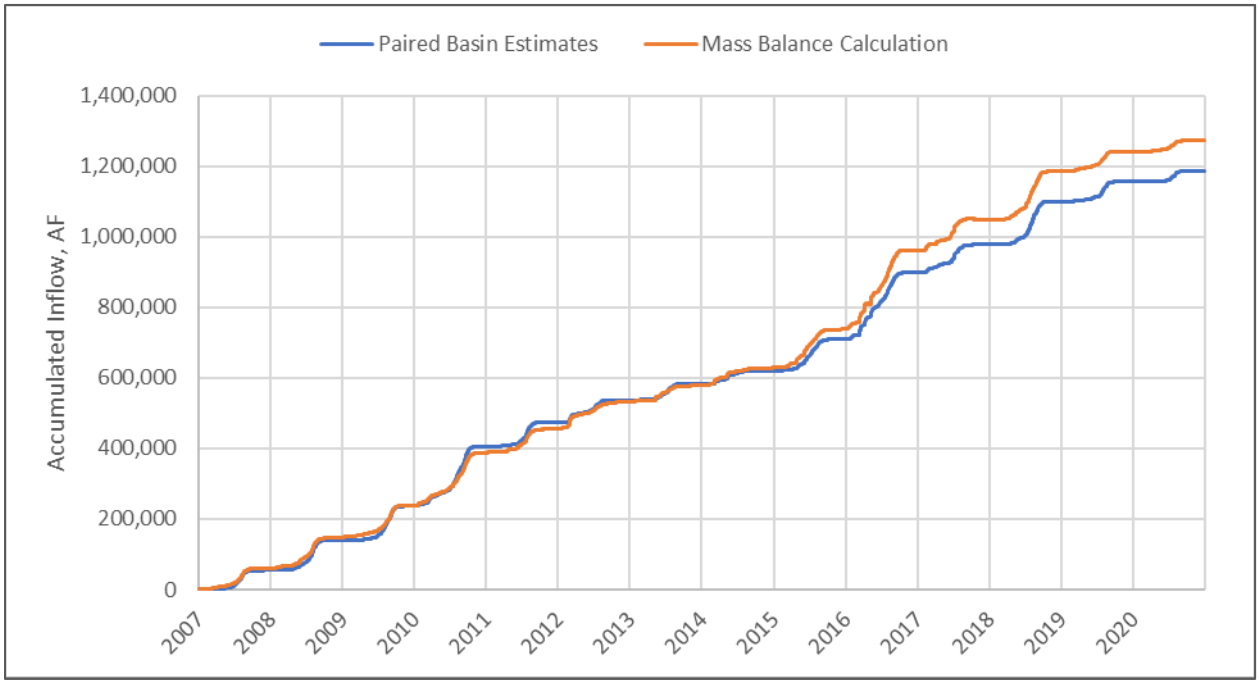


Figure 5-2. Accumulated Inflow Calculations, Bowman Reservoir, Water Years 2008–2021

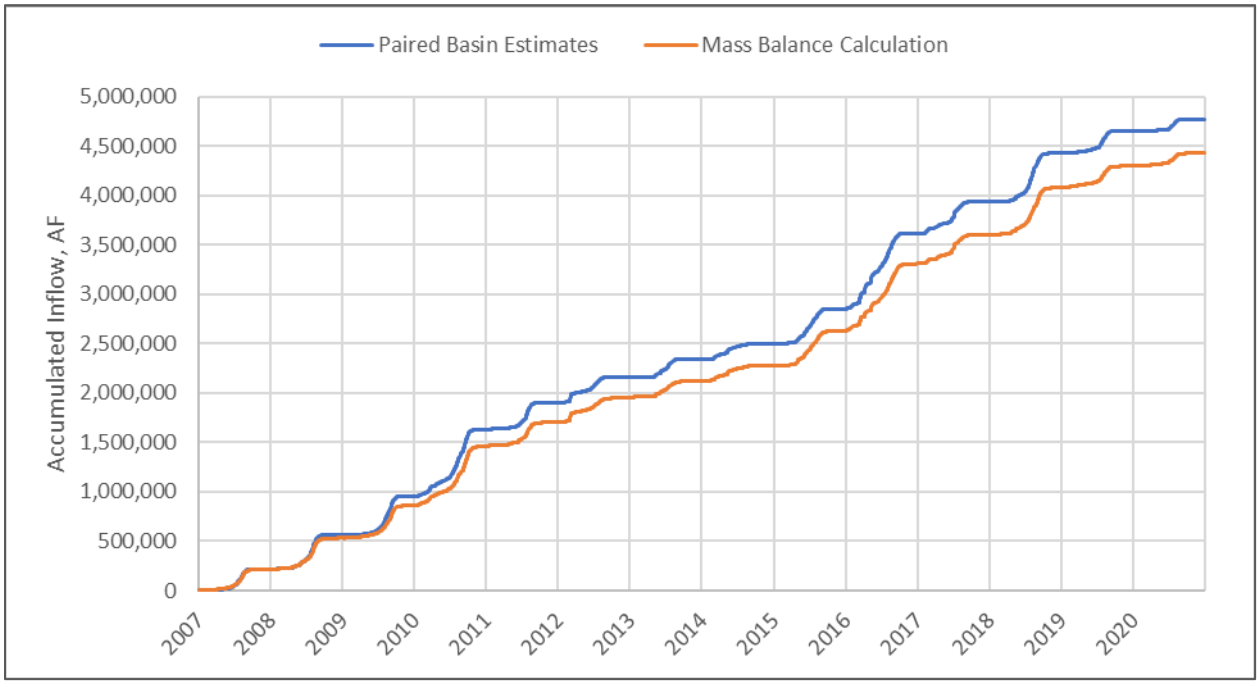


Figure 5-3. Accumulated Inflow Calculations, Lake Spaulding, Water Years 2008–2021

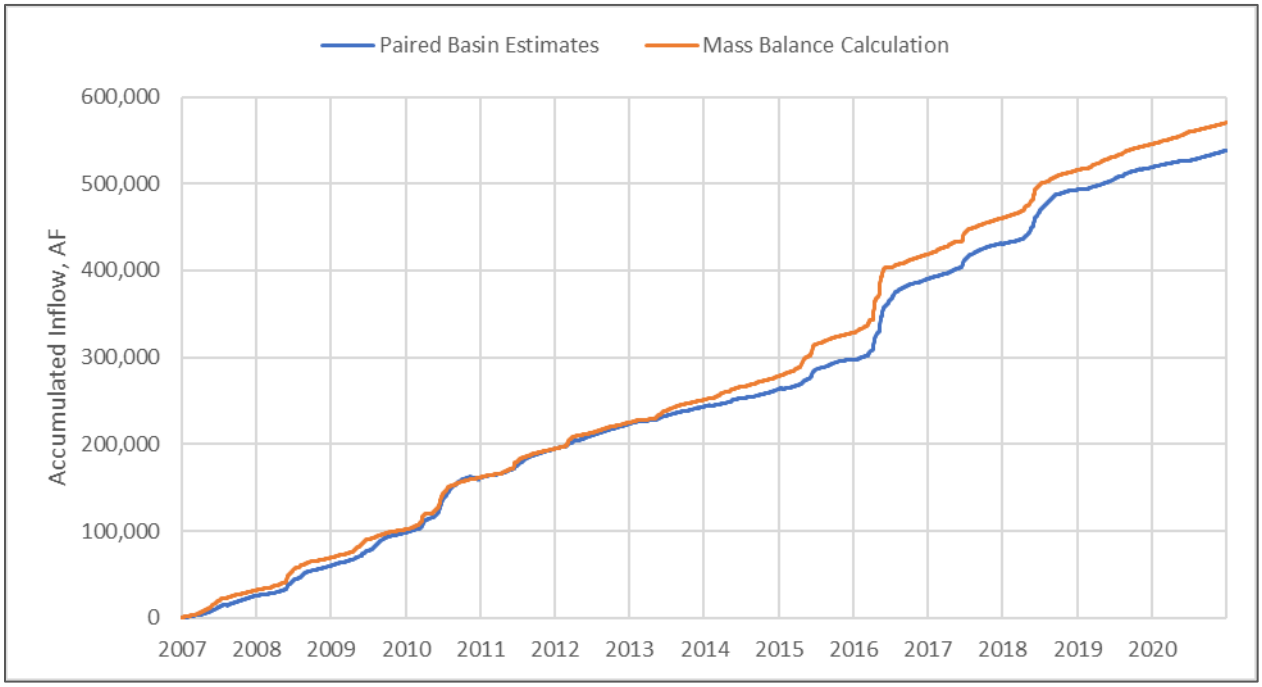


Figure 5-4. Accumulated Inflow Calculations, Scotts Flat Reservoir, Water Years 2008–2021

5.2. Recent Historical Deliveries

Recent historical deliveries were developed for model calibration and for modeling Placer County Water Agency (PCWA) demands[1]. To develop recent historical demand sets, the daily average delivery was calculated at each demand node. The gages used for each demand node are listed in Table 5-2. An example of the average delivery calculation for PCWA's Boardman canal is shown in Figure 5-5, and an example of the average delivery calculation for NID's delivery from Lake Combie is shown in Figure 5-6.

Table 5-2. Gages Used in Calculating Historical Deliveries

Model Demand Node	Diversion Location	Gages Used for Calculation*
NID-1	Rock Creek Reservoir	YB-64 + YB-86 + YB-108 + YB-255
NID-2	Auburn Ravine	YB-132 + YB-136 + YB-259
NID-3	Lake Combie	BR-301 + BR-311
NID-4	Cascade Canal	DC-102
NID-5a	DS Canal	DC-145
NID-5b	Newtown Canal	DC-131
NID-5c	Tunnel Canal	DC-140
PCWA-1	Lake Arthur	YB-184 + YB-95 – YB-288
PCWA-2	Halsey Forebay	YB-56 + YB-87 + YB-288
PCWA-3	Rock Creek Reservoir	YB-69
PCWA-4	Wise Forebay	YB-73

[1] Data received by email correspondence: from Chirs Sanderson, Hydrographer at PG&E, on 9/6/2022 and 9/8/2022.

PCWA-5	Auburn Ravine	YB-75 + YB-76 + YB-78 + YB-91 + YB-278

* Note: gage codes follow NID, PG&E and PCWA gage codes. These agencies group their gages by projects (YB=Yuba Bear System, DC=Deer Creek System, BR = Bear River)

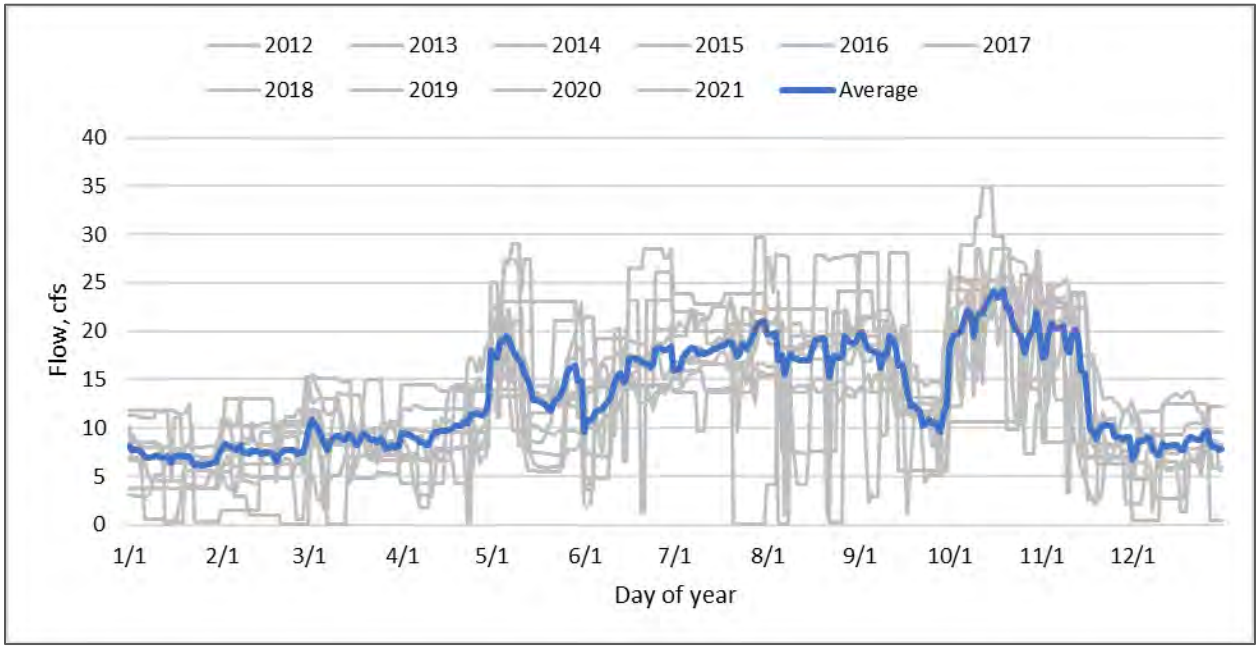


Figure 5-5. Historical Deliveries in Boardman Canal

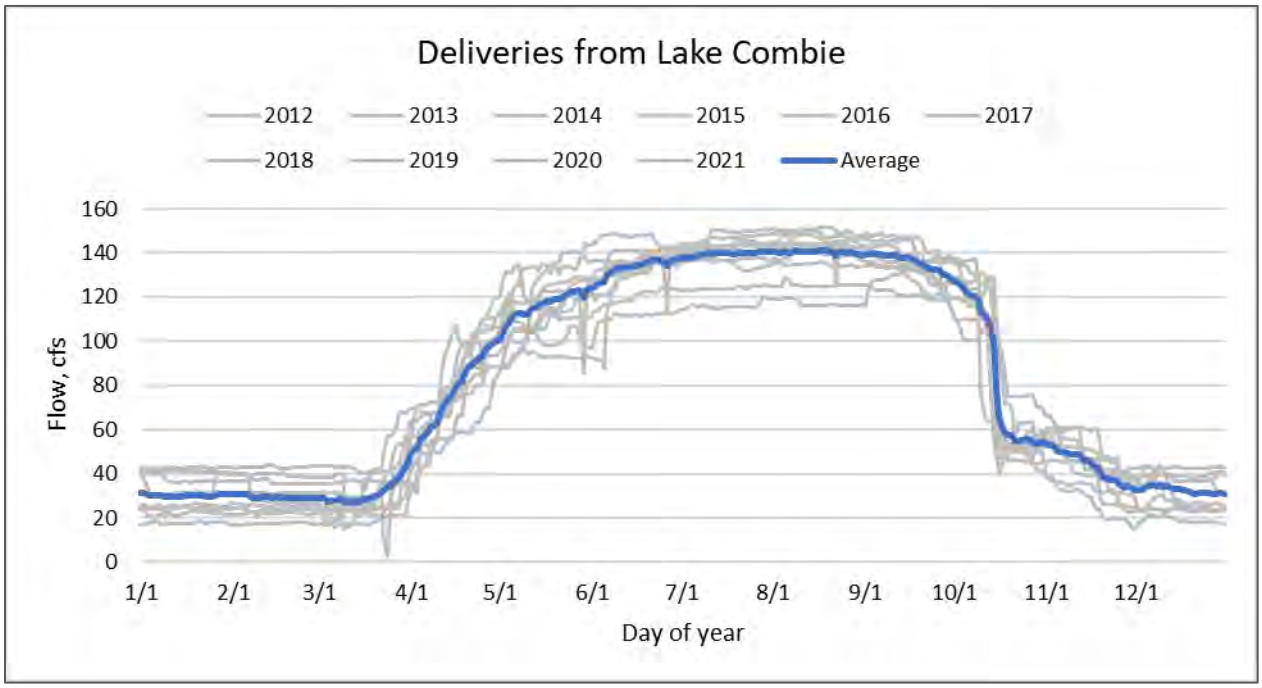


Figure 5-6. Historical Deliveries from Lake Combie

5.3. USACE Hydrologic Engineering Center ResSim Model

5.3.1. Description of the Software Package

The HEC-ResSim software is developed by the USACE HEC and is used to model reservoir operations for reservoir systems. The software is widely used for water supply and flood management in planning studies. The model features rule-based operations that attempts to reproduce the decision-making process that reservoir operators use in reservoir management. The software is Java-based and allows the user to write scripts in Jython, an implementation of the python programming language in Java, which augments the model's flexible rule structures.

5.3.2. Selection Rationale

The HEC-ResSim modeling software is widely used throughout California to model hydropower and water supply projects. The software has all the features needed to model NID's system; previous models of NID's system have been built on HEC-ResSim, making it easier to incorporate previous work done to refine the modeling of NID's system.

5.4. Model Development

5.4.1. Rebuild in Current ResSim Software Version

The latest version of HEC-ResSim is version 3.3, released in 2021, and the NID FERC relicensing model was built in HEC-ResSim version 3.0, released in 2007. Models built in version 3.0 cannot run using the latest ResSim software. Given the software incompatibility issue, the model had to be rebuilt in the current software version. Rules and facility information from the previous model were imported into the new model version, and Jython scripts were written to automate some input and output processing that was previously done in spreadsheets before and after a modeling study was run.

5.4.2. Model Facilities

Reservoirs that are modeled with usable storage are listed in Table 5-3. Additional reservoirs are included in the model that do not have usable storage, such as diversion dams, forebays, and afterbays, which are modeled as nodes or modeled as full at all times.

5.4.2.1 Reservoirs Modeled

Table 5-3. Reservoirs Modeled in the Reservoir Operations Model

Reservoir	Modeled Storage Capacity (AF[1])
Jackson Meadows Reservoir	67,435
French Lake	13,940
Faucherie Lake	3,740
Sawmill Lake	3,030
Jackson Lake	1,330
Bowman Reservoir	66,722
Upper Rock Lake	207

Lower Rock Lake	48
Culbertson Lake	953
Upper Lindsey Lake	17
Middle Lindsey Lake	110
Lower Lindsey Lake	289
Feely Lake	739
Carr Lake	150
Blue Lake	1,186
Rucker Lake	648
Kidd Lake	1,505
Upper Peak Lake	1,697
Lower Peak Lake	484
White Rock Lake	570
Meadow Lake	4,841
Lake Sterling	1,824
Fordyce Lake	49,426
Lake Spaulding	74,890
Kelly Lake	334
Lake Valley Reservoir	7,902
Rollins Reservoir	55,140
Lake Combie	2,790
Rock Creek Reservoir	319
Scotts Flat Reservoir	43,143

[1]Storage Capacity includes normal operating capacity with spill gates closed or flashboards in place and does not include additional reservoir space above spillway in which the reservoir may surcharge during times of high inflow.

5.4.2.2 Demand Nodes

The model has diversions for consumptive demands at seven locations for NID and five locations for PCWA, shown in Table 5-4.

Table 5-4. Model Consumptive Demand Nodes

Model ID	Diversion	Diversion Location
NID-1	North Auburn WTP and Combie-Ophir Canal	Rock Creek Reservoir
NID-2	Auburn Ravine	Auburn Ravine
NID-3	Combie Phase I and Magnolia Canals	Lake Combie
NID-4	Cascade Canal	Deer Creek
NID-5a	DS Canal	Deer Creek
NID-5b	Newtown Canal	Deer Creek
NID-5c	Tunnel Canal	Deer Creek
PCWA-1	Boardman Canal	Lake Arthur
PCWA-2	Ragsdale and Bowman Canals	Halsey Forebay
PCWA-3	Middle Fiddler Green Canal	Rock Creek Reservoir
PCWA-4	Lower Fiddler Green Canal	Wise Forebay
PCWA-5	Auburn Ravine and Dutch Ravine	Auburn Ravine

5.4.2.3 Conduit Capacities

Table 5-5 lists the canals and conduits that are explicitly modeled in the reservoir operations model.

Table 5-5. Conduit Capacities and Loss Rates

Conduit	Capacity (cfs)	Modeled Loss Rate
Milton-Bowman Conduit	425	0
Bowman-Spaulding Conduit		
At Bowman Reservoir	300	0
–Below Texas Creek Div Dam	300	0
–Below Clear Creek Div Dam	310	0
–Below Fall Creek Div Dam	320	0
–Below Trap Creek Div Dam	325	0
–Below Rucker Creek Div Dam	325	0
Spaulding Powerhouse No 1	645	0
Spaulding Powerhouse No 2	200	0
Spaulding Powerhouse No 3	334	0
Drum Canal	840	7.8%
Bear River Canal	470	6.9%
Wise Canal	488	0
South Canal	395	0
South Yuba Canal	90	14.3%
Chalk Bluff Canal	85	0[1]
Deer Creek Powerhouse	110	0
Towle Canal	42	12%
Pulp Mill Canal	25	0
Boardman Canal	58	0
Lake Valley Canal	24	0

[1]14.3% loss rate modeled in the South Yuba Canal is the combined loss for South Yuba Canal and Chalk Bluff Canal.

5.4.3. Significant Changes from the Previous NID ResSim Model

5.4.3.1 Lake Valley Canal Capacity

The Lake Valley Canal was piped in 2014, resulting in less capacity to move water to the Drum Canal. The model was updated to reflect this lowered capacity. The updated model uses a capacity of 26 cfs, while previous models have used a capacity of 36 cfs. Average daily flow in the Lake Valley Canal over three time periods is shown in Figure 5-7. An ensemble of daily flow rates in the Lake Valley Canal for 2016–2021 is shown in Figure 5-8, demonstrating that flow rates rarely exceed 26 cfs.

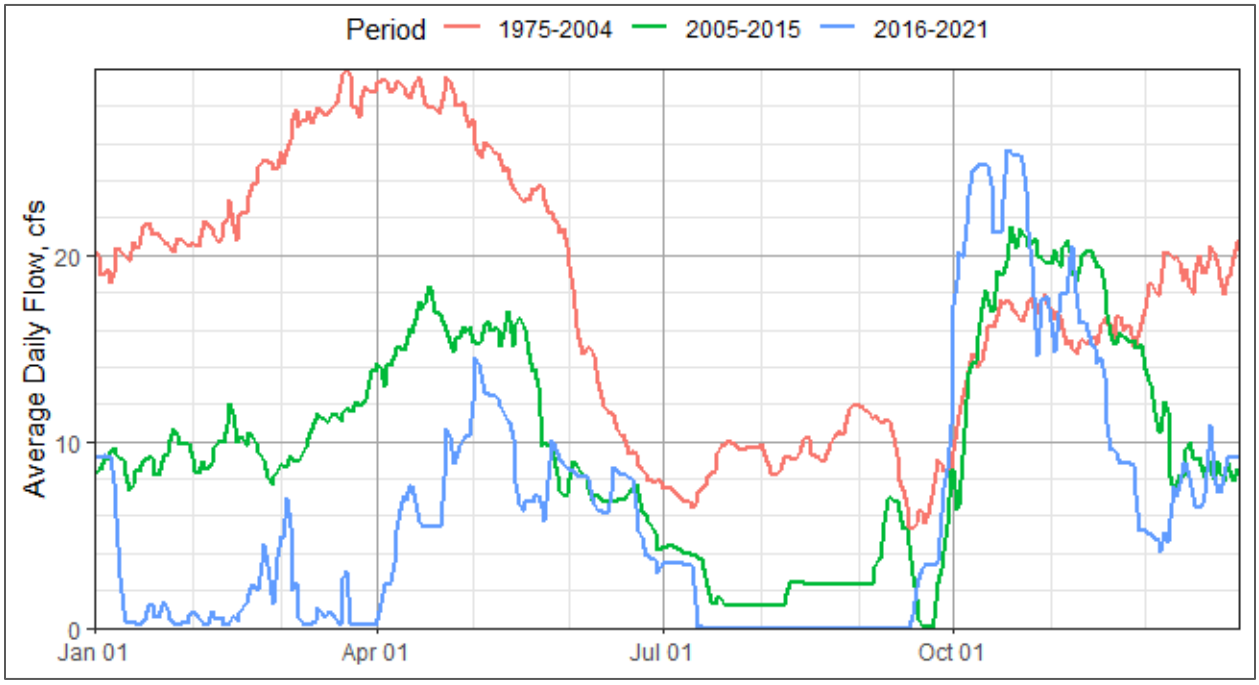


Figure 5-7. Lake Valley Canal Historic Daily Average Flow

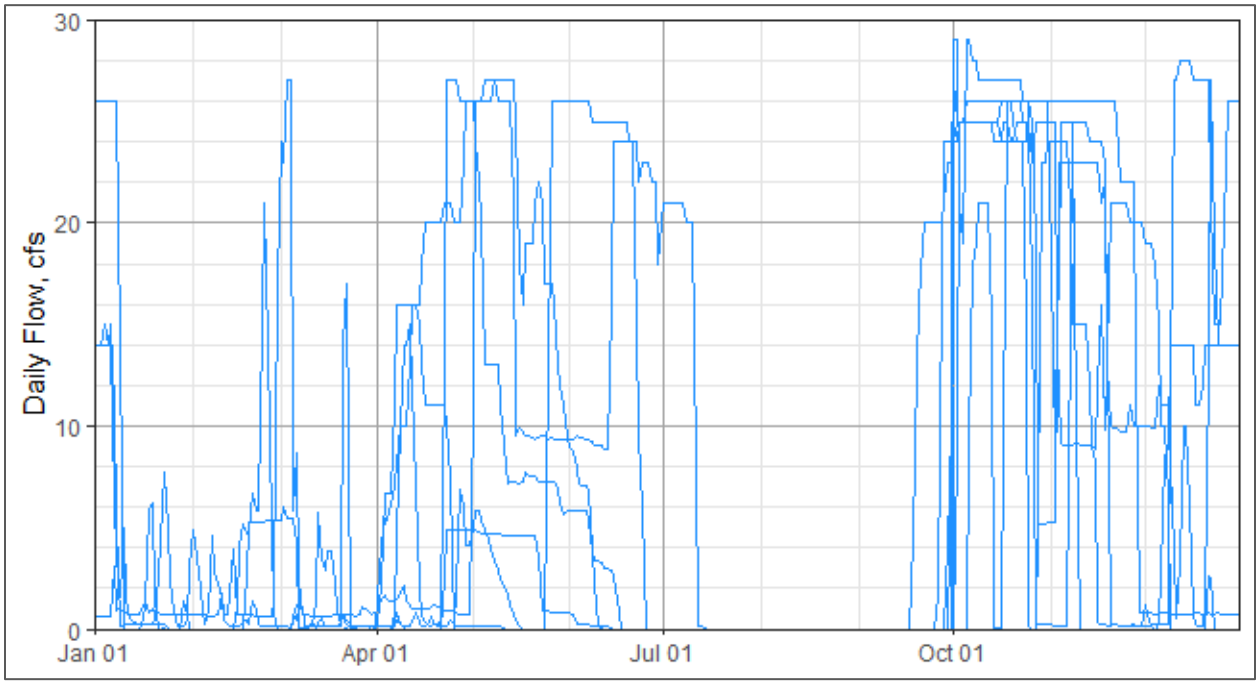


Figure 5-8. Lake Valley Canal Flow Ensemble, 2016–2021

5.4.3.2 Fordyce Lake Seepage (Increase in Seepage Estimate from 2020 SWRCB Document)

Previous modeling had seepage from Fordyce Lake up to a maximum of 24 cfs at full pool. In their Fordyce Lake Seepage Mitigation Project, Pacific Gas & Electric (PG&E) has estimated that Fordyce Lake seepage

ranges from 24 to 60 cfs (SWRCB 2020). Historic data were analyzed to estimate the relationship between seepage and reservoir water surface elevation. The resulting relationship is shown in Figure 5-9 which shows that flow below Fordyce Dam increases with increasing water surface elevation above water surface elevations of around 6310 feet. Since minimum flow requirements and discretionary releases are not based on water surface elevations, this near-linear increase in flow below Fordyce Dam is likely due to increased seepage as reservoir head increases.

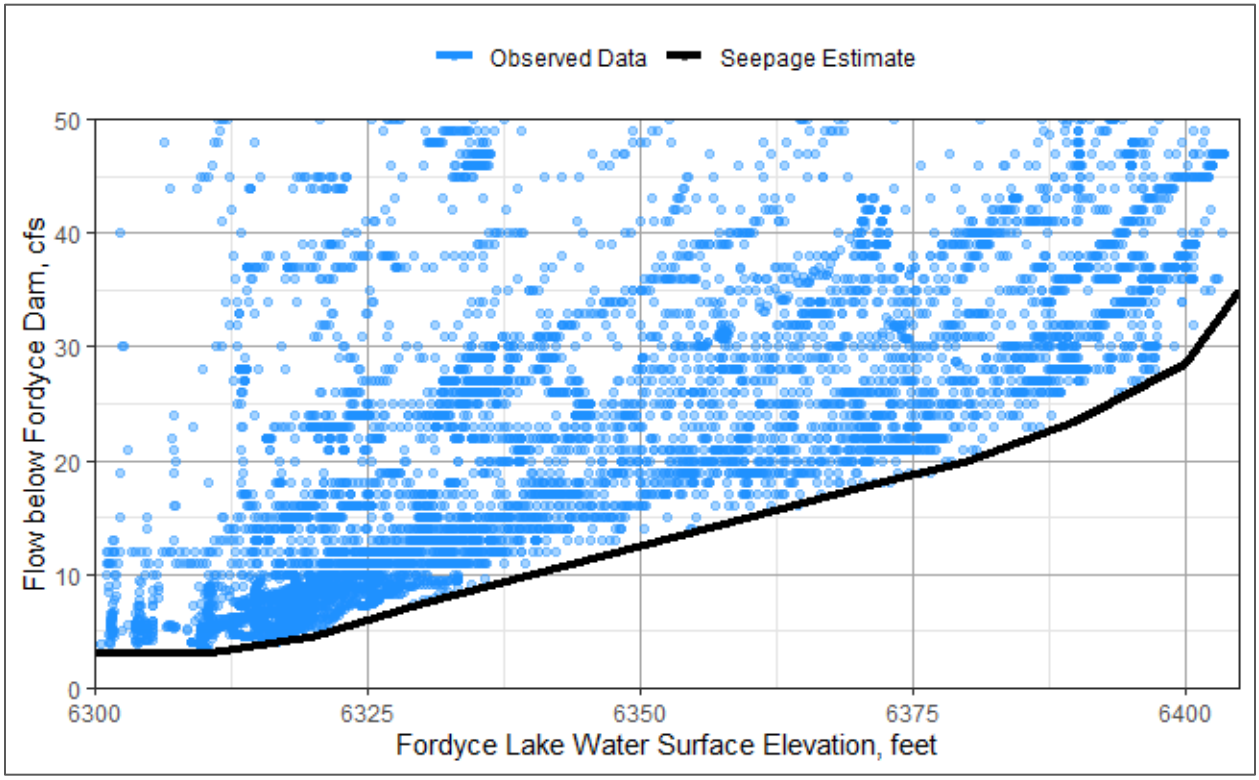


Figure 5-9. Fordyce Dam Seepage Estimate

5.4.4. Implementation of the Integrated Red-Blue Model

The model simulates the integrated operations of NID's Yuba-Bear Project, PG&E's Drum-Spaulding Project, PG&E's Deer Creek Project, and some non-FERC facilities that receive water from FERC projects. A system of tracking the ownership of NID and PG&E water throughout the projects is needed to properly process results. In the FERC relicensing process, this tracking was implemented in a post-processing spreadsheet named the "YB and DS Water Allocation Module" (Red-Blue Spreadsheet), which instituted a "water coloring" scheme where NID water is blue and PG&E water is red. This spreadsheet necessitated a workflow in which the ResSim model results do not correctly track water ownership and the true ownership was calculated in the Red-Blue Spreadsheet. Because the model did not have access to the ownership calculations, it could not implement restrictions on diversions based on ownership.

The updated model integrates ownership calculations into the model code. This allows for the model to make decisions based on ownership during runtime. The model assigns the ownership of water using the

definitions contained in the COA between NID and PG&E (NID 2018). The model tracks ownership of water at the following locations:

- Inflow to Lake Spaulding: NID owns all water diverted into the Bowman-Spaulding Conduit at the Bowman Diversion Dam. PG&E owns Texas-Fall Creek Water diverted into Lake Spaulding between July 1 and November 30, up to 30 cfs and up to 3,500 AF/year. NID owns the remaining Texas-Fall Creek Water diverted into Lake Spaulding.
- Head of South Yuba Canal: All water in the South Yuba Canal that flows past the South Yuba Waste Gate is NID water.
- Head of Drum Canal: NID water in the Drum Canal is equal to NID inflows to Lake Spaulding minus NID flow in the South Yuba Canal. The remaining flow in the Drum Canal is PG&E water.
- Inflow to Rollins Reservoir: NID imports to Rollins Reservoir are equal to NID water in the Drum Canal minus a 7.8% canal loss. PG&E imports to Rollins Reservoir are equal to PG&E water in the Drum Canal plus diversions into the Lake Valley Canal minus a 7.8% canal loss, minus water diverted from Drum Forebay into Canyon Creek. PG&E diversions through the South Yuba Waste Gate or the Drum Canal Waste Gate are considered additional PG&E imports to Rollins Reservoir. PG&E natural flow into Rollins Reservoir is equal to the first 350 cfs of Bear River runoff into Rollins Reservoir. NID natural flow into Rollins Reservoir is any Bear River runoff into Rollins Reservoir in excess of 350 cfs.
- Outflow from Rollins Reservoir: Diversions from Rollins Reservoir into the Bear River Canal are determined from PG&E and NID demands along the canal. Releases from Rollins Reservoir that flow past the Bear River Diversion Dam are considered NID water.
- Storage in Rollins Reservoir: Change in storage in Rollins Reservoir for each storage account is calculated as Inflow minus outflow minus a fraction of evaporation equal to the fraction of each account's storage to the total storage volume.
- Bear River Canal: NID delivers any NID water diverted into the Bear River Canal minus a 6.9% canal loss. Remaining water in the Bear River Canal is PG&E water. Any minimum flow releases out of the Bear River Canal at Rock Creek or Dry Creek are from PG&E.

The model enforces the following restrictions based on ownership of water:

- NID diversions to the South Yuba Canal must be less than or equal to NID inflows to Lake Spaulding. As outlined in the COA, there is an exception to this restriction during the Bowman-Spaulding Conduit outage period.
- NID diversions to the Bear River Canal must be less than or equal to NID inflow to Rollins Reservoir plus NID storage in Rollins Reservoir minus minimum flow requirements below the Bear River diversion Dam.
- PG&E diversions to the Bear River Canal must be less than or equal to PG&E inflow to Rollins Reservoir plus PG&E storage in Rollins Reservoir.

5.4.5. Historical Conditions Model

The model was used to develop a simulation using historical inflow hydrology, recent historical consumptive demands, and regulatory requirements from the existing FERC licenses over a historical period of record covering water years 1976–2021. These modeling studies were calibrated to the last 10 years of record, water years 2012–2021.

5.4.6. Model Calibration and Validation

A model that is built with existing facility characteristics, historical hydrology, historic deliveries, and historic regulatory requirements should match historic observed data. Errors in historical hydrology estimation, differences between estimated evaporation and historic evaporation, anomalies in historic deliveries that are not modeled (canal collapse, etc.), anomalies in the meeting of regulatory requirements that are not modeled (variances obtained from FERC, accidental non-compliance, etc.), and errors or low precision in observed gage data will all cause the model to deviate from historic observed data. The process of calibrating a reservoir operations model is to find deviations from observed data and identify the cause to verify that the model is working correctly but is not meant to model the errors or anomalies that contribute to the deviation from observed data.

Additionally, at some reservoirs, releases are made to provide discretionary generation, or generation releases that are not required but made strictly for power generation revenue. This can be summer and fall generation in which the discretionary generation is used to generate during times of high prices, or winter and spring generation, in which the discretionary generation is made to make some revenue instead of reservoir spills. Discretionary generation is often scheduled in near real-time using estimates available in the moment that have a degree of uncertainty (weather forecasts, inflow forecasts, power price forecasts) and those decisions are difficult to reconstruct when building a planning model. Calibrating a model to these discretionary generation releases is generally a process of taking an average over a few variables (by month, by water year type, by reservoir elevation) and making a generalized rule that fits some years' observed data better than others.

Most reservoirs in the model match observed data well. An example of one of these reservoirs is shown in Figure 5-10 for Jackson Meadows Reservoir.

A few of the reservoirs on the Texas-Fall Creek system do not match observed data very well. While there are limited observed data at most of these reservoirs, it is likely that the deviations from observed data are due to the difficulty of creating estimated historical hydrology for these very small watersheds. An example of one of the Texas-Fall Creek reservoirs that do not match historical data is shown in Figure 5-11 for Culbertson Lake.

The large reservoirs that do not match observed data very well are Bowman Reservoir and Lake Spaulding. At both reservoirs this is mostly due to a wide variation in the carryover level in the observed data. The model has a simple rule for carryover level at Bowman Reservoir that does not have as wide a range as observed data. Bowman Reservoir storage calibration is shown in Figure 5-12. The carryover level at Lake Spaulding is mostly driven by discretionary generation, which historically varies year to year based on a variety of factors that are not modeled. One example is that in 2015, Lake Spaulding closed the spill gates in early February, which is much earlier than normal, whereas the model closes the spill gates on April 1

every year. This created a deviation in storage through the end of 2015. Lake Spaulding storage validation is shown in Figure 5-13.

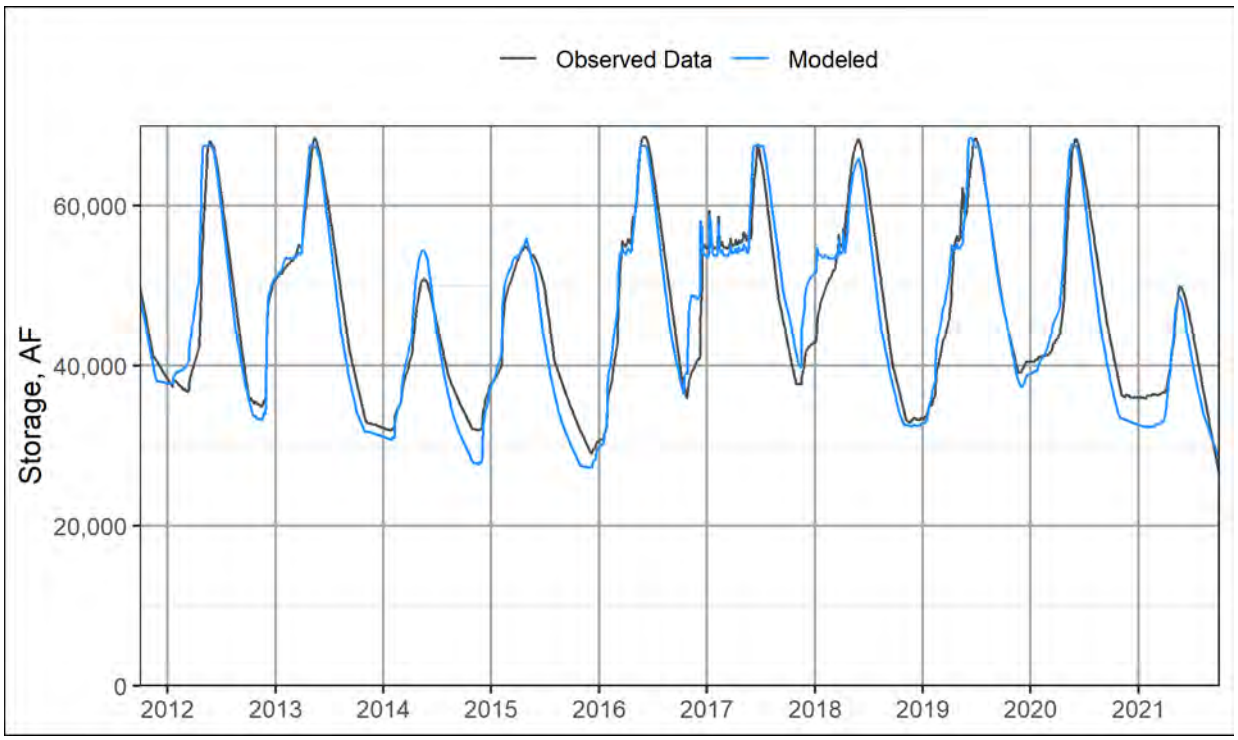


Figure 5-10. Jackson Meadows Reservoir Storage, Water Years 2012–2021

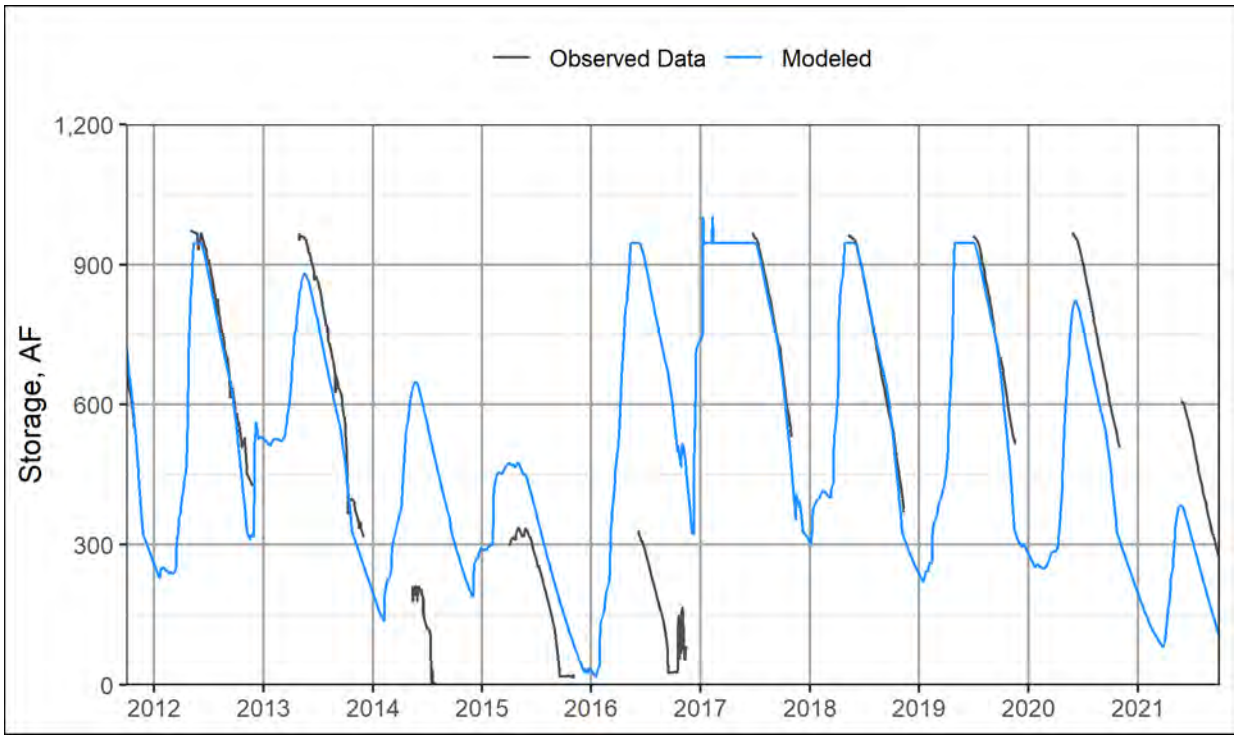


Figure 5-11. Culbertson Lake Storage, Water Years 2012–2021

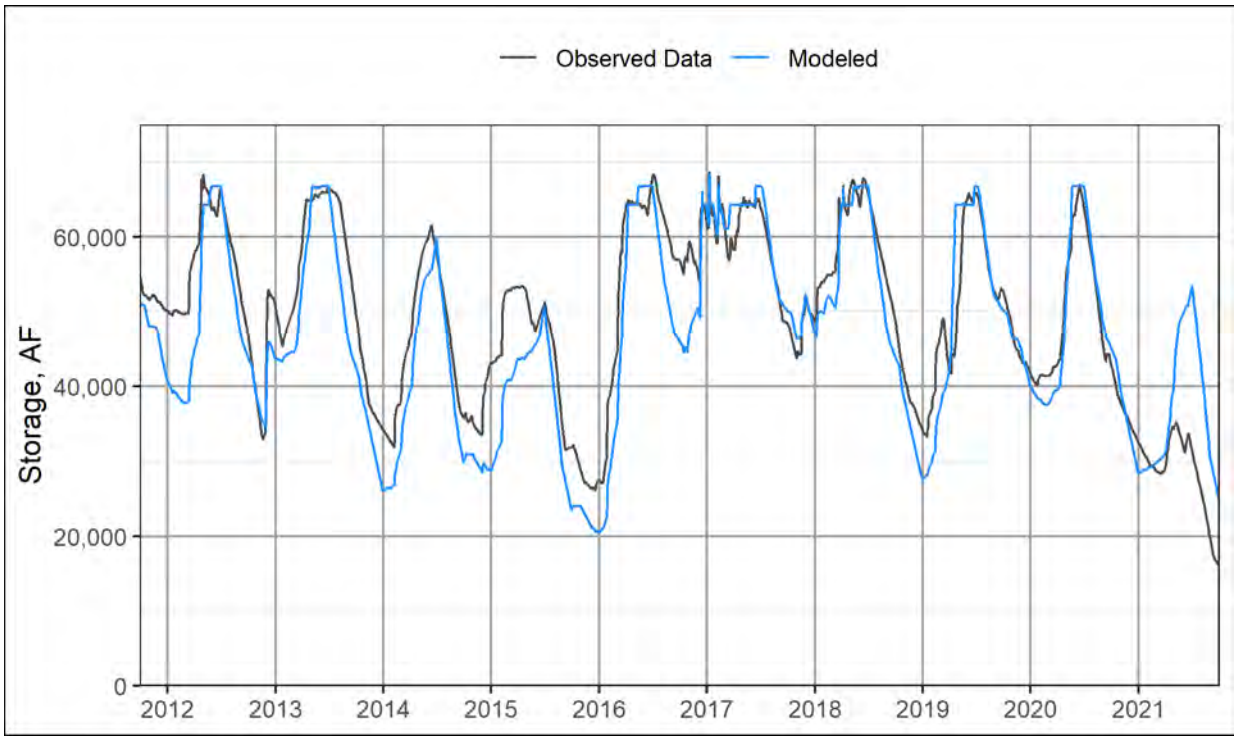


Figure 5-12. Bowman Reservoir Storage, Water Years 2012–2021

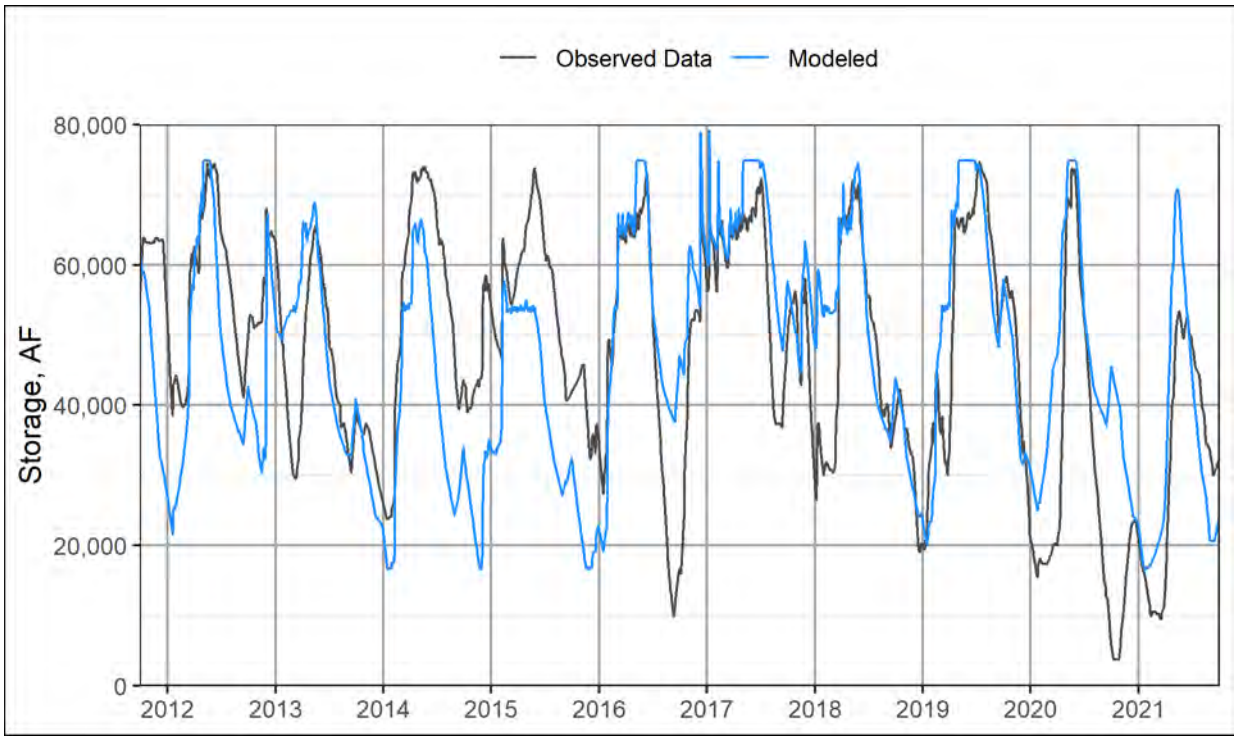


Figure 5-13. Lake Spaulding Storage, Water Years 2012–2021

5.5. Projection Inputs

5.5.1. Integrated Water Flow Model Demand Calculator (IDC) Demands

The model uses demands developed using the DWR's IDC built for NID's service area (NID PFW Demand Model), described in Chapter 4. The NID PFW Demand Model was used to develop 10 demand sets for use in the ResSim model. Annual Demands for these demand sets are summarized in Table 5-6. Annual Demands for each NID demand location in the ResSim model are summarized in Table 5-7.

Table 5-6. Annual Demands from IDC Model

	Dry Climate Bookend	Median Climate Scenario	Wet Climate Bookend
Low Demand	107,657	109,088	109,705
Baseline Demand	149,654	151,806	152,238
High Demand	181,616	183,483	184,638
2022 Demand	N/A	150,100	N/A

Table 5-7. Annual Demands at Each NID Demand Node

Demand Level		Low			Baseline			High		
Climate Bookend		Dry	Med	Wet	Dry	Med	Wet	Dry	Med	Wet
ID	Location	Demands (AF)								
1	Rock Creek Reservoir	3,954	4,018	4,045	6,027	6,135	6,152	7,539	7,664	7,694
2	Auburn Ravine	21,362	21,716	21,900	32,786	33,384	33,526	41,805	42,336	42,653
3	Lake Combie	41,437	42,073	42,379	59,316	60,484	60,567	72,490	73,558	74,033
4	Cascade Canal	15,090	15,120	15,143	17,218	17,210	17,261	18,923	18,887	18,965
5A	DS Canal	14,591	14,910	14,983	21,718	21,981	22,106	27,235	27,424	27,639
5B	Newtown Canal	4,943	4,952	4,951	5,189	5,187	5,194	5,370	5,366	5,377
5C	Tunnel Canal	6,280	6,298	6,303	7,400	7,424	7,433	8,255	8,247	8,277

5.5.2. HEC-HMS Climate Change Hydrology

The HEC-HMS Climate Change Hydrology Model, described in Chapter 2. Hydrological Model, developed three input datasets for the reservoir operations model: (1) a dry bookend scenario, (2) a wet bookend scenario, and (3) a median scenario. These projected hydrology datasets were generated for a 50-year projected period for WYs 2022–2073. The datasets do not predict what will happen, but rather represent what could happen under various climate scenarios. Average annual unimpaired flows in major NID watersheds are summarized for the climate change scenarios in Table 5-8. Average annual unimpaired inflow to all NID reservoirs is shown graphically in Figure 5-14. Daily average unimpaired flow to all NID reservoirs is shown in Figure 5-15 through Figure 5-17.

Table 5-8. Average Annual Unimpaired Flow in NID Watersheds

Unimpaired Flow Location	Average Annual Unimpaired Flow Volume (AF)			
	Historic Hydrology	Dry Climate Scenario	Median Climate Scenario	Wet Climate Scenario
Middle Yuba River at Milton	87,357	67,699	79,470	90,726
Canyon Creek at Bowman	88,811	68,749	82,023	85,097
Deer Creek at Scotts Flat	36,415	14,310	20,822	25,298
Bear River at Lake Combie	171,183	107,410	159,730	193,843
Total Unimpaired Inflow to all NID Reservoirs	383,766	258,168	342,046	394,964

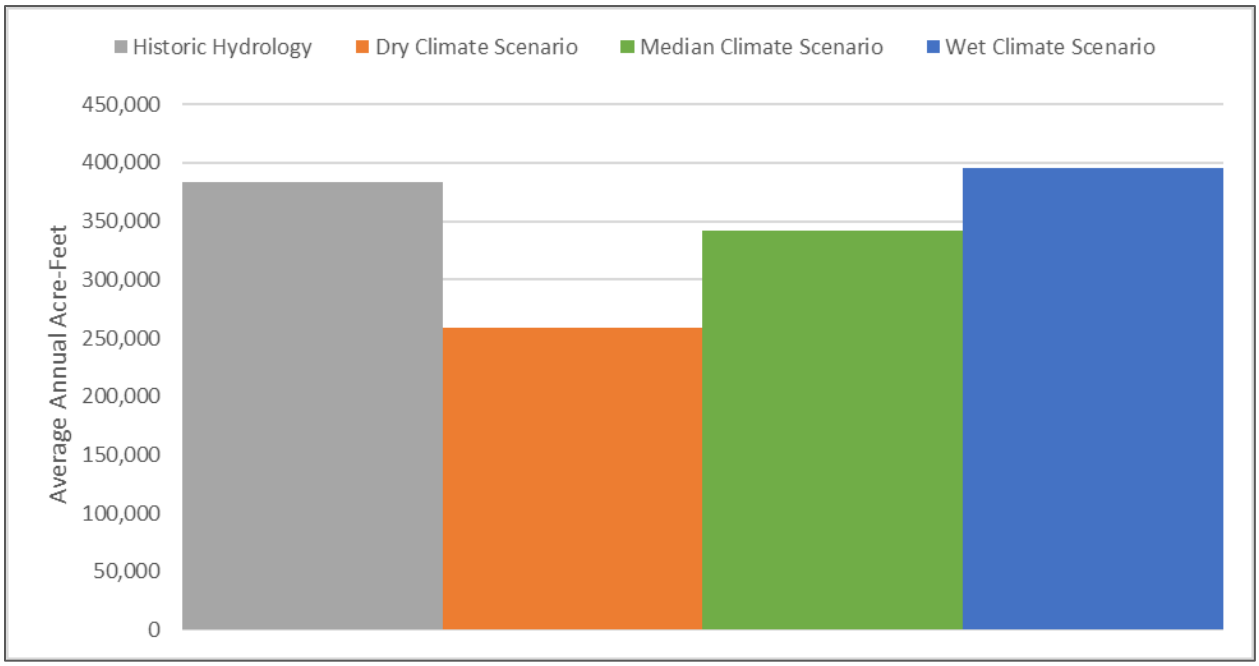


Figure 5-14. Average Annual Unimpaired Inflow to NID Reservoirs in Climate Change Hydrology

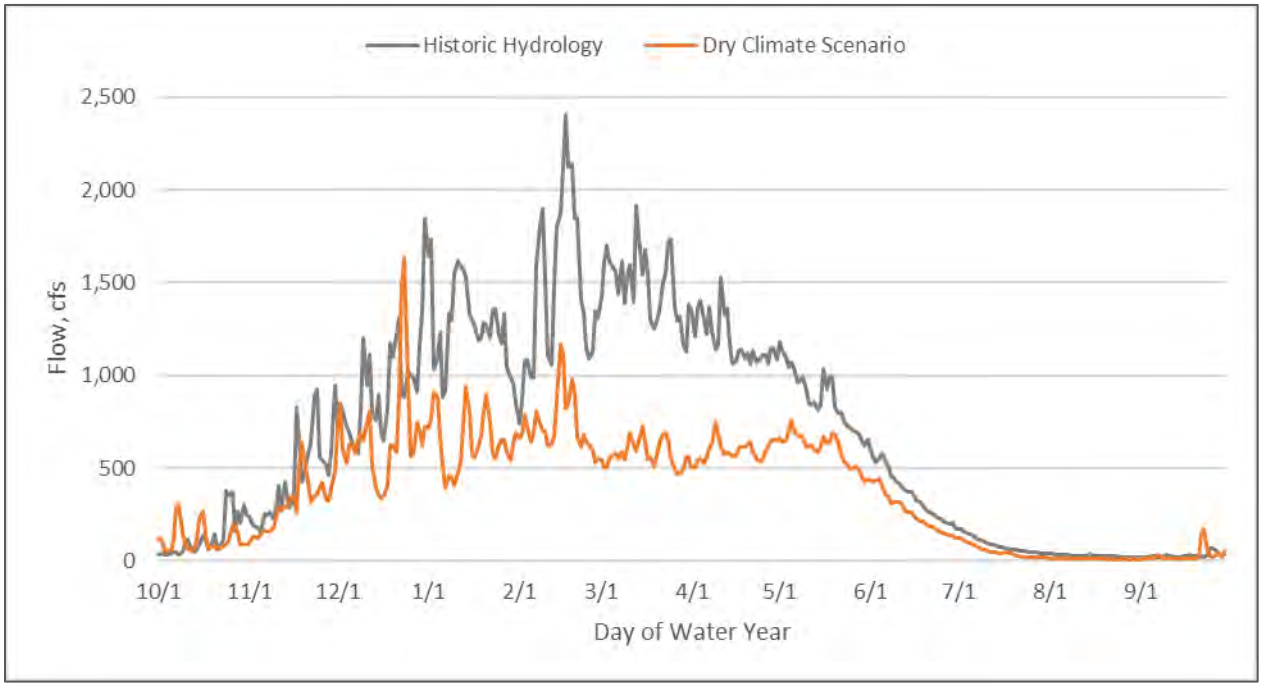


Figure 5-15. Daily Average Unimpaired Inflow to NID Reservoirs in Dry Climate Change Hydrology

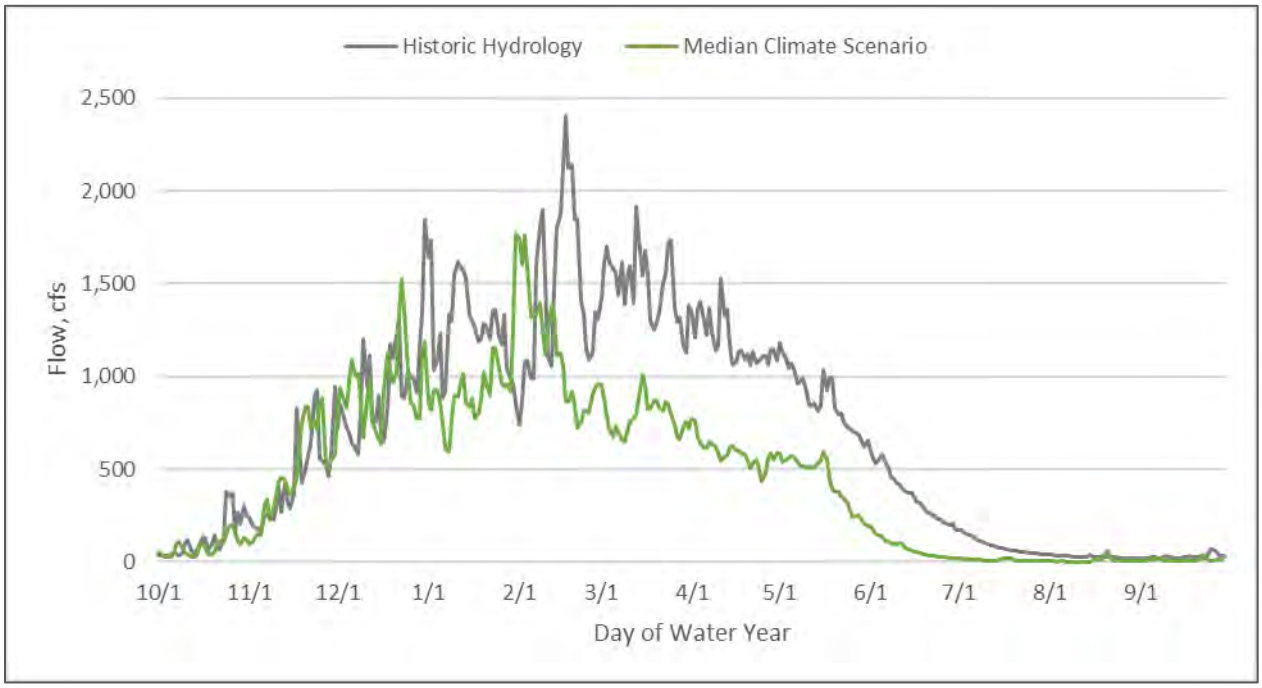


Figure 5-16. Daily Average Unimpaired Inflow to NID Reservoirs in Median Climate Change Hydrology

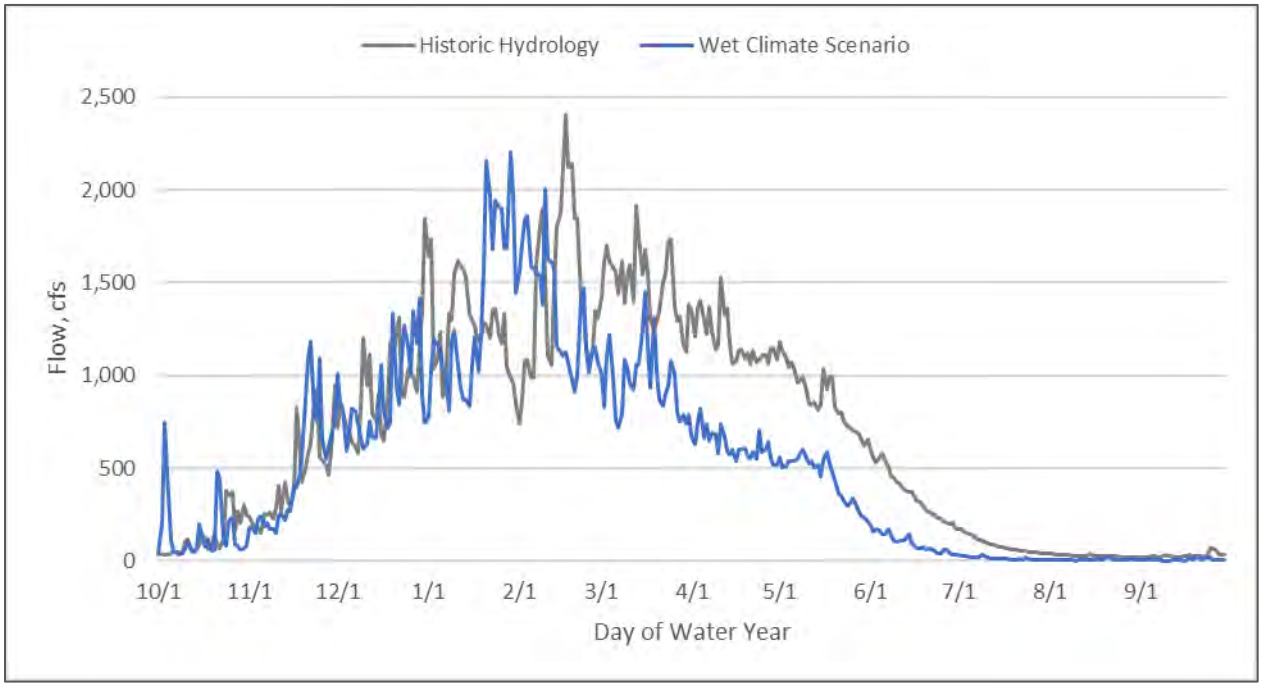


Figure 5-17. Daily Average Unimpaired Inflow to NID Reservoirs in Wet Climate Change Hydrology

5.6. Simulation Results Based on Existing Operations

5.6.1. Assumptions

Existing Operations scenarios were developed that simulate existing operations using each of the projection inputs discussed in Section 5.5. The use of these projection inputs is shown in Table 5-9. The Existing Operations scenarios each contain:

- Future FERC requirements for the Yuba-Bear, Upper Drum-Spaulding, Lower Drum-Spaulding, and Deer Creek Hydroelectric Projects from the 2014 Final Environmental Impact Statement for these projects (FERC 2014).
- 2018 COA accounting mechanisms.
- Existing facilities.
- The current Drought Contingency Plans for both NID deliveries and PG&E deliveries to PCWA.
- Recent historical deliveries are used to estimate PCWA demands.

Table 5-9. Existing Operations Scenario numbering.

	Low Demands	Baseline Demands	High Demands
Dry Climate	1	2	3
Median Climate	4	5	6
Wet Climate	7	8	9

5.6.2. Comparison to Historical Conditions

A modeling study was created to form a basis of comparison for the Existing Operations studies. This modeling study has the following assumptions:

- Historical inflow hydrology discussed in Section 5.1.
- Future FERC requirements for the Yuba-Bear, Upper Drum-Spaulding, Lower Drum-Spaulding, and Deer Creek Hydroelectric Projects from the 2014 Final Environmental Impact Statement for these projects (FERC 2014).
- 2018 COA accounting mechanisms.
- Existing Facilities.
- The current Drought Contingency Plans for both NID deliveries and PG&E deliveries to PCWA.
- Recent historical deliveries are used to estimate NID and PCWA demands.

Direct comparisons of the Existing Operations studies to the historical conditions are not possible due to the different periods of record of the hydrology inputs. Historical hydrology is derived from gage data for the 1976–2021 period. Climate hydrology projection scenarios represent the 2022–2073 period. Comparisons can be made by first calculating daily or annual averages over the respective periods of record. Sections 5.6.2.1 through 5.6.2.4 provide comparisons of selected storage, flows, deliveries, and generation under historic conditions to the climate scenarios using this approach.

5.6.2.1 Reservoir Storage Results

Figure 5-18 shows historic (1976–2021) and projected (2022–2073) average storage for Jackson Meadows as a function of the day of the year under Existing Operations. On average, under climate change, reservoir storage peaks earlier in the season, which is a common feature for all reservoirs due to earlier snow melting. This feature is observed in Figure 5-19 for Bowman Reservoir, Figure 5-20 for Rollins Reservoir, and Figure 5-21 for Scott Flats Reservoir.

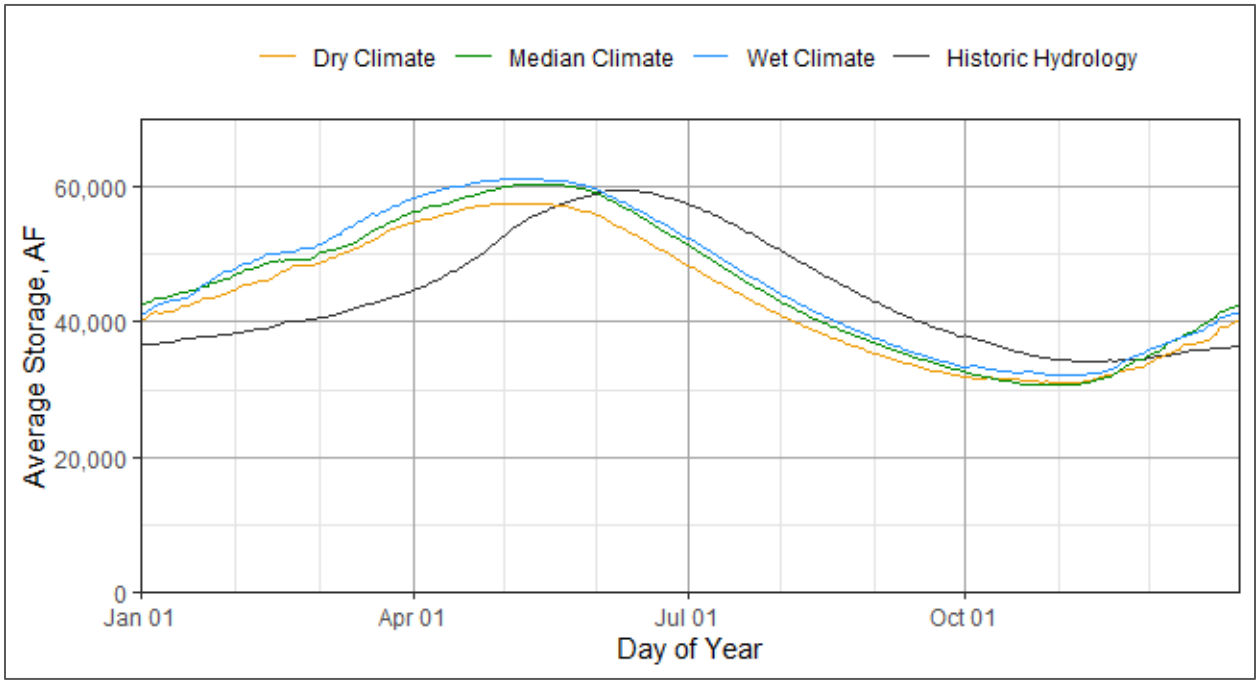


Figure 5-18. Jackson Meadows Reservoir Average Daily Storage, Existing Operations Simulation Results

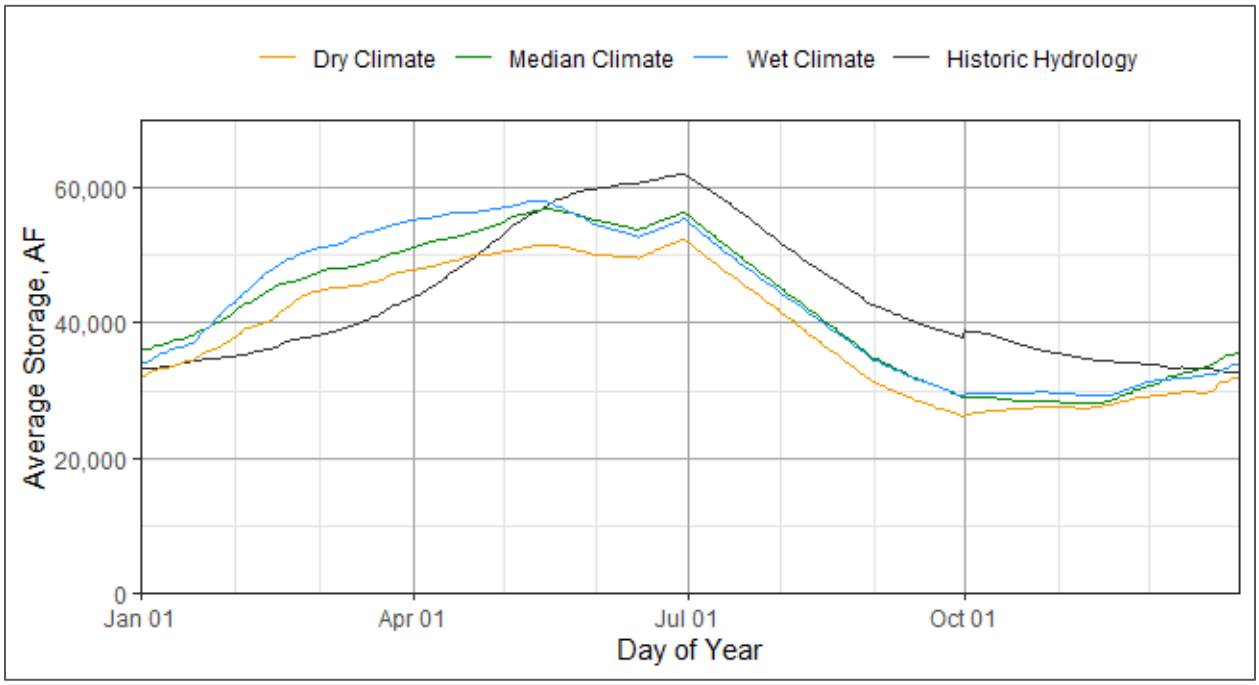


Figure 5-19. Bowman Reservoir Average Daily Storage, Existing Operations Simulation Results

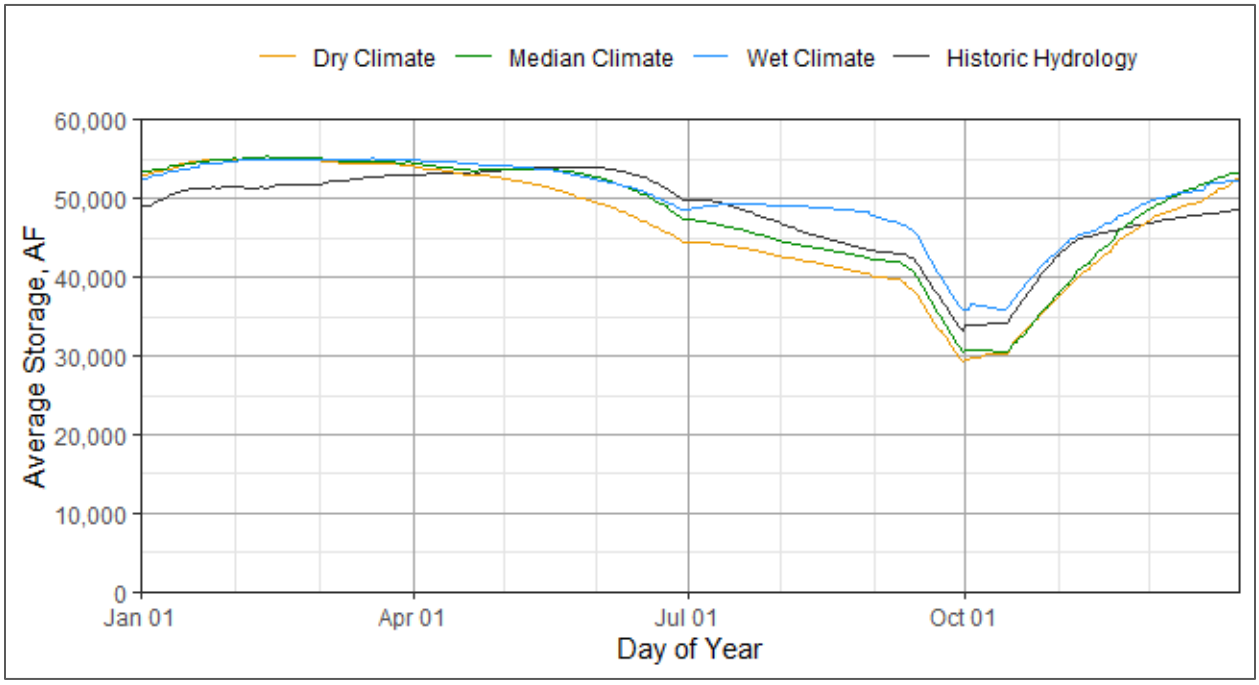


Figure 5-20. Rollins Reservoir Average Daily Storage, Existing Operations Simulation Results

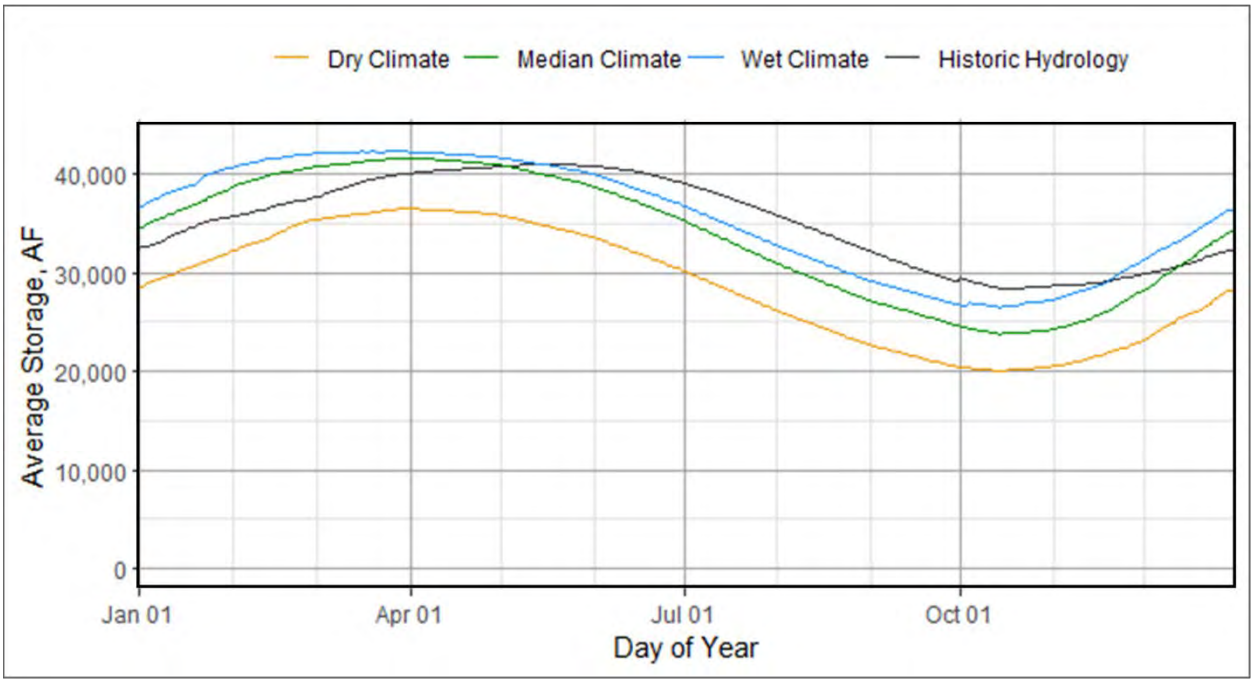


Figure 5-21. Scotts Flat Reservoir Average Daily Storage, Existing Operations Simulation Results

Table 5-10. Average Carryover Storage, Baseline Demands

Reservoir	Carryover Storage with Baseline Demands (AF)			
	Historic Hydrology	Dry Climate	Median Climate	Wet Climate
Jackson Meadows Reservoir	34,366	31,024	30,703	31,934
Bowman Reservoir	35,228	27,600	27,404	31,887
Sawmill Lake	1,670	1,625	1,561	1,548
French Lake	8,503	8,726	8,602	8,650
Faucherie Lake	2,109	2,170	2,144	2,167
Jackson Lake	994	962	891	874
Rollins Reservoir	42,051	36,981	37,339	36,907
Scotts Flat Reservoir	28,525	20,323	24,200	27,124
Lake Combie	1,126	1,857	1,972	2,097
Total	142,818	120,524	124,440	131,774

5.6.2.2 Flow Results

Average annual flows through selected conveyance structures are shown in Table 5-11. Figure 5-22 shows the average diversions from the Middle Yuba River to the Milton-Bowman Conduit as a function of day of year. The earlier runoff in the climate change hydrology causes reservoirs to make spill avoidance releases earlier in the year. This pattern is consistent across all major diversions in the system and can be observed for diversions into the Bowman-Spaulding Conduit in Figure 5-23, diversions from the South Yuba River into the Deer Creek Powerhouse in Figure 5-24, diversions from the South Yuba River into the Drum Canal in Figure 5-25, diversions from Rollins Reservoir into the Bear River Canal in Figure 5-26, diversions from Deer Creek into NID's Cascade Canal, DS Canal, Newtown Canal, and Tunnel Canal in Figure 5-27, and diversions from Lake Combie in Figure 5-28.

Table 5-11. Average Annual Diversions into Canals, Baseline Demands, AF

	Historical Hydrology	Dry Climate	Median Climate	Wet Climate
Diversions into Milton-Bowman Conduit	51,018	41,646	48,721	49,751
Diversions into Bowman-Spaulding Conduit	88,236	81,473	89,631	93,029
Diversions through Deer Creek Powerhouse	35,010	40,745	43,225	45,735
NID Diversions into Drum Canal	68,007	50,902	56,222	58,841
NID Diversions into Bear River Canal	38,494	28,969	33,166	31,650

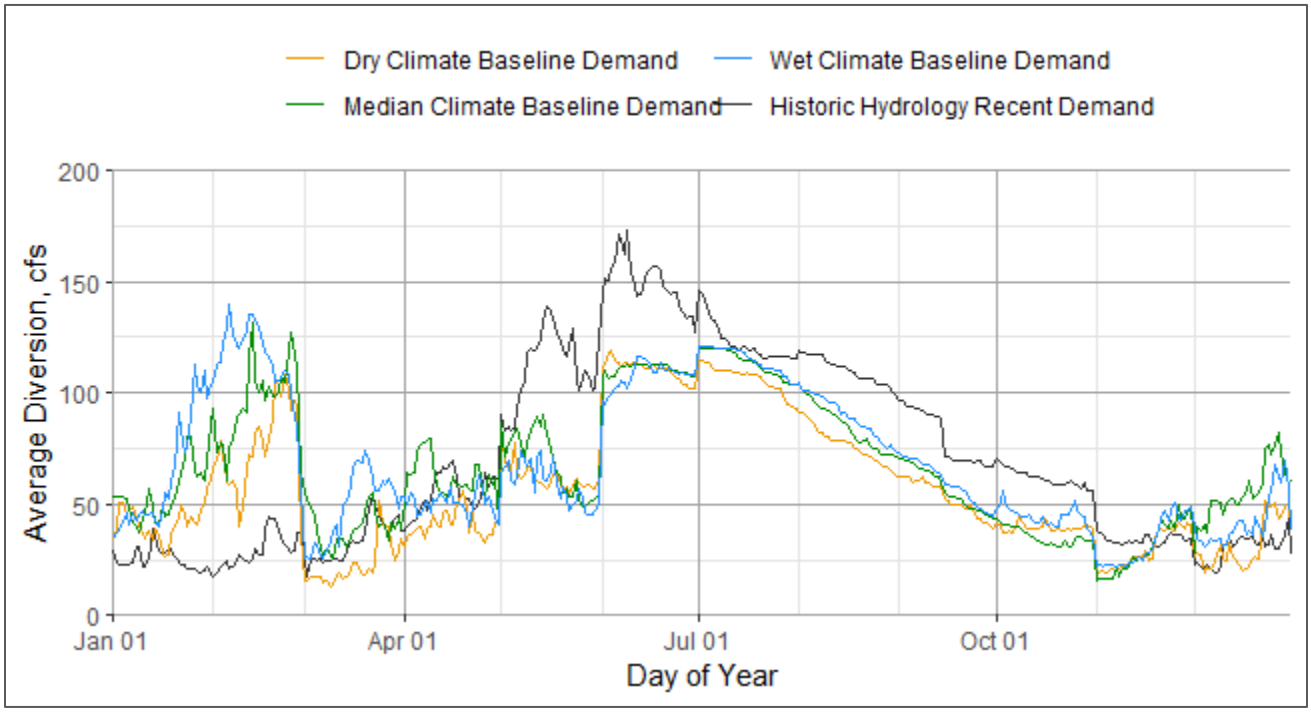


Figure 5-22. Average Daily Flow in Milton-Bowman Conduit, Existing Operations Simulation Results

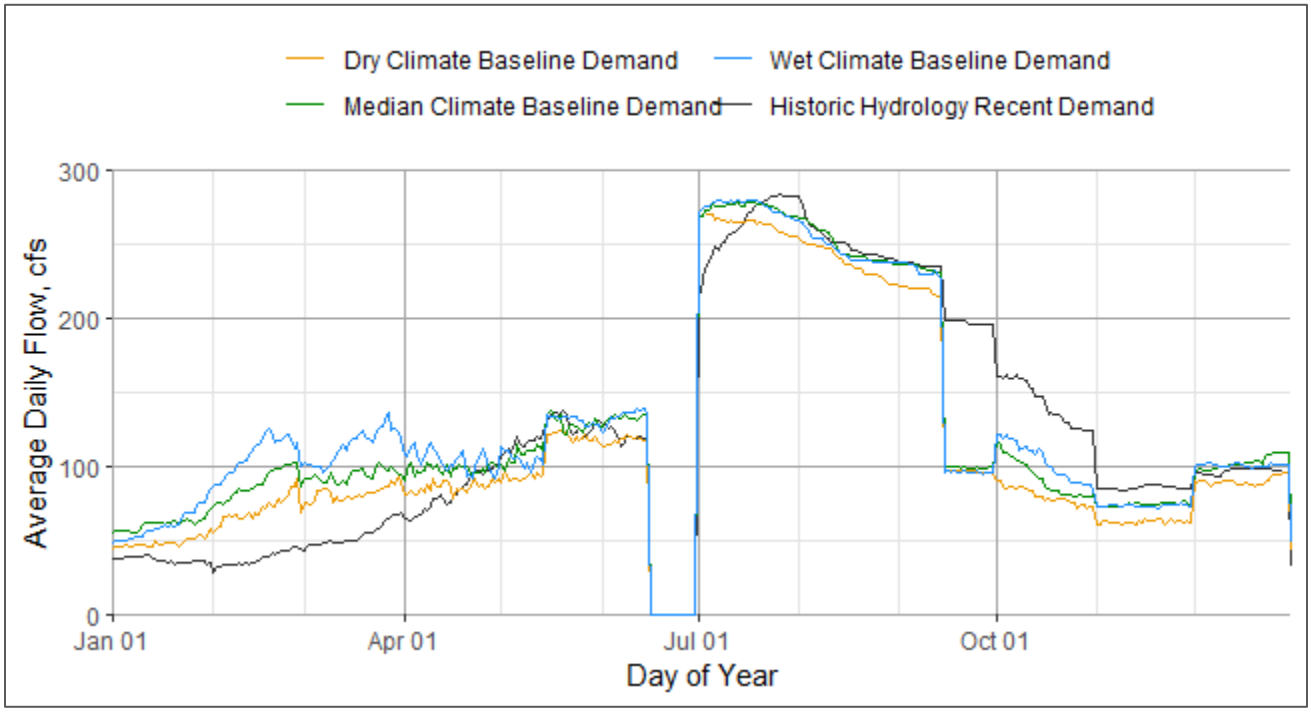


Figure 5-23. Average Daily Flow in Bowman-Spaulding Conduit at Bowman Reservoir, Existing Operations Simulation Results

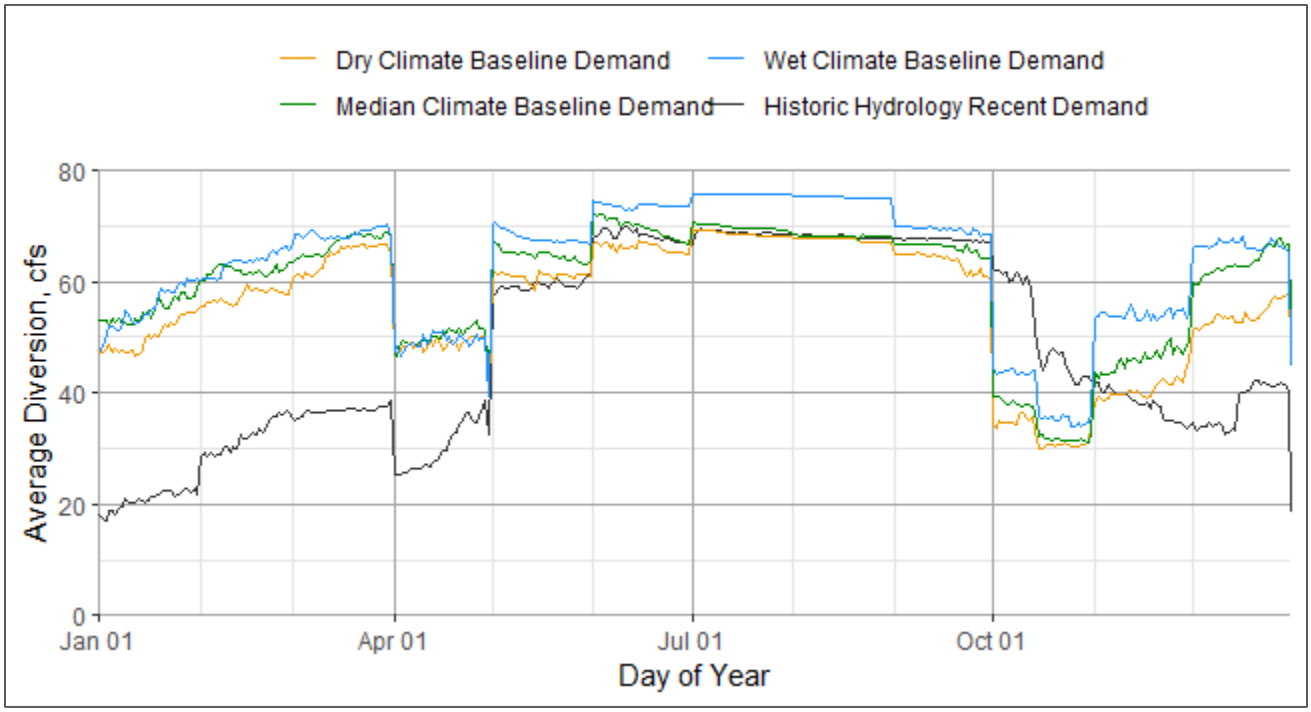


Figure 5-24. Average Daily Flow in Deer Creek Powerhouse, Existing Operations Simulation Results

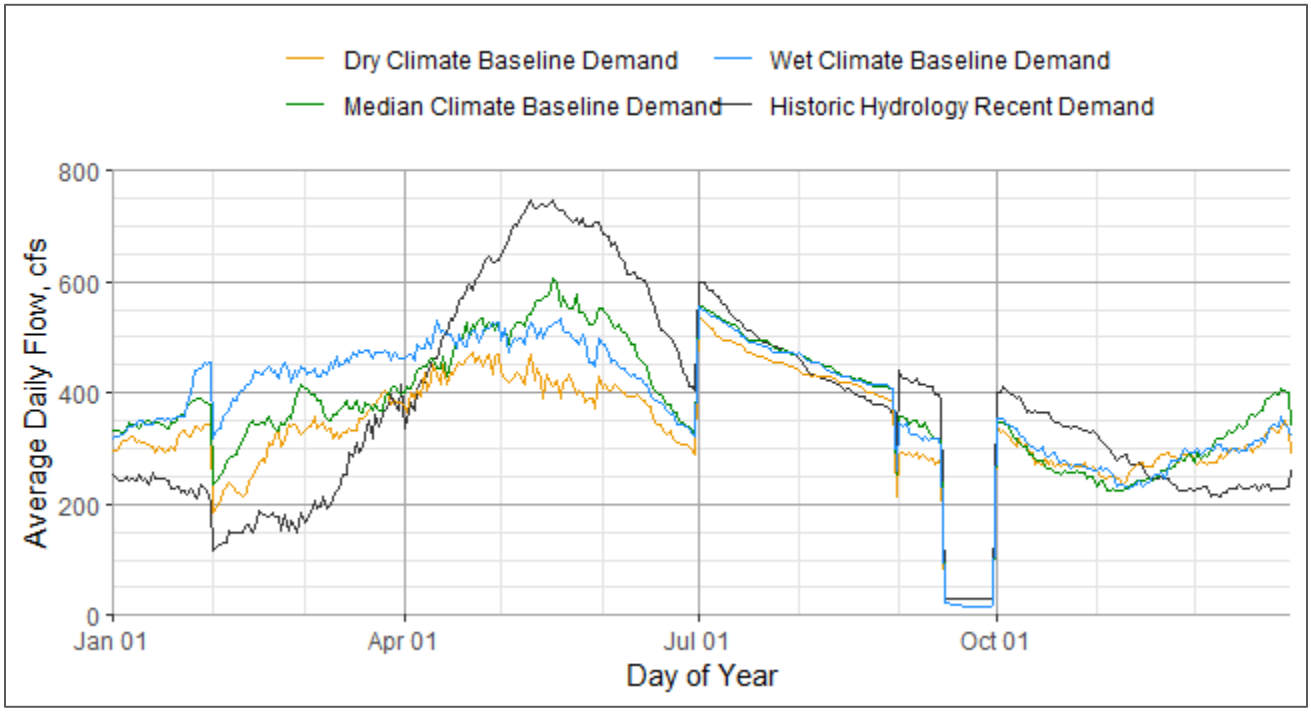


Figure 5-25. Average Daily Flow in Drum Canal below Spaulding Powerhouse No. 1, Existing Operations Simulation Results

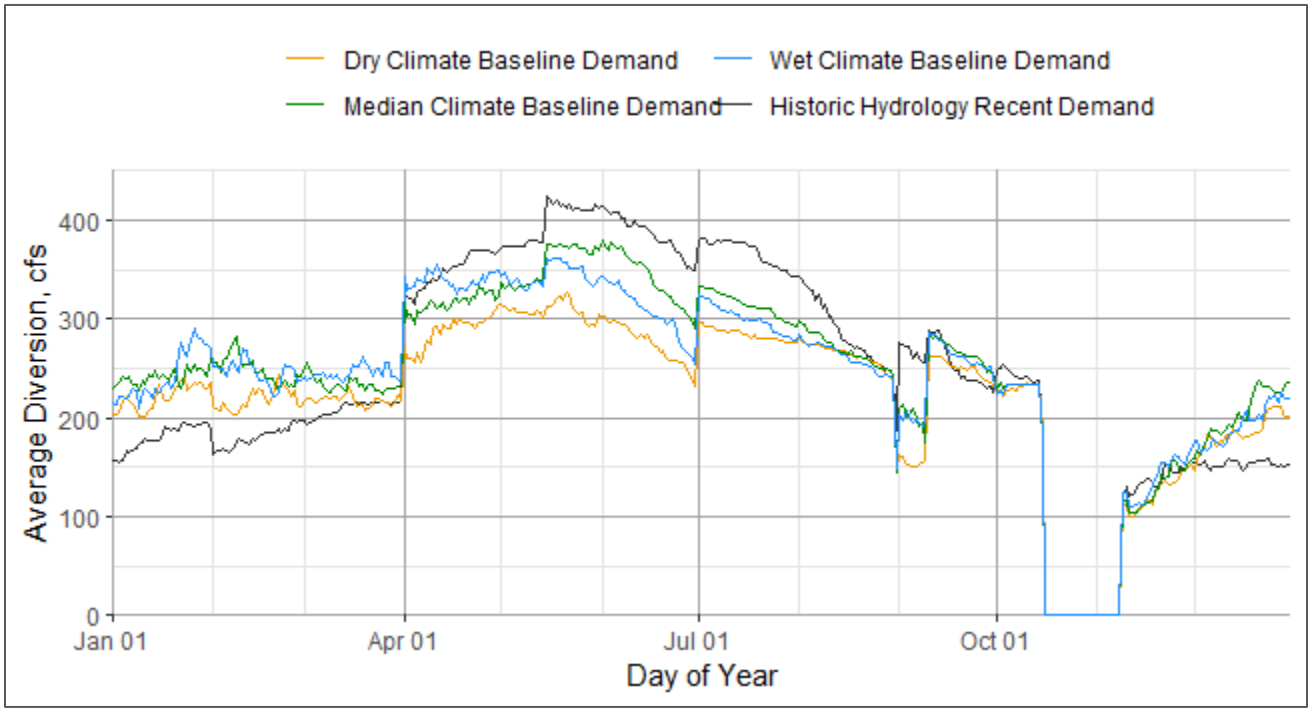


Figure 5-26. Average Daily Flow in Bear River Canal, Existing Operations Simulation Results

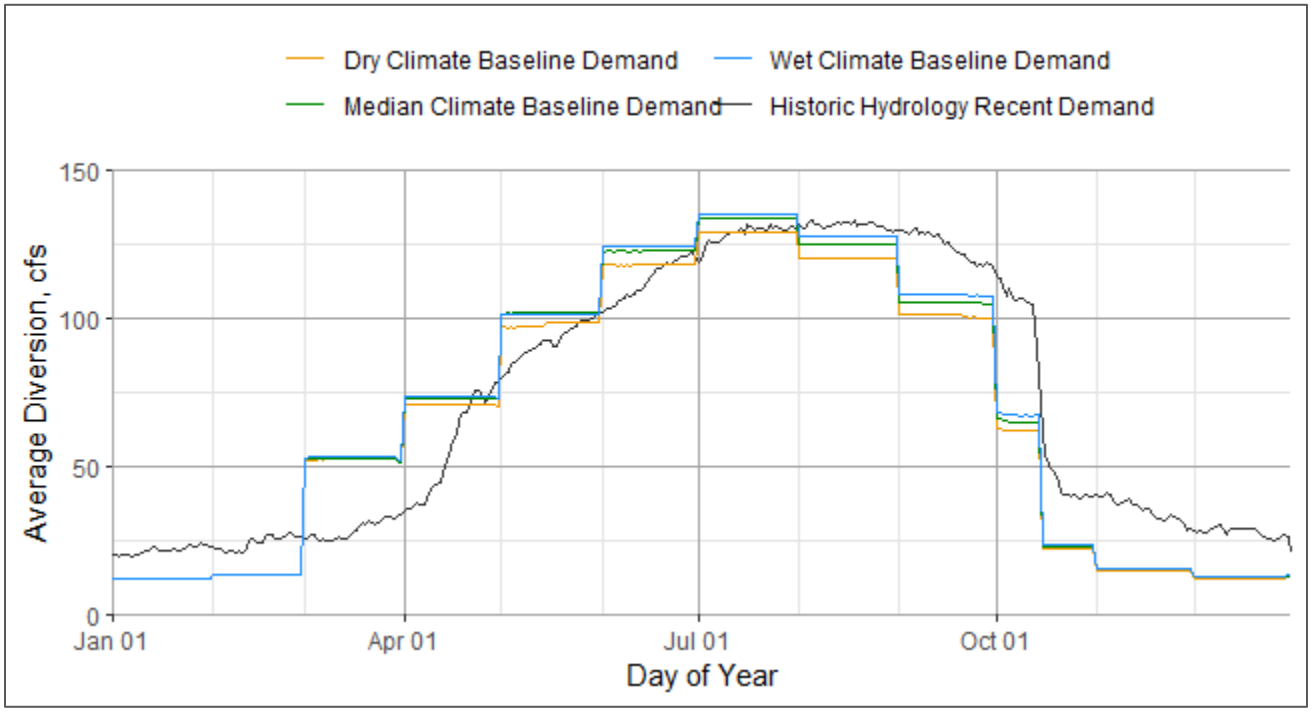


Figure 5-27. Average Daily Diversion from Deer Creek, Existing Operations Simulation Results

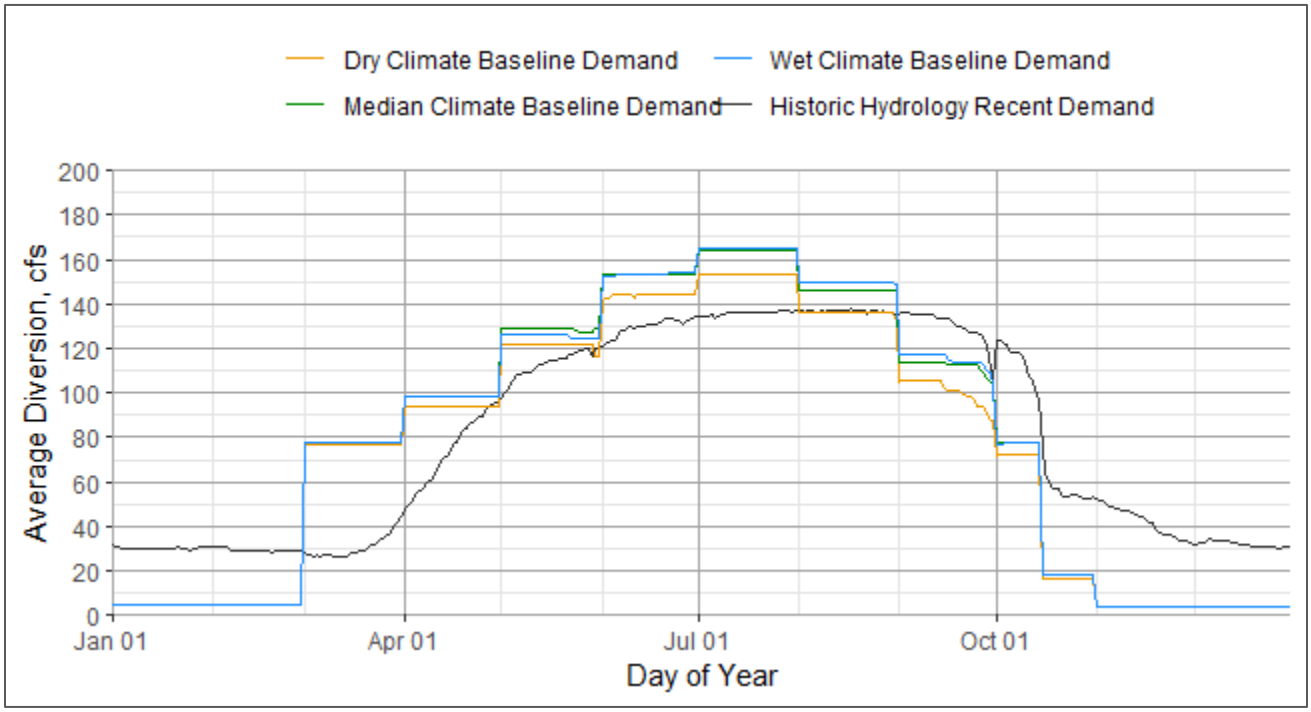


Figure 5-28. Average Daily Diversion from Lake Combie, Existing Operations Simulation Results

5.6.2.3 Deliveries

Average annual deliveries are shown in Table 5-12.

Table 5-12. Average Annual Deliveries in Existing Operations Studies, AF

	Dry Climate	Median Climate	Wet Climate
Low Demand	98,643	103,348	103,942
Baseline Demand	128,991	137,706	137,555
High Demand	146,458	159,371	161,611

Exceedance charts of annual deliveries, separated by demand level, are shown in Figure 5-29 through Figure 5-31. Figure 5-29 shows the low demand simulations, which have lower deliveries than the historic simulation due to the lower total demands. Figure 5-30 shows the baseline demand simulations, which generally have slightly lower deliveries than the historic simulation. Figure 5-31 shows the high demand simulations, which have higher deliveries in wet years due to the higher demands and lower deliveries in dry years than the historic simulation.

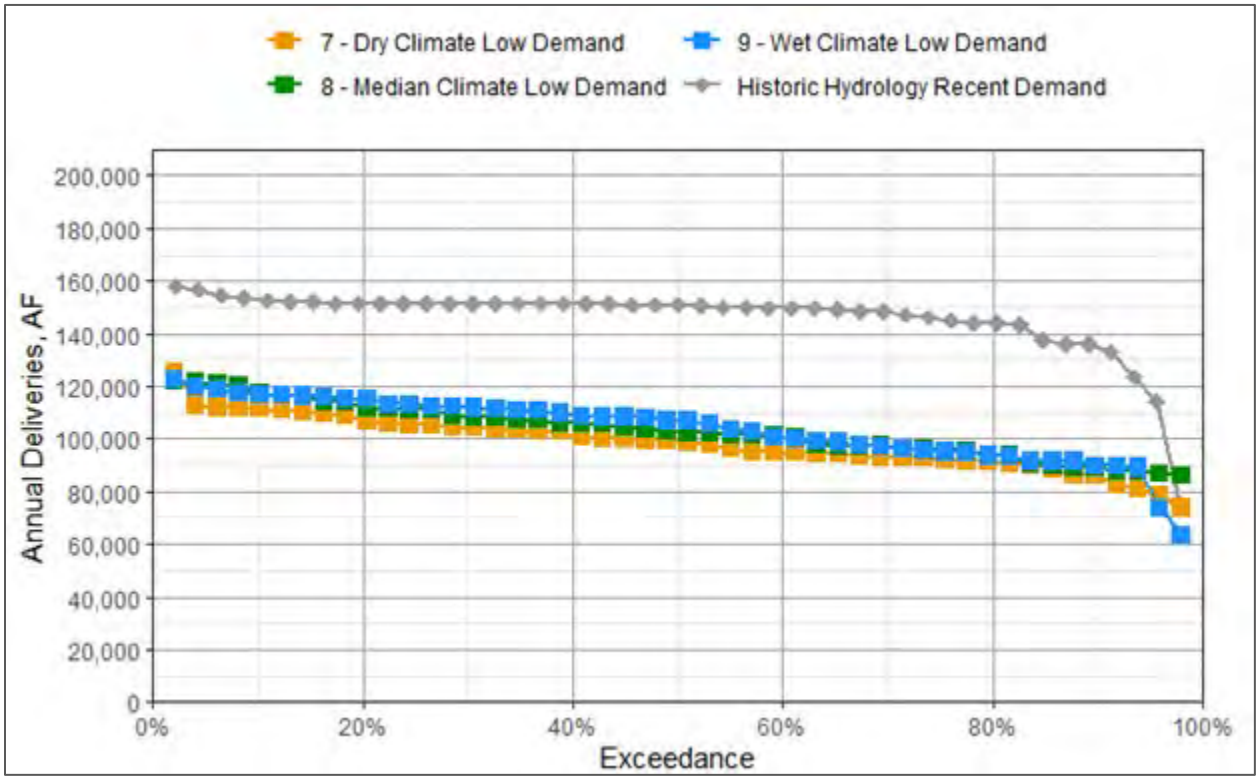


Figure 5-29. Annual Delivery Exceedance, Low Demand Existing Operations Studies

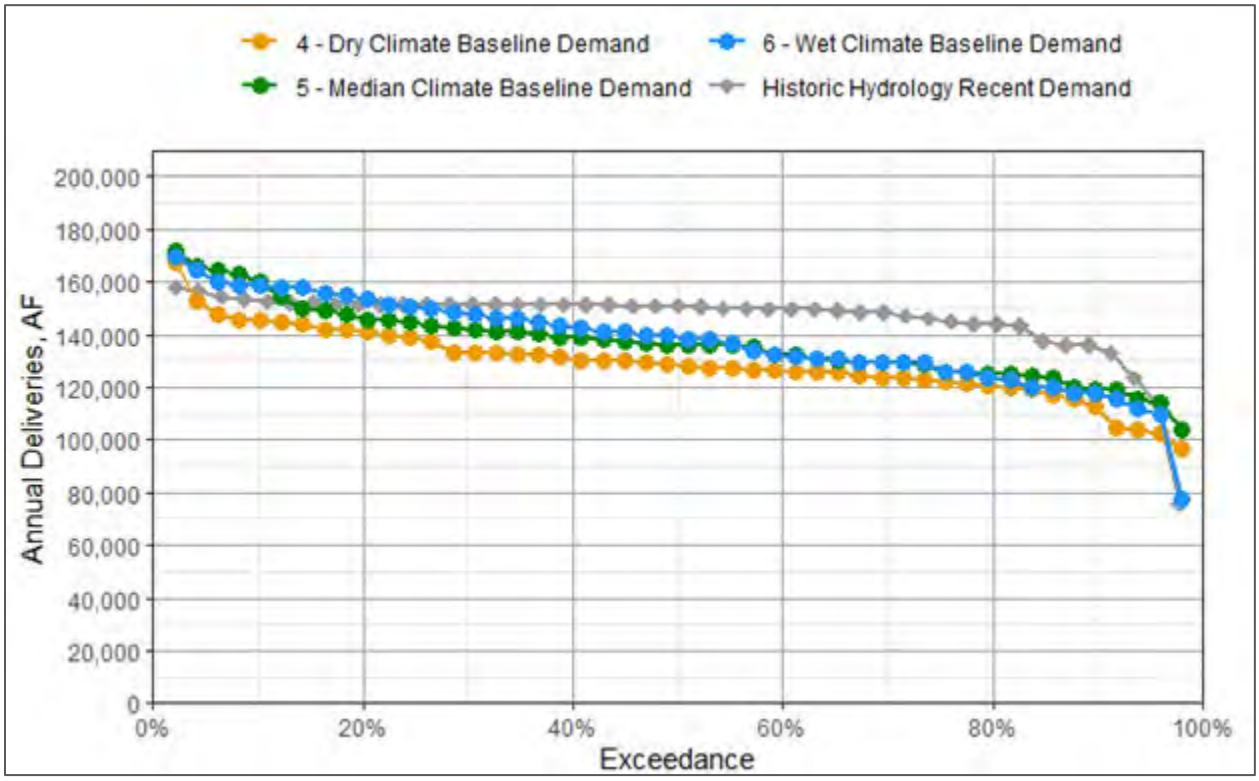


Figure 5-30. Annual Delivery Exceedance, Baseline Demand Existing Operations Studies

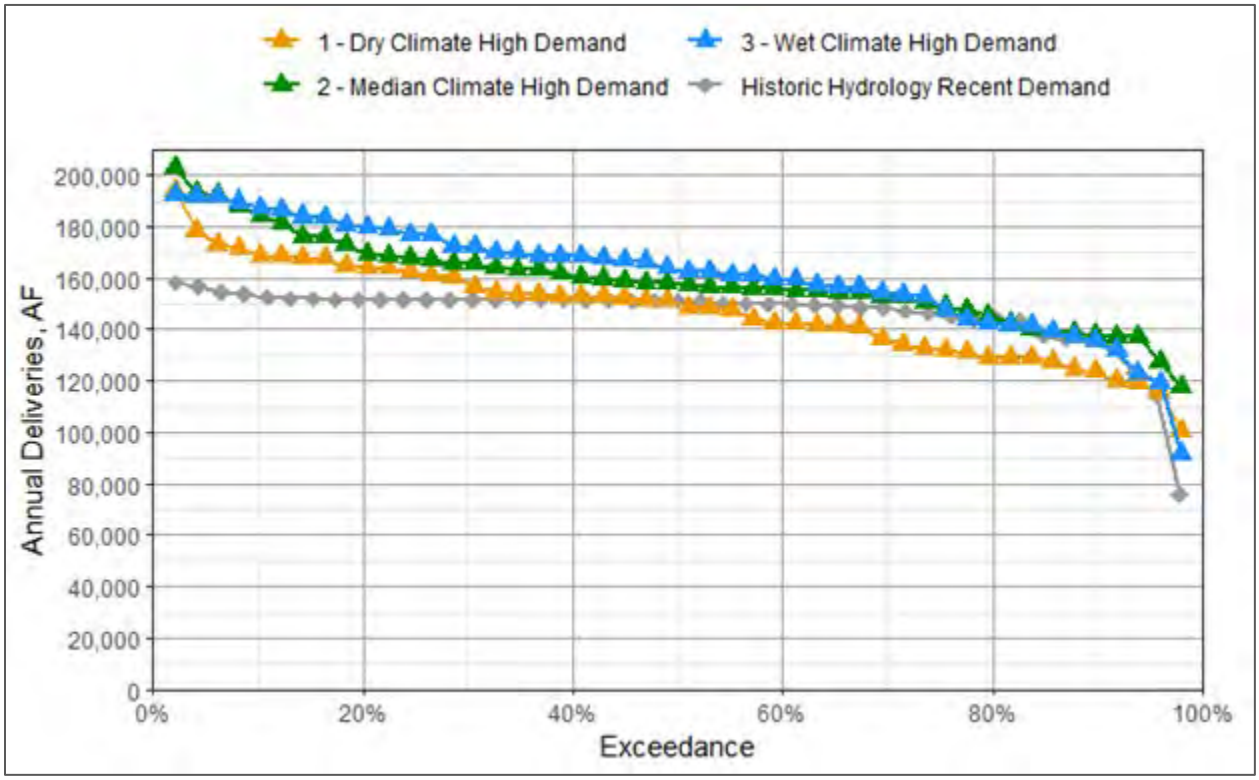


Figure 5-31. Annual Delivery Exceedance, High Demand Existing Operations Studies

Each baseline study results in some amount of unmet demands. Average annual unmet demands are shown in Table 5-13.

Table 5-13. Average Annual Unmet Demands in Existing Operations Studies, AF

	Dry Climate	Median Climate	Wet Climate
Low Demand	9,014	5,740	5,763
Baseline Demand	20,663	14,099	14,683
High Demand	35,158	24,112	23,027

Exceedance charts of annual unmet demand, separated by demand level, are shown in Figure 5-32, Figure 5-33, and Figure 5-34.

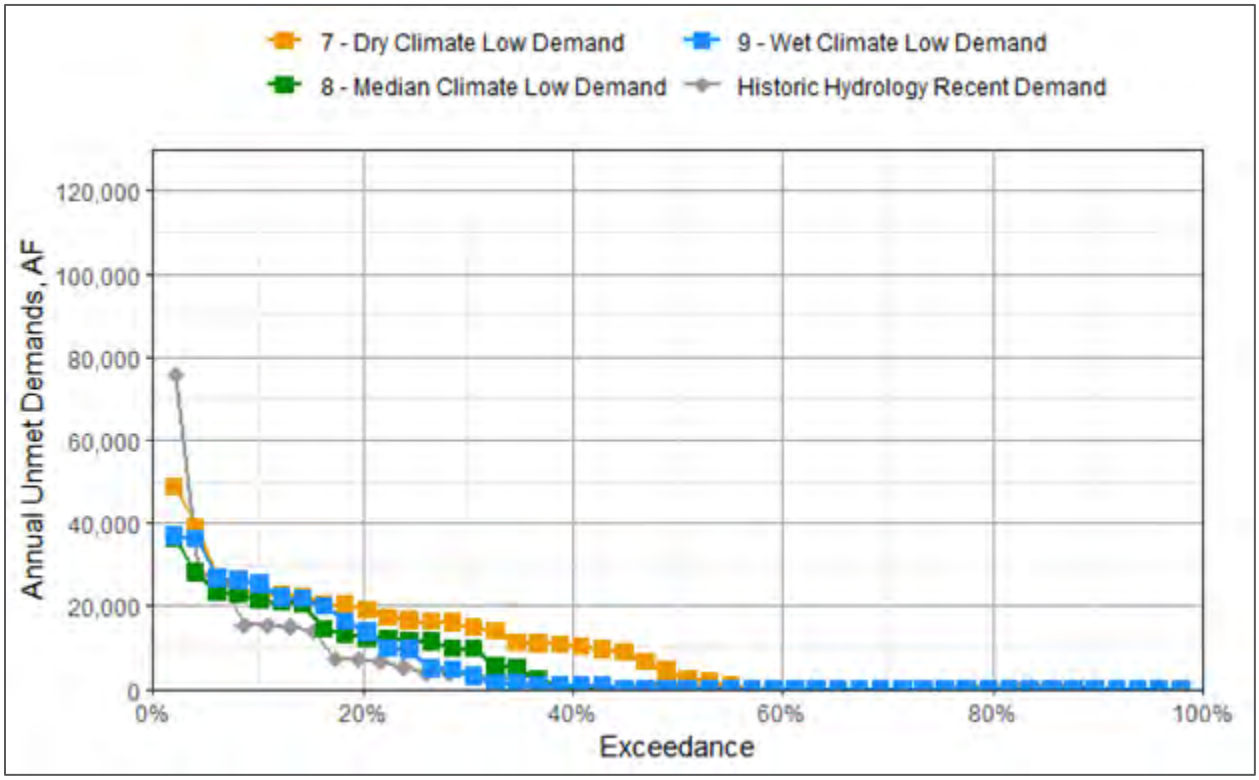


Figure 5-32. Unmet Demands Exceedance, Low Demand Existing Operations Studies

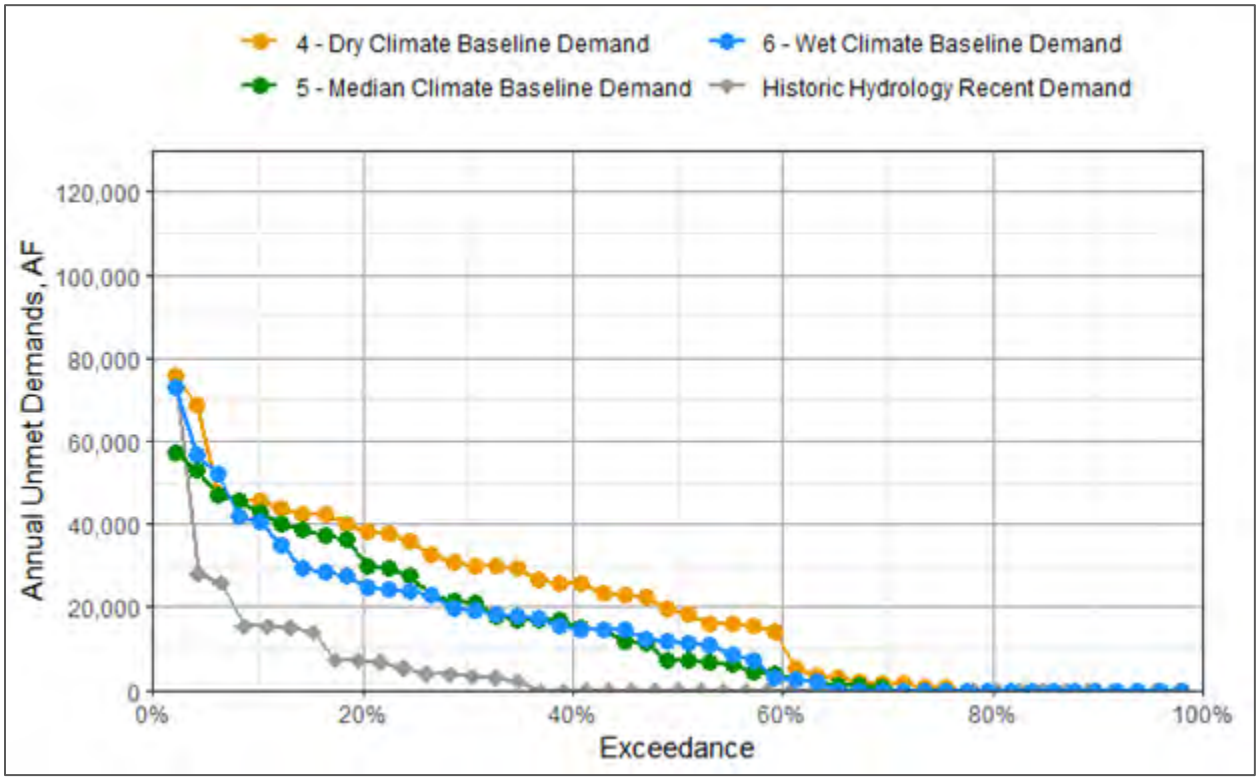


Figure 5-33. Unmet Demands Exceedance, Baseline Demand Existing Operations Studies

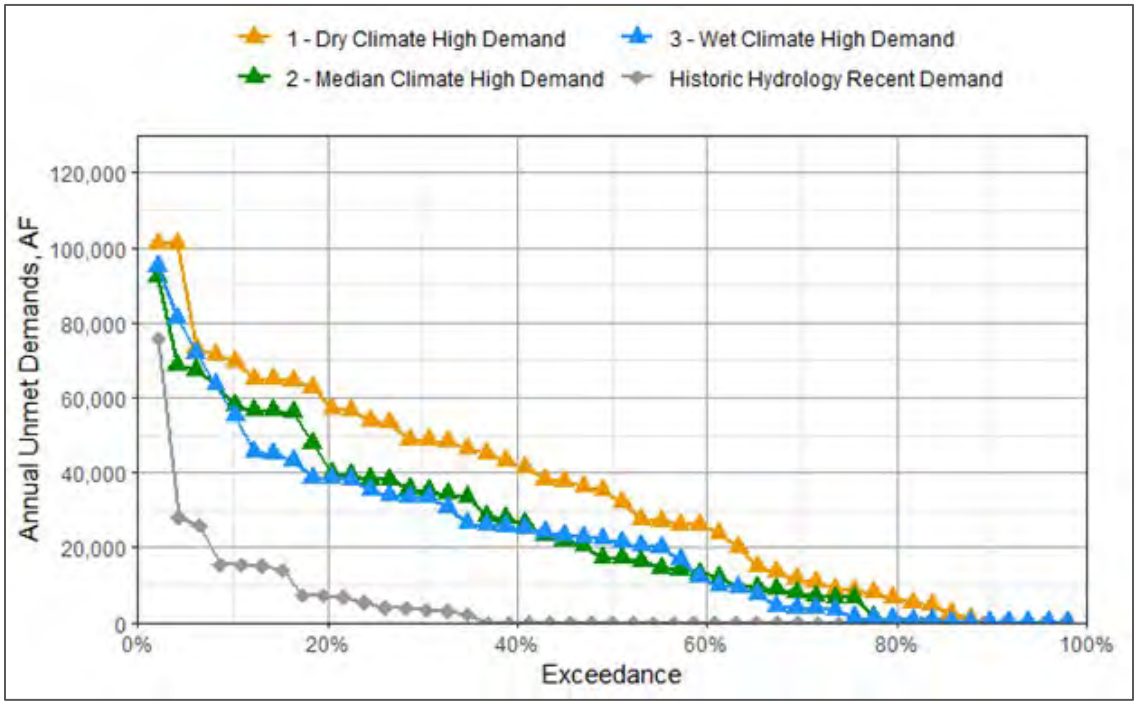


Figure 5-34. Unmet Demands Exceedance, High Demand Existing Operations Studies

5.6.2.4 Generation

Annual average power generation in the baseline studies is shown in Table 5-14. For comparison, the average annual generation in the historic hydrology calibration study is 251.4 GWh.

Table 5-14. Average Annual NID Generation, Existing Operations Studies, GWh

	Dry Climate	Median Climate	Wet Climate
Low Demand	205.7	238.2	254.0
Baseline Demand	205.0	237.5	258.7
High Demand	203.7	236.4	250.0

5.6.3. Results Summary

The results of the nine Existing Operations studies were presented to the NID BOD and stakeholders for consideration to carry forward for evaluation of strategic alternatives. For this evaluation, three of the nine Existing Operations scenarios were chosen. The chosen scenarios were:

- Dry Climate with High Demands
- Median Climate with Baseline Demands
- Wet Climate with Low Demands

These scenarios provide dry and wet bookends with a median climate scenario to represent a mid-point. Use of these scenarios provides a wide range of hydrologic conditions and consumptive demands; the scenarios are suitable for testing the strategic alternatives designed to improve NID's water supply security in the face of shifting runoff patterns and volumes in the projected climate scenarios.

Chapter 6. Strategic Alternatives

Seven strategic alternatives were selected as potential measures to increase NID's future water security. Each strategic alternative was layered onto each of the three Existing Operations scenarios. The benefits of the strategic alternatives were then determined by comparing them to each of the selected Existing Operations studies.

6.1. Existing Operations Studies

As discussed in Section 1.6.3, three Existing Operations scenarios were chosen for measuring the benefit of each of the strategic alternatives.

To establish a basis for measuring benefit, exceedance curves of unmet demands, total NID carryover storage, and total NID generation for these selected Existing Operations scenarios are shown as Figure 6-1 through Figure 6-3. Exceedance curves are graphical representations used to analyze and visualize the likelihood of exceeding a certain threshold or level for a given variable. As an example (Example 1), if one wanted to know how often Annual Unmet Demand exceeds 60,000 AF under the Dry Climate High Demand Scenario, based on Figure 6-1, the answer is 20% of the time.

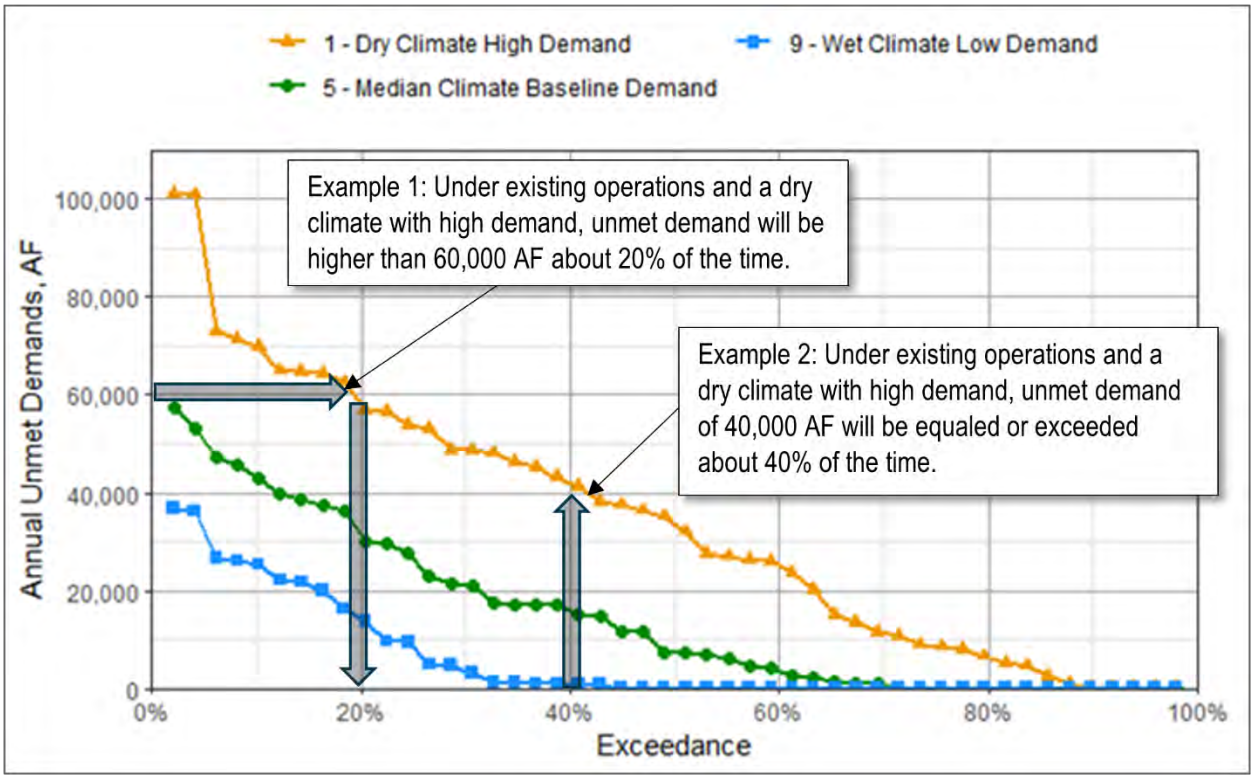


Figure 6-1. Annual Unmet Demands Exceedance, Selected Existing Operations Scenarios

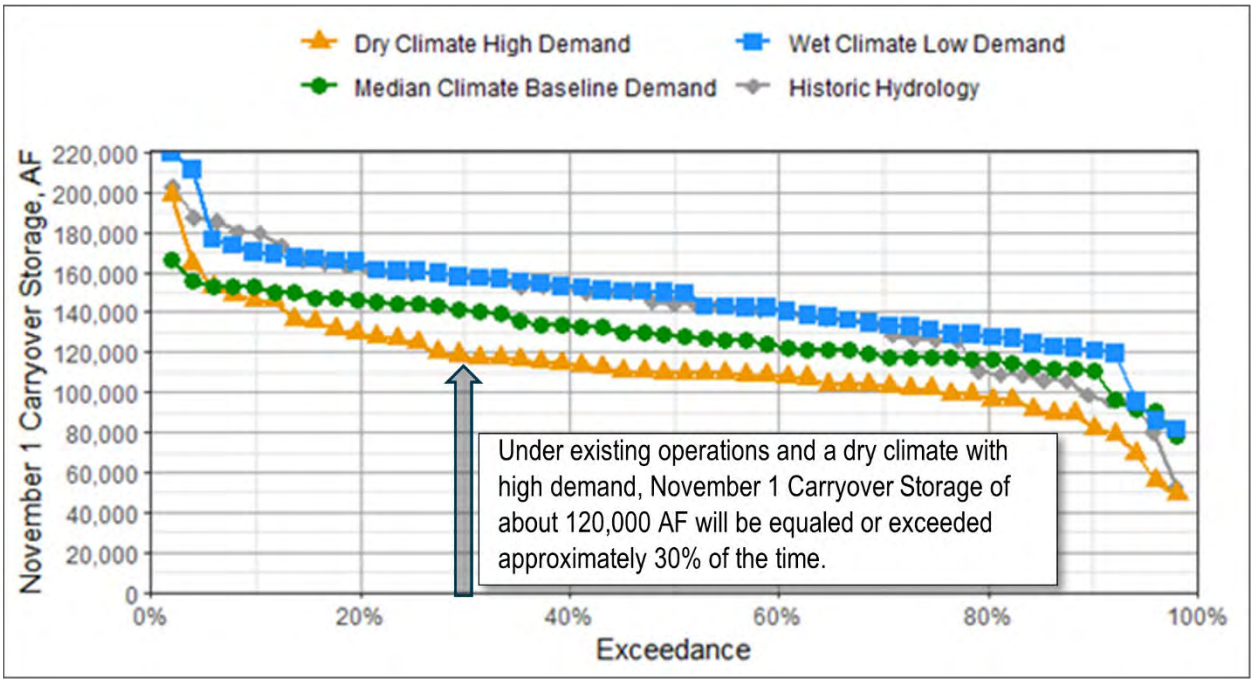


Figure 6-2. November 1 Carryover Storage Exceedance, Selected Existing Operations Scenarios

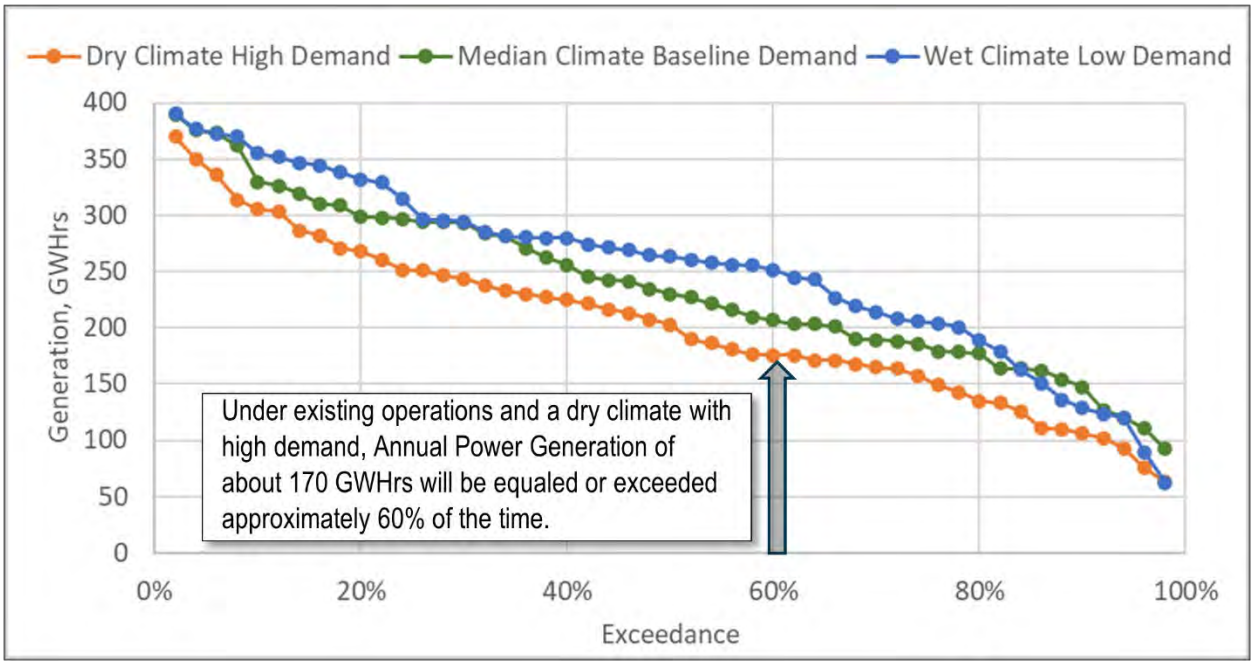


Figure 6-3. Annual NID Generation Exceedance, Selected Existing Operations Scenarios

6.2. Strategic Alternatives Chosen for Modeling

Seven strategic alternatives were chosen for modeling:

- Extended Irrigation Season
- Rollins Reservoir 10,000 AF Storage Increase
- Rollins Reservoir 50,000 AF Storage Increase
- Centennial Reservoir
- Revised Carryover Targets
- Water Purchases from PG&E
- Revised Carryover Targets + Water Purchases from PG&E

Sections 6.3 through 6.9 describe each alternative and provide summary modeling results.

6.3. Extended Irrigation Season

NID's current irrigation season runs through October 15th. The extended irrigation season strategic alternative extends the end of the irrigation season through October 31st. Irrigation deliveries in the second half of October are assumed to match irrigation deliveries in the first half of October. Municipal Deliveries to water treatment plants are left unchanged. Average annual demands are shown in Table 6-1.

Table 6-1. Average Annual Demands, Regular Irrigation Season and Extended Irrigation Season

Scenario	Average Annual Demand, Current Irrigation Season (AF)	Average Annual Demand, Extended Irrigation Season (AF)	Difference (AF)
Dry Climate High Demand	181,616	188,055	6,439
Median Climate Baseline Demand	151,806	157,318	5,512
Wet Climate Low Demand	109,705	113,531	3,826

Modeling of the extended irrigation season shows that this alternative would result in more irrigation deliveries but a reduction in the November 1 carryover storage. This is summarized in Table 6-2. Demand, delivery, and unmet demands for each scenario are shown in Table 6-3. Resulting unmet demand exceedance for the Extended Irrigation Season Alternative is shown in Figure 6-4.

Table 6-2. Increase in Demand and Deliveries in Extended Irrigation Season

Scenario	Increase in Demand	Increase in Deliveries	Change in Carryover Storage
Dry Climate High Demand	6,439	5,193	-265
Median Climate Baseline Demand	5,512	4,001	-2,078
Wet Climate Low Demand	3,826	3,334	-2,656

Table 6-3. Deliveries and Unmet Demand, Extended Irrigation Alternative

Scenario	Project Condition	Demand	Delivery	Unmet Demand
Dry Climate High Demand	Regular Irrigation Season	181,616	146,458	35,158
	Extended Irrigation Season	188,055	151,651	36,405
Median Climate Baseline Demand	Regular Irrigation Season	151,806	137,706	14,099
	Extended Irrigation Season	157,318	141,707	15,611
Wet Climate Low Demand	Regular Irrigation Season	109,705	103,941	5,763
	Extended Irrigation Season	113,531	107,275	6,256

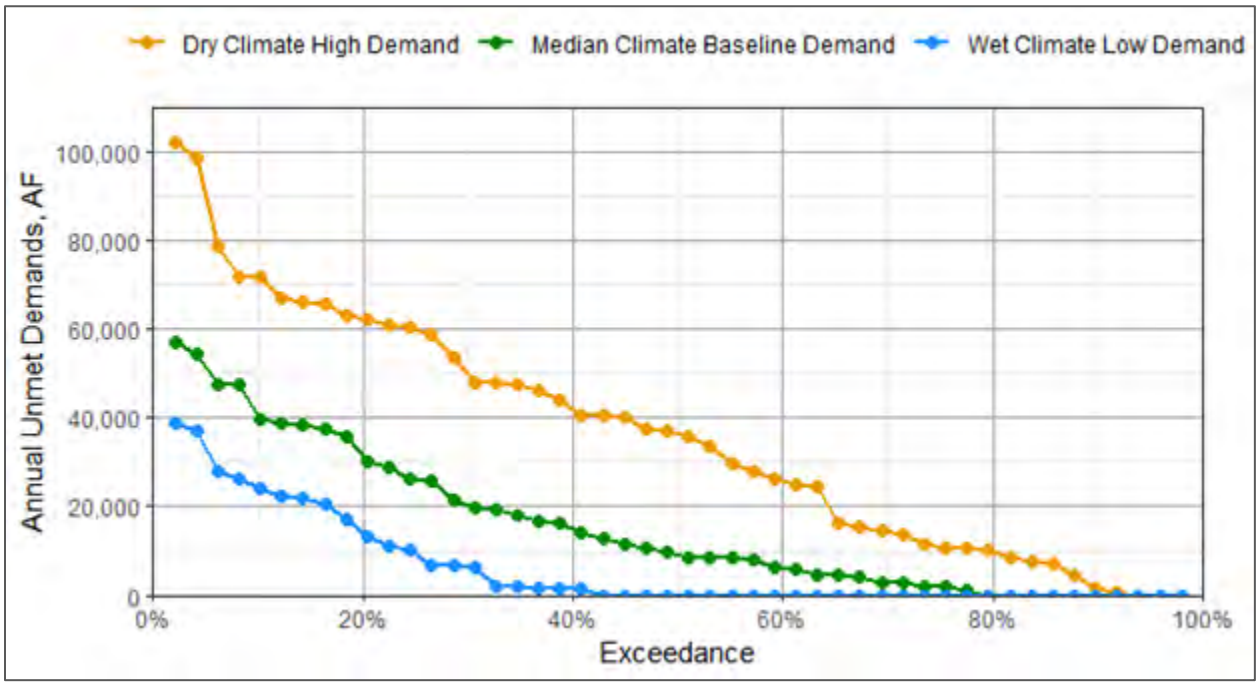


Figure 6-4. Annual Unmet Demand Exceedance, Extended Irrigation Season Alternative

6.4. Rollins Reservoir 10,000 AF Storage Capacity Increase

A modified Rollins Reservoir was built into the model simulating an additional 10,000 AF of usable storage capacity at Rollins Reservoir. All outlet works are assumed to have the same capacities as the current Rollins Reservoir outlet works. Proposed future FERC minimum flow requirements and minimum pool requirements were also assumed.

This strategic alternative allows for more water to be stored in Rollins Reservoir ahead of the summer storage dispatch season, allowing a larger buffer from minimum pool levels. Currently, Rollins Reservoir spills most years, and there is water available to be stored in nearly all years. Rollins Reservoir storage with this strategic alternative is shown for the Dry Climate High Demand scenario in Figure 6-5, for the Median Climate Baseline Demand scenario in Figure 6-6, and for the Wet Climate Low Demand scenario in Figure 6-7. These figures all show that Rollins Reservoir continues to fill and spill in most years with the expanded storage capacity.

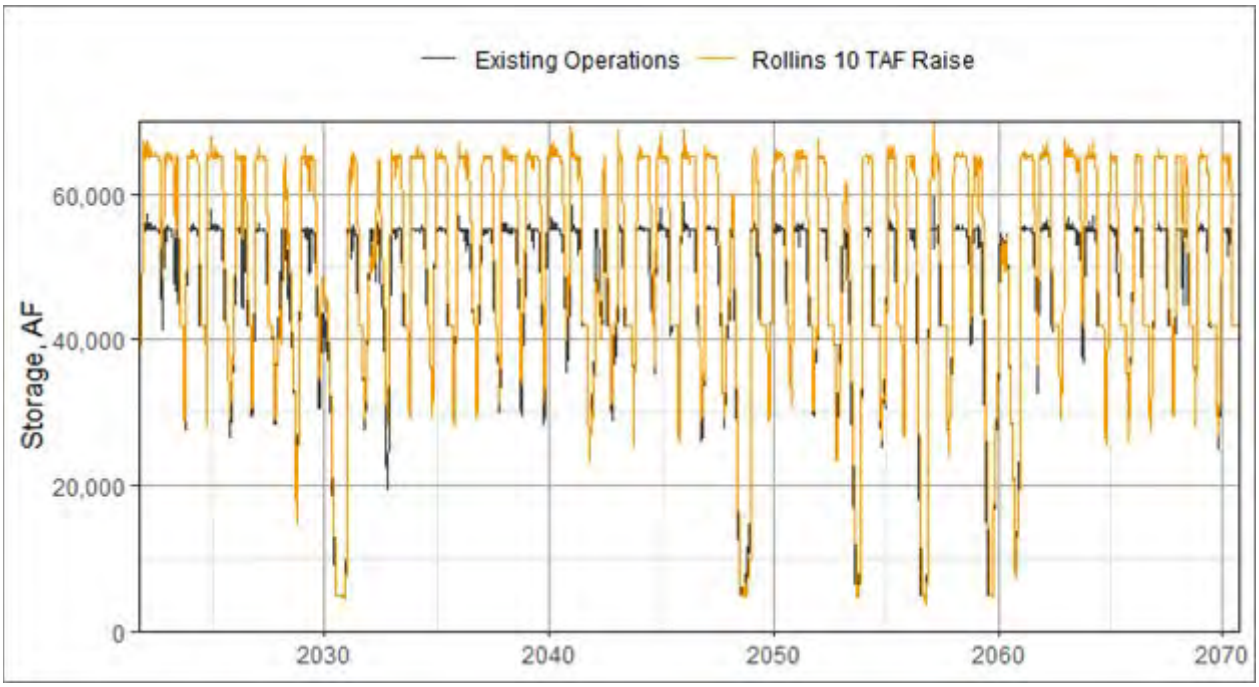


Figure 6-5. Rollins Reservoir Storage, Rollins 10 TAF Raise Alternative, Dry Climate High Demands Scenario

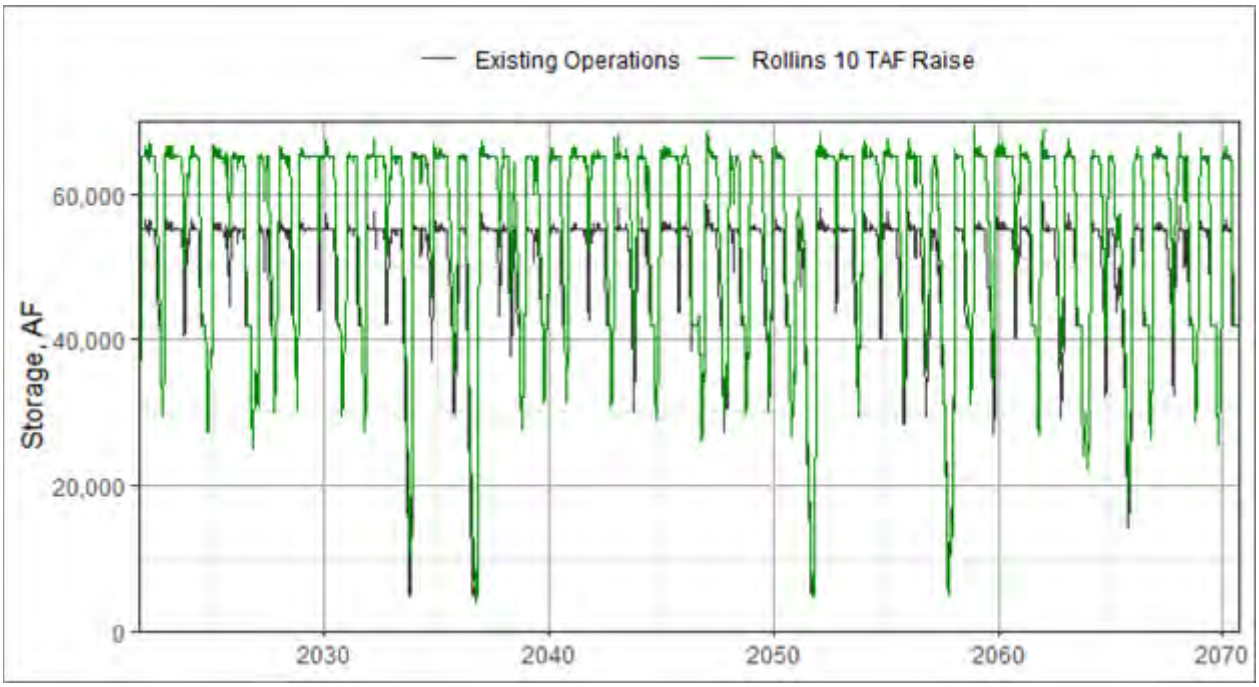


Figure 6-6. Rollins Reservoir Storage, Rollins 10 TAF Raise Alternative,
Median Climate Baseline Demands Scenario

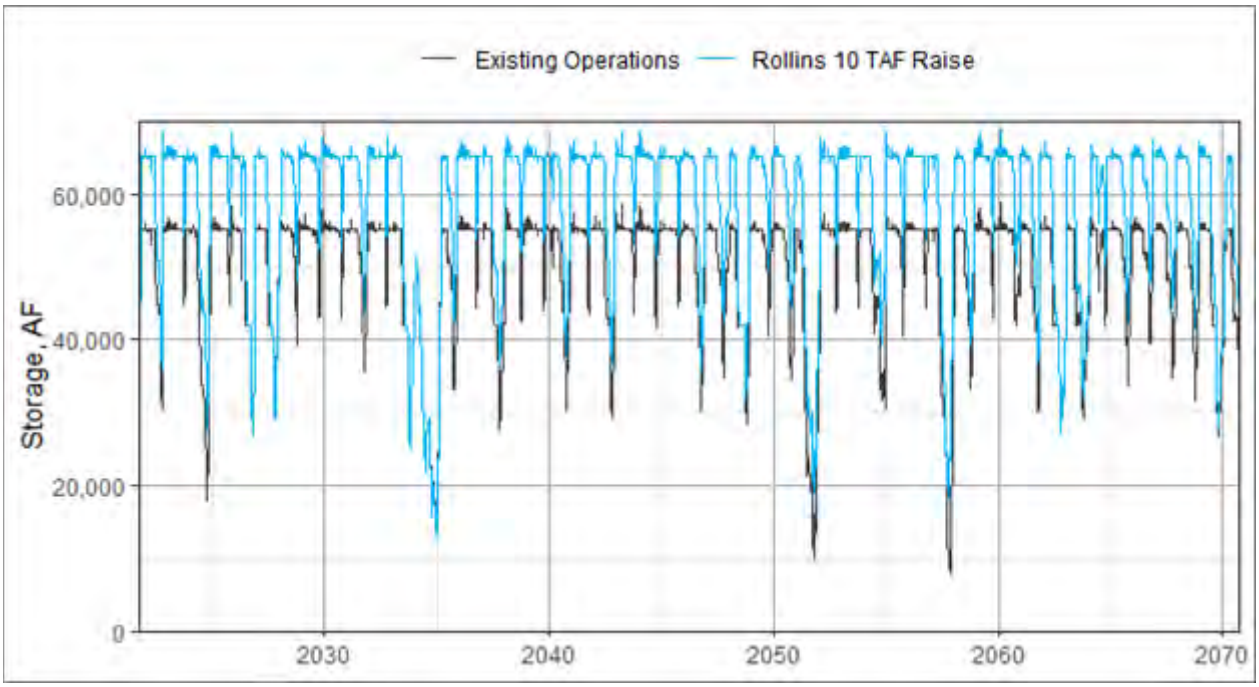


Figure 6-7. Rollins Reservoir Storage, Rollins 10 TAF Raise Alternative, Wet Climate Low Demands Scenario

This additional storage on the Bear River increases NID's ability to make deliveries by increasing delivery allocations and reducing storage constraints at Rollins Reservoir. Demands, deliveries, and unmet demands are shown in Table 6-4. An exceedance plot of the annual unmet demand is shown in Figure 6-8.

Table 6-4. Demand, Delivery, and Unmet Demands, AF, Rollins 10 TAF Raise Alternative

Scenario	Project Condition	Demand	Delivery	Unmet Demand
Dry Climate High Demand	Existing Operations	181,616	146,458	35,158
	Rollins 10 TAF increase	181,616	152,544	29,072
Median Climate Baseline Demand	Existing Operations	151,806	137,706	14,099
	Rollins 10 TAF increase	151,806	142,221	9,585
Wet Climate Low Demand	Existing Operations	109,705	103,941	5,763
	Rollins 10 TAF increase	109,705	105,485	4,220

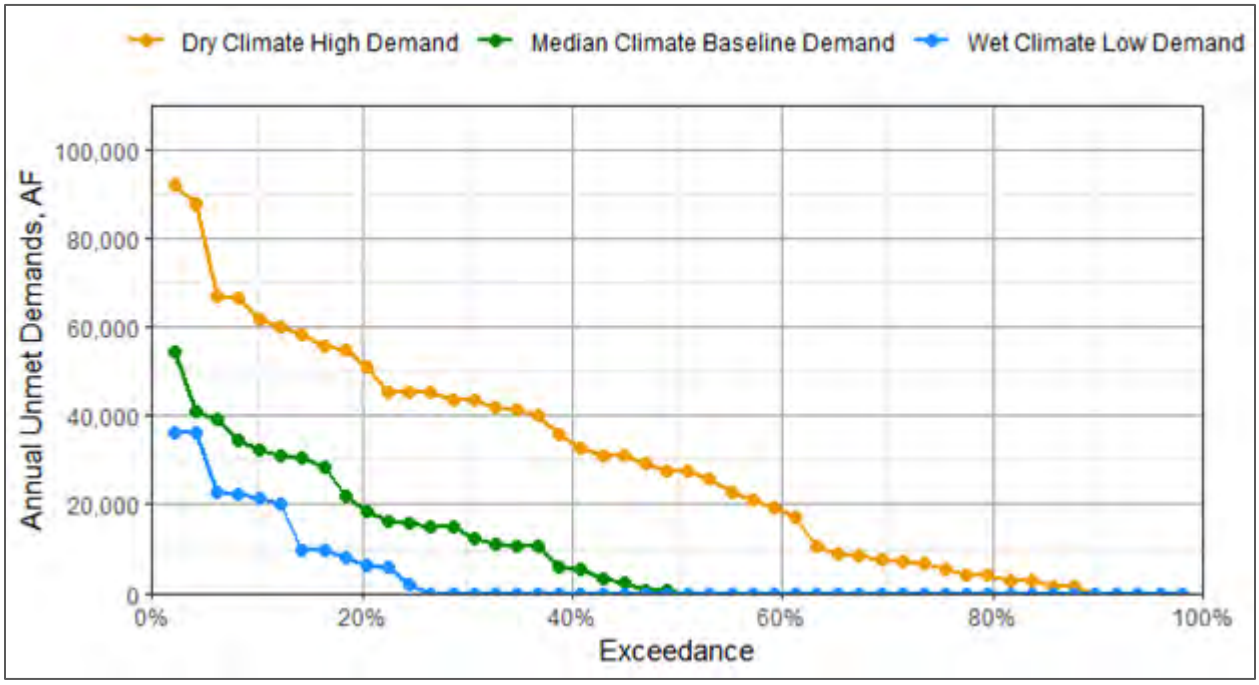


Figure 6-8. Annual Unmet Demand Exceedance, Rollins 10 TAF Raise Alternative

6.5. Rollins Reservoir 50,000 AF Storage Capacity Increase

A modified Rollins Reservoir was built into the model that simulates an additional 50,000 AF of usable storage capacity at Rollins Reservoir. All outlet works are assumed to have the same capacities as the current Rollins Reservoir outlet works. Proposed future FERC minimum flow requirements and minimum pool requirements were also assumed.

This strategic alternative allows for more water to be stored in Rollins Reservoir ahead of the summer storage dispatch season, which allows a larger buffer from minimum pool levels. Currently, Rollins Reservoir spills most years, and there is water available to be stored in nearly all years. Rollins Reservoir storage with the Rollins Reservoir 50 TAF storage increase strategic alternative is shown for the Dry Climate High Demand scenario in Figure 6-9, for the Median Climate Baseline Demand scenario in Figure 6-10, and for the Wet Climate Low Demand scenario in Figure 6-11. These figures show that, under this scenario, Rollins reservoir will not be filled every single year by the additional capacity of 50,000 AF, but storage is higher than the current capacity every year.

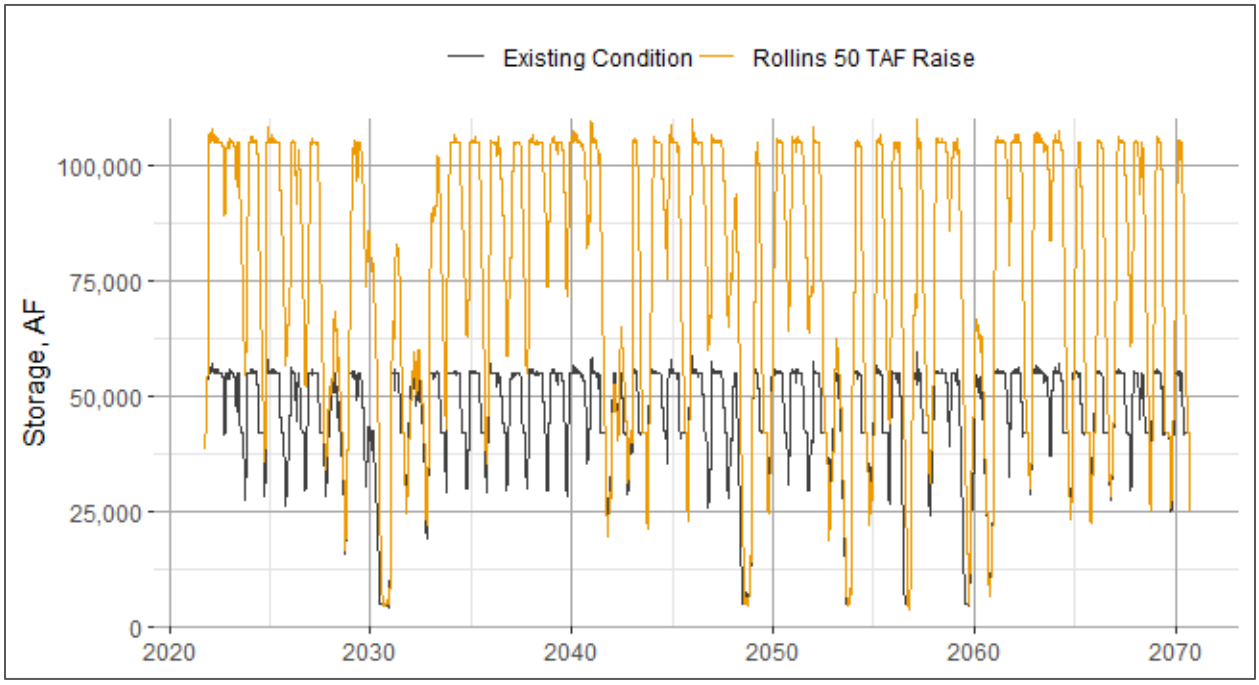


Figure 6-9. Rollins Reservoir Storage, Rollins 50 TAF Raise Alternative,
Dry Climate High Demands Scenario

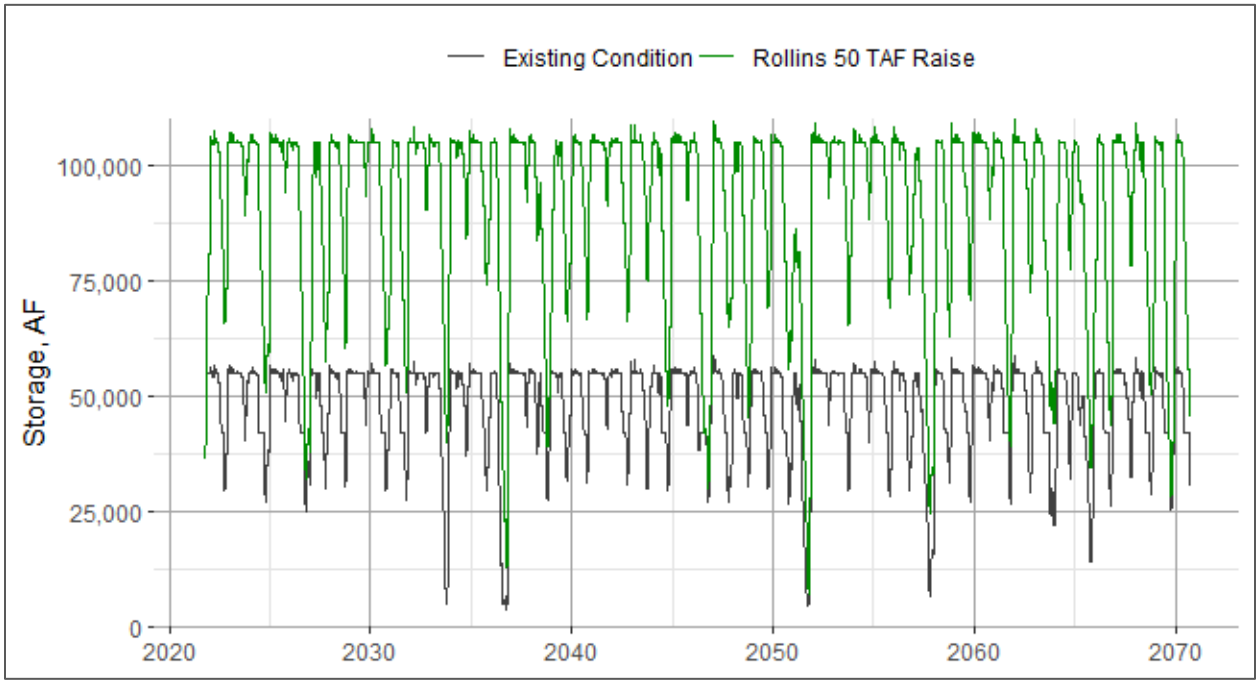


Figure 6-10. Rollins Reservoir Storage, Rollins 50 TAF Raise Alternative,
Median Climate Baseline Demands Scenario

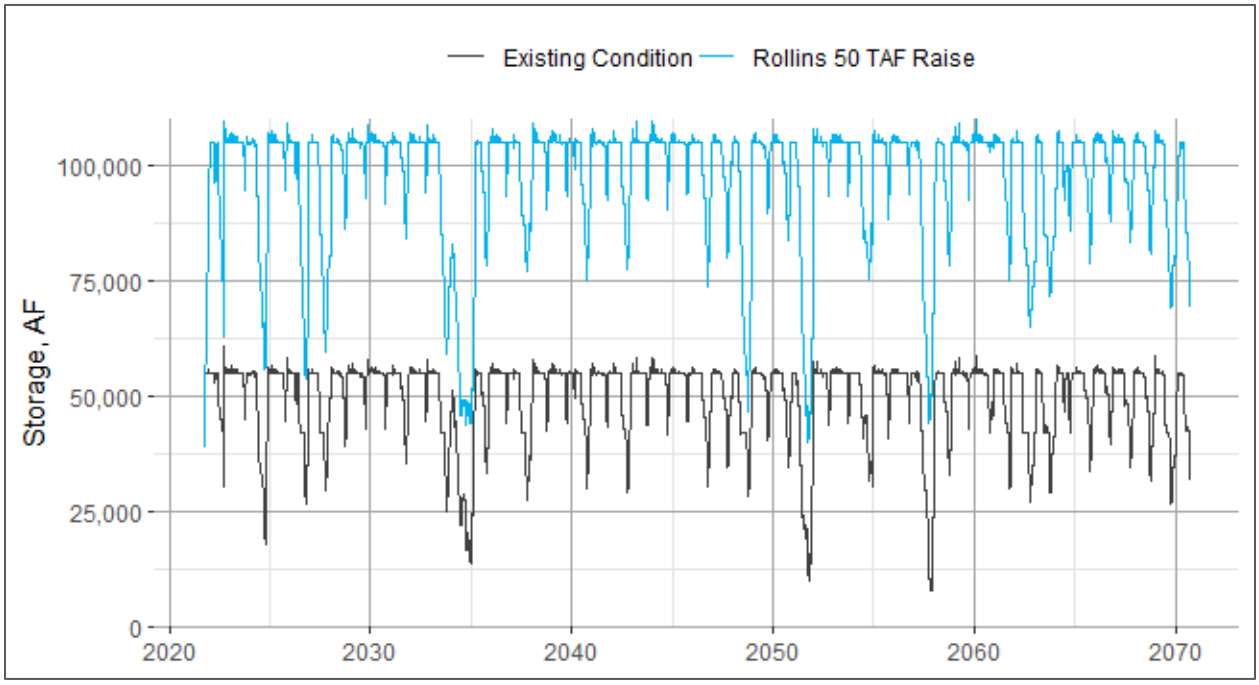


Figure 6-11. Rollins Reservoir Storage, Rollins 50 TAF Raise Alternative, High Climate Low Demands Scenario

Demand, delivery, and unmet demands for the Rollins 50 TAF Raise Alternative are shown in Table 6-5, and an exceedance plot of unmet demands for the Rollins 50 TAF Raise Alternative is shown in Figure 6-12.

Table 6-5. Demand, Delivery, and Unmet Demands, AF, Rollins 50 TAF Raise Alternative.

Scenario	Project Condition	Demand	Delivery	Unmet Demand
Dry Climate High Demand	Existing Operations	181,616	146,458	35,158
	Rollins 50 TAF increase	181,616	167,384	14,232
Median Climate Baseline Demand	Existing Operations	151,806	137,706	14,099
	Rollins 50 TAF increase	151,806	150,092	1,714
Wet Climate Low Demand	Existing Operations	109,705	103,941	5,763
	Rollins 50 TAF increase	109,705	108,892	813

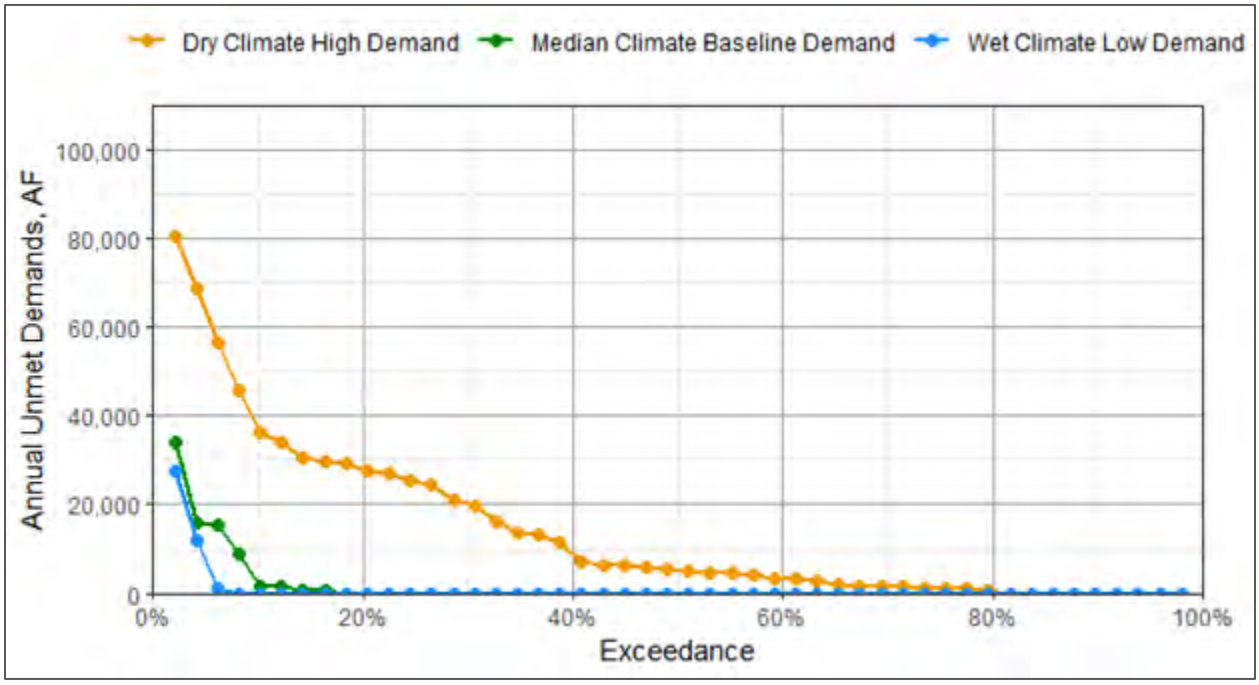
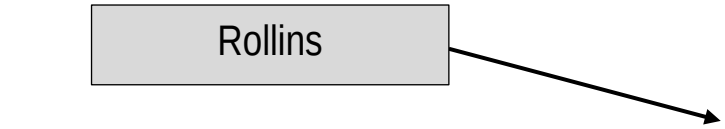
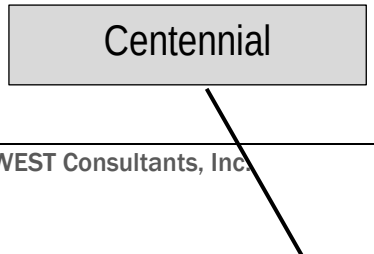


Figure 6-12. Unmet Demands Exceedance, Rollins 50 TAF Raise Alternative

6.6. Centennial Reservoir

A potential Centennial Reservoir was built into the model that provides for 96,660 AF of usable storage on the Bear River below Rollins Reservoir and above Lake Combie. The location of Centennial Reservoir in the Project schematic is shown in Figure 6-13. The reservoir was modeled with a low-level outlet with 300 cfs of capacity, an ungated spillway with a maximum capacity of 30,000 cfs, and no powerhouse. Minimum flow requirements below Centennial Reservoir were assumed to be the same as Lake Combie. Centennial Reservoir would be used to store water in the winter and spring and provide water to Lake Combie for deliveries into the Combie Phase I and Magnolia III canals in the summer and fall. Lake Combie can only drop 5 ft throughout the summer, and currently, these deliveries are made to Lake Combie from Rollins Reservoir. With Centennial Reservoir making these deliveries, Rollins Reservoir inflows and storage can be used exclusively in the Bear River Canal.





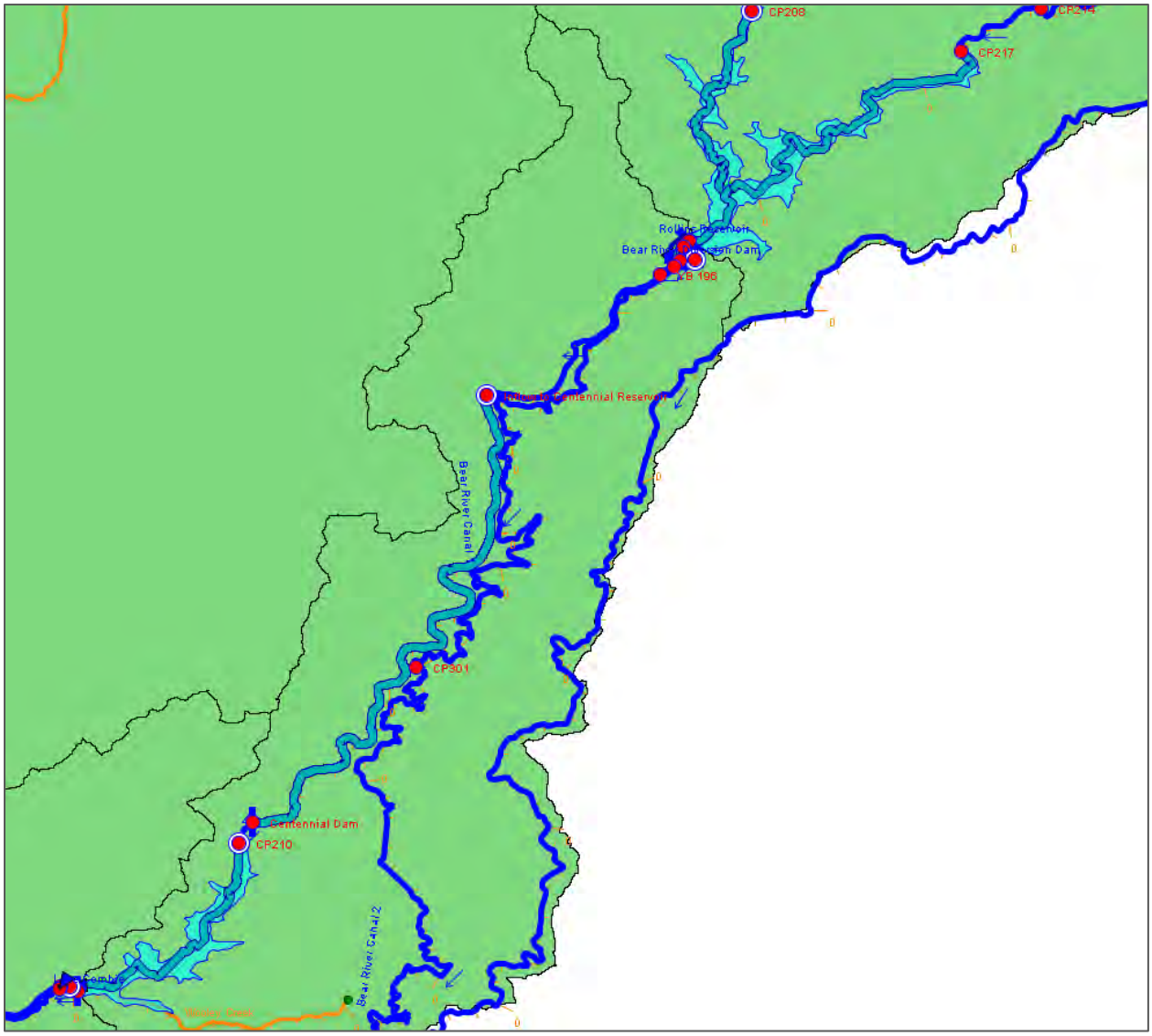


Figure 6-13. Centennial Reservoir Project Schematic

Centennial Reservoir storage is shown in Figure 6-14. The additional delivery and resulting reduction in unmet demand is shown in Table 6-6, and an exceedance plot of unmet demands for the Centennial Reservoir Alternative is shown in Figure 6-15.

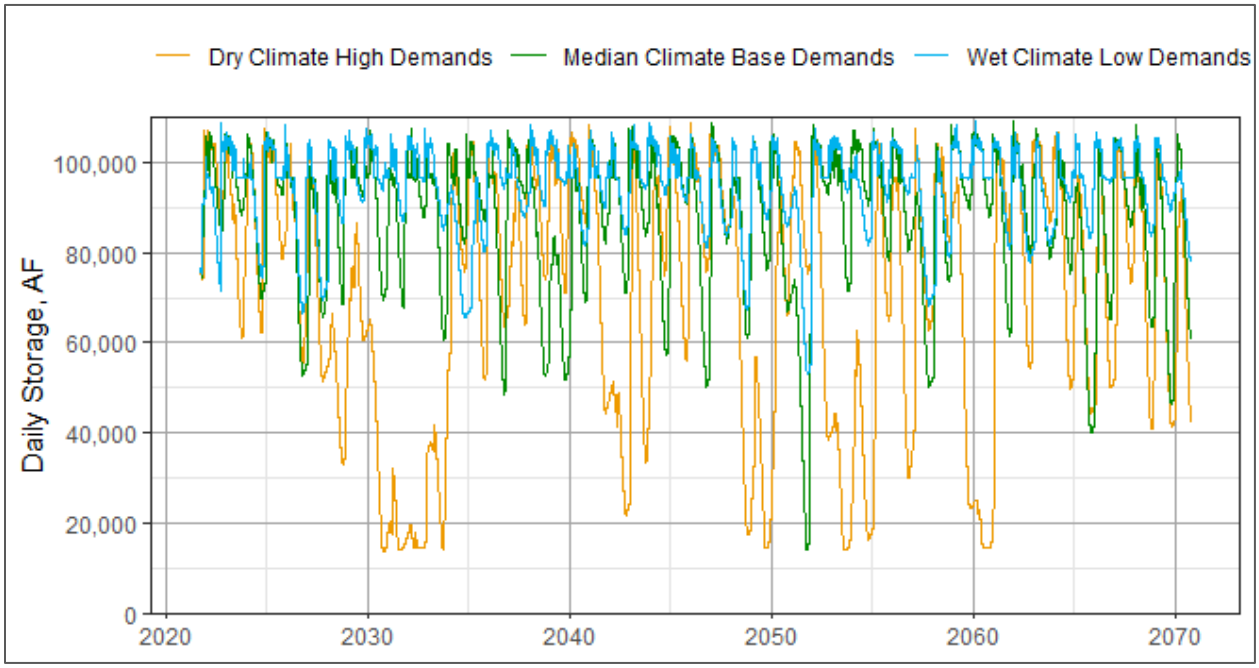


Figure 6-14. Centennial Reservoir Storage

Table 6-6. Demand, Delivery, and Unmet Demands, AF, Centennial Reservoir Alternative

Scenario	Project Condition	Demand	Delivery	Unmet Demand
Dry Climate High Demand	Existing Operations	181,616	146,458	35,158
	Centennial Reservoir	181,616	165,322	16,294
Median Climate Baseline Demand	Existing Operations	151,806	137,706	14,099
	Centennial Reservoir	151,806	144,332	7,473
Wet Climate Low Demand	Existing Operations	109,705	103,941	5,763
	Centennial Reservoir	109,705	108,815	890

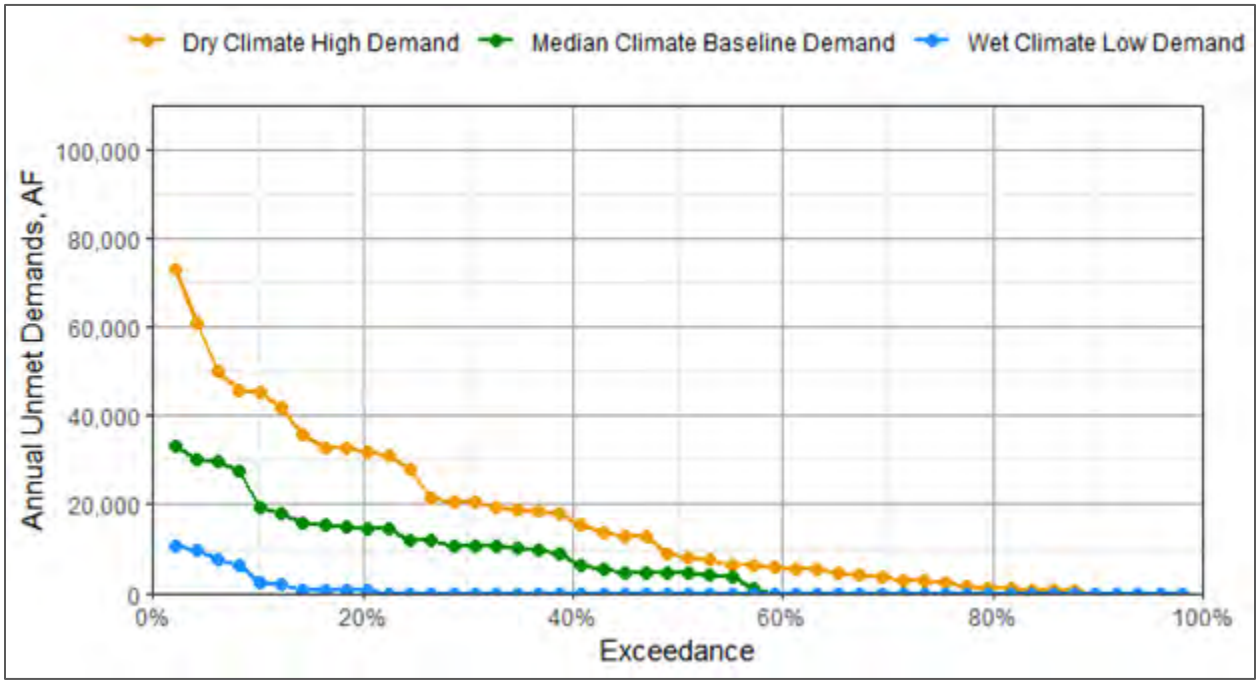


Figure 6-15. Unmet Demands Exceedance, Centennial Reservoir Alternative

6.7. Revised Carryover Targets

The revised carryover targets alternative lowers carryover targets at NID reservoirs. Existing Operations carryover targets use the average historical reservoir carryover level. In dry years, NID draws their reservoirs lower than the average carryover level. The revised carryover targets represent the level that NID would set reservoir carryover levels in a drought and better represent unmet demands in dry years. Existing Operations carryover targets and revised carryover targets are listed in Table 6-7.

Table 6-7. Revised Carryover Targets

Reservoir	Existing Operations Carryover Target	Revised Carryover Target
Jackson Meadows Reservoir	35,000	21,000
Bowman Reservoir	30,000	14,500
Sawmill Lake	1,500	1,000
French Lake	7,000	5,000
Faucherie Lake	2,100	1,500
Jackson Lake	600	1,000
Rollins Reservoir	40,000	25,000
Scotts Flat Reservoir	23,000	17,000
Lake Combie	2,500	2,500
Total	141,700	88,500

The revised carryover targets result in further drawdown of the reservoirs by the end of the year, and more storage capture in the winter and spring before the initiation of spill. These revised carryover targets did not significantly affect the ability of these reservoirs to fill in most years.

The additional delivery and resulting reduction in unmet demand is shown in Table 6-8, and an exceedance plot of unmet demands for the Centennial Reservoir Alternative is shown in Figure 6-16.

Table 6-8. Demand, Delivery, and Unmet Demands, AF, Revised Carryover Targets Alternative

Scenario	Project Condition	Demand	Delivery	Unmet Demand
Dry Climate High Demand	Existing Operations	181,616	146,458	35,158
	Revised Carryover Targets	181,616	150,528	27,715
Median Climate Baseline Demand	Existing Operations	151,806	137,706	14,099
	Revised Carryover Targets	151,806	138,963	9,814
Wet Climate Low Demand	Existing Operations	109,705	103,941	5,763
	Revised Carryover Targets	109,705	104,218	3,079

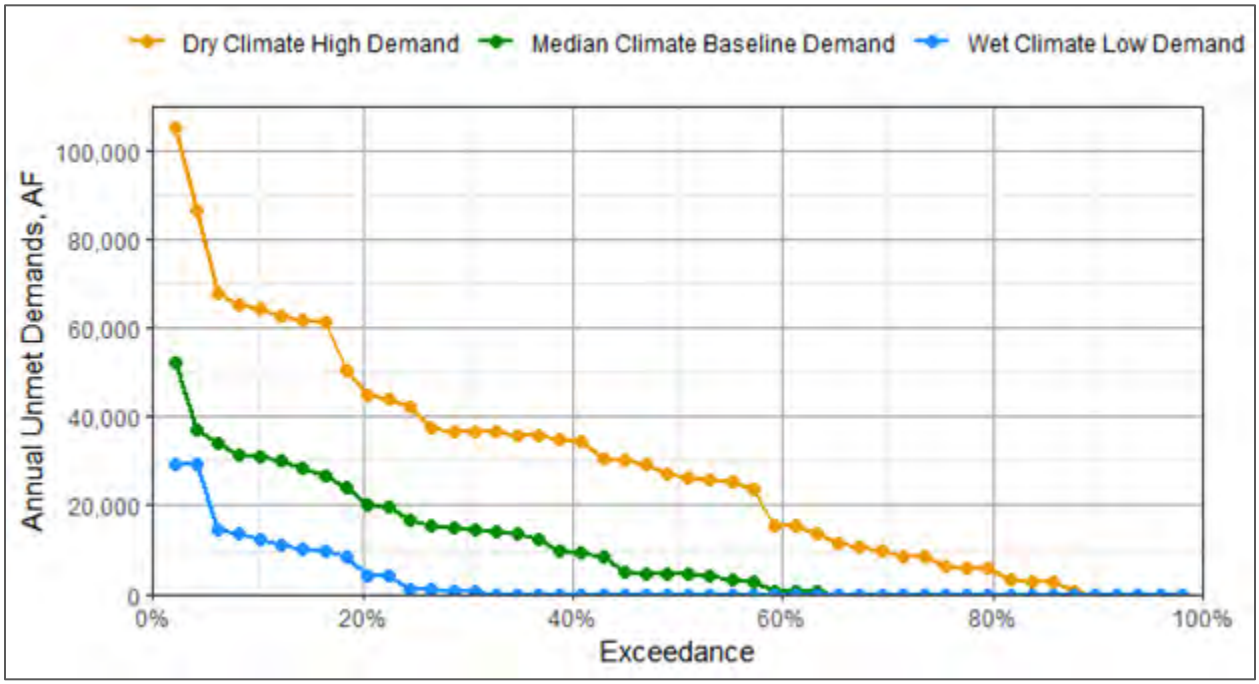


Figure 6-16. Unmet Demands Exceedance, Revised Carryover Targets Alternative

6.8. Purchase of Additional Supply from PG&E

The COA (NID 2018) specifies amounts of water that will be made available for purchase by NID from PG&E. These monthly purchase volumes and maximum flow rates are based on the Sacramento Valley Index, a water year type index defined and calculated by the DWR. Available monthly purchase volumes at the Deer Creek Powerhouse are shown in Figure 6-17, and available monthly purchase volumes on the Bear River Canal are shown in Figure 6-18. In Dry and Critically Dry Years the amount of water available

for purchase in July through December are the volumes shown multiplied by the Sacramento Valley Index divided by the 50-year average of the Sacramento Valley Index.

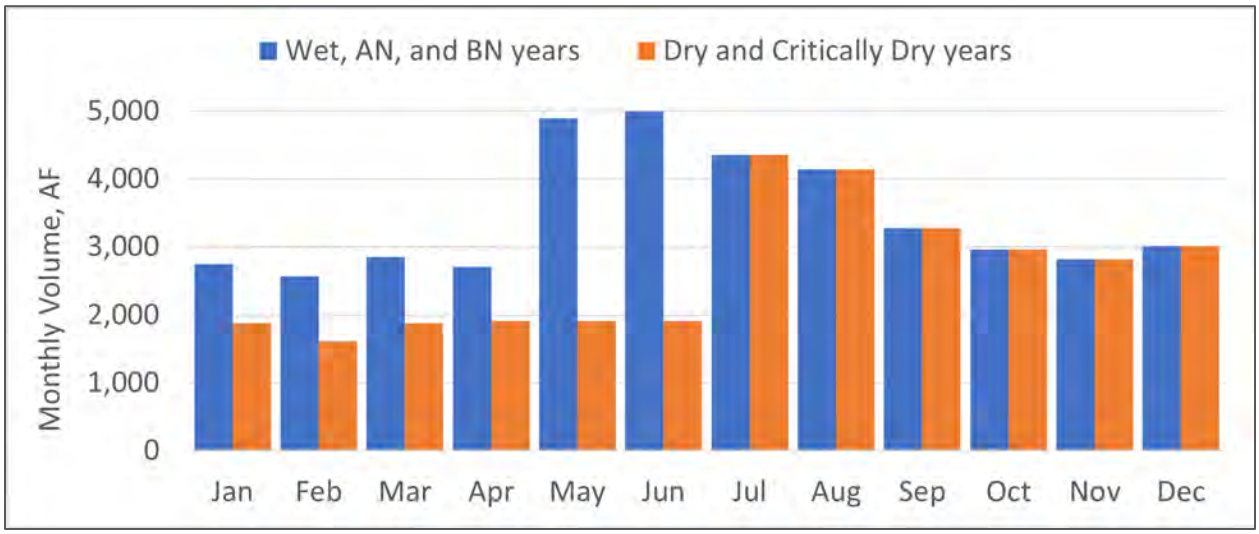


Figure 6-17. Available Monthly Purchase Volumes at the Deer Creek Powerhouse

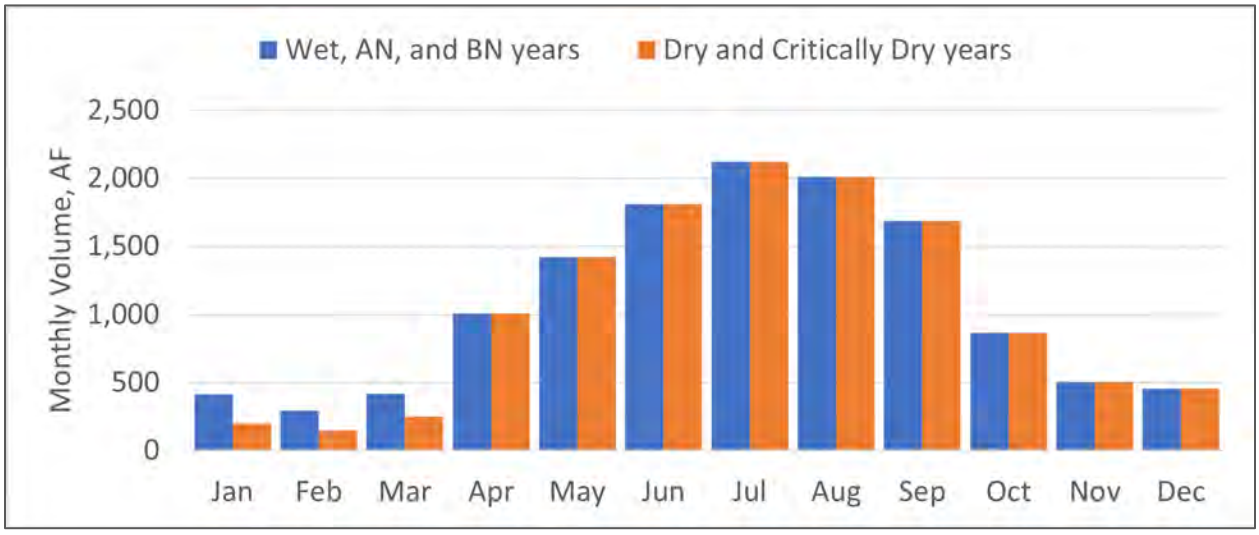


Figure 6-18. Available Monthly Purchase Volumes on the Bear River Canal

Monthly water volumes available for purchase were estimated using a regression for each of the developed climate change hydrology datasets. Current operations modeling study results were used to determine when unmet demands were occurring and identify water that could be purchased to meet or reduce those unmet demands. Identified useful water purchase annual volumes are shown in Figure 6-19.

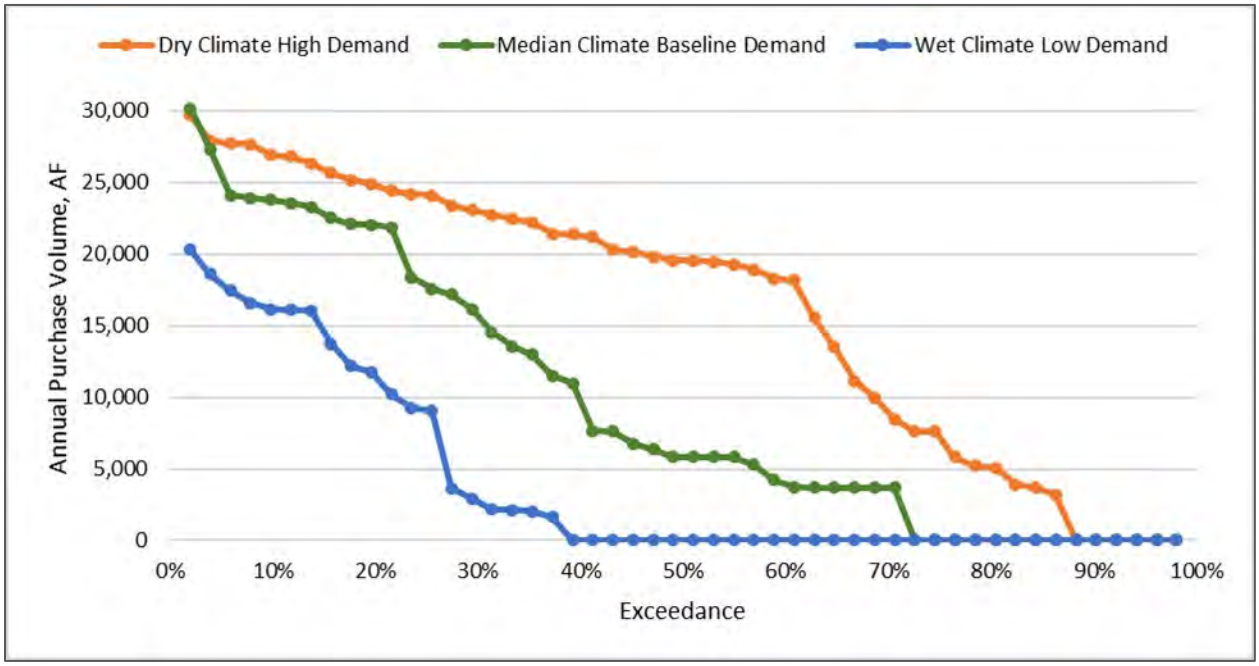


Figure 6-19. Annual Purchase Volumes Exceedance; Purchase of Additional Supply from PG&E Alternative

The model was run adding the identified useful water purchases at Deer Creek Powerhouse to NID diversions to Deer Creek, or displacing NID diversions to Deer Creek with purchase water results in more NID water available to be moved to the Bear River. Water purchases on the Bear River Canal are incorporated into the water balance calculations at Rollins Reservoir. NID allocation calculations incorporated the additional supply when determining annual delivery allocations.

The additional delivery and resulting reduction in unmet demand is shown in Table 6-9, and an exceedance plot of unmet demands for the Centennial Reservoir Alternative is shown in Figure 6-20.

Table 6-9. Demand, Delivery, and Unmet Demands, AF, Water Purchases from PG&E Alternative

Scenario	Project Condition	Demand	Delivery	Unmet Demand
Dry Climate High Demand	Existing Operations	181,616	146,458	35,158
	Purchase of additional supply	181,616	152,344	29,272
Median Climate Baseline Demand	Existing Operations	151,806	137,706	14,099
	Purchase of additional supply	151,806	141,892	9,914
Wet Climate Low Demand	Existing Operations	109,705	103,941	5,763
	Purchase of additional supply	109,705	105,868	3,837

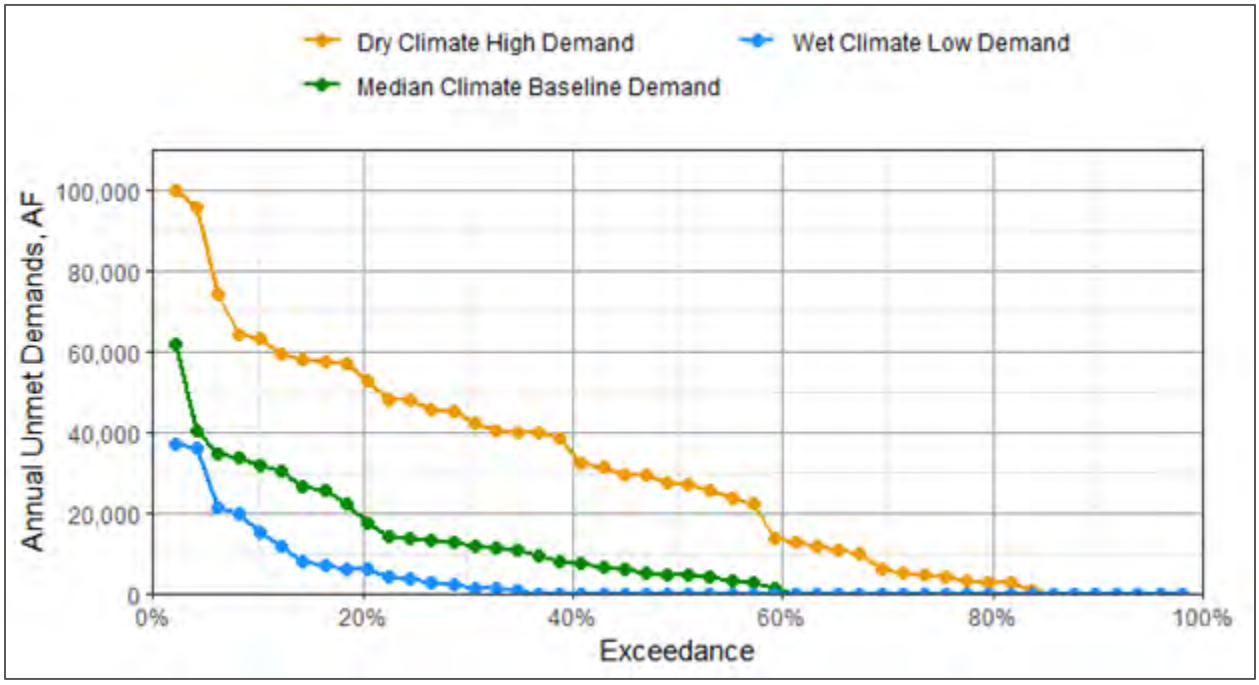


Figure 6-20. Annual Unmet Demands Exceedance, Purchase of Additional Supply from PG&E Scenario

6.9. Revised Carryover Targets and Purchase of Additional Supply from PG&E

An additional modeling study was performed that combined the revised carryover targets with the purchase of additional supply from PG&E. These alternatives work together to reduce the unmet demand further than the individual alternatives. Purchase volumes are reduced slightly, shown in the exceedance plot in Figure 6-21.

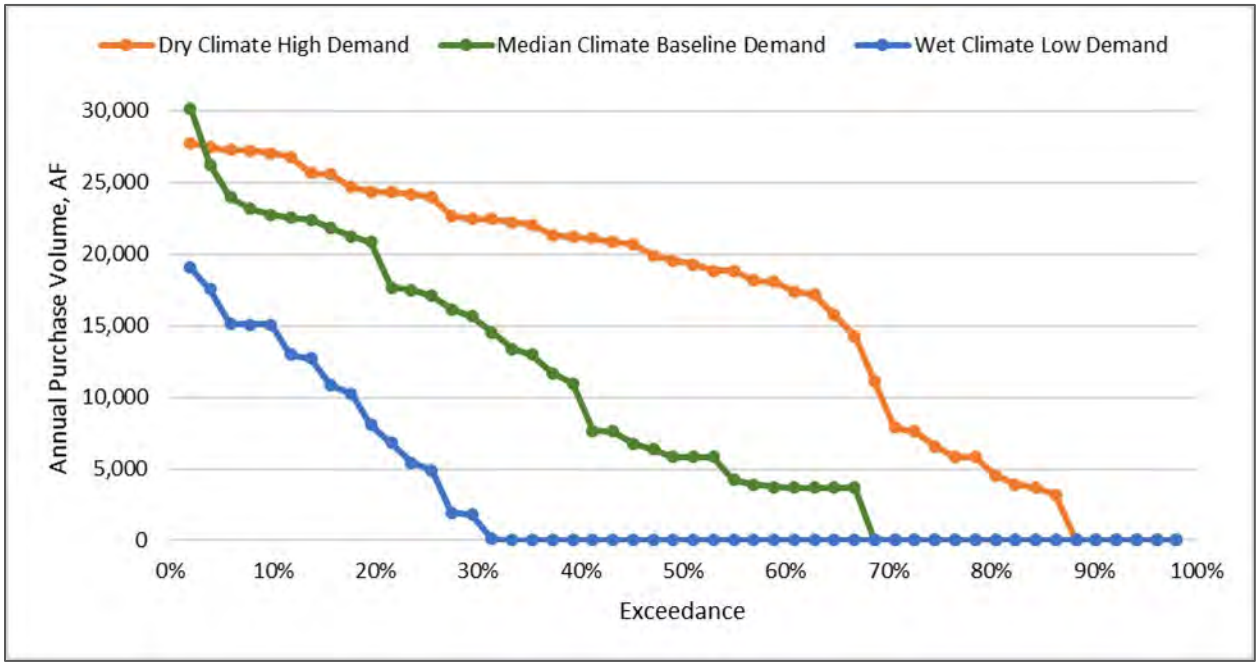


Figure 6-21. Annual purchase volumes exceedance, Revised Carryover Targets and Purchase of additional supply from PG&E alternative

The additional delivery and resulting reduction in unmet demand is shown in Table 6-10, and an exceedance plot of unmet demands for the Centennial Reservoir Alternative is shown in Figure 6-22.

Table 6-10. Demand, Delivery, and Unmet Demands, AF, Revised Carryover Targets and Water Purchases from PG&E Alternative

Scenario	Project Condition	Demand	Delivery	Unmet Demand
Dry Climate High Demand	Existing Operations	181,616	146,458	35,158
	Revised Carryover Targets and Purchase of additional supply	181,616	158,277	23,338
Median Climate Baseline Demand	Existing Operations	151,806	137,706	14,099
	Revised Carryover Targets and Purchase of additional supply	151,806	145,636	6,170
Wet Climate Low Demand	Existing Operations	109,705	103,941	5,763
	Revised Carryover Targets and Purchase of additional supply	109,705	107,762	1,943

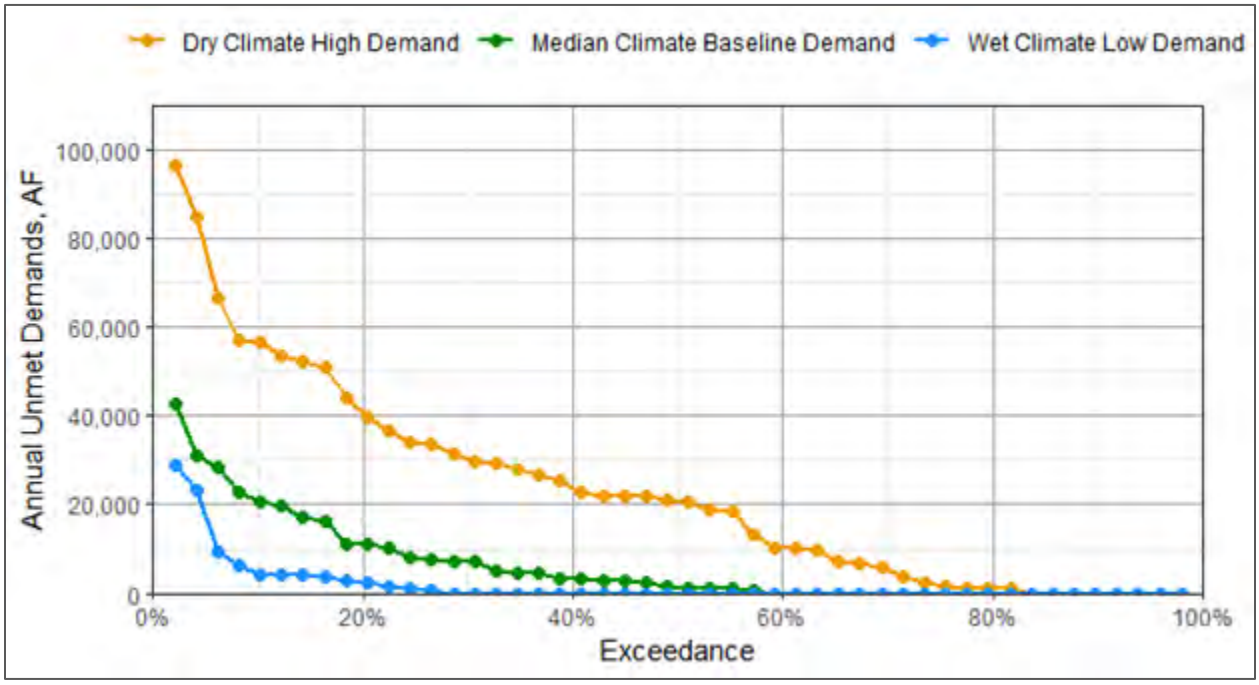


Figure 6-22. Annual Unmet Demands Exceedance, Revised Carryover Targets and Purchase of Additional Supply from PG&E Scenario

6.10. Summary

Deliveries, unmet demands, and carryover storage are summarized for the strategic alternatives for the Wet Climate Low Demand scenarios in Table 6-11, for the Median Climate Low Demand scenarios in Table 6-12, and for the Dry Climate Low Demand scenarios in Table 6-13.

Table 6-11. Strategic Alternatives Deliveries, Unmet Demands, and Carryover Storage, Wet Climate Low Demand Scenarios

Strategic Alternative	Average Annual Delivery (AF)	Average Annual Unmet Demand (AF)	Carryover Storage (AF)
Existing Operations	103,941	5,763	147,800
Extended Irrigation Season	107,275	6,256	144,800
Rollins Reservoir 10,000 AF Storage Incr.	105,485	4,220	154,200
Rollins Reservoir 50,000 AF Storage Incr.	108,892	813	190,200
Centennial Reservoir	108,815	890	231,400
Revised Carryover Targets	104,218	3,079	134,300
Water Purchases from PG&E	105,868	3,837	146,700
Revised Carryover Targets + Water Purchases from PG&E	107,762	1,943	135,500

Table 6-12. Strategic Alternatives Deliveries, Unmet Demands, and Carryover Storage, Median Climate Baseline Demand Scenarios

Strategic Alternative	Average Annual Delivery (AF)	Average Annual Unmet Demand (AF)	Carryover Storage (AF)
Existing Operations	137,706	14,099	131,400
Extended Irrigation Season	141,707	15,611	126,500
Rollins Reservoir 10,000 AF Storage Incr.	142,221	9,585	132,400
Rollins Reservoir 50,000 AF Storage Incr.	150,092	1,714	162,800
Centennial Reservoir	144,332	7,473	205,900
Revised Carryover Targets	138,963	9,814	114,700
Water Purchases from PG&E	141,892	9,914	129,200
Revised Carryover Targets + Water Purchases from PG&E	145,636	6,170	116,300

Table 6-13. Strategic Alternatives Deliveries, Unmet Demands, and Carryover Storage, Dry Climate High Demand Scenarios

Strategic Alternative	Average Annual Delivery (AF)	Average Annual Unmet Demand (AF)	Carryover Storage (AF)
Existing Operations	146,458	35,158	110,800
Extended Irrigation Season	151,651	36,405	106,300
Rollins Reservoir 10,000 AF Storage Incr.	152,544	29,072	117,000
Rollins Reservoir 50,000 AF Storage Incr.	167,384	14,232	129,700
Centennial Reservoir	165,322	16,294	163,100
Revised Carryover Targets	150,528	27,715	91,700
Water Purchases from PG&E	152,344	29,272	115,100
Revised Carryover Targets + Water Purchases from PG&E	158,277	23,338	93,200

Deliveries across all strategic alternatives for the wet hydrology low demand scenarios is shown in Figure 6-23, for the median hydrology baseline demand scenarios in Figure 6-24, and in the dry hydrology low demand scenarios in Figure 6-25.

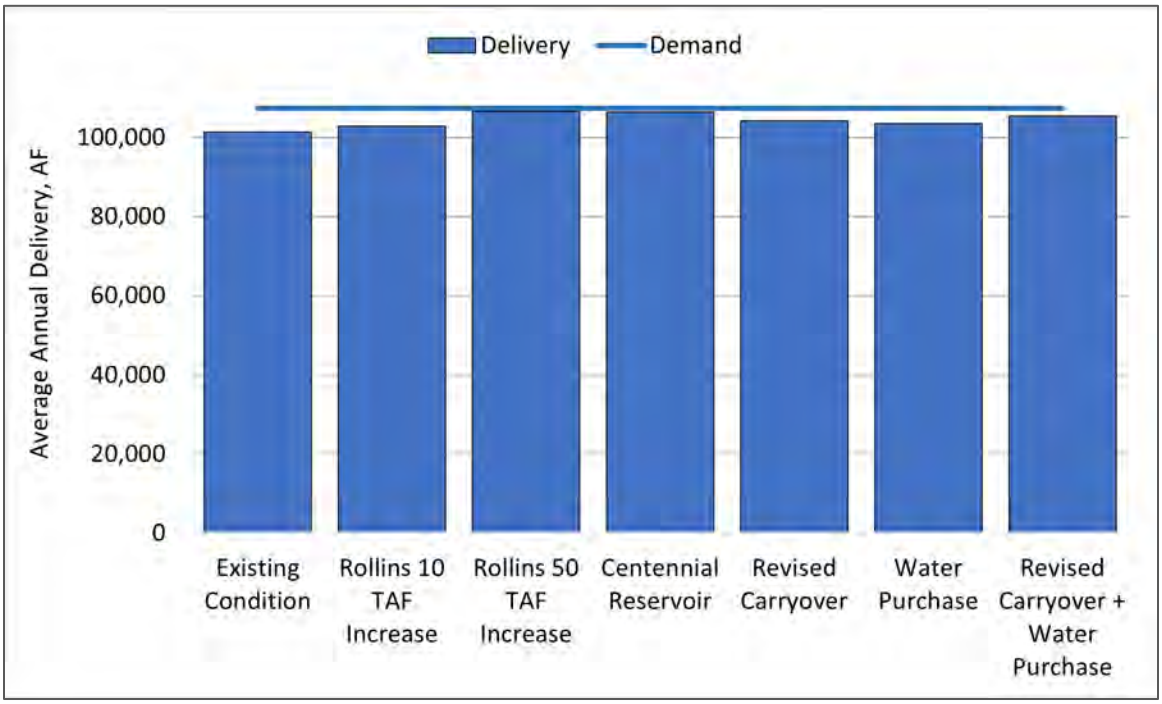


Figure 6-23. Deliveries in Strategic Alternatives, Wet Climate Low Demand Scenarios

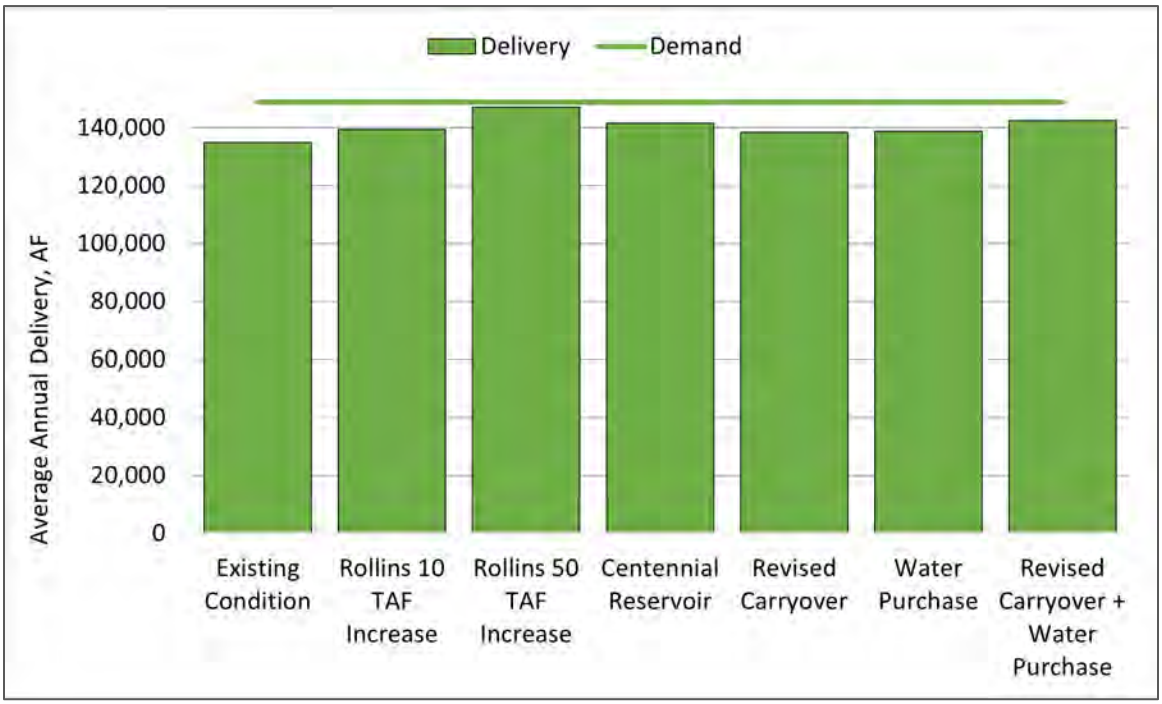


Figure 6-24. Deliveries in Strategic Alternatives, Median Climate Baseline Demand Scenarios

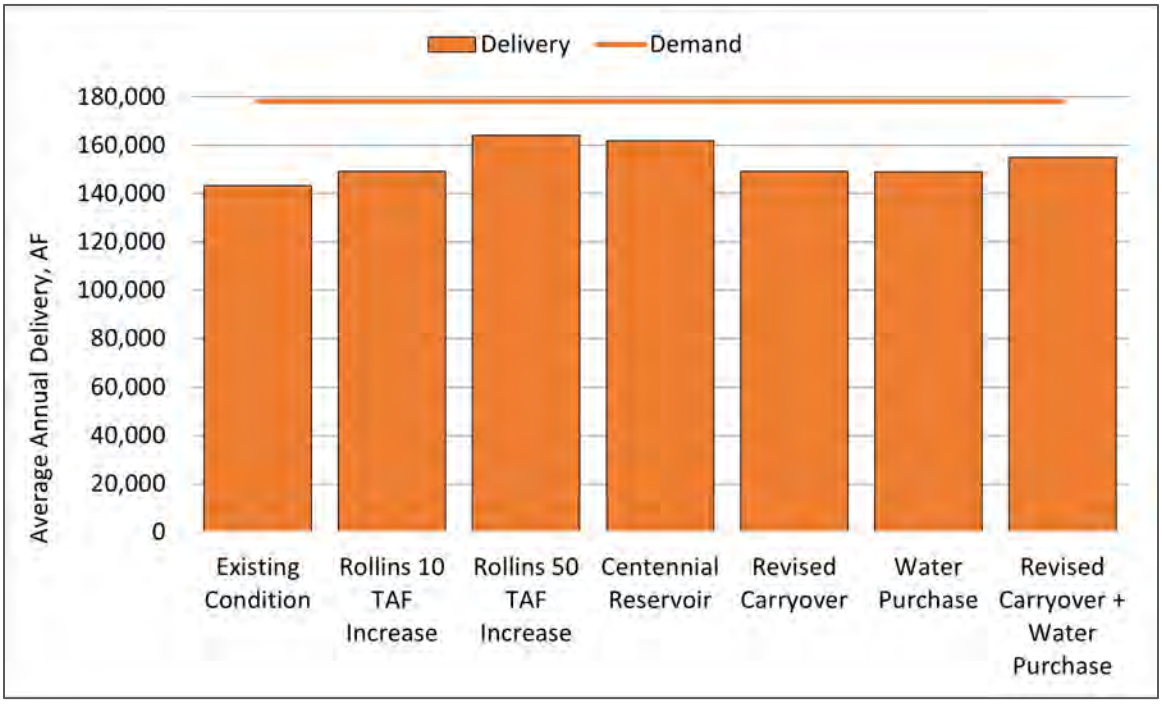


Figure 6-25. Deliveries in Strategic Alternatives, Dry Climate High Demand Scenarios

Unmet demands across all strategic alternatives for the wet hydrology low demand scenarios is shown in Figure 6-26, for the median hydrology baseline demand scenarios in Figure 6-27, and in the dry hydrology low demand scenarios in Figure 6-28.

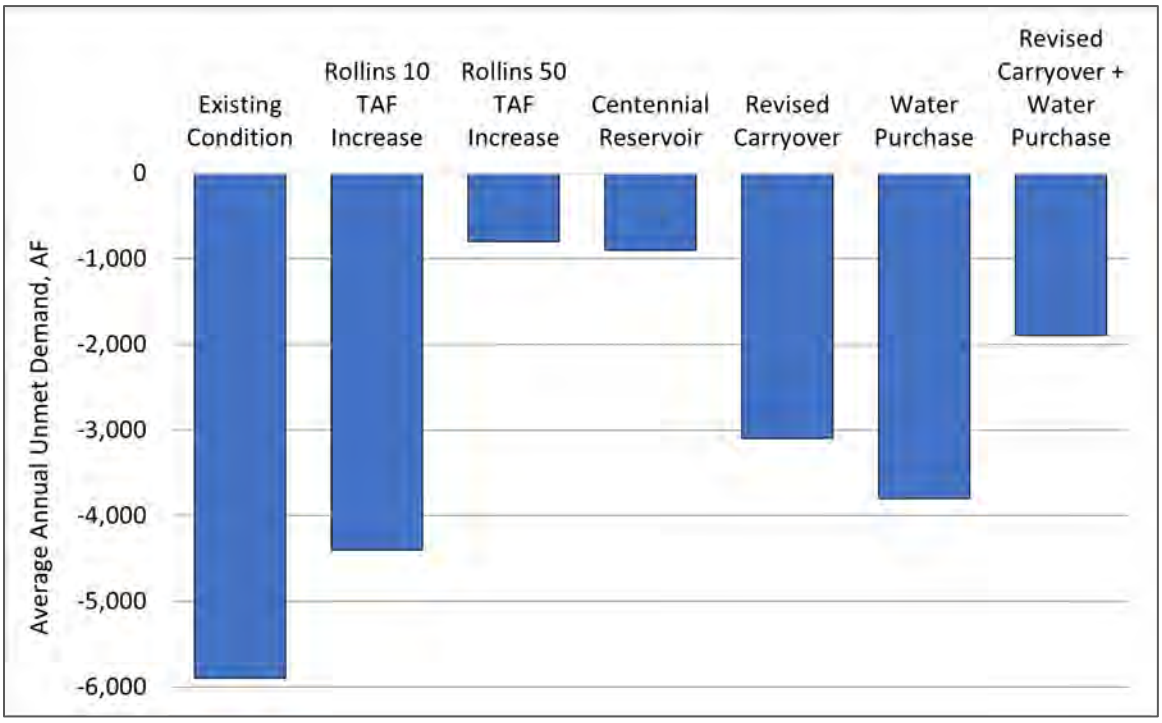


Figure 6-26. Unmet Demands in Strategic Alternatives, Wet Climate Low Demand Scenarios

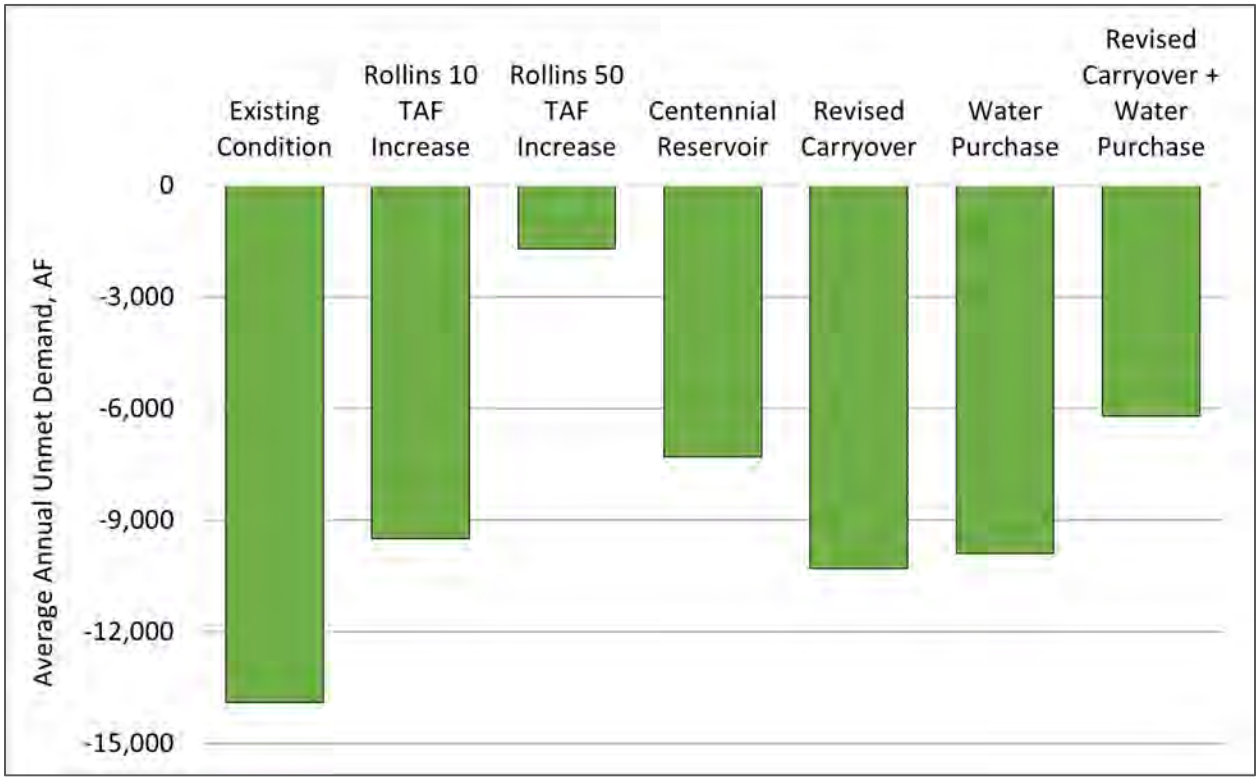


Figure 6-27. Unmet Demands in Strategic Alternatives, Median Climate Baseline Demand Scenarios

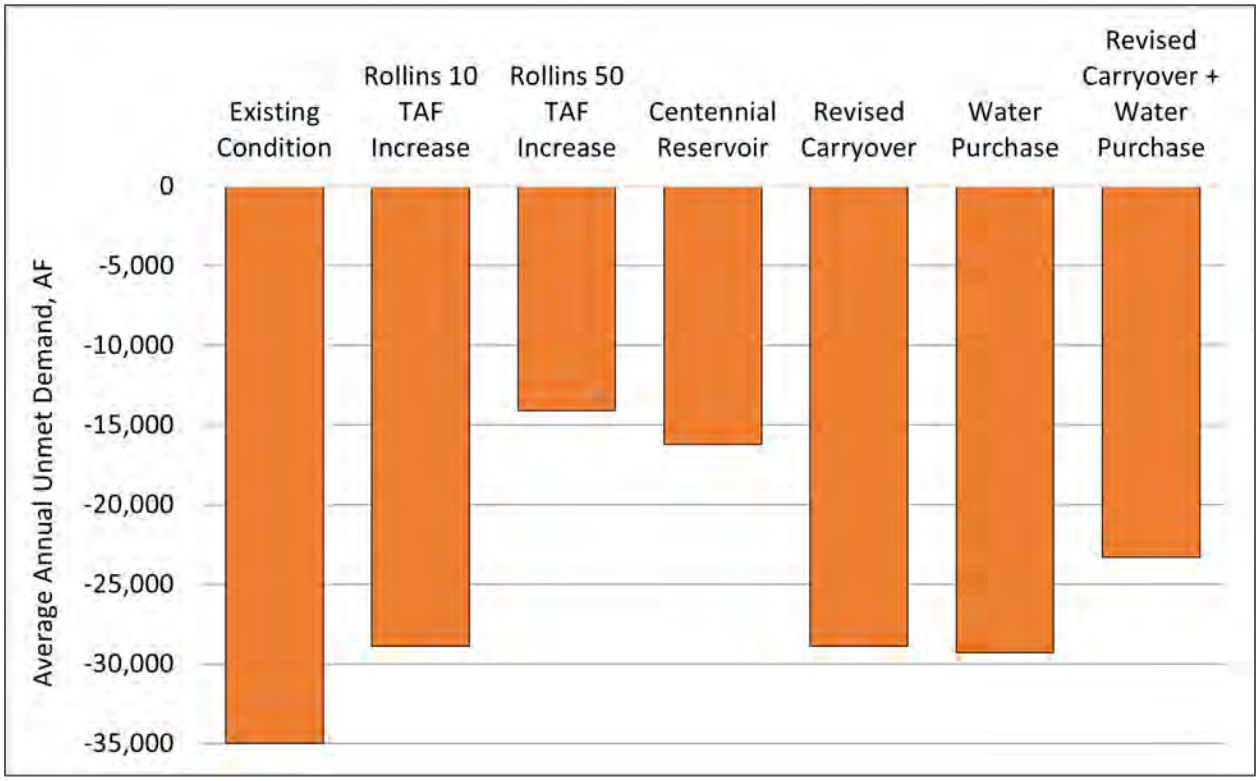


Figure 6-28. Unmet Demands in Strategic Alternatives, Dry Climate High Demand Scenarios

Average November 1 carryover storage across all strategic alternatives for the wet hydrology low demand scenarios is shown in Figure 6-29, for the median hydrology baseline demand scenarios in Figure 6-30, and in the dry hydrology low demand scenarios in Figure 6-31.

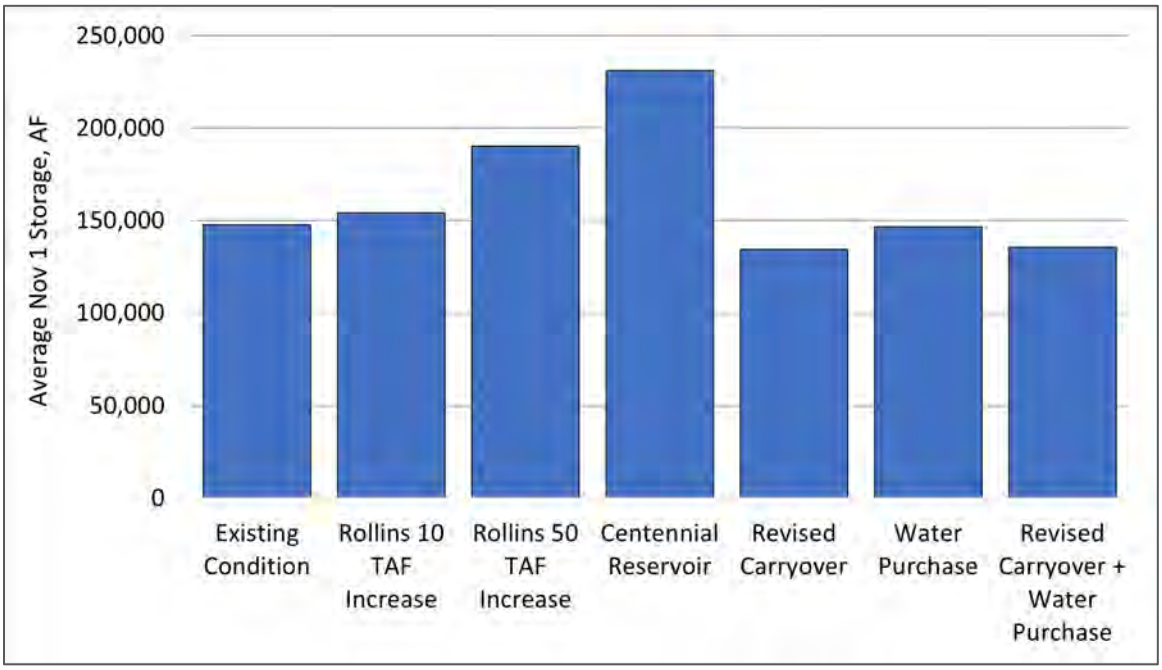


Figure 6-29. Average November 1 Carryover Storage in Strategic Alternatives, Wet Climate Low Demand Scenarios

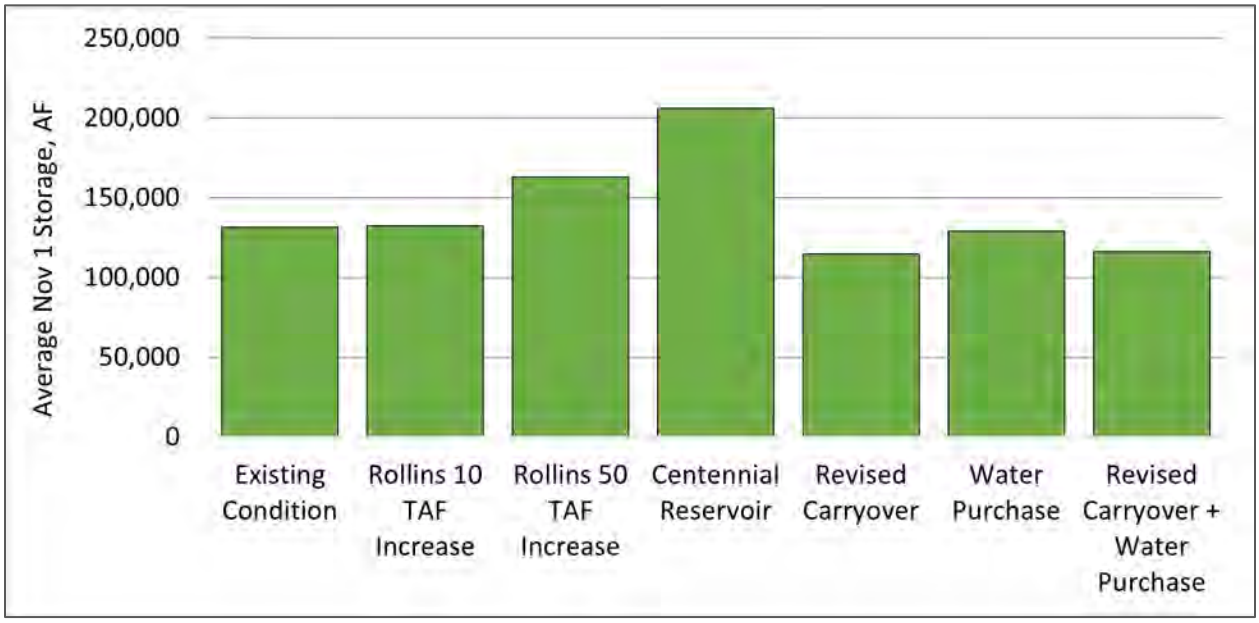


Figure 6-30. Average November 1 Carryover Storage in Strategic Alternatives, Median Climate Baseline Demand Scenarios

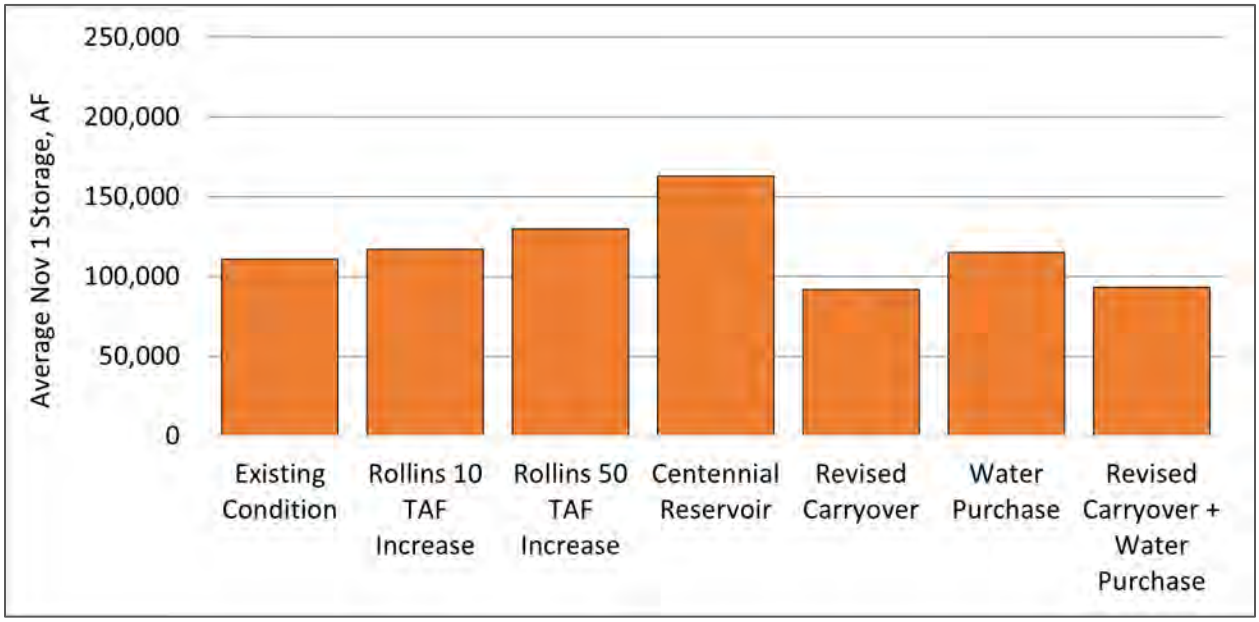


Figure 6-31. Average November 1 Carryover Storage in Strategic Alternatives, Dry Climate High Demand Scenarios

Chapter 7. Summary and Recommendations

The goal of the PFW is to help guide NID's future water management under anticipated changes in climate, runoff, water use, and regulation. The PFW offers a range of potential scenarios for the NID's BOD to consider when assessing ways to best meet customer demands for water over the next 50 years. This report documents the analyses performed to provide actionable information on NID's historical and projected water supply and demand to support the BOD's decision making.

Nine scenarios were initially developed representing various combinations of climate change projections, Dry, Median and Wet, and various combinations of projected customer demands, Low, Baseline and High (Table 5-9). The BOD selected 3 scenarios for further analysis:

- Dry Climate with High Demands
- Median Climate with Baseline Demands
- Wet Climate with Low Demands

These scenarios provide a dry and wet bookend with a median climate scenario to represent a mid-point, and they provide a wide range of hydrologic conditions and consumptive demands. Results of all three scenarios indicate that the ability to meet full customer demands in the future will likely be diminished under existing conditions because of climate change (Figure 6-1).

Seven strategic alternatives were identified by the NID's BOD for investigation to better meet projected customer water demand. The three existing conditions scenarios selected by the BOD for further analysis were used to estimate the relative benefits gained from each of the seven strategic alternatives. The Strategic alternatives analyzed were:

- Extended Irrigation Season
- Rollins Reservoir 10,000 AF Storage Increase
- Rollins Reservoir 50,000 AF Storage Increase
- Centennial Reservoir
- Revised Carryover Targets
- Water Purchases from PG&E
- Revised Carryover Targets + Water Purchases from PG&E

Comparisons of average annual delivery, average annual unmet demand, and carryover were made relative to the three projected climate existing operations scenarios (Table 6-11, Table 6-12, and Table 6-13). While each of the strategic alternatives increased average annual deliveries, some alternatives also resulted in a reduction in carryover storage. A decrease in carryover storage indicates a reduction in available NID water supply in subsequent years. Alternatives that both increase water deliveries and increase carryover storage are much more valuable, from a water supply perspective, than an increase in water deliveries alone.

With the results of the analysis presented in this report, NID's board and directions and community have the necessary information to make scientifically informed decisions.

It is acknowledged that estimating projected water supply and customer demands inherently involves high uncertainties. Uncertainties are also inherent in the social, political, and policy aspects that might influence water resources management. While the most current data and recommended methods were applied in the analysis, uncertainties still exist, and cannot be completely removed from the process. To minimize the effects of uncertainties in decision-making, it is recommended that NID update the analyses in this report as new methods and data become available or policies change. PFW updates every five years is a reasonable and prudent plan going forward.

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APPENDIX A:

CHAPTER 2 SUPPLEMENTAL INFORMATION

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Appendix A. Chapter 2 Supplemental Information

A.1. HEC-HMS Subbasin

Table A-1 presents subbasin names and their respective drainage areas, detailed in Appendix A.

Table A-1. HEC-HMS Model—Subbasin Summary

Name	Area (sq. mi.)
NY_NorthYuba_S10	33.729
NY_NorthYuba_S20	17.091
NY_HayPressCreek_S10	31.489
NY_NorthYuba_S30	4.480
NY_LavezzolaCreek_S10	28.547
NY_DownieRiver_S10	17.511
NY_PauleyCreek_S10	25.361
NY_DownieRiver_S20	0.556
NY_NorthYuba_S40	54.639
NY_DownieRiver_S30	0.517
NY_NorthYuba_S50	36.229
NY_CanyonCreek_S10	60.982
NY_NorthYuba_S60	36.442
NY_SlateCreek_S10	49.480
NY_SlateCreek_S20	11.942
NY_NorthYuba_S70	2.930
NY_NorthYuba_S80	39.059
NY_BridgerCreek_S10	22.526
NY_NorthYuba_S90	15.693
MY_PassCreek_S10	18.704
MY_MiddleYuba_S10	17.706
MY_MiddleYuba_S20	0.682
MY_MiddleYuba_S30	2.456
MY_MiddleYuba_S40	1.052
MY_MiddleYuba_S50	19.458
MY_EastForkCreek_S10	13.201
MY_MiddleYuba_S60	12.964
MY_WolfCreek_S10	8.693
MY_MiddleYuba_S70	21.582
MY_KanakaCreek_S10	17.961
MY_MiddleYuba_S80	9.734
MY_OregonCreek_S10	29.175
MY_MiddleYuba_S90	17.136
MY_OregonCreek_S20	6.097

Name	Area (sq. mi.)
SY_SouthYuba_S80	11.616
SY_SouthYuba_S90	22.299
SY_HumbugCreek_S10	10.818
SY_SouthYuba_S100	44.248
SY_SouthYuba_S110	34.606
YR_YubaRiver_S20	18.265
SY_SouthYuba_S120	6.988
YR_YubaRiver_S30	23.666
YR_DeerCreek_S10	5.761
YR_DeerCreek_S20	14.529
YR_DeerCreek_S30	13.959
YR_DeerCreek_S40	10.855
YR_DeerCreek_S50	10.599
DC_SquirrelCreek_S10	25.045
YR_DeerCreek_S60	1.462
YR_DeerCreek_S70	7.615
YR_DryCreek_S10	107.900
YR_YubaRiver_S40	15.403
YR_YubaRiver_S50	22.534
BR_DryCreek_S10	33.032
BR_BestSlough_S10	99.463
BR_BestSlough_S20	45.665
BR_BearRiver_S140	0.438
BR_BearRiver_S150	0.361
BR_BearRiver_S10	1.591
BR_BearRiver_S20	10.637
BR_LittleBearCreek_S10	1.588
BR_BearRiver_S30	7.292
BR_BearRiver_S40	0.369
BR_SteephollowCreek_S10	23.798
BR_BearRiver_S50	6.963
BR_GreenhornCreek_S10	40.786
BR_BearRiver_S60	4.483
BR_BearRiver_S70	5.953

Name	Area (sq. mi.)
MY_MiddleYuba_S100	13.485
NY_NorthYuba_S100	1.698
YR_YubaRiver_S10	14.534
SY_SouthYuba_S10	0.735
SY_SouthYuba_S20	0.289
SY_SouthYuba_S30	0.538
SY_SouthYuba_S40	51.161
SY_FordyceCreek_S10	1.270
NC_WhiteRockCreek_S10	1.147
SY_FordyceCreek_S20	1.009
SY_FordyceCreek_S30	27.502
SY_FordyceCreek_S40	22.538
SY_SouthYuba_S50	6.415
SY_JordanCreek_S10	0.575
SY_JordanCreek_S20	0.246
SY_RuckerCreek_S10	0.282
SY_RuckerCreek_S20	1.226
SY_RuckerCreek_S30	0.291
CC_LakeCreek_S30	5.063
TC_LindseyCreek_S10	0.162
TC_LindseyCreek_S20	0.247
TC_LindseyCreek_S30	0.510
TC_TexasCreek_S10	0.447
TC_TexasCreek_S20	0.186
TC_TexasCreek_S30	0.098
TC_TexasCreek_S40	3.828
SY_ClearCreek_S10	1.765
SY_FallCreek_S10	0.614
CC_LakeCreek_S10	0.433
CC_LakeCreek_S20	0.081
SY_SouthYuba_S60	5.081
CC_CanyonCreek_S10	4.997
CC_CanyonCreek_S20	4.500
CC_CanyonCreek_S30	7.869
CC_JacksonCreek_S10	0.642
CC_CanyonCreek_S40	10.486
SY_SouthYuba_S70	18.625
CC_CanyonCreek_S50	16.498
SY_Poorman_Creek_S10	23.308

Name	Area (sq. mi.)
BR_BearRiver_S80	19.717
BR_BearRiver_S85	12.534
BR_WolfCreek_S10	37.513
WC_SouthWoolfCreek_S10	33.423
BR_BearRiver_S90	13.478
BR_WolfCreek_S20	7.106
BR_BearRiver_S100	30.529
BR_BearRiver_S120	17.705
BR_BearRiver_S110	0.351
BR_BearRiver_S130	16.527
RC_DryCreek_S10	0.978
RC_DryCreek_S20	0.693
RC_DryCreek_S30	1.434
RC_DryCreek_S40	2.148
RC_RaccoonCreek_S10	49.579
RC_DotyCreek_S10	24.846
RC_RaccoonCreek_S20	29.761
RC_BunkhamSlough_S10	26.829
RC_AuburnRavine_S10	36.080
RC_OrchardCreek_S10	22.356
RC_OrchardCreek_S20	18.214
RC_RaccoonCreek_S30	11.270
RC_PleasantGroveCreek_S10	46.578
RC_CurryCreek_S10	16.793
RC_PleasantGroveCreek_S20	6.087
RC_PleasantGroveCreek_S30	1.592
NFA_NFAmerican_S10	75.531
NFA_BigGraniteCreek_S10	17.952
NFA_NFNorthAmerican_S10	4.374
NFA_NFNorthAmerican_S20	0.611
NFA_NFNorthAmerican_S30	3.882
NFNA_EastForkNFAmerican_S10	17.559
NFA_NFNorthAmerican_S40	6.457
NFA_NFAmerican_S20	47.669
NFA_NFNorthAmerican_S50	21.796
NFA_CanyonCreek_S10	1.533
NFA_CanyonCreek_S20	4.095
NFA_NFAmerican_S30	15.897

A.2. USGS Schematics

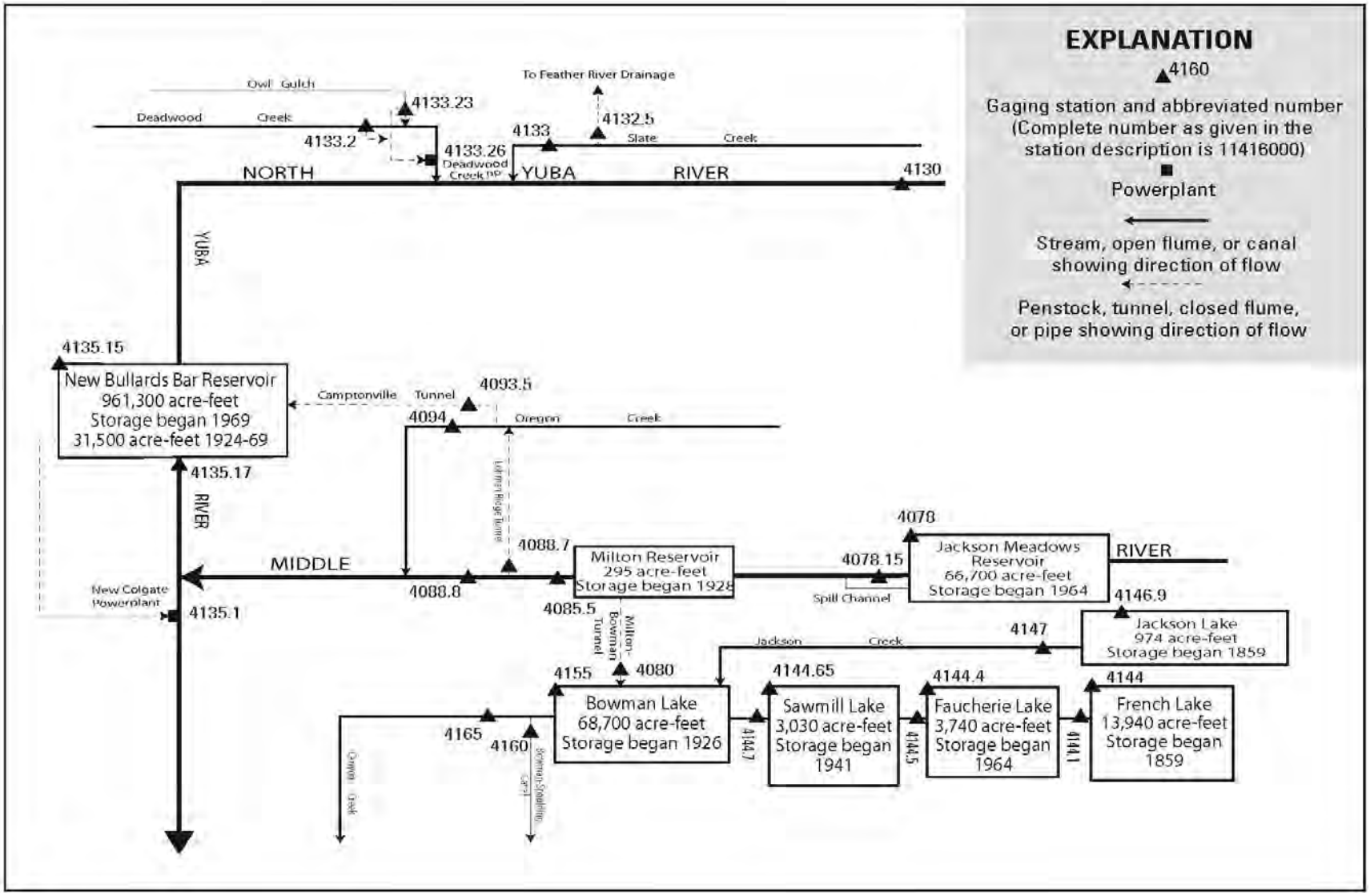


Figure A-1. Diversions and Storage in North and Middle Yuba River Basins, WY2010

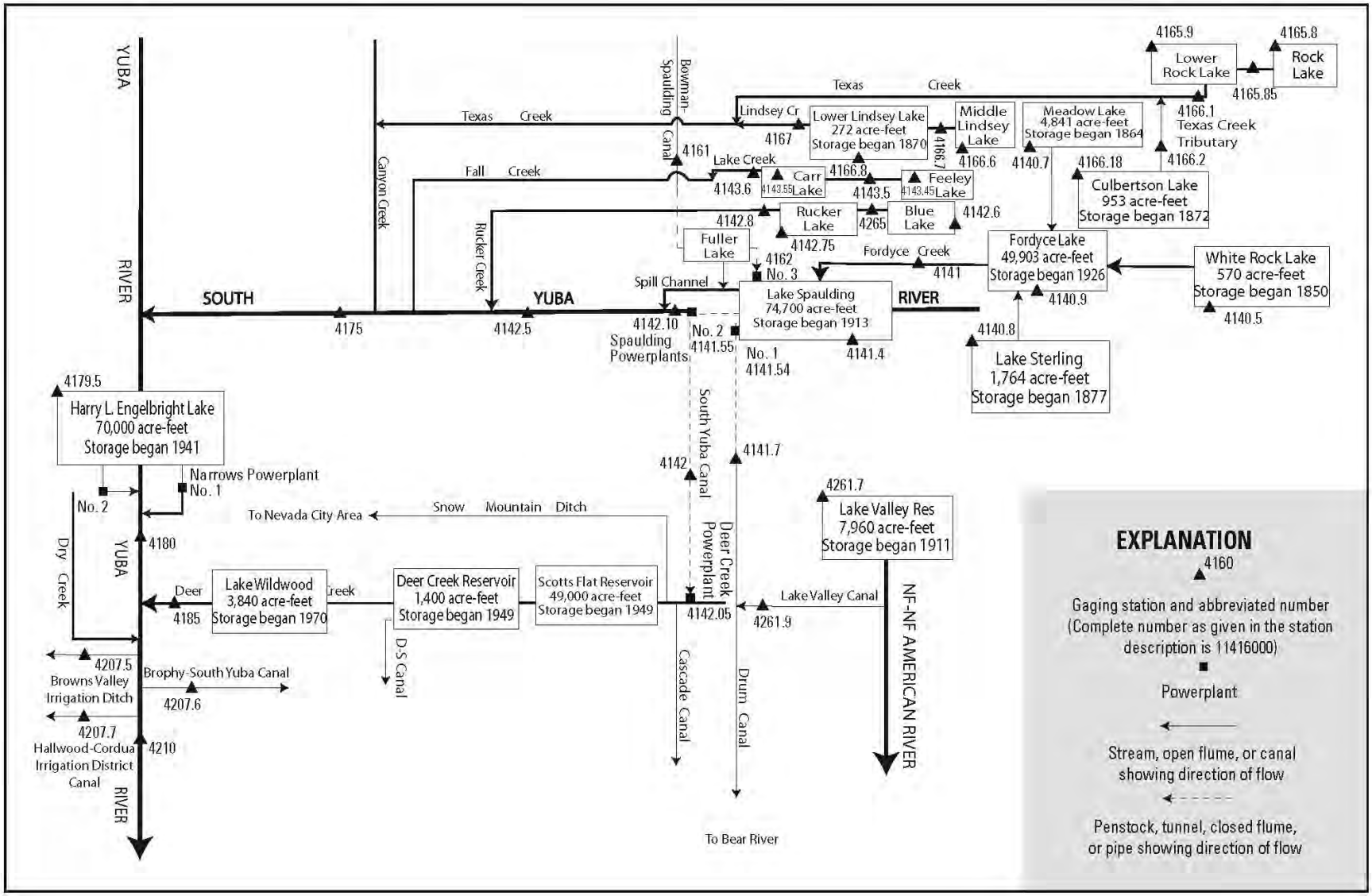


Figure A-2. Diversions and Storage in South Yuba River Basin, WY2010

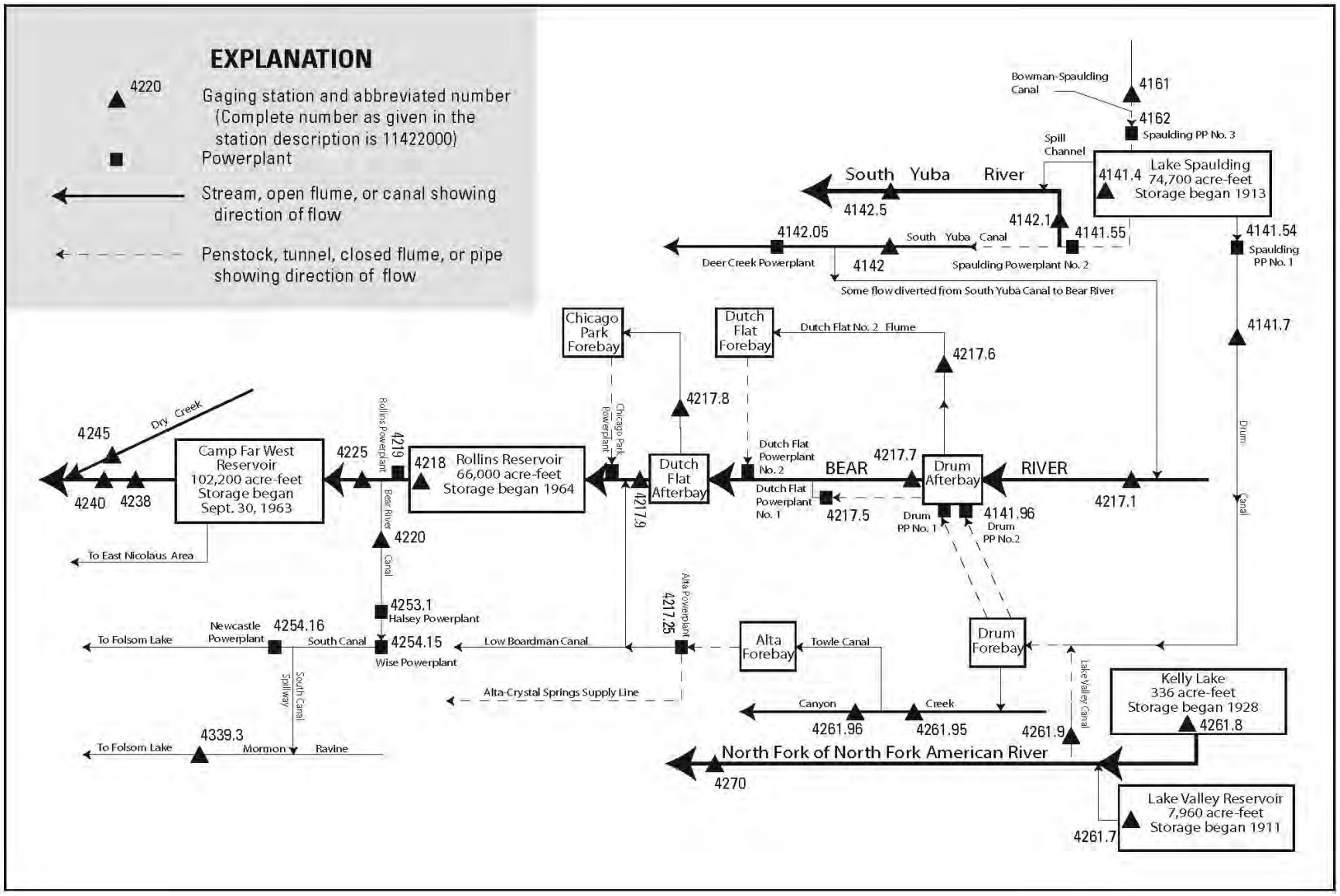


Figure A-3. Diversions and Storage in Bear River Basin, WY2010

A.3. Calibration Parameters

Sensitivity analysis was performed to determine the most sensitive model parameters to improve calibration. The results indicated that the calibration procedure should focus on baseflow groundwater fractions, snow parameters (PX and base temperatures and Wet Meltrate coefficient), and constant loss rate.

Table A-2. HEC-HMS Calibration Parameters

Process	Parameter	Calibration Approach
Streamflow Routing	Length	Not adjusted during model calibration.
	Slope	Not adjusted during model calibration.
	Manning's n	Not adjusted during model calibration.
	Index Celerity	Set to 5 ft/s. Not adjusted during model calibration.
	8-point Cross Section Shape	Not adjusted during model calibration.
	Manning's n (Left and Right)	Set to 0.07. Not adjusted during model calibration.
Evapotranspiration and Canopy	Initial Storage	Set to 0% for each subbasin. Not adjusted during model calibration.
	Max Storage	Specified for each subbasin. Estimated by the Canopy Storage Depths for NLCD Land Cover Classifications. Not adjusted during model calibration.
	Crop Coefficient	Set to 1. Not adjusted during model calibration.
	Hamon Coefficient	Set to 0.0065. Not adjusted during model calibration.
Runoff Transform	Time of Concentration (T_c)	Due to the use of daily average precipitation and a relatively long computational interval, little to no overland flow was generated during any simulation. Therefore, runoff transform parameters were not calibrated as part of this modeling effort.
	Storage Coefficient (R)	Due to the use of daily average precipitation and a relatively long computational interval, little to no overland flow was generated during any simulation. Therefore, runoff transform parameters were not calibrated as part of this modeling effort.
Snowmelt	PX Temperature	This value was initially calibrated for four stations during the snowmelt calibration (refer to Section 6). Further refinement was implemented to better match runoff generation in certain upstream subbasins during model calibration.
	Base Temperature	This value was initially calibrated for four stations during the snowmelt calibration (refer to Section 6). Further refinement was implemented to better match runoff generation in certain upstream subbasins during model calibration.
	Wet Meltrate	This value was initially calibrated for four stations during the snowmelt calibration (refer to Section 6). Further refinement was implemented to better match runoff generation in certain upstream subbasins during model calibration.
	Rain Rate Limit	Set during snow model calibration. Not adjusted during HEC-HMS model calibration.

Process	Parameter	Calibration Approach
Snowmelt, continued	ATI-Meltrate Function	This value was initially calibrated for four stations during the snowmelt calibration (refer to Section 6). Further refinement was implemented to better match runoff generation in certain upstream subbasins during model calibration.
	ATI-Coldrate Function	Set during snow model calibration. Not adjusted during HEC-HMS model calibration.
	Snowpack Water Capacity	Set during snow model calibration. Not adjusted during HEC-HMS model calibration.
	Ground melt	Set during snow model calibration. Not adjusted during HEC-HMS model calibration.
Infiltration	Initial Deficit	Set to 0. Not adjusted during calibration.
	Maximum Deficit	Set to 2 inches. over the active soil layer depth. Not adjusted during HEC-HMS model calibration.
	Constant Loss Rate	Initially set to 0.1 in/hr. Adjusted to guarantee the generation of minimal to no excess precipitation and maximize runoff using the linear reservoir baseflow routine. The final values all fall between 0.06 and 0.13 in/hr.
	% Impervious Cover	Not adjusted during model calibration
Baseflow	GW 1 Initial Discharge	Initial discharge set to 0.
	GW 1 Fraction	Set to 0.5 adjusted between 0 and 0.5 during HEC-HMS model calibration. Whenever the GW 1 and GW 2 fractions do not equal 1.0, the difference between 1.0 and the sum is the percentage that does not contribute to runoff and is instead lost to a deep aquifer.
	GW 1 Storage Coefficient	GW 1 was conceptualized to represent the fast-responding portion of baseflow. Therefore, this coefficient was set to a smaller value than the GW 2 storage coefficient. This value was set to 2 times the storage coefficient. Minor modifications to this parameter were made during modeling calibration.
	GW 1 # of Reservoirs	Set to 1. Not adjusted during model calibration.
	GW 2 Initial Discharge	Initial discharge is event specific and can vary throughout the year within a single subbasin. Parameter was set to an appropriate value within each subbasin for each water year that provided adequate agreement with observed data.
	GW 2 Fraction	Set to 0.5 and varied between 0 and 0.5 during HEC-HMS model calibration. Whenever the GW 1 and GW 2 fractions do not equal 1.0, the difference between 1.0 and the sum is the percentage that does not contribute to runoff and is instead lost to a deep aquifer.
	GW 2 Storage Coefficient	Set to a larger value than the GW 1 storage coefficient. Minor modifications to this parameter were made during modeling calibration.
	GW 2 # of Reservoirs	Set to 1. Not varied during model calibration.

A.4. Calibration Results for Selected Water Years

A.4.1. Calibration Results for WY1997

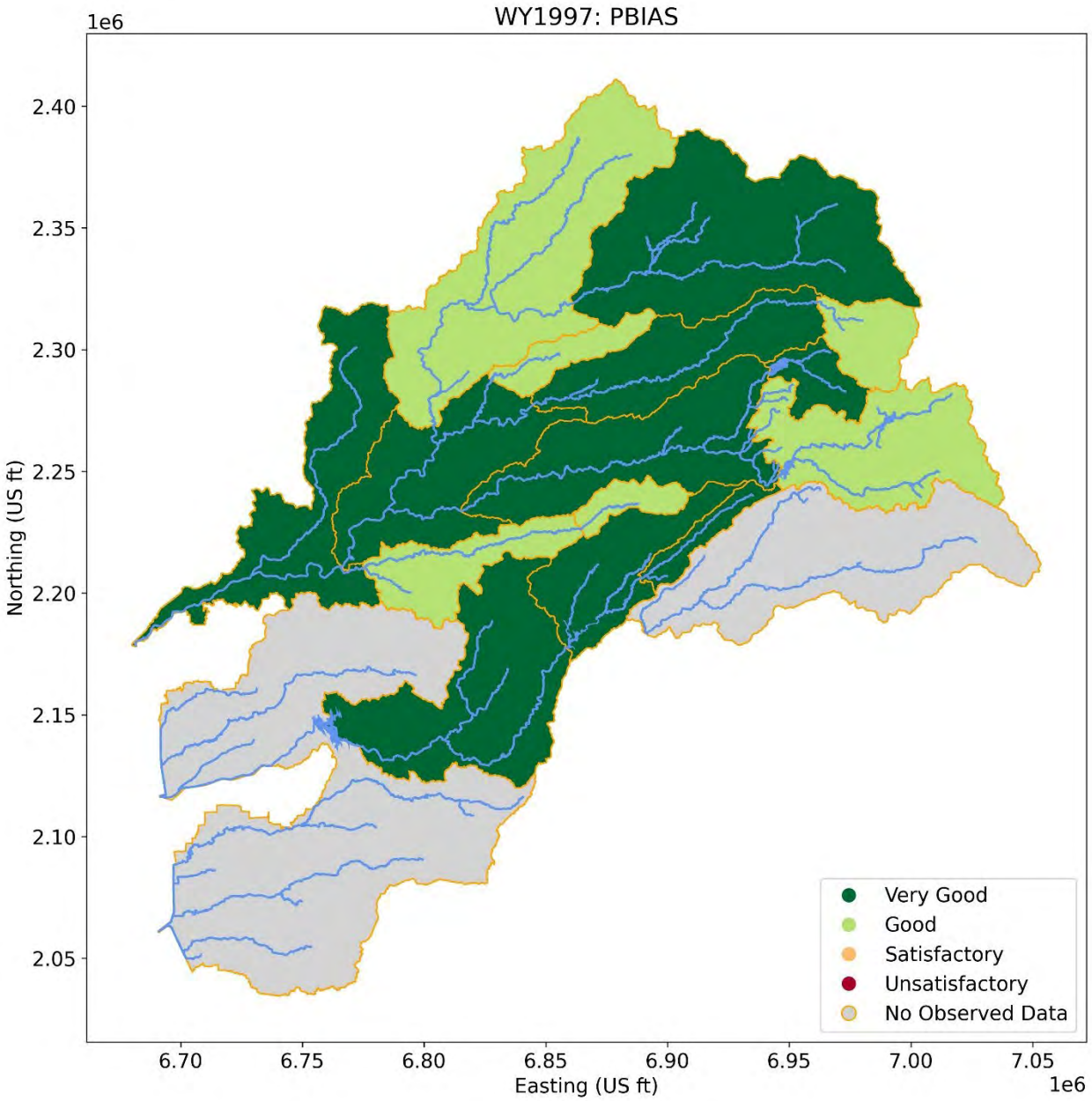


Figure A-4. WY1997 Percent Bias (PBIAS) Calibration Results for the Entire Calibrated Watersheds

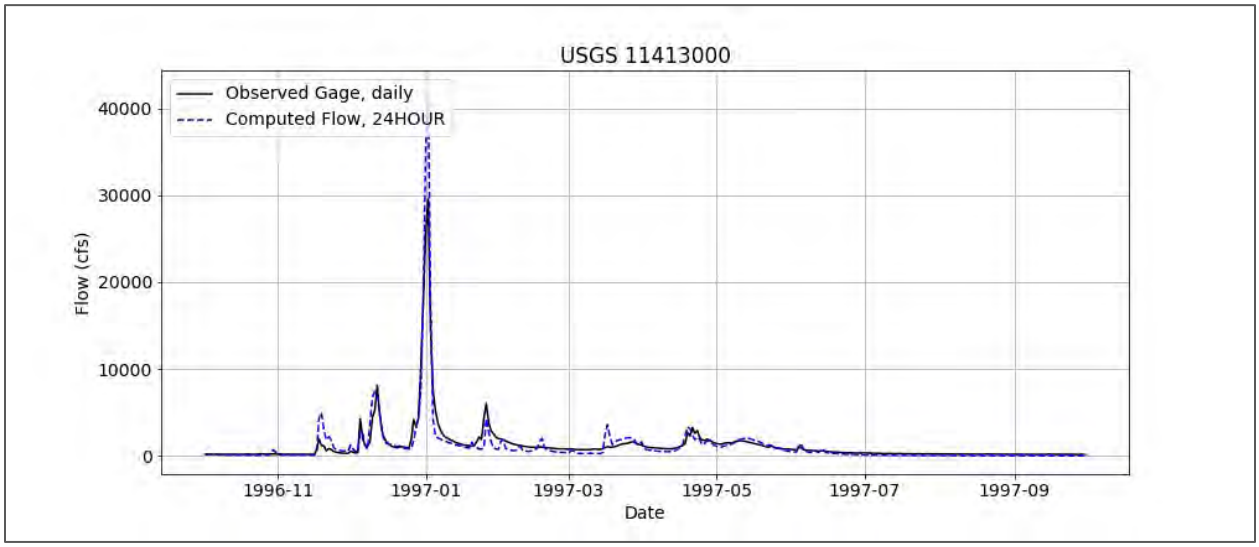


Figure A-5. WY1997 Calibration Results for Calibration Location USGS Gage 11413000

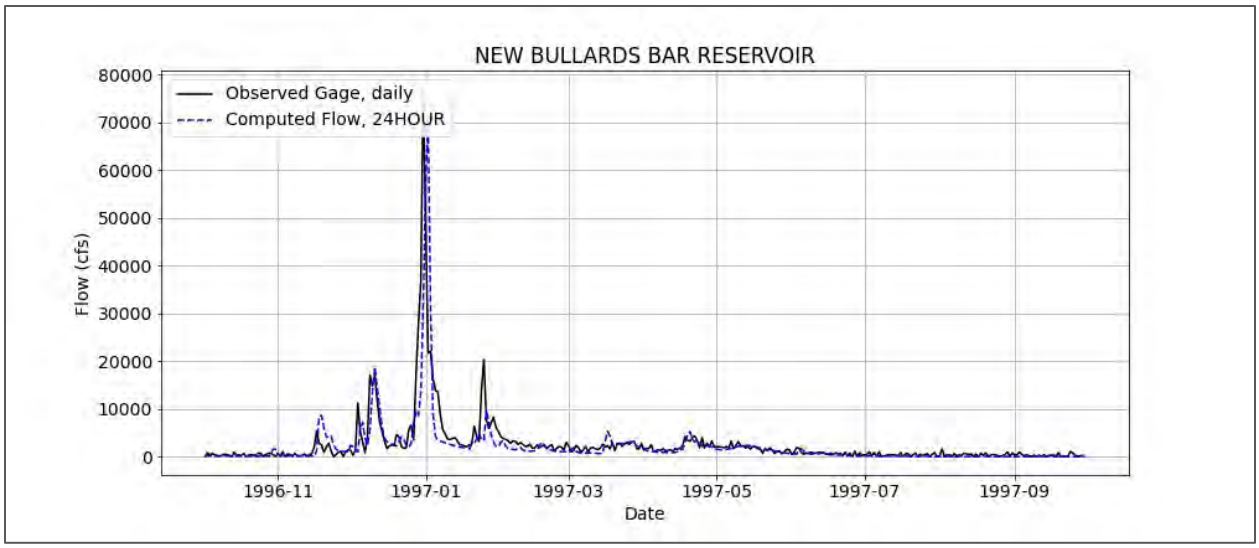


Figure A-6. WY1997 Calibration Results for Calibration Location New Bullards Bar Reservoir

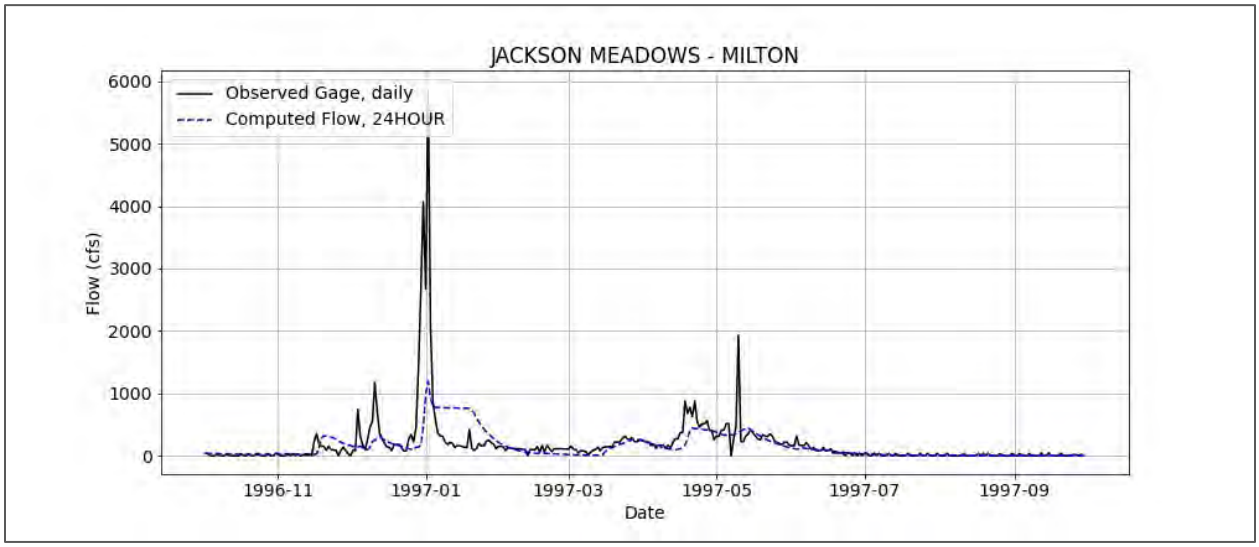


Figure A-7. WY1997 Calibration Results for Calibration Location Jackson Meadows and Milton Reservoirs

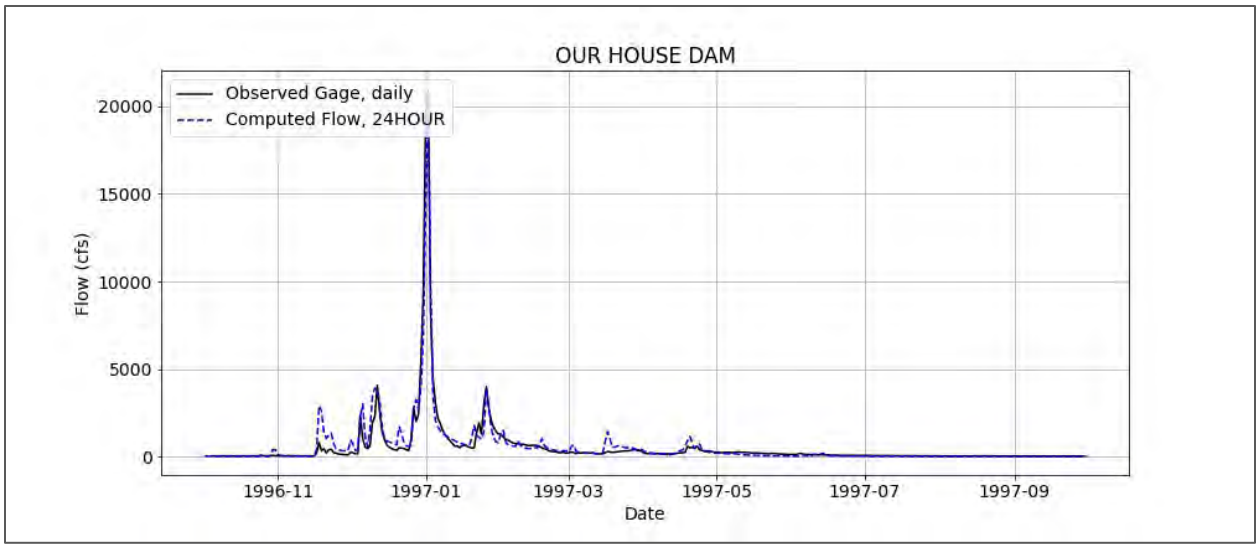


Figure A-8. WY1997 Calibration Results for Calibration Location Our House Dam

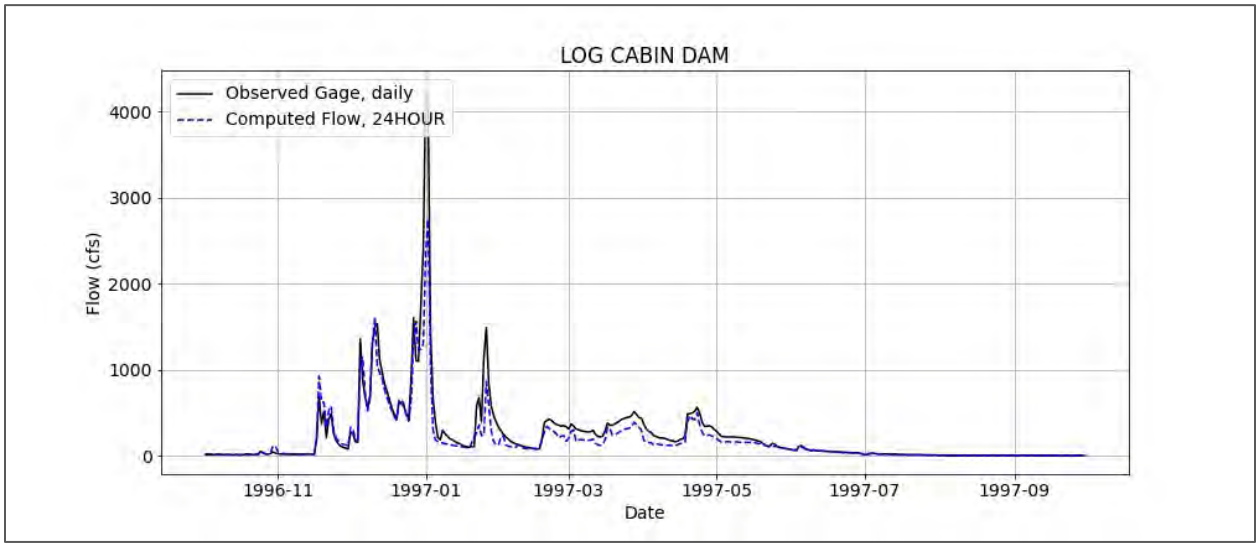


Figure A-9. WY1997 Calibration Results for Calibration Location Log Cabin Dam

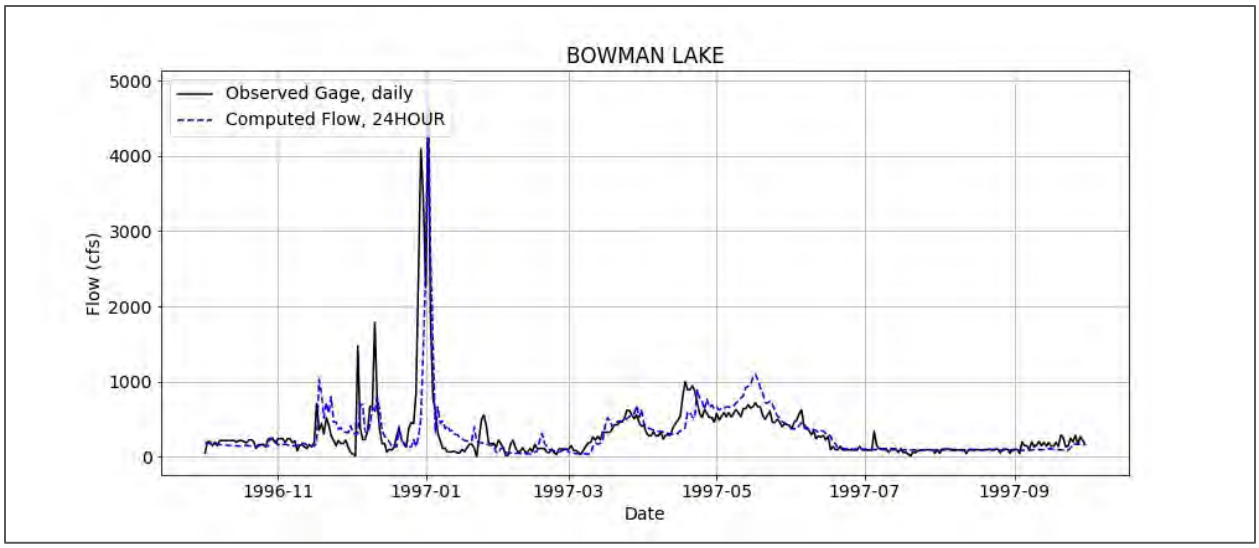


Figure A-10. WY1997 Calibration Results for Calibration Location Bowman Lake

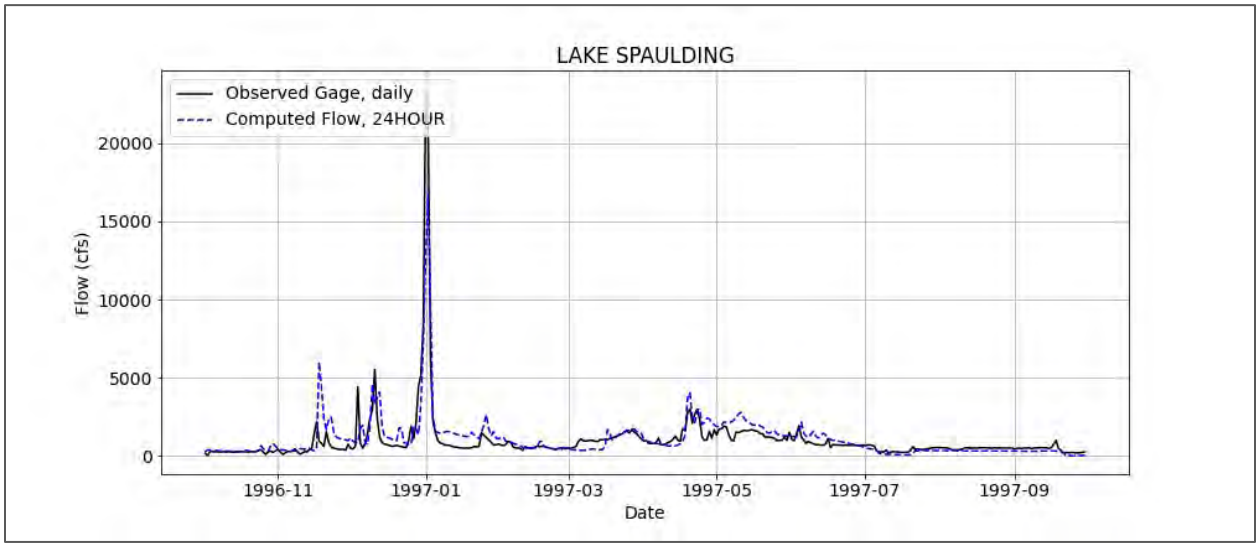


Figure A-11. WY1997 Calibration Results for Calibration Location Lake Spaulding

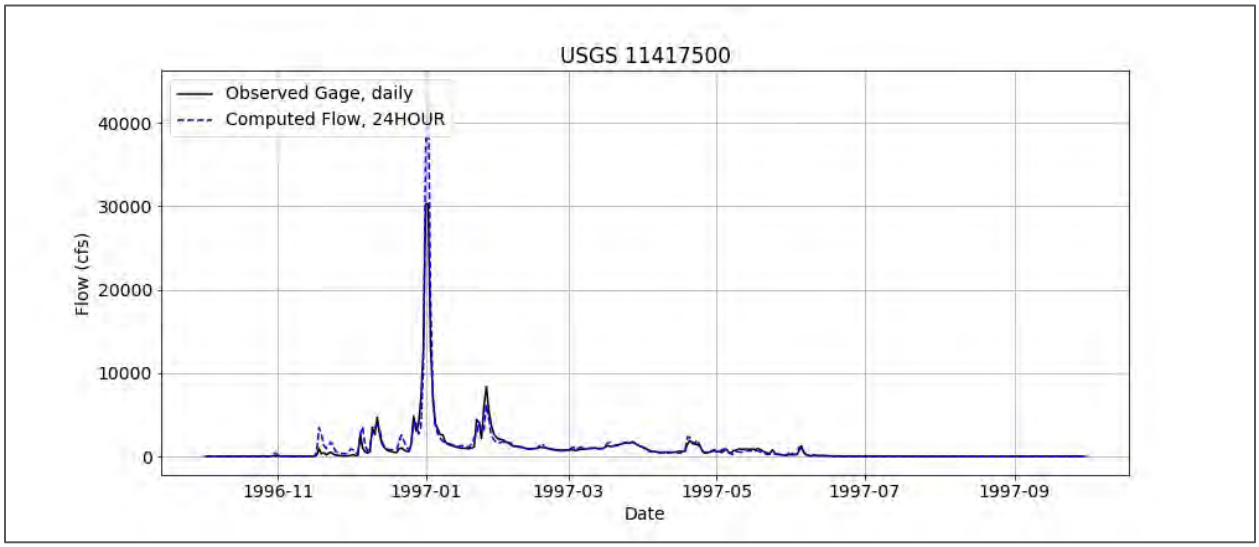


Figure A-12. WY1997 Calibration Results for Calibration Location USGS Gage 11417500

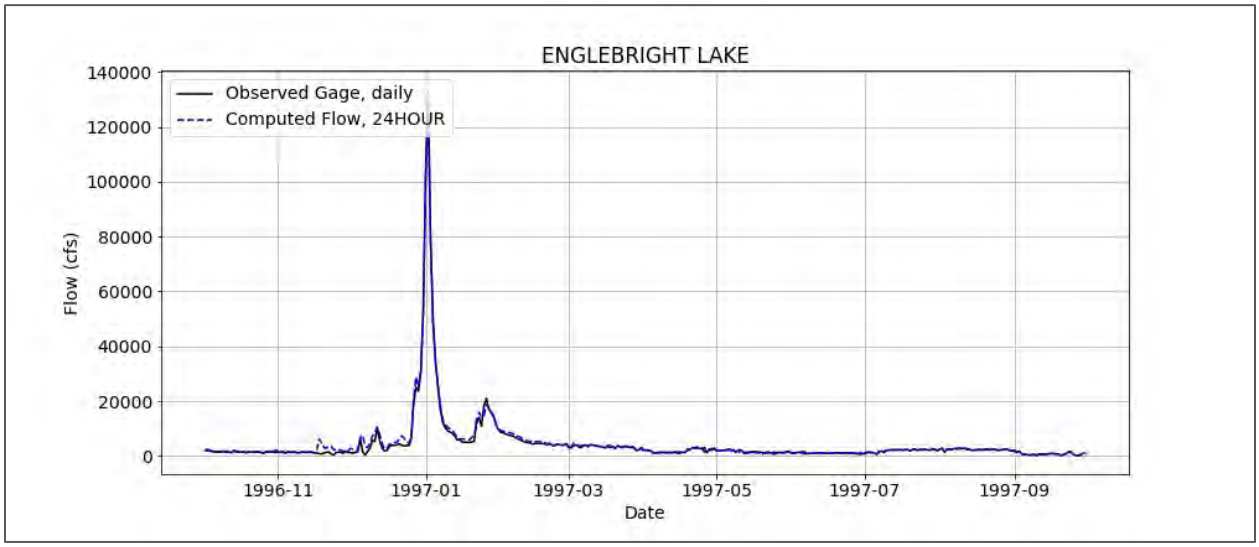


Figure A-13. WY1997 Calibration Results for Calibration Location Englebright Lake

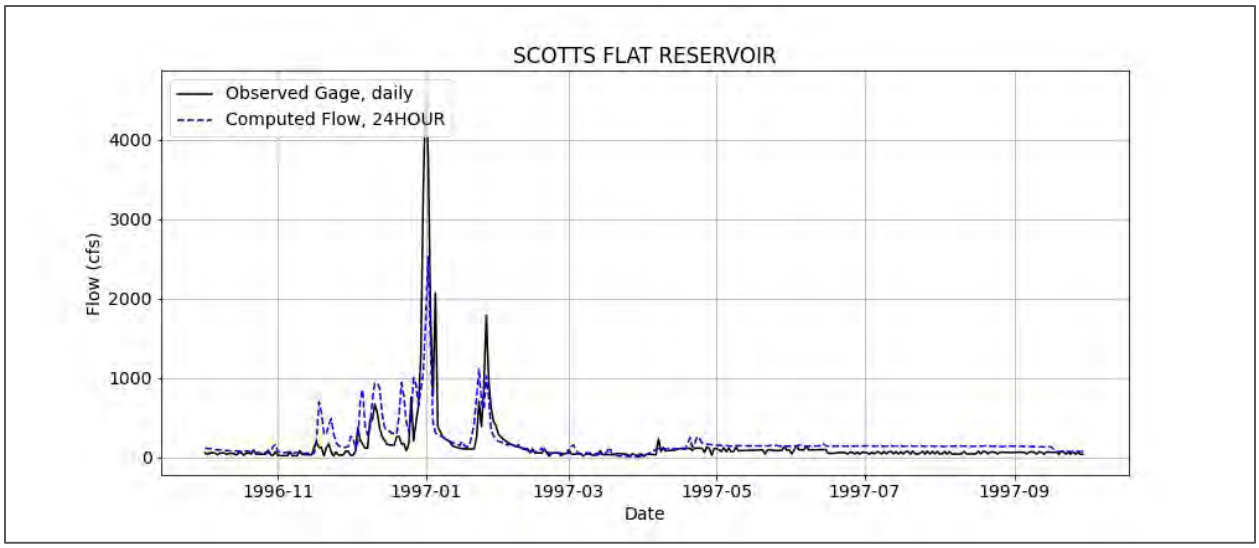


Figure A-14. WY1997 Calibration Results for Calibration Location Scotts Flat Reservoir

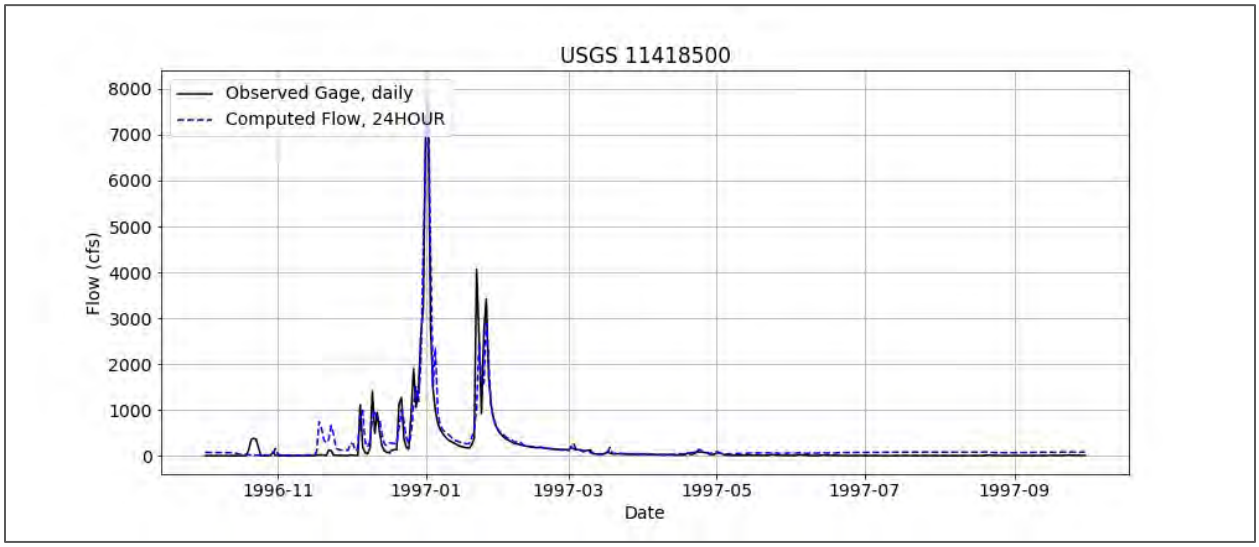


Figure A-15. WY1997 Calibration Results for Calibration Location USGS Gage 11418500

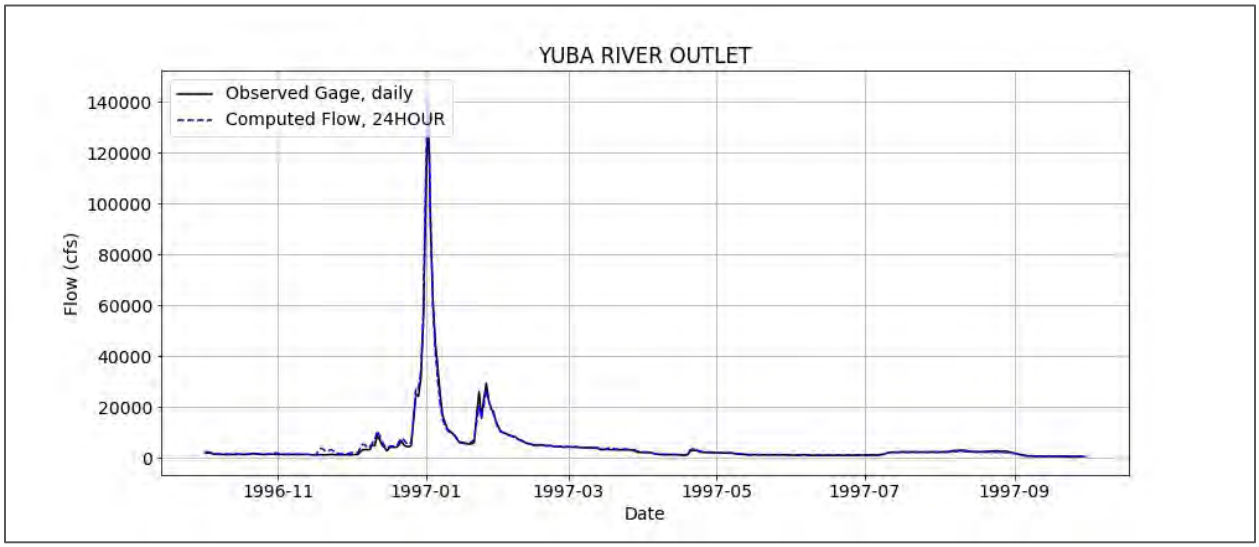


Figure A-16. WY1997 Calibration Results for Calibration Location Yuba River Outlet

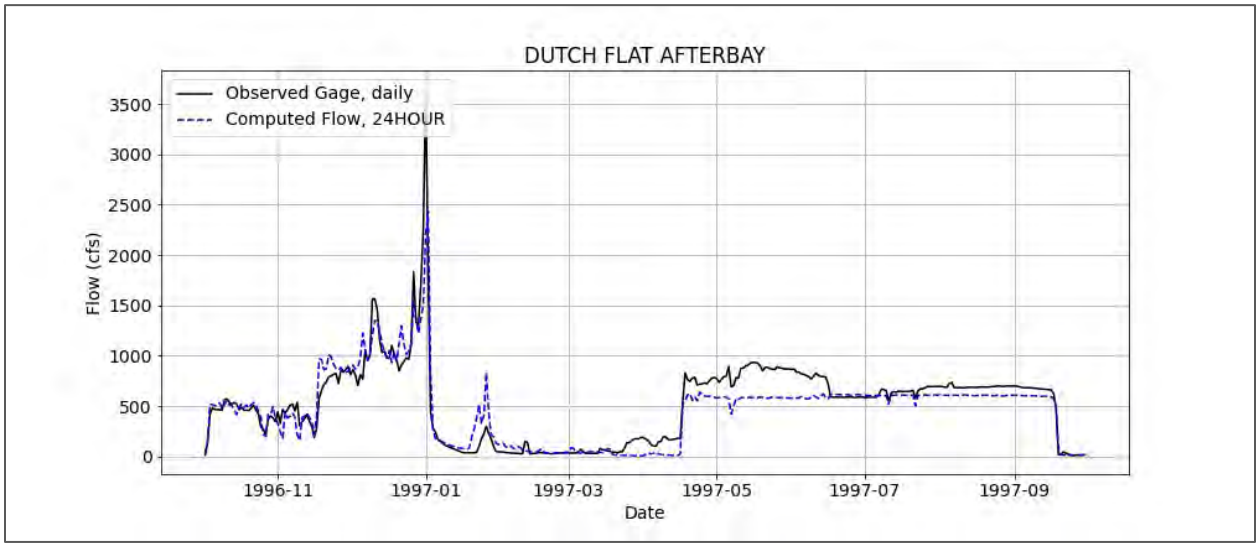


Figure A-17. WY1997 Calibration Results for Calibration Location Dutch Flat Afterbay

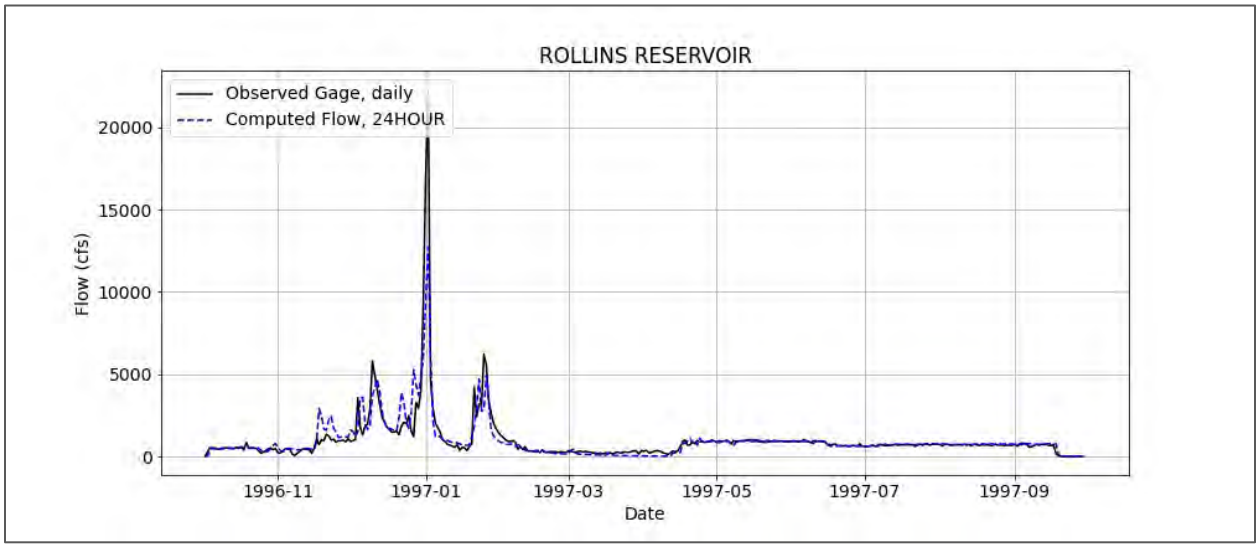


Figure A-18. WY1997 Calibration Results for Calibration Location Rollins Reservoir

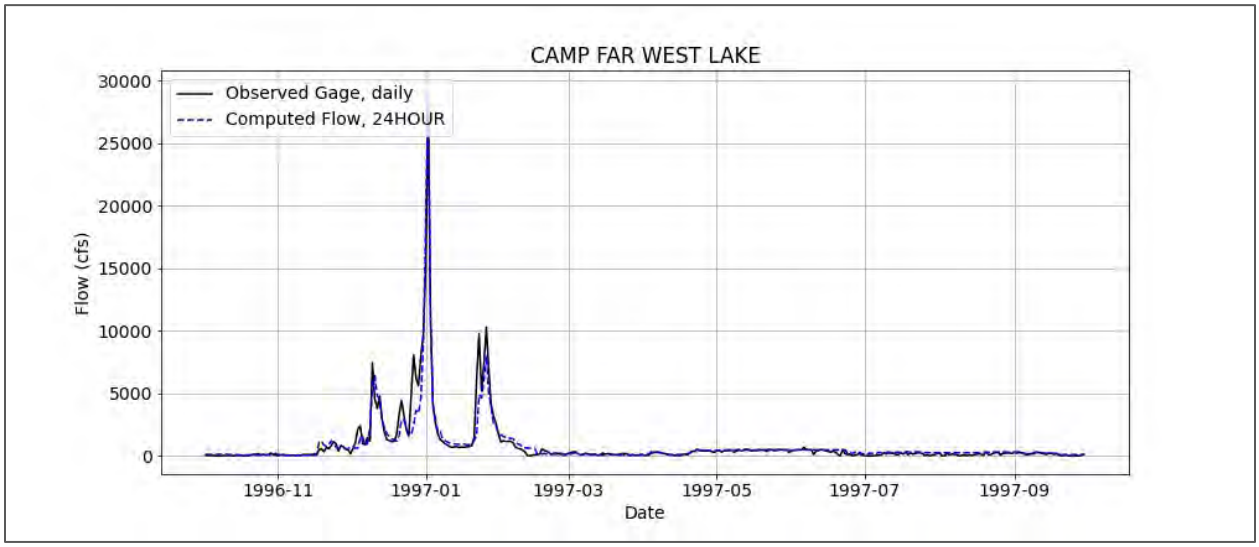


Figure A-19. WY1997 Calibration Results for Calibration Location Camp Far West Lake

A.4.2. Calibration Results for WY2004

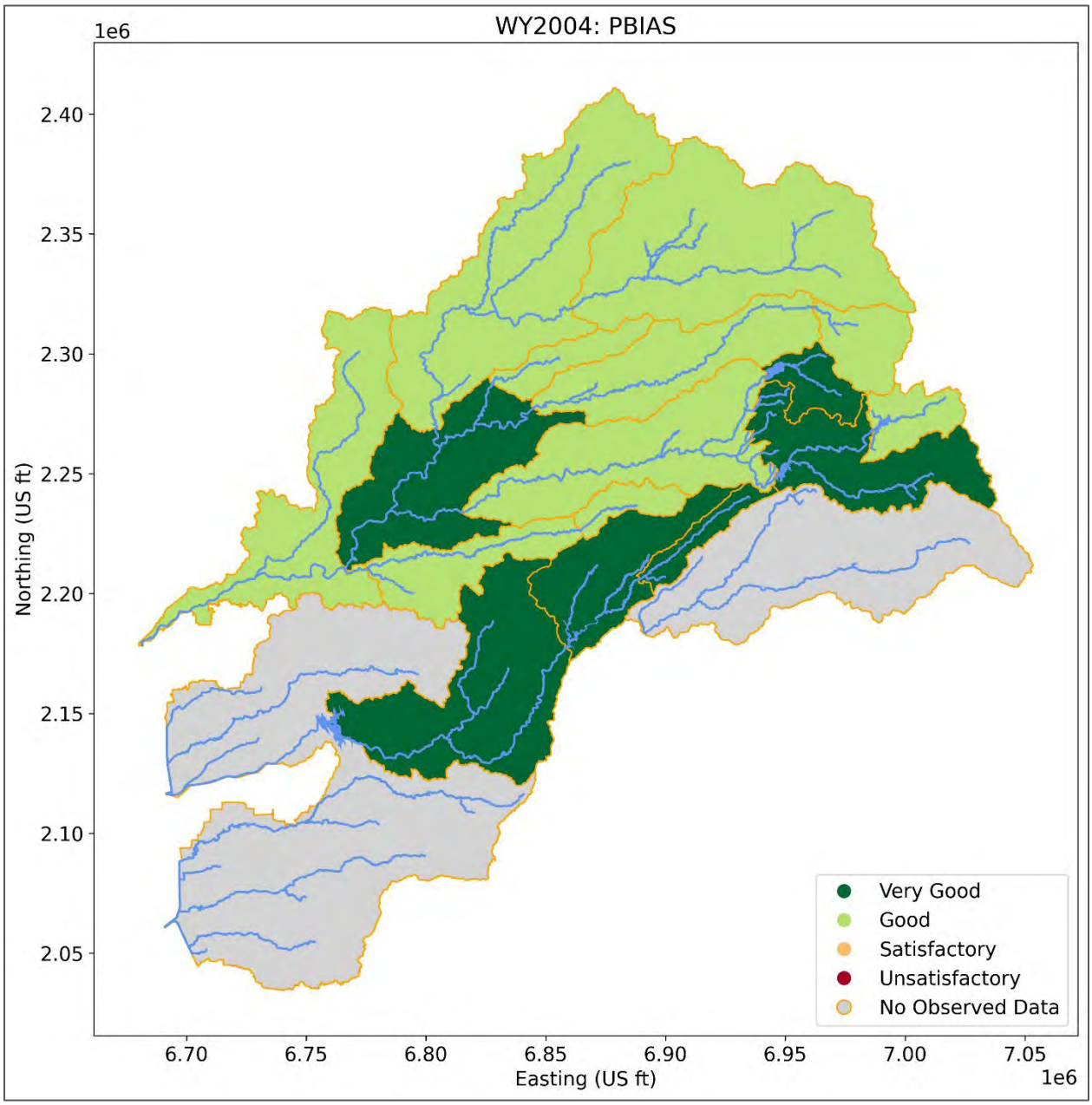


Figure A-20. WY2004 Percent Bias (PBIAS) Calibration Results for the Entire Calibrated Watersheds

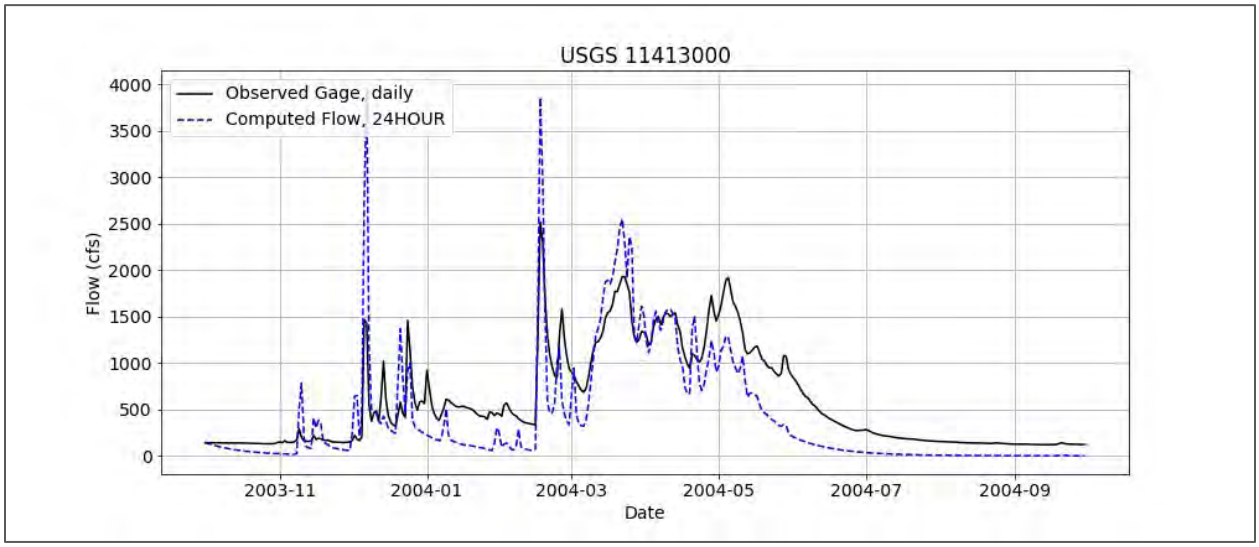


Figure A-21. WY2004 Calibration Results for Calibration Location USGS Gage 11413000

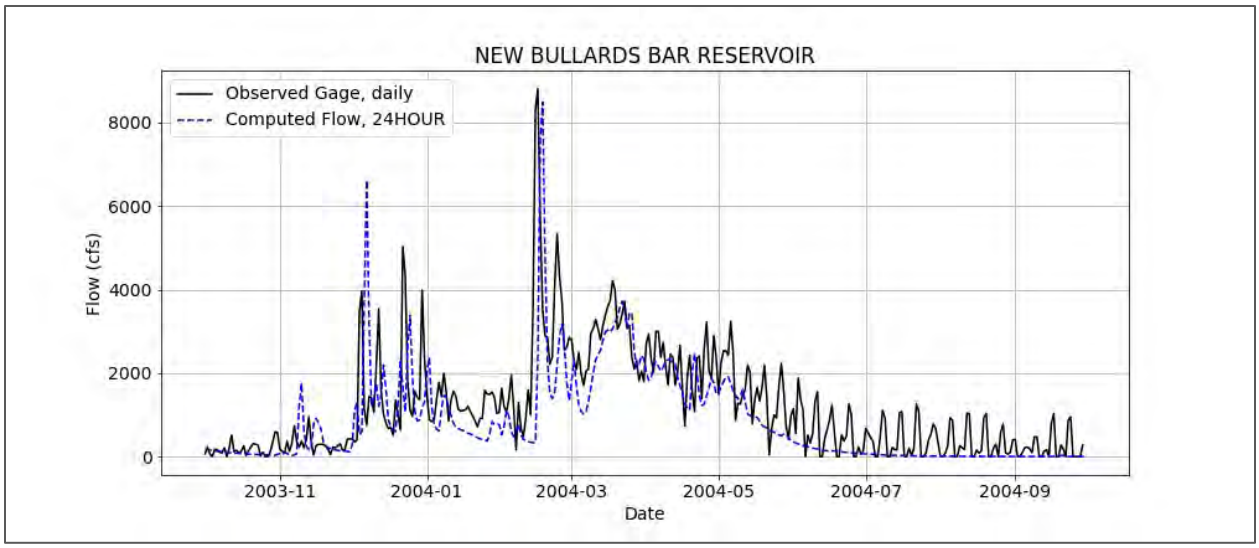


Figure A-22. WY2004 Calibration Results for Calibration Location New Bullards Bar Reservoir

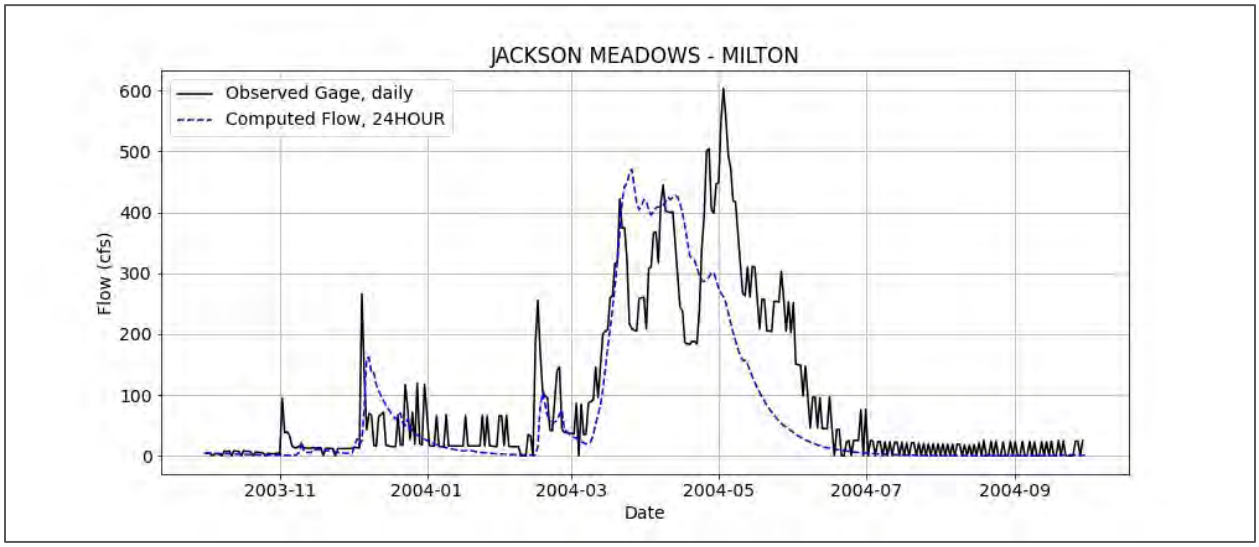


Figure A-23. WY2004 Calibration Results for Calibration Location Jackson Meadows and Milton Reservoirs

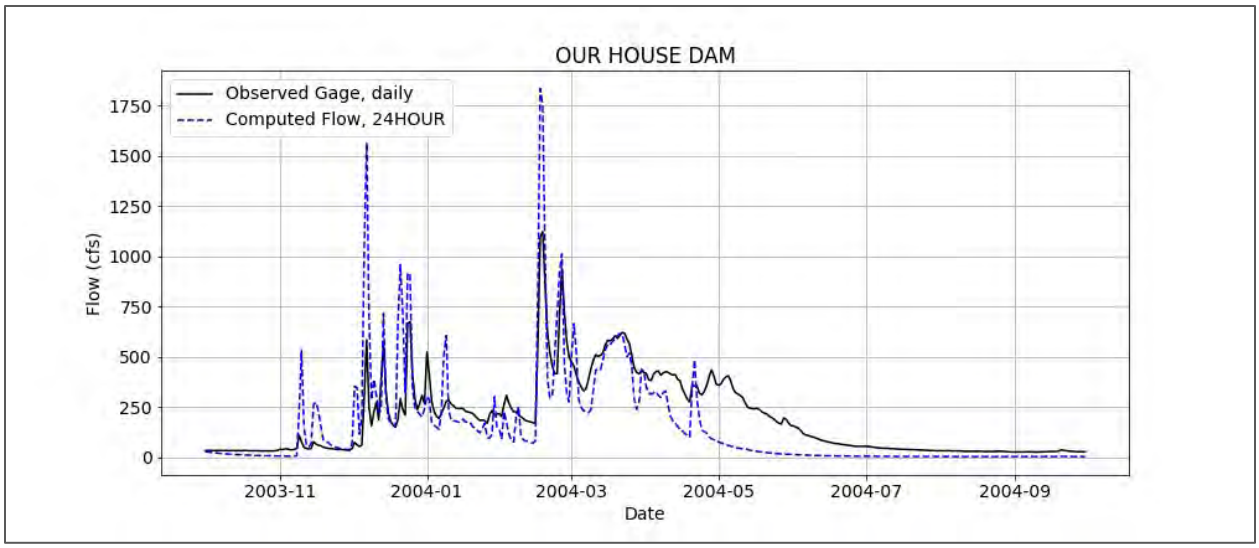


Figure A-24. WY2004 Calibration Results for Calibration Location Our House Dam

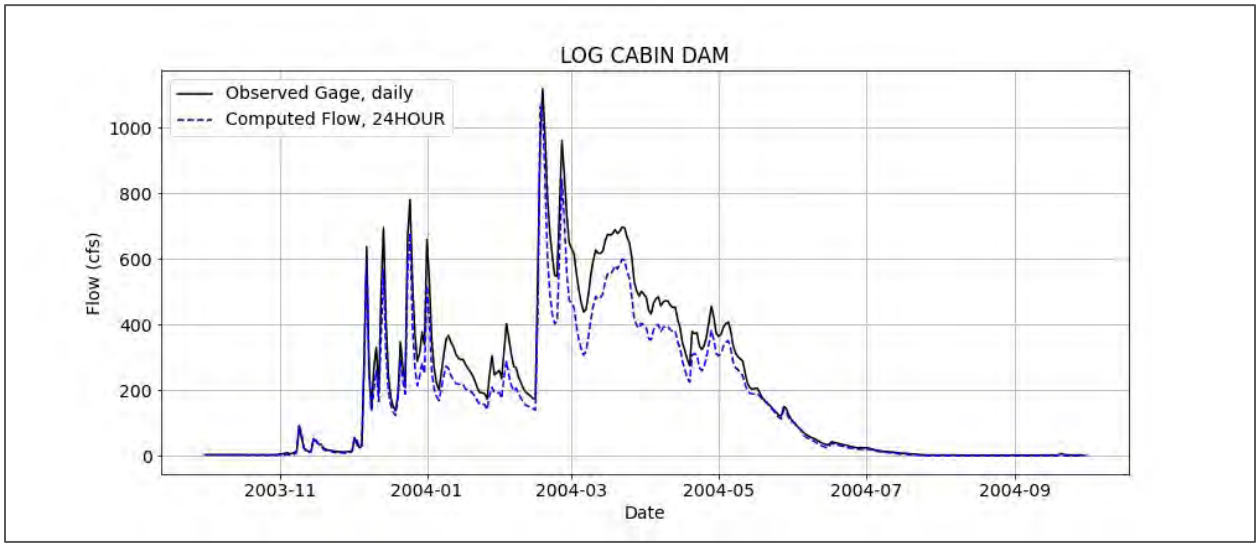


Figure A-25. WY2004 Calibration Results for Calibration Location Log Cabin Dam

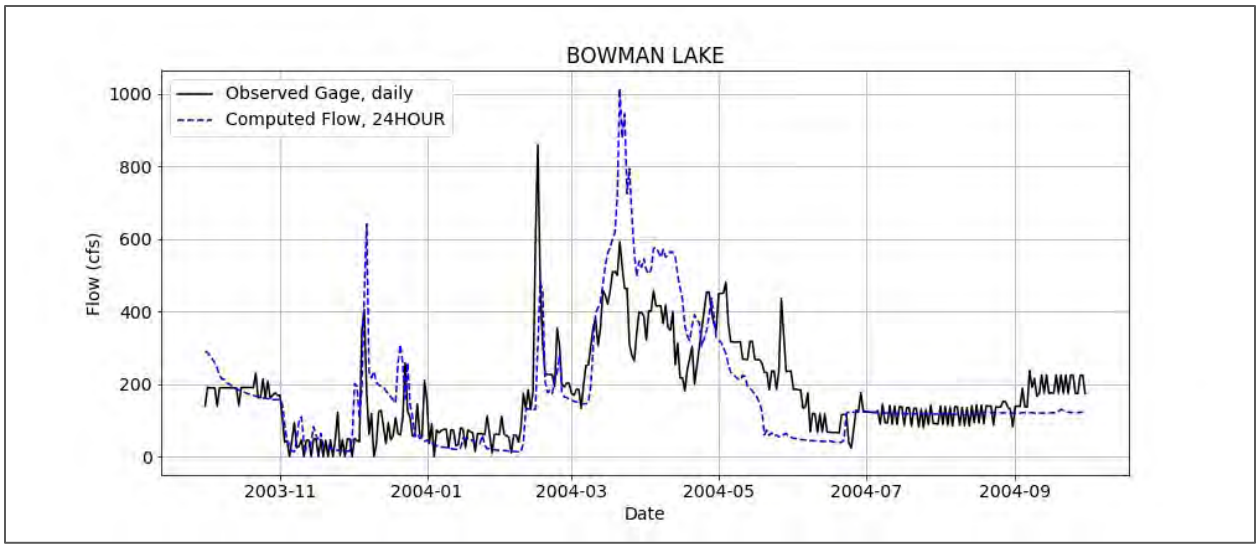


Figure A-26. WY2004 Calibration Results for Calibration Location Bowman Lake

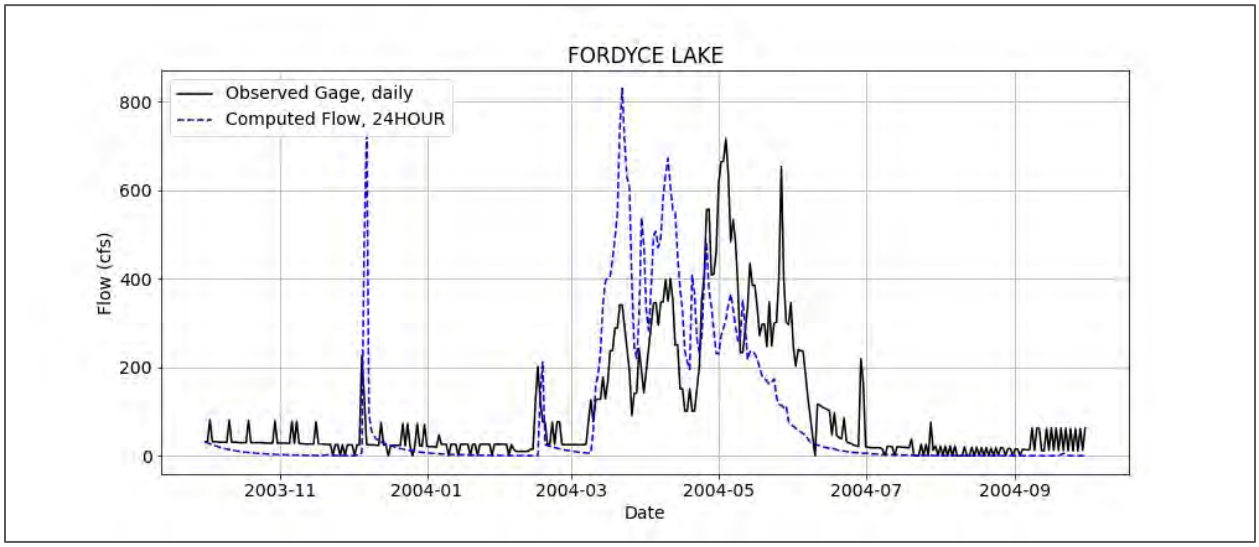


Figure A-27. WY2004 Calibration Results for Calibration Location Fordyce Lake

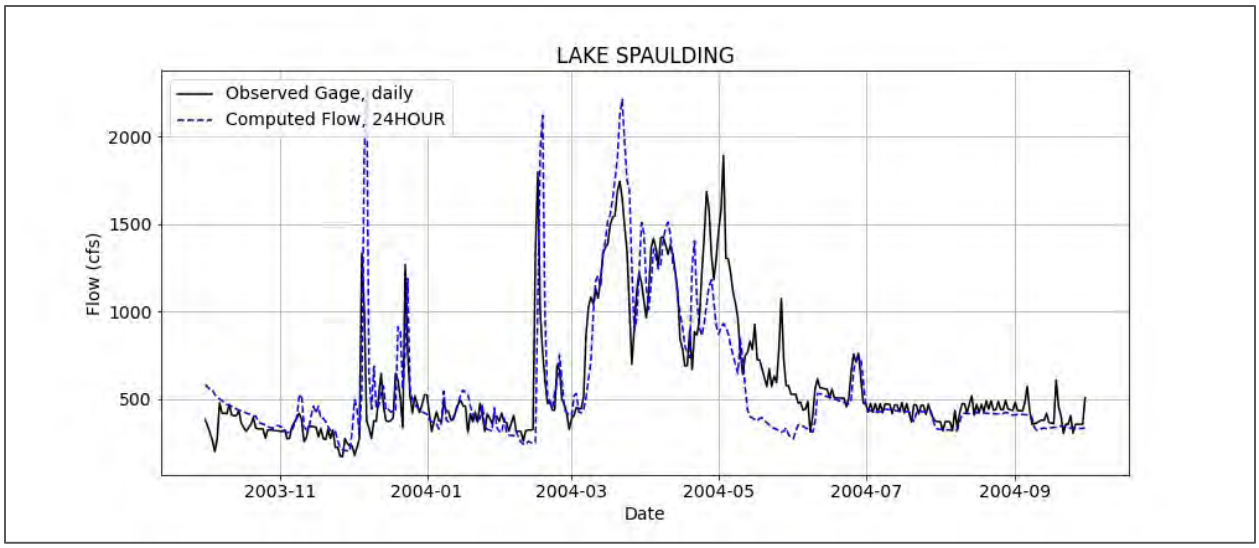


Figure A-28. WY2004 Calibration Results for Calibration Location Lake Spaulding

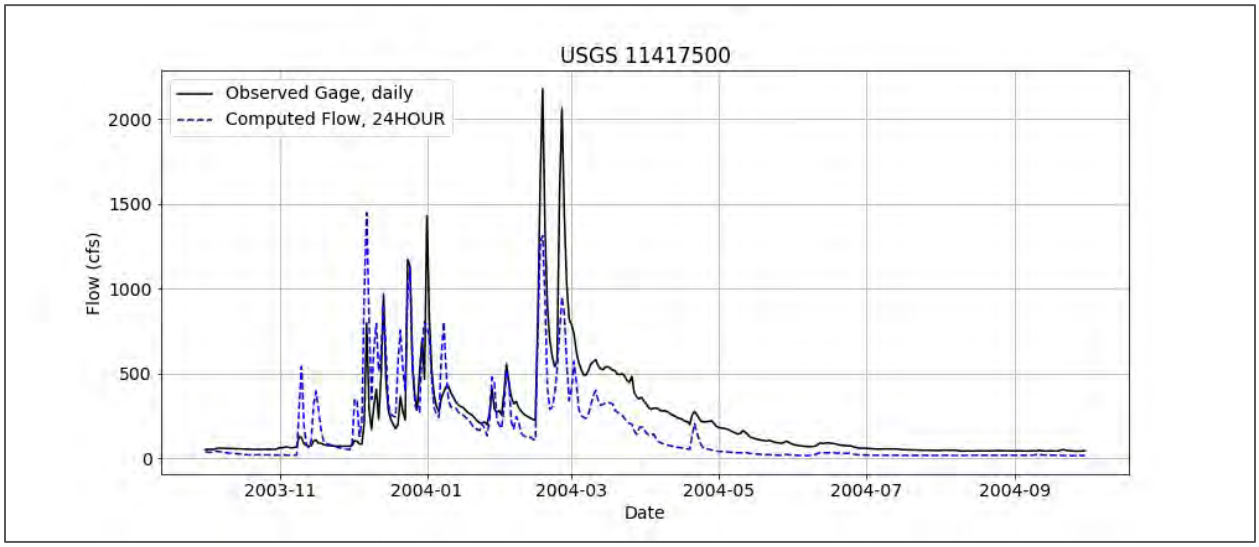


Figure A-29. WY2004 Calibration Results for Calibration Location USGS Gage 11417500

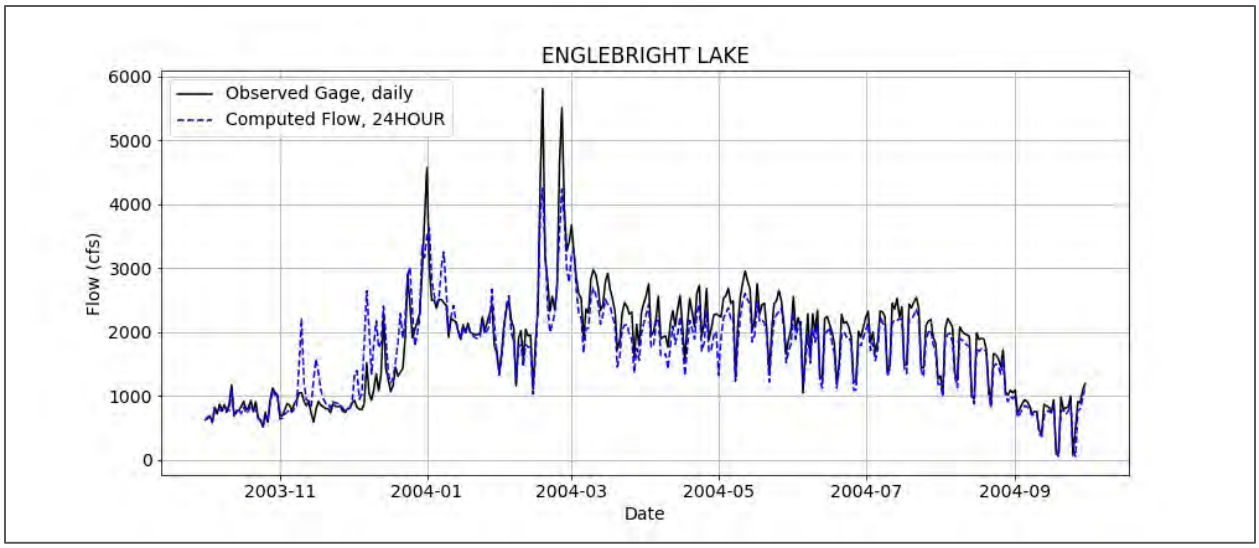


Figure A-30. WY2004 Calibration Results for Calibration Location Englebright Lake

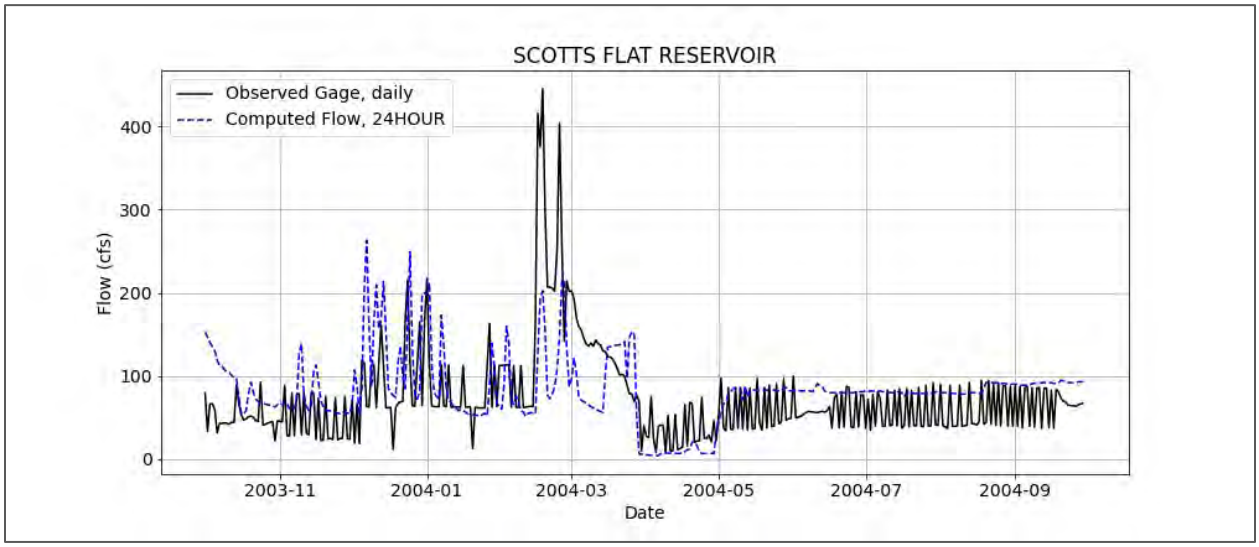


Figure A-31. WY2004 Calibration Results for Calibration Location Scotts Flat Reservoir

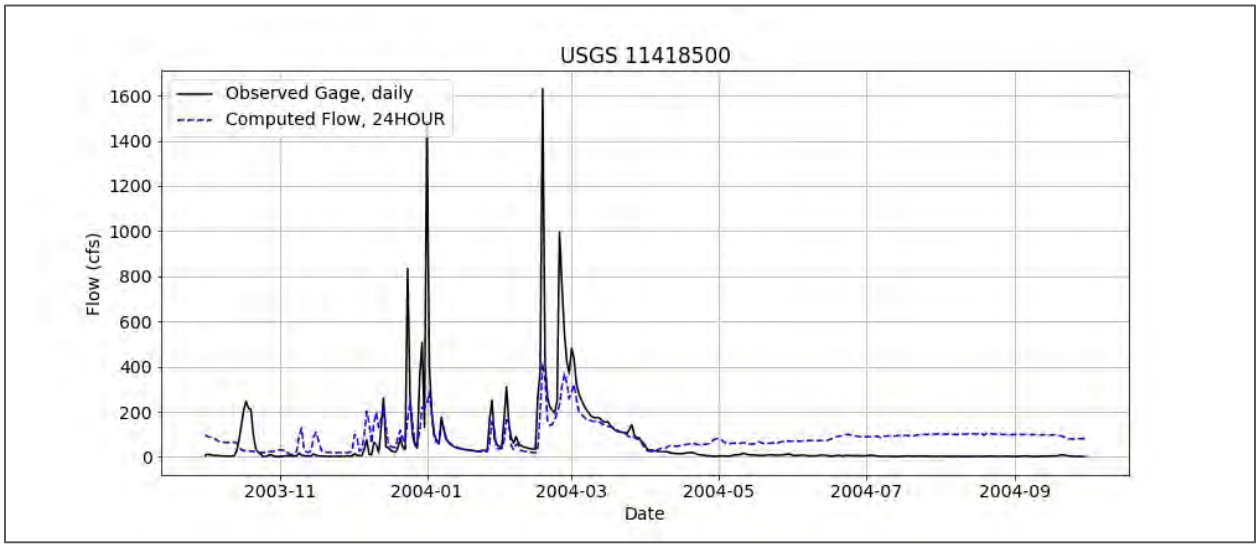


Figure A-32. WY2004 Calibration Results for Calibration Location USGS Gage 11418500

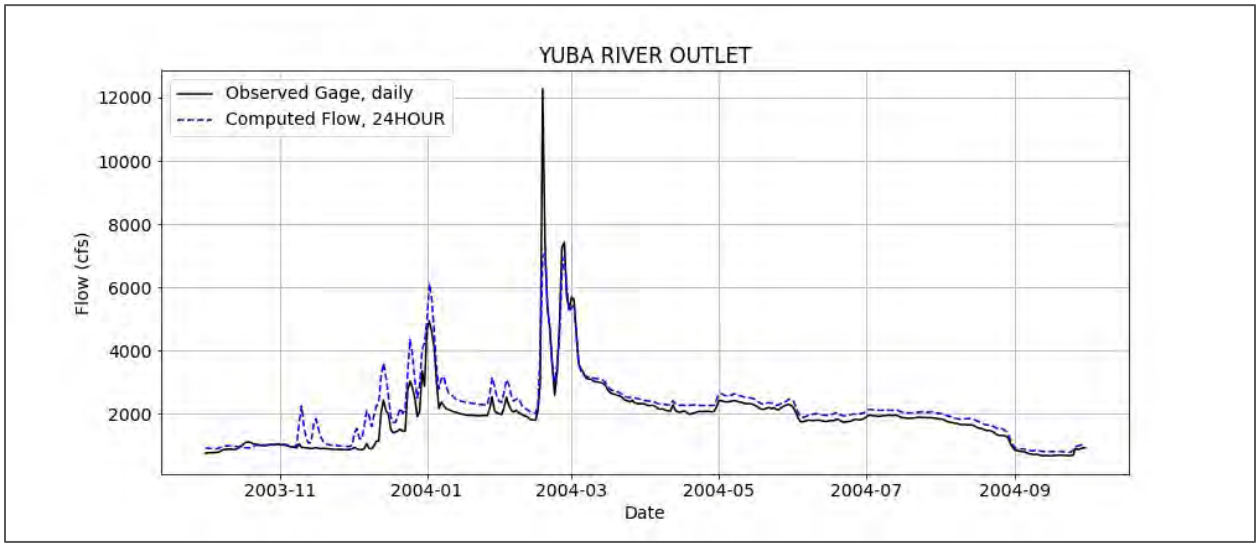


Figure A-33. WY2004 Calibration Results for Calibration Location Yuba River Outlet

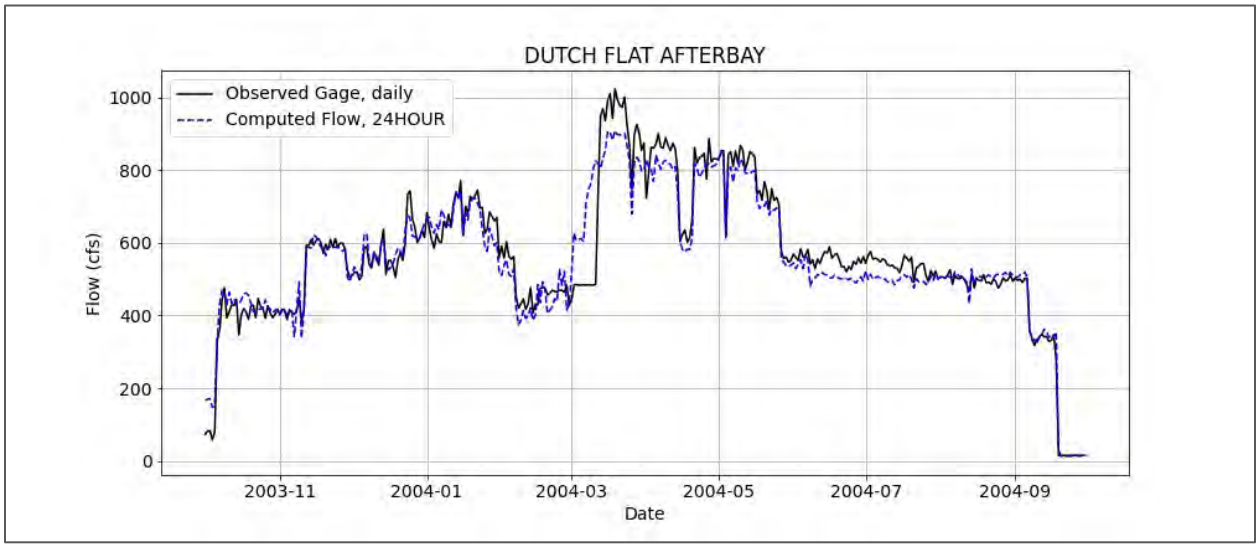


Figure A-34. WY2004 Calibration Results for Calibration Location Dutch Flat Afterbay

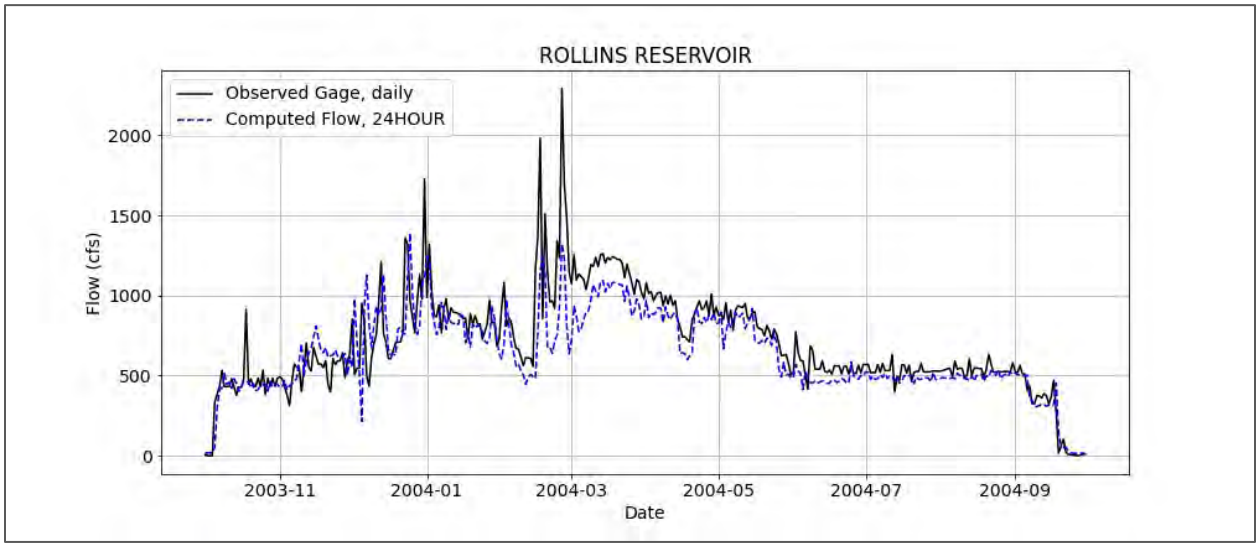


Figure A-35. WY2004 Calibration Results for Calibration Location Rollins Reservoir

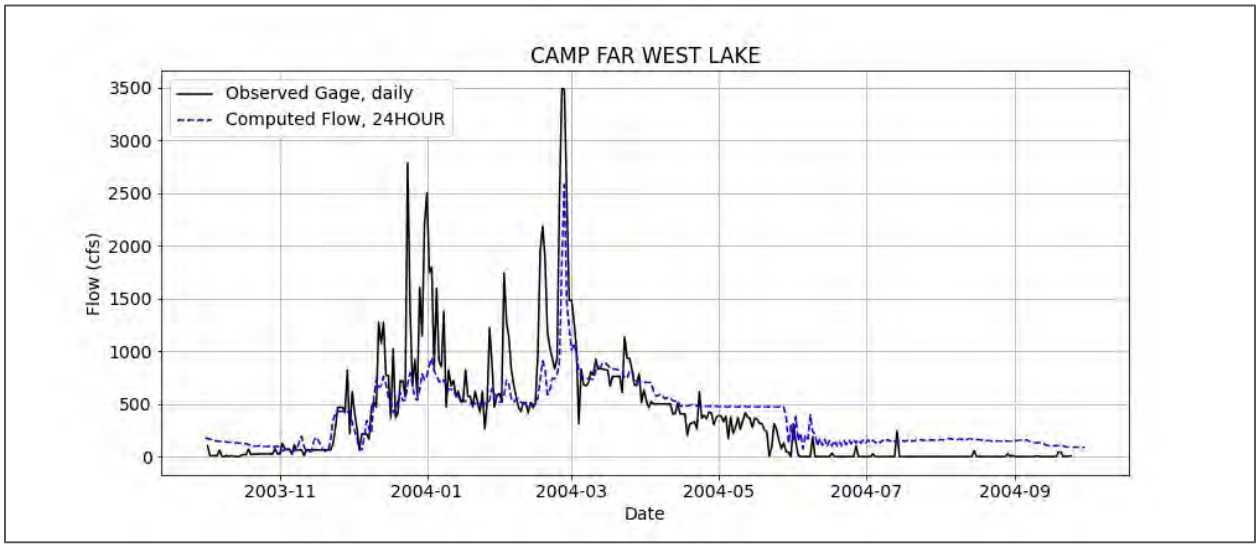


Figure A-36. WY2004 Calibration Results for Calibration Location Camp Far West Lake

A.4.3. Calibration Results for WY2006

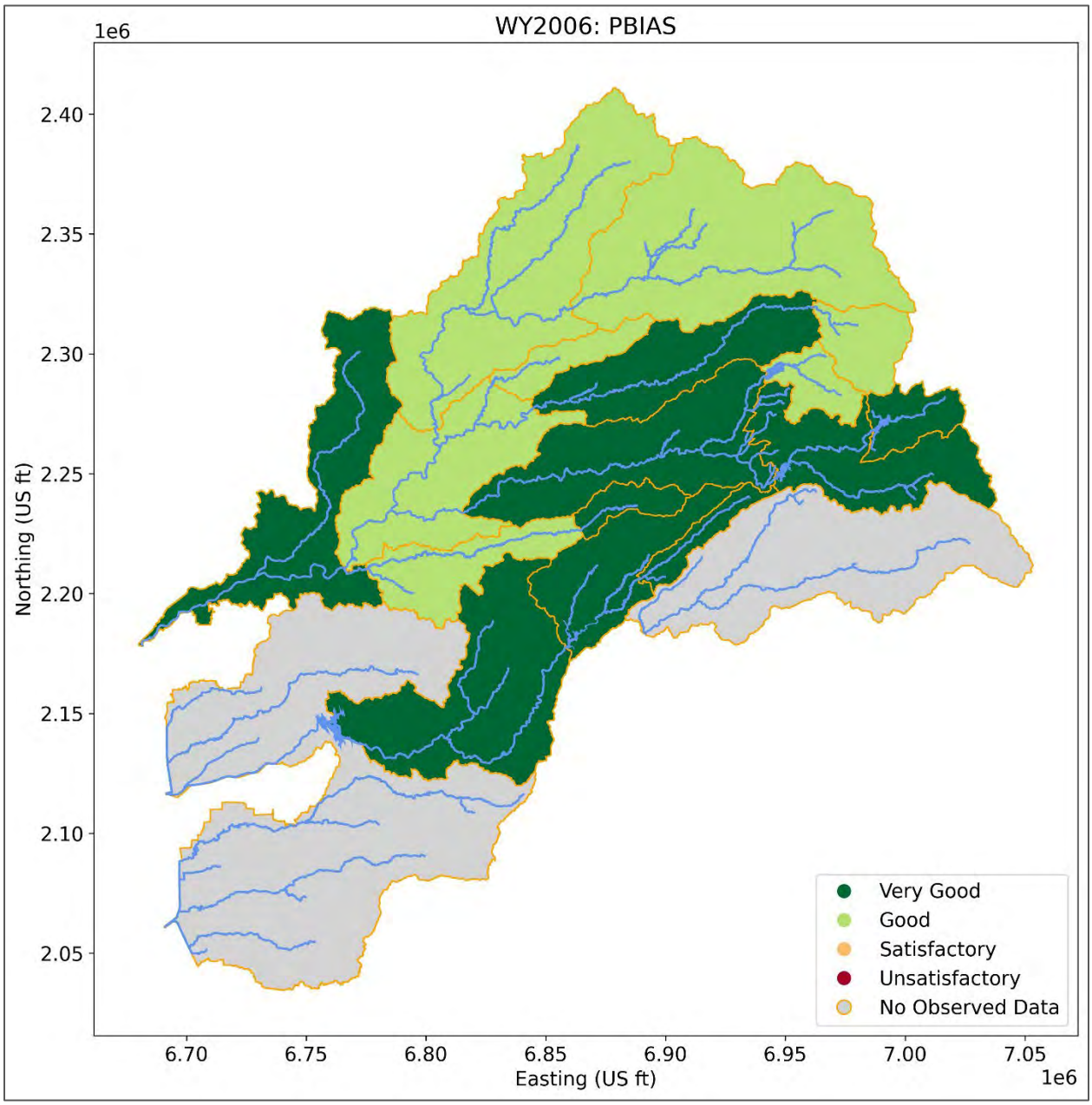


Figure A-37. WY2006 Percent Bias (PBIAS) Calibration Results for the Entire Calibrated Watersheds

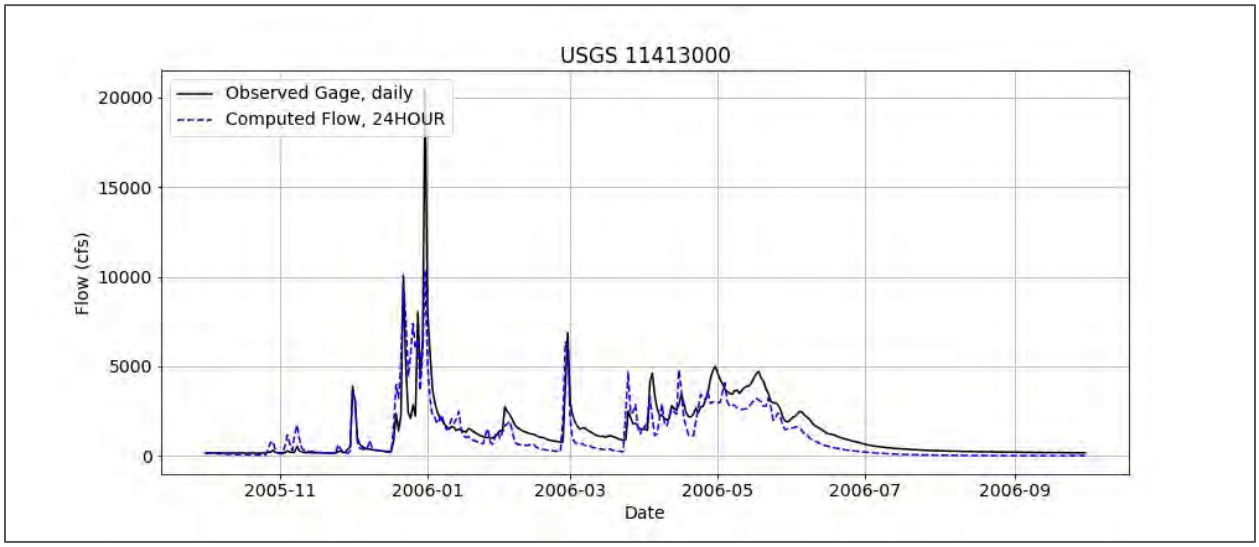


Figure A-38. WY2006 Calibration Results for Calibration Location USGS Gage 11413000

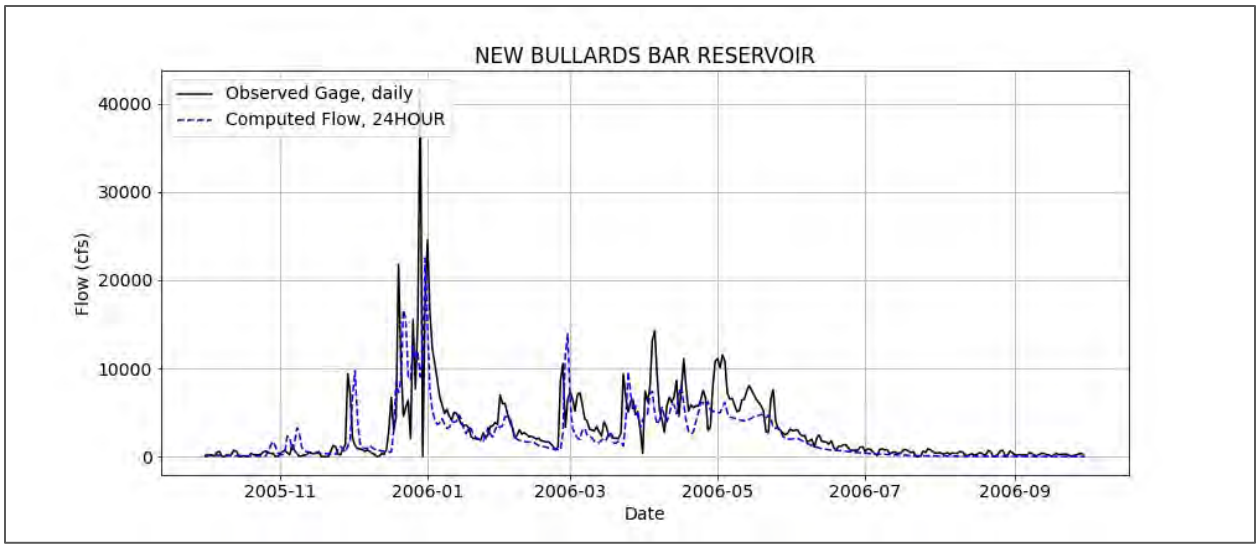


Figure A-39. WY2006 Calibration Results for Calibration Location New Bullards Bar Reservoir

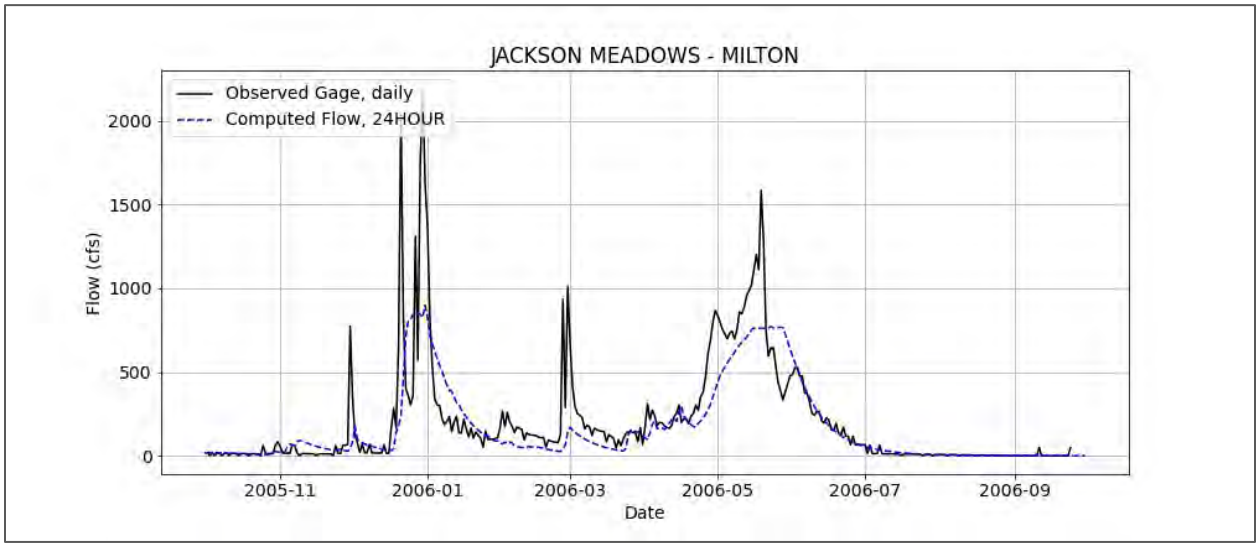


Figure A-40. WY2006 Calibration Results for Calibration Location Jackson Meadows and Milton Reservoirs

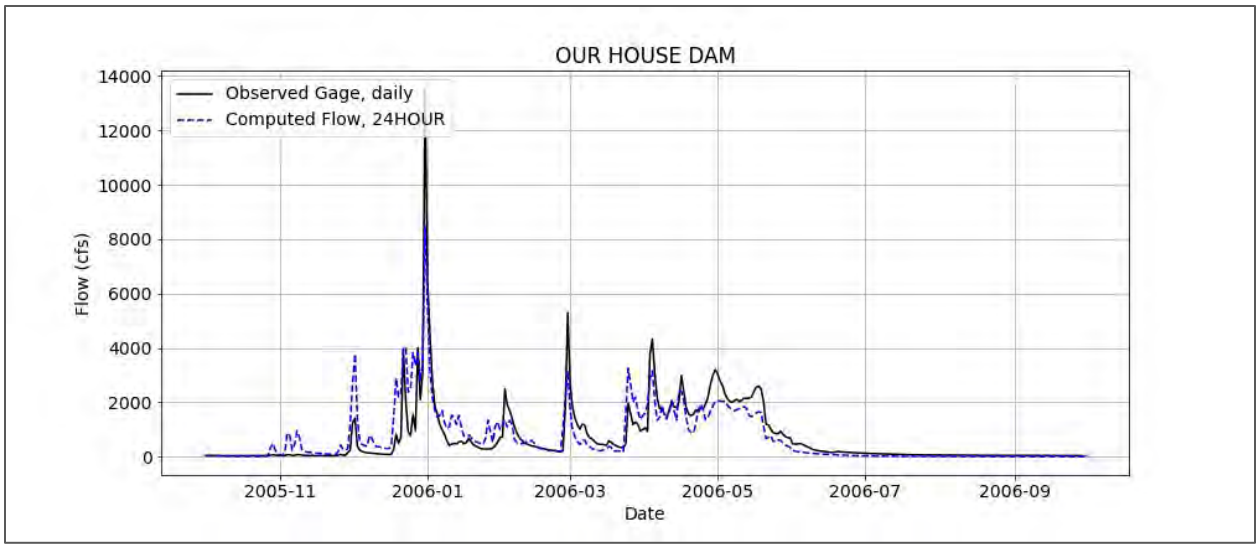


Figure A-41. WY2006 Calibration Results for Calibration Location Our House Dam

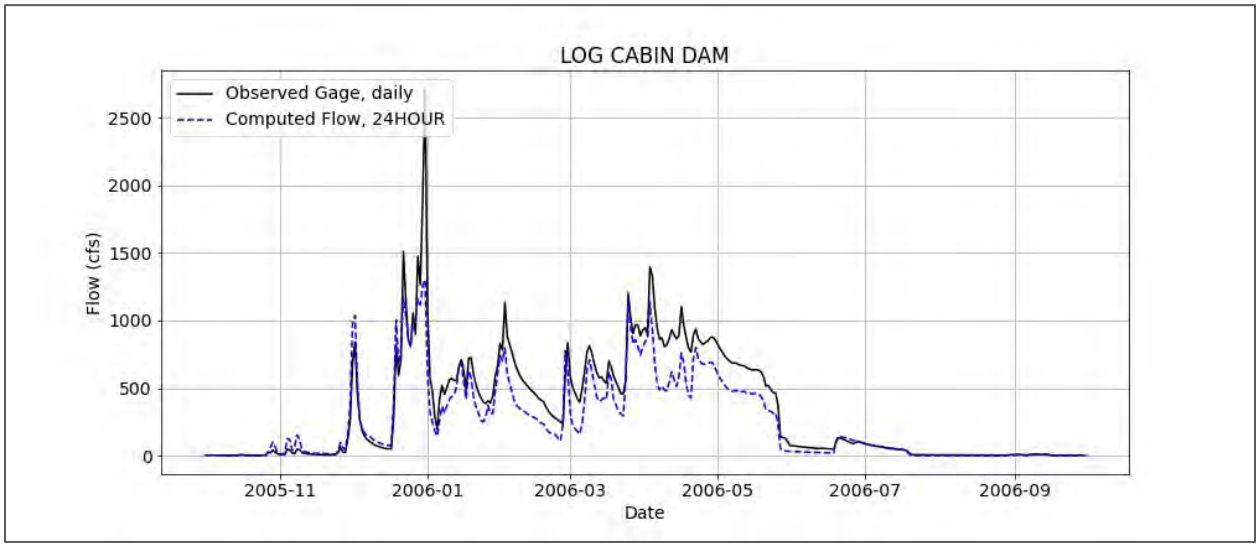


Figure A-42. WY2006 Calibration Results for Calibration Location Log Cabin Dam

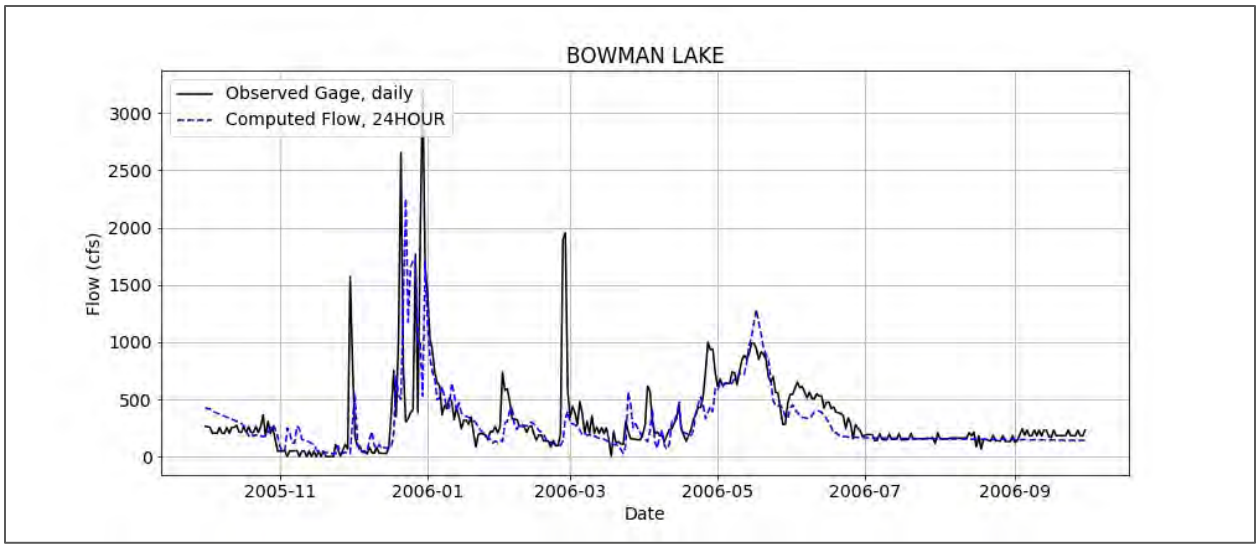


Figure A-43. WY2006 Calibration Results for Calibration Location Bowman Lake

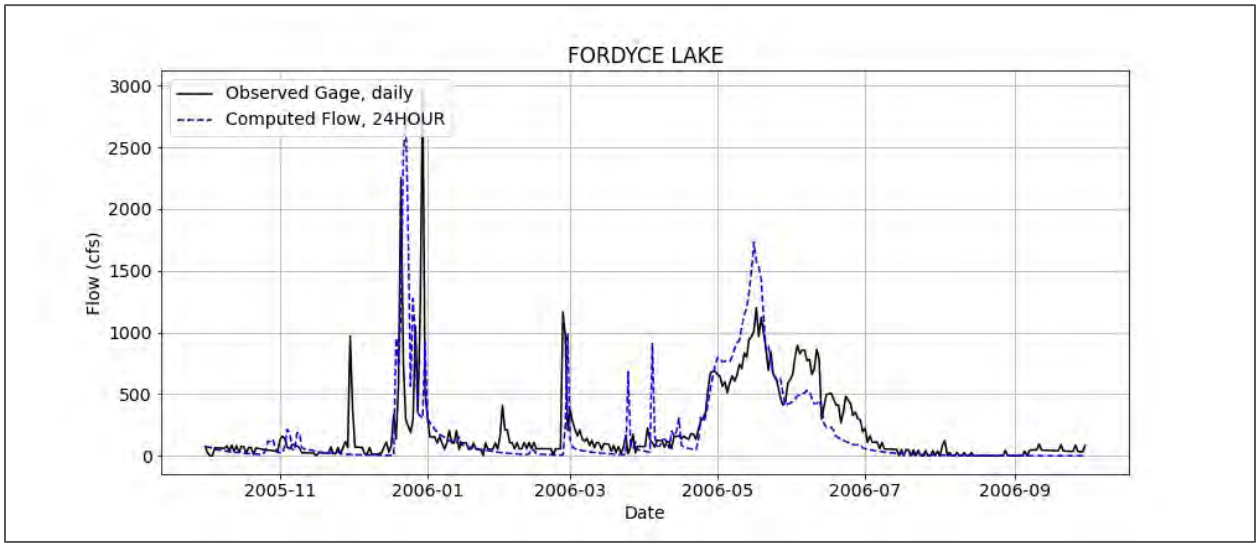


Figure A-44. WY2006 Calibration Results for Calibration Location Fordyce Lake

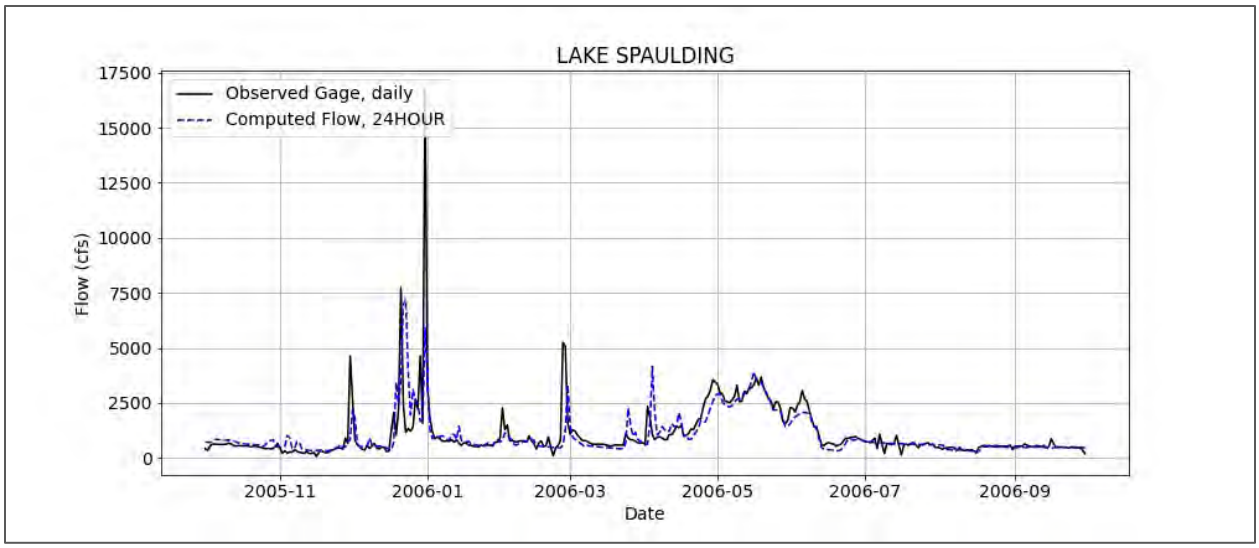


Figure A-45. WY2006 Calibration Results for Calibration Location Lake Spaulding

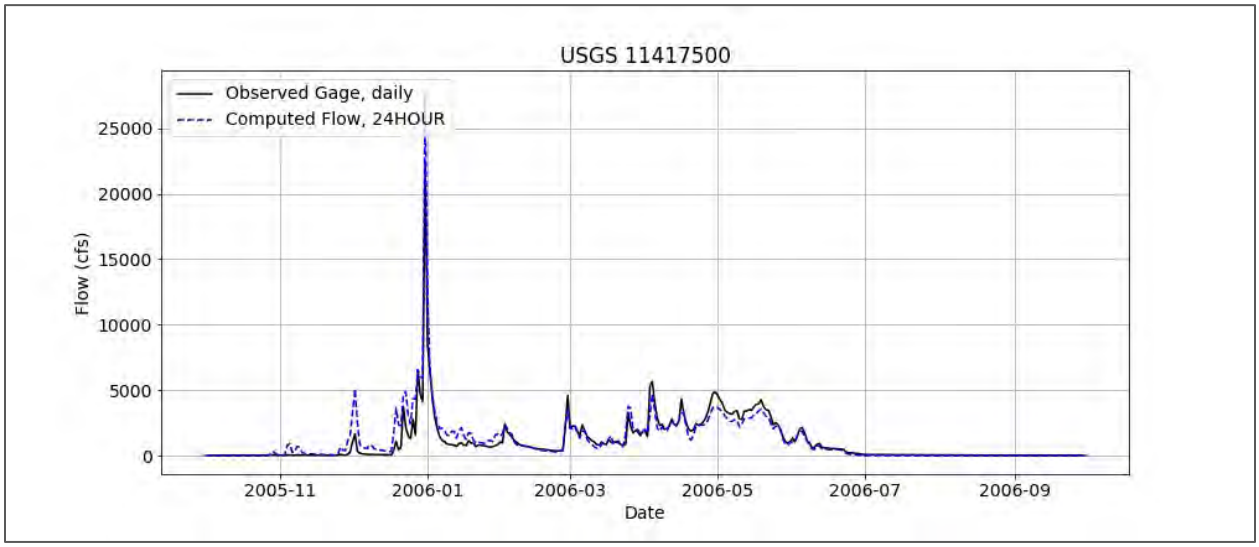


Figure A-46. WY2006 Calibration Results for Calibration Location USGS Gage 11417500

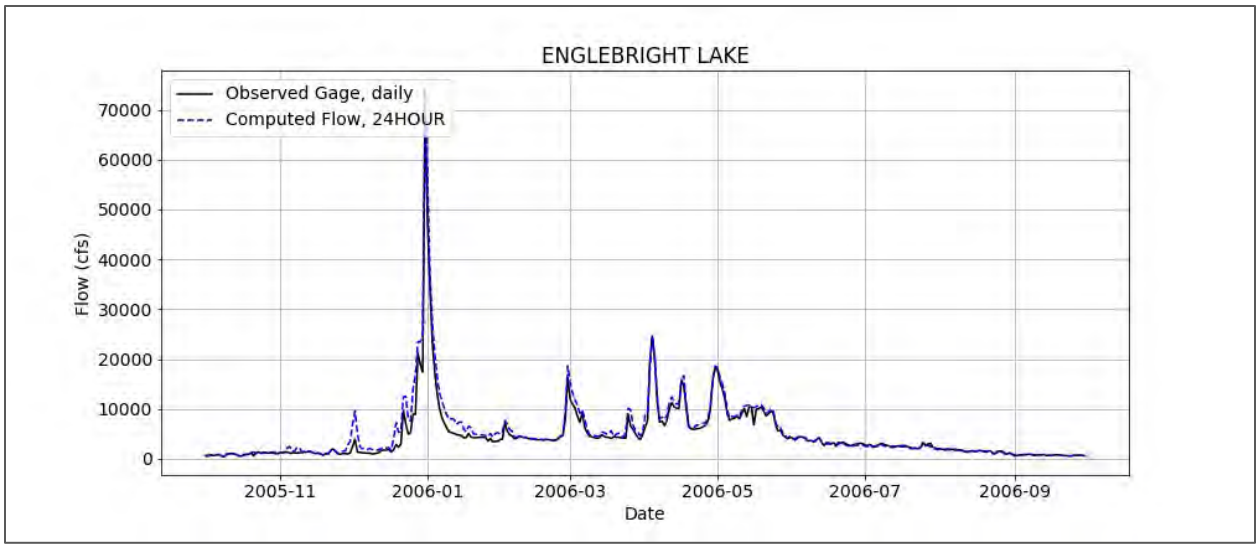


Figure A-47. WY2006 Calibration Results for Calibration Location Englebright Lake

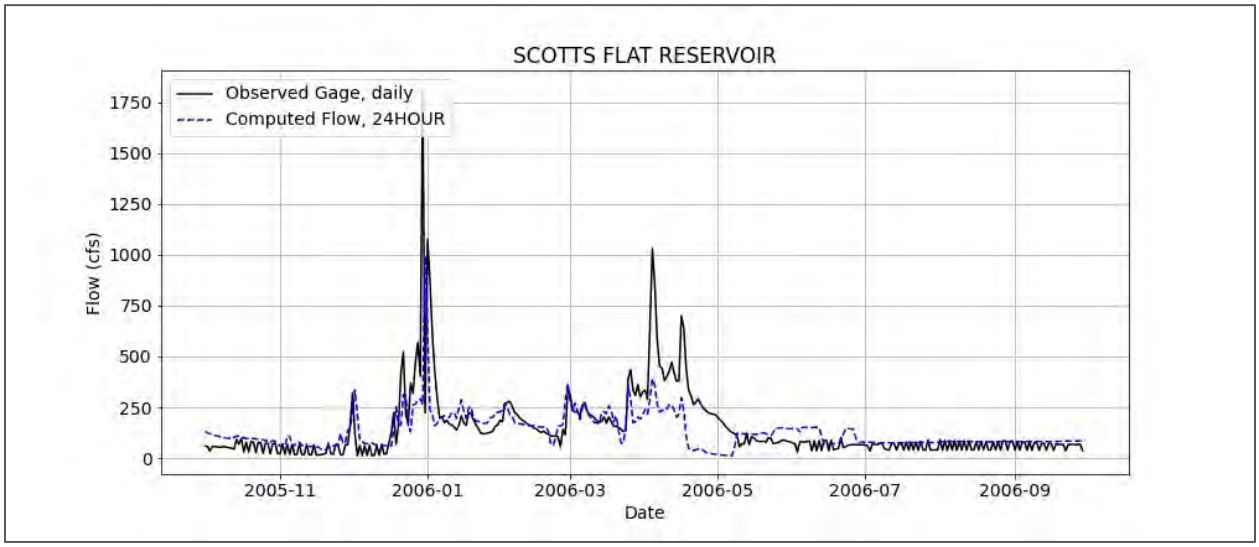


Figure A-48. WY2006 Calibration Results for Calibration Location Scotts Flat Reservoir

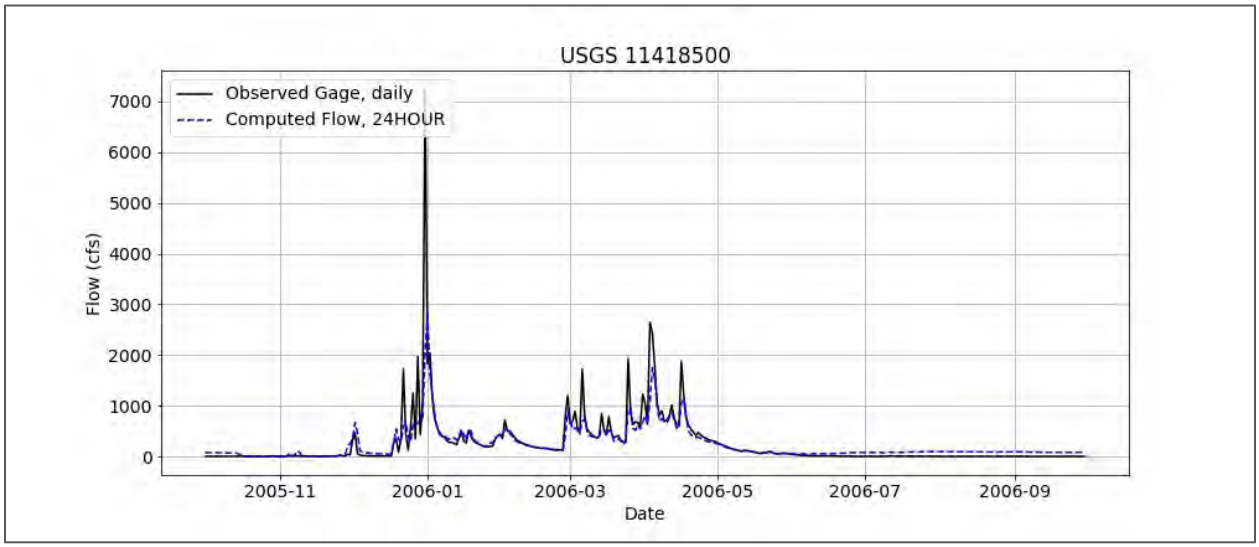


Figure A-49. WY2006 Calibration Results for Calibration Location USGS Gage 11418500

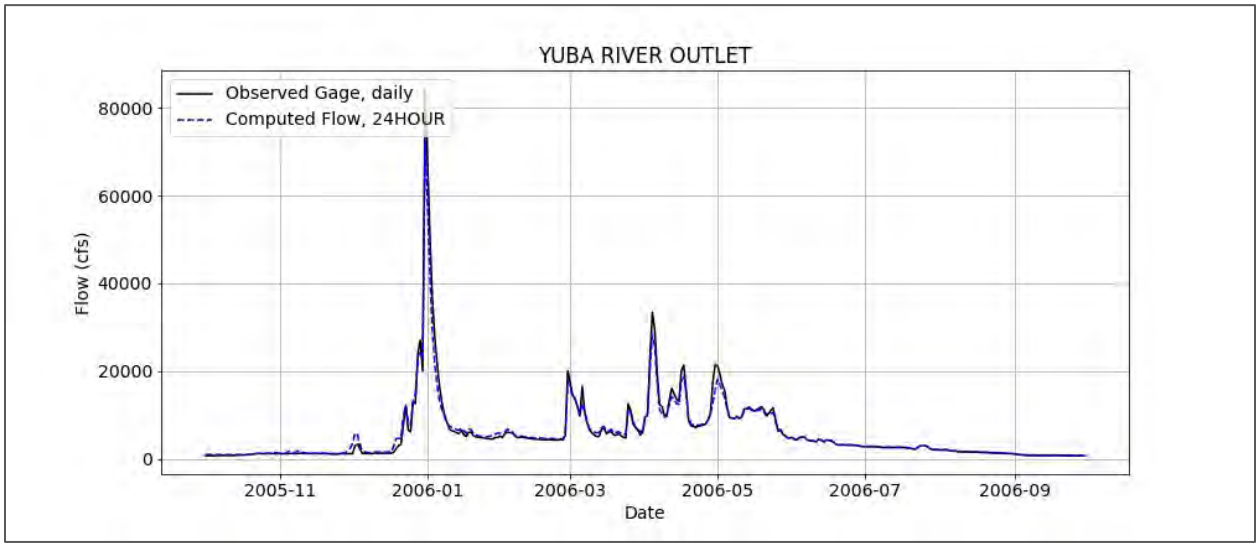


Figure A-50. WY2006 Calibration Results for Calibration Location Yuba River Outlet

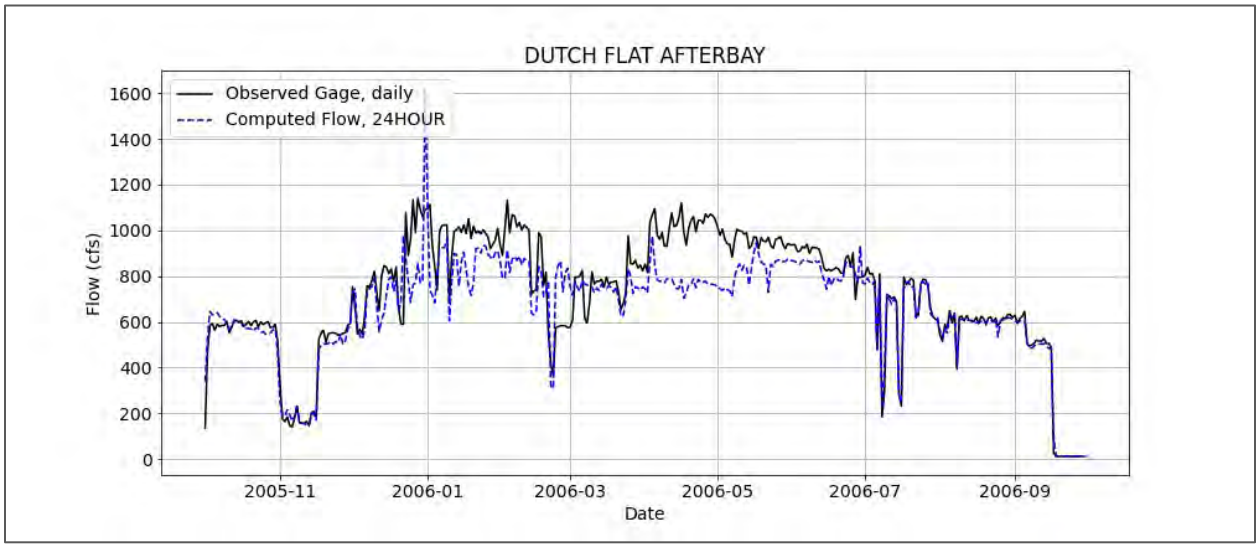


Figure A-51. WY2006 Calibration Results for Calibration Location Dutch Flat Afterbay

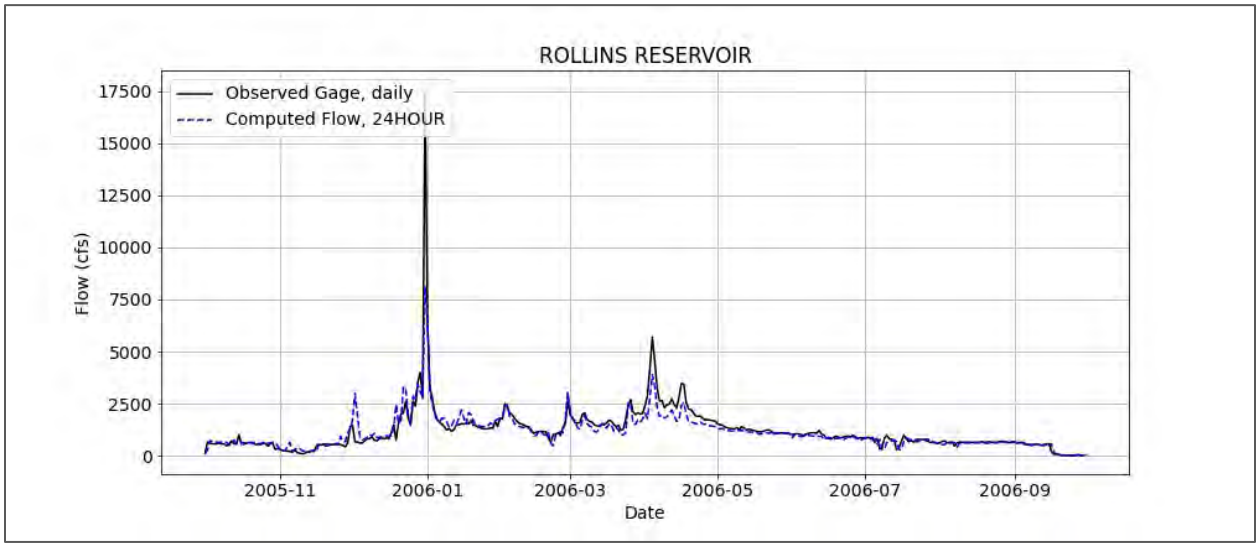


Figure A-52. WY2006 Calibration Results for Calibration Location Rollins Reservoir

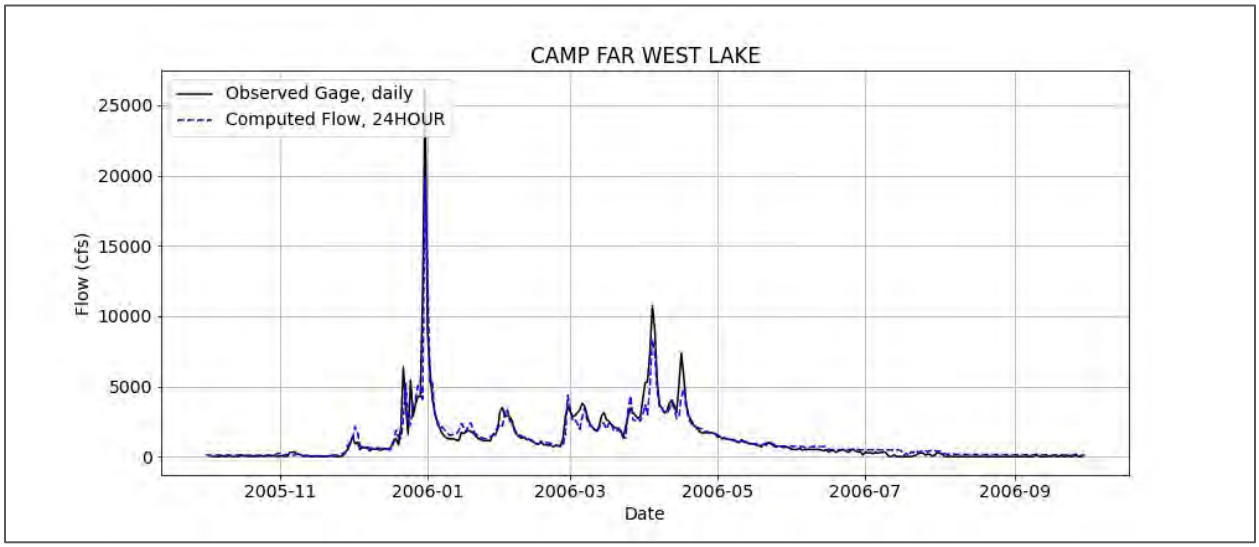


Figure A-53. WY2006 Calibration Results for Calibration Location Camp Far West Lake

A.4.4. Calibration Results for WY2015

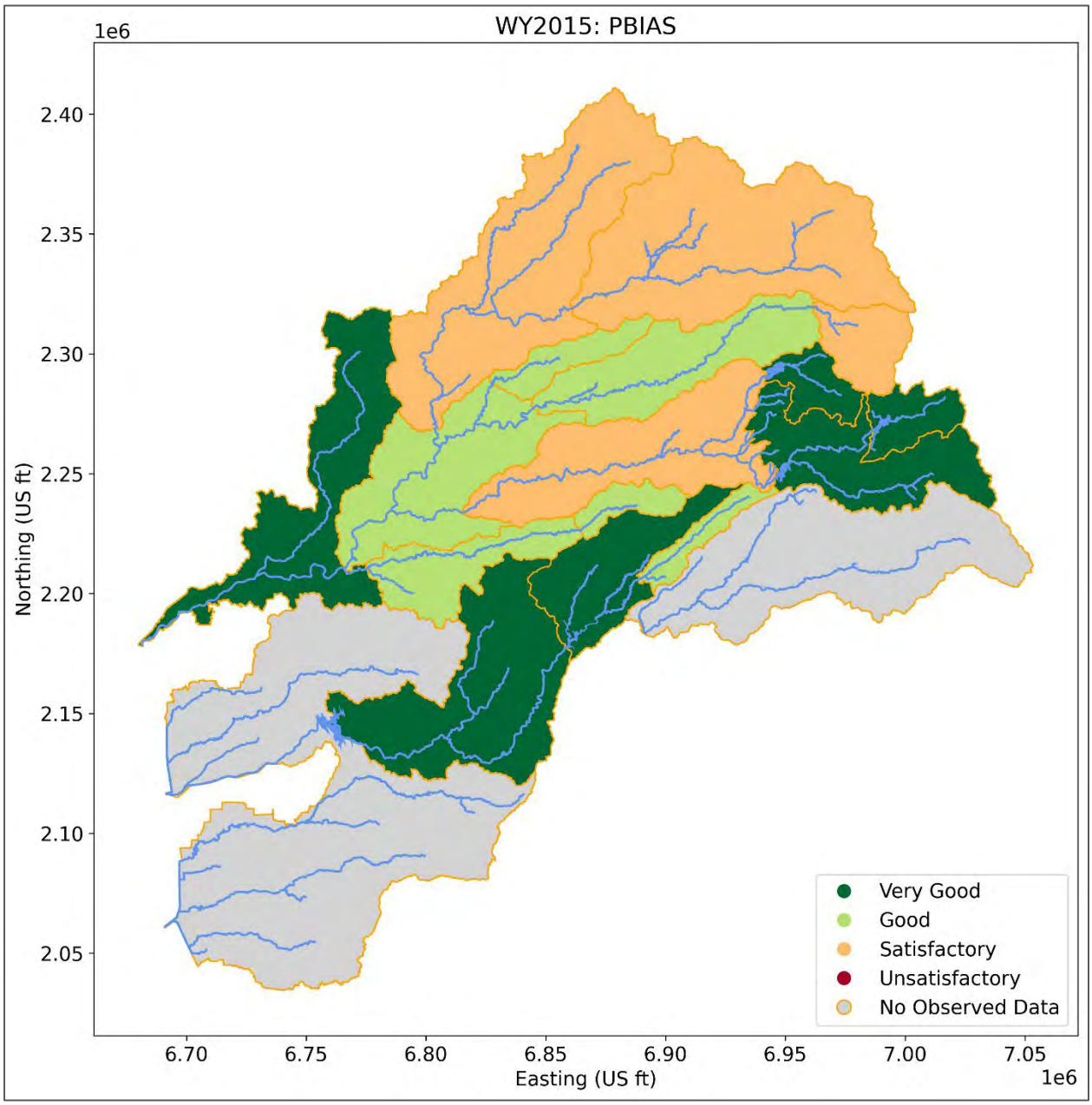


Figure A-54. WY2015 Percent Bias (PBIAS) Calibration Results for the Entire Calibrated Watersheds

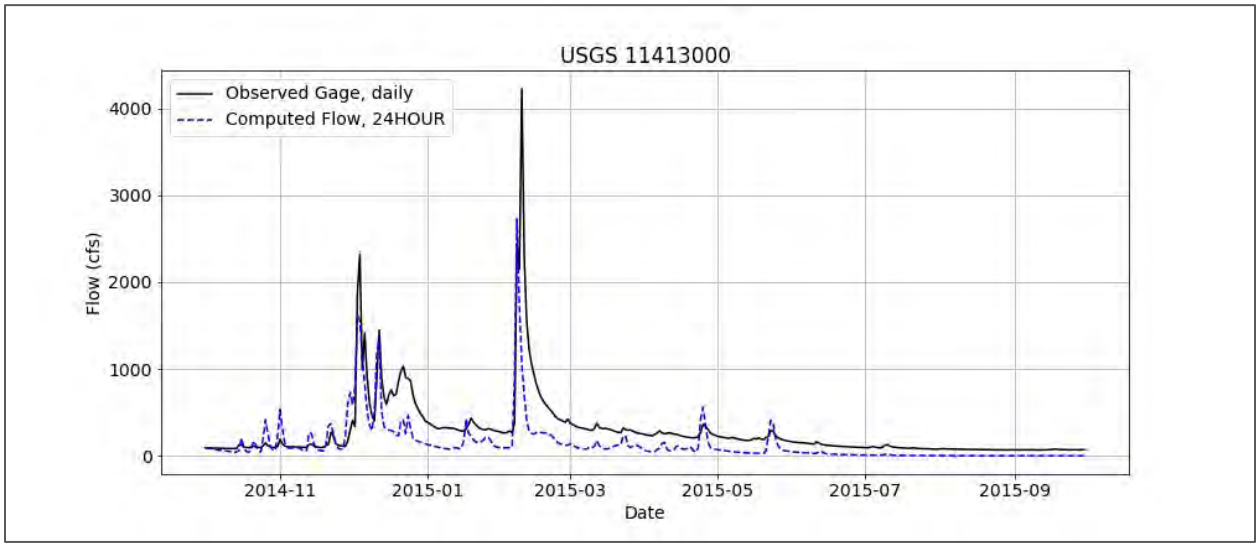


Figure A-55. WY2015 Calibration Results for Calibration Location USGS Gage 11413000

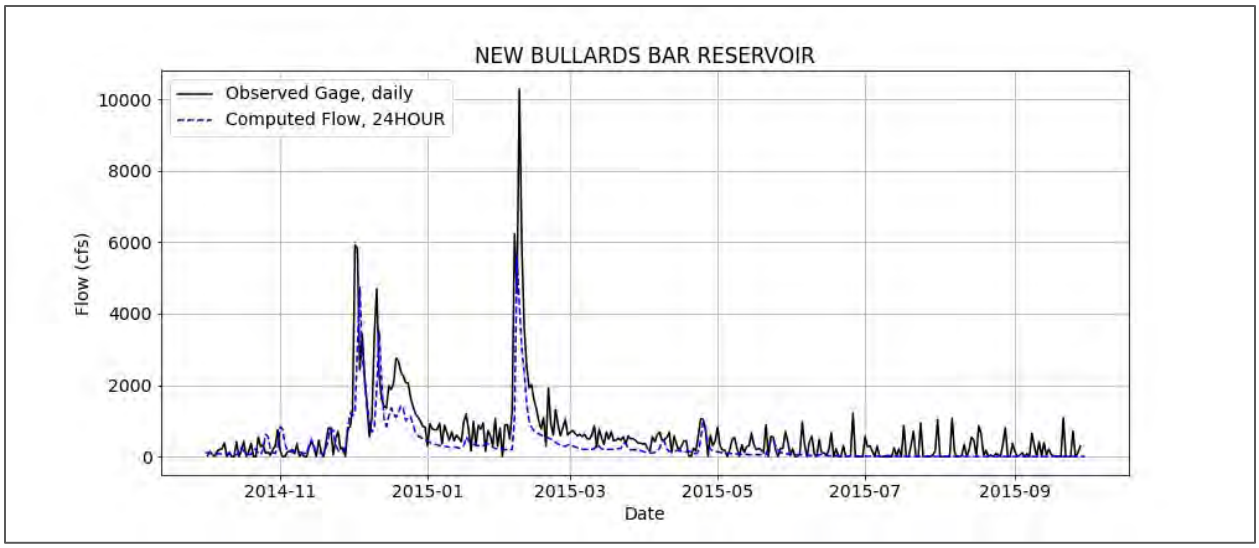


Figure A-56. WY2015 Calibration Results for Calibration Location New Bullards Bar Reservoir

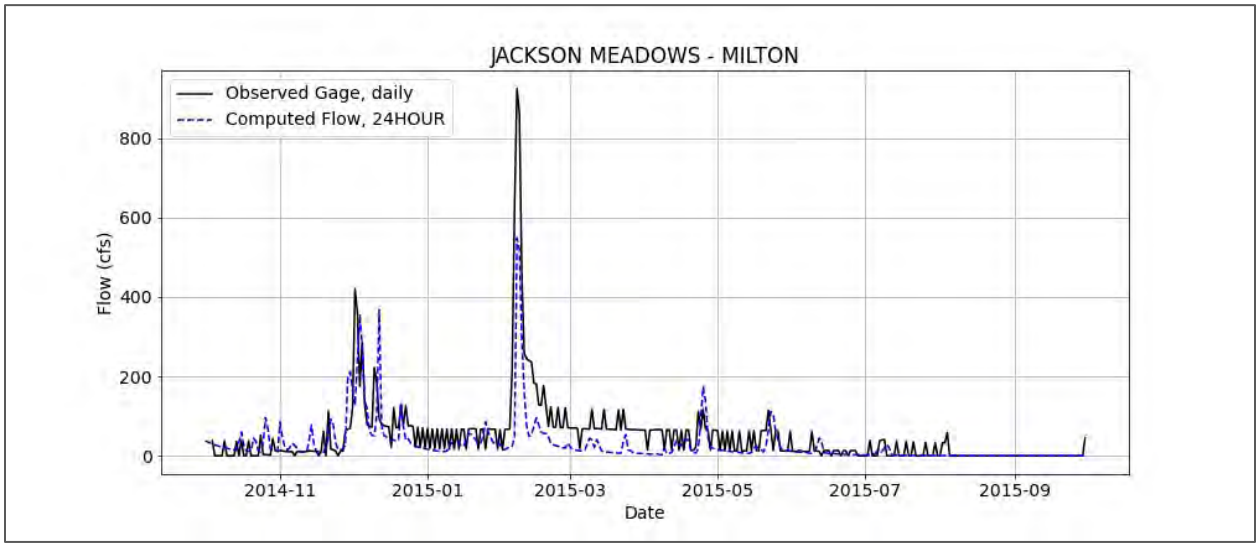


Figure A-57. WY2015 Calibration Results for Calibration Location Jackson Meadows and Milton Reservoirs

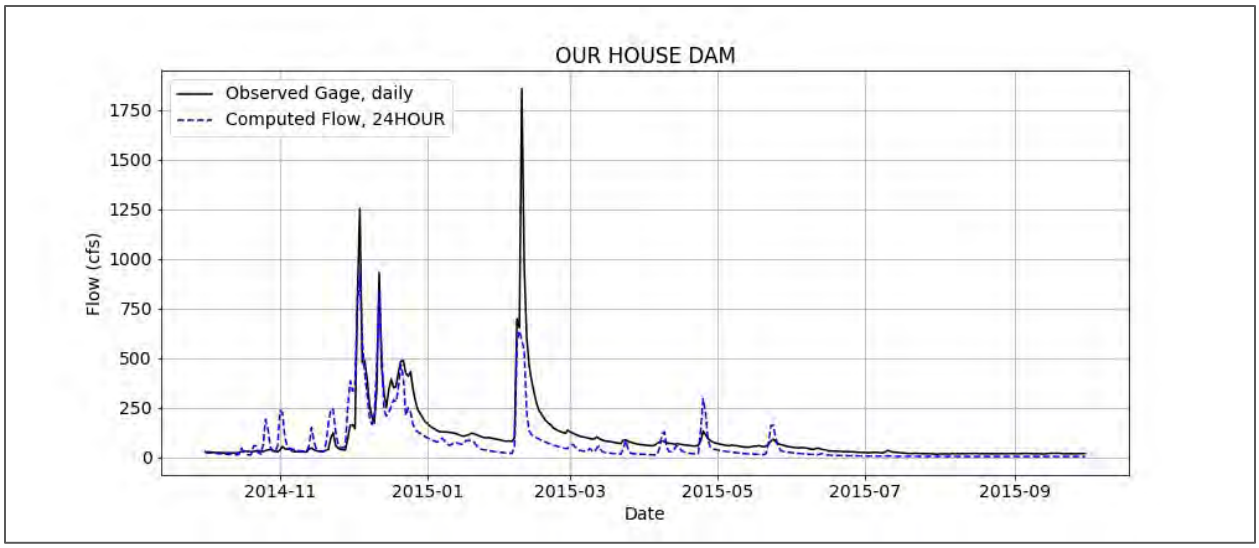


Figure A-58. WY2015 Calibration Results for Calibration Location Our House Dam

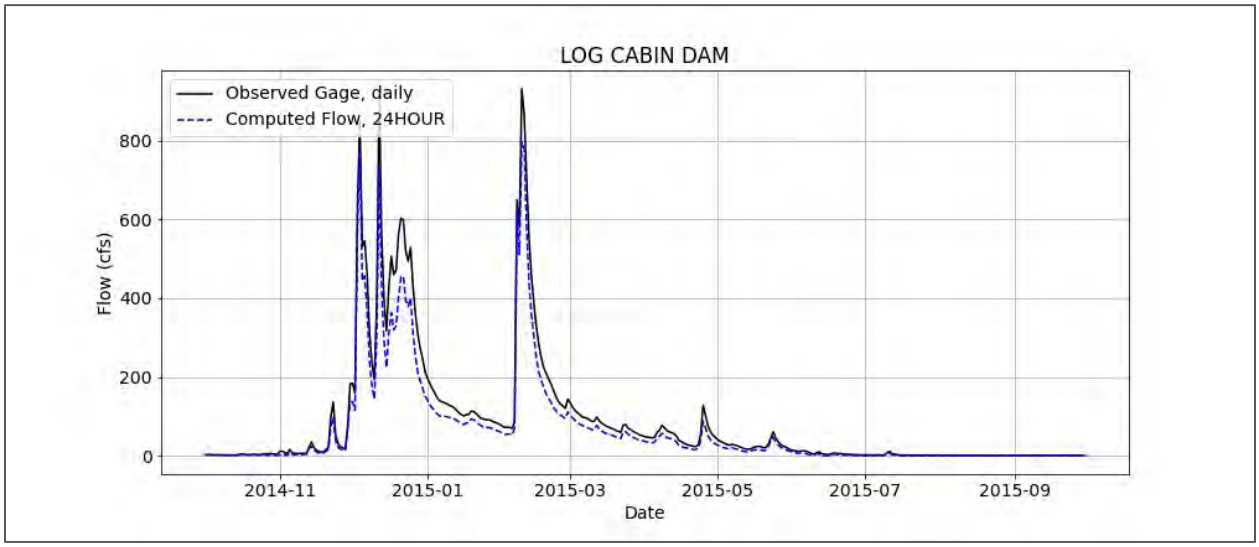


Figure A-59. WY2015 Calibration Results for Calibration Location Log Cabin Dam

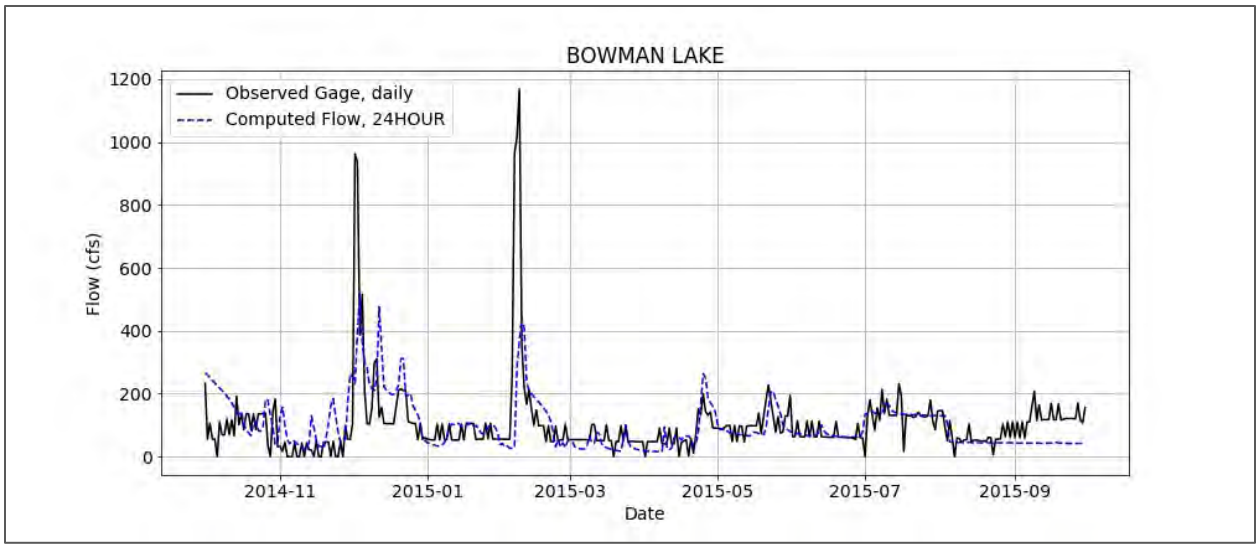


Figure A-60. WY2015 Calibration Results for Calibration Location Bowman Lake

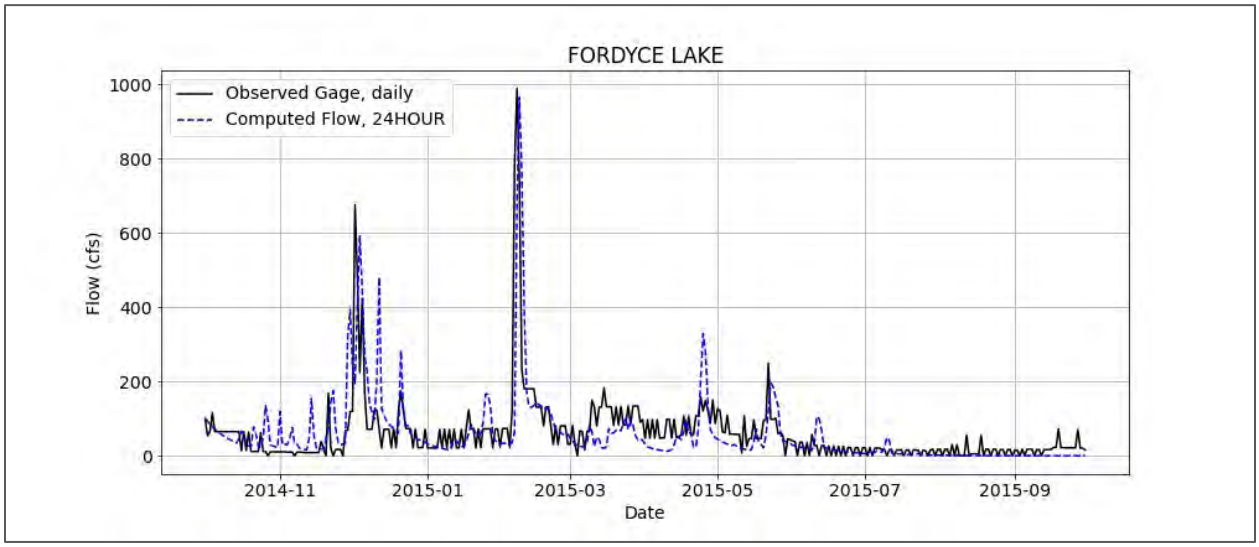


Figure A-61. WY2015 Calibration Results for Calibration Location Fordyce Lake

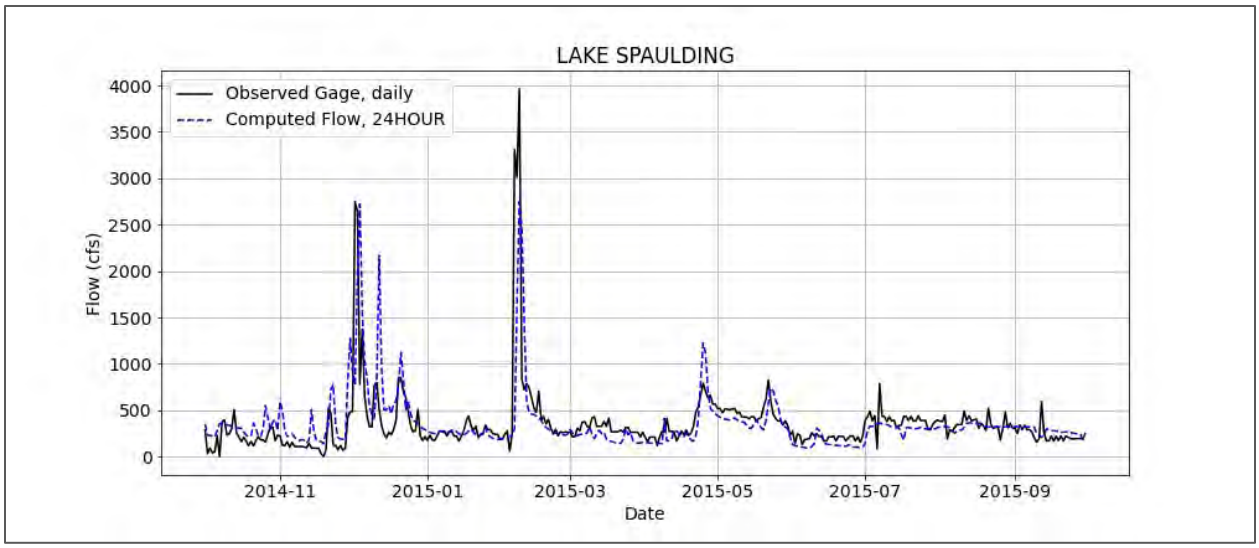


Figure A-62. WY2015 Calibration Results for Calibration Location Lake Spaulding

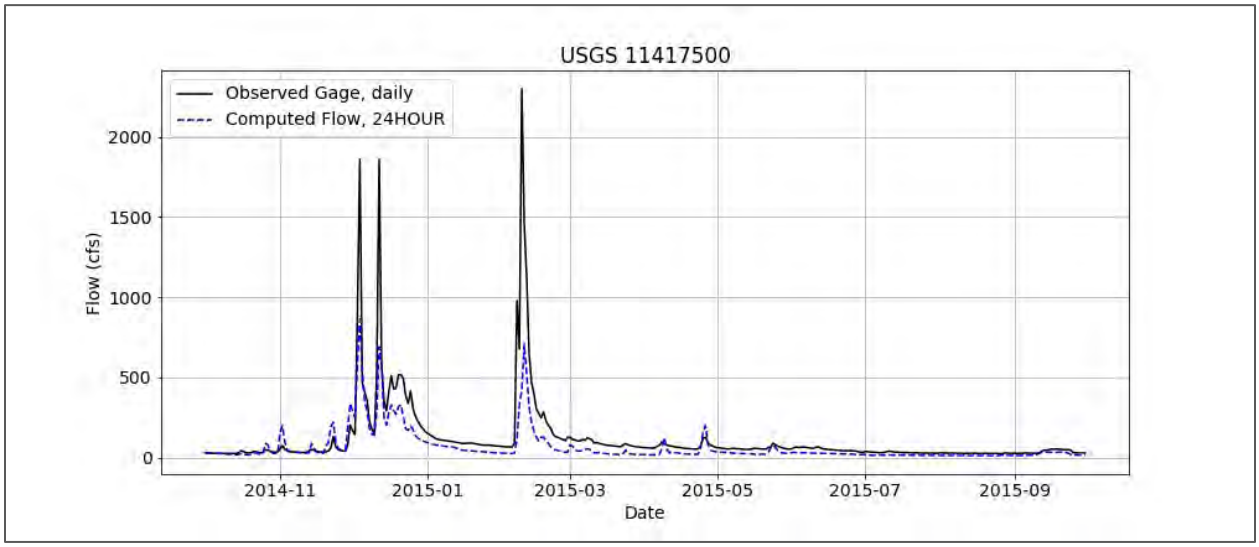


Figure A-63. WY2015 Calibration Results for Calibration Location USGS Gage 11417500

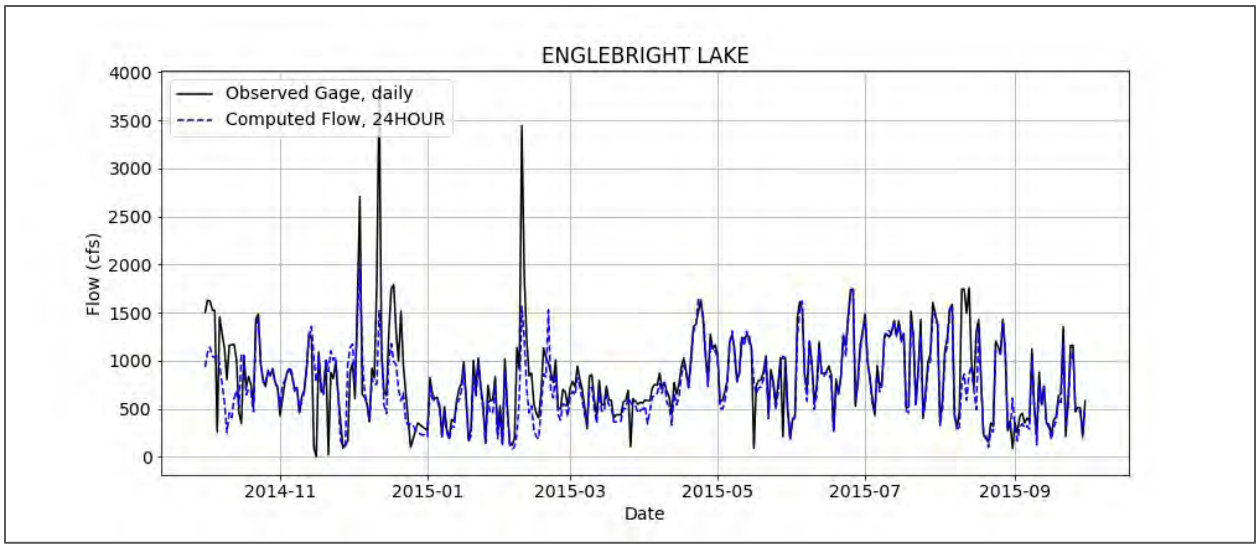


Figure A-64. WY2015 Calibration Results for Calibration Location Englebright Lake

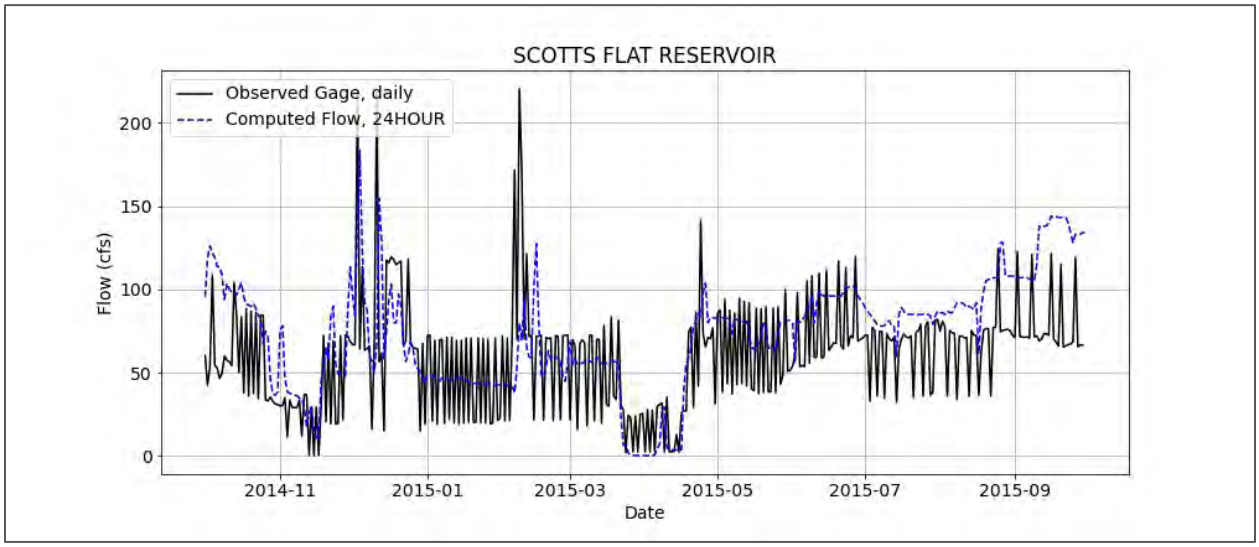


Figure A-65. WY2015 Calibration Results for Calibration Location Scotts Flat Reservoir

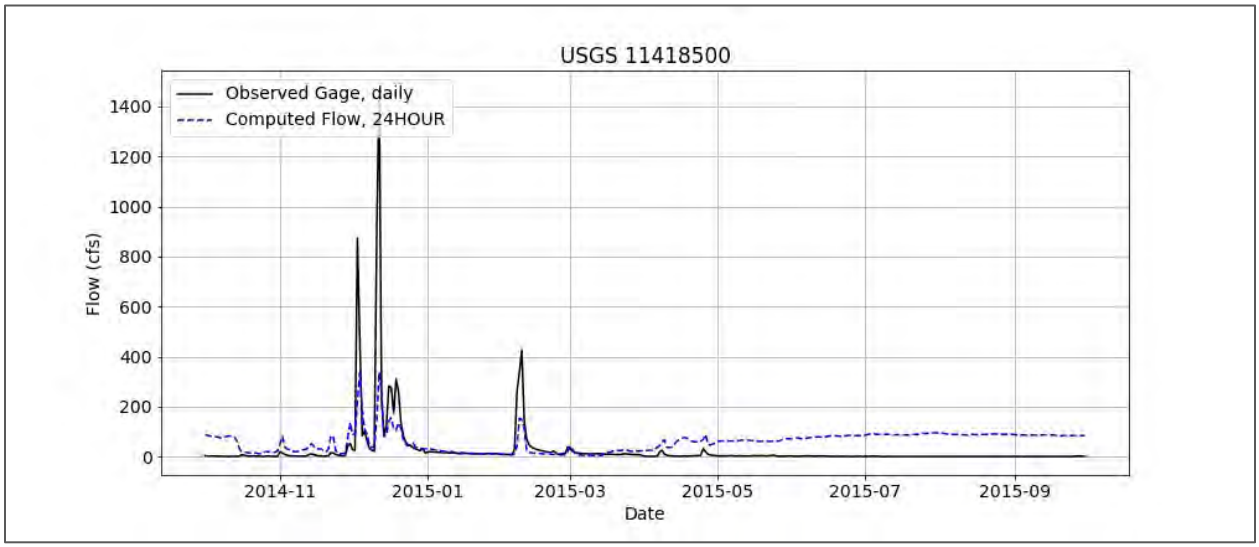


Figure A-66. WY2015 Calibration Results for Calibration Location USGS Gage 11418500

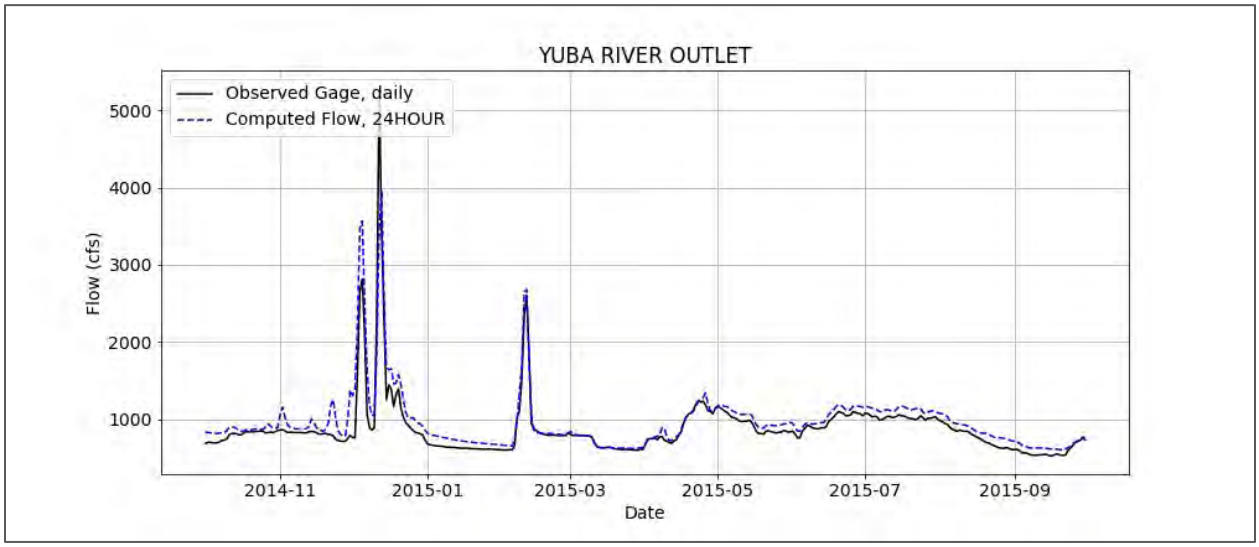


Figure A-67. WY2015 Calibration Results for Calibration Location Yuba River Outlet

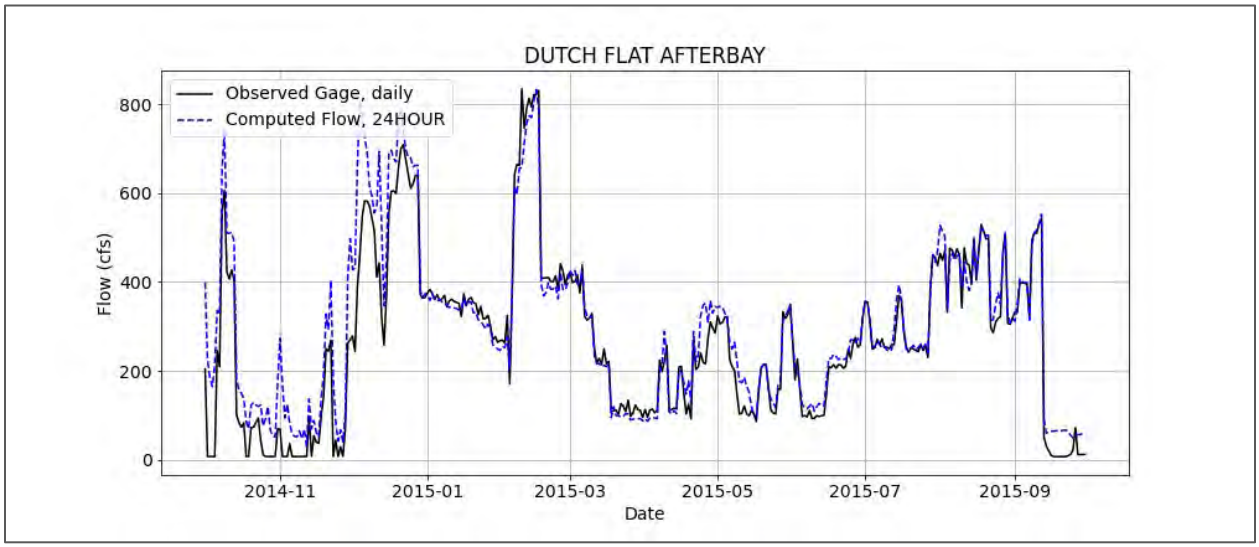


Figure A-68. WY2015 Calibration Results for Calibration Location Dutch Flat Afterbay

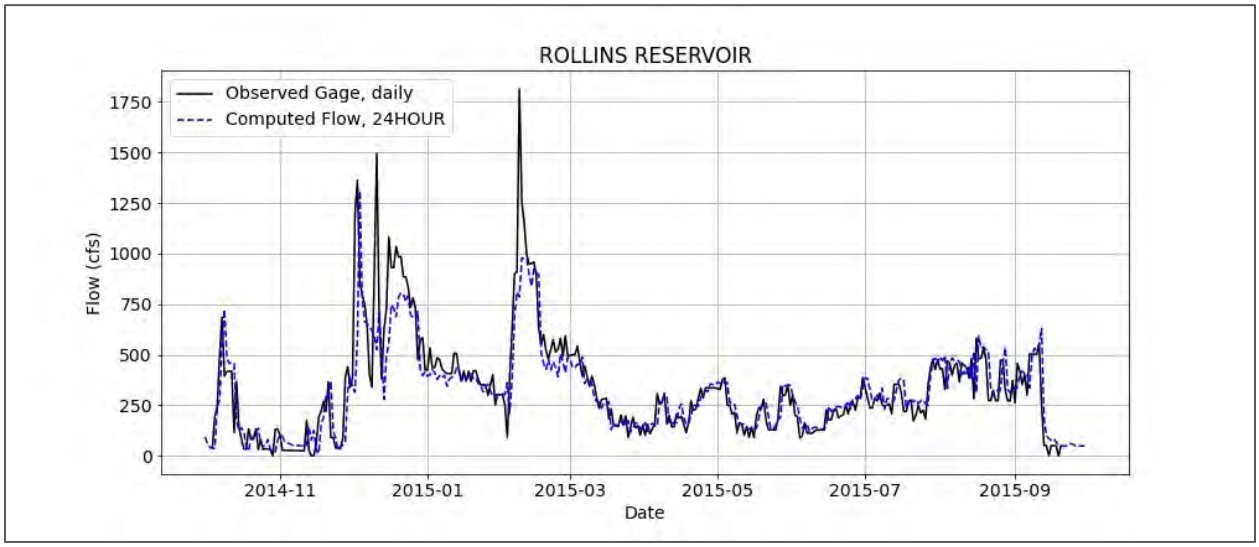


Figure A-69. WY2015 Calibration Results for Calibration Location Rollins Reservoir

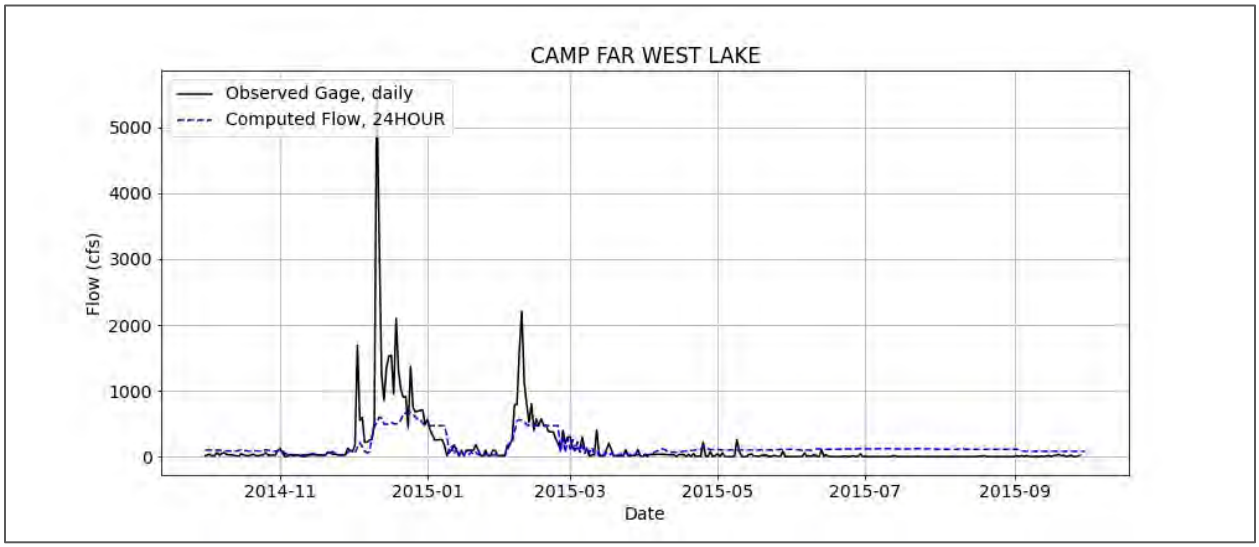


Figure A-70. WY2015 Calibration Results for Calibration Location Camp Far West Lake

A.4.5. Calibration Results for WY2021

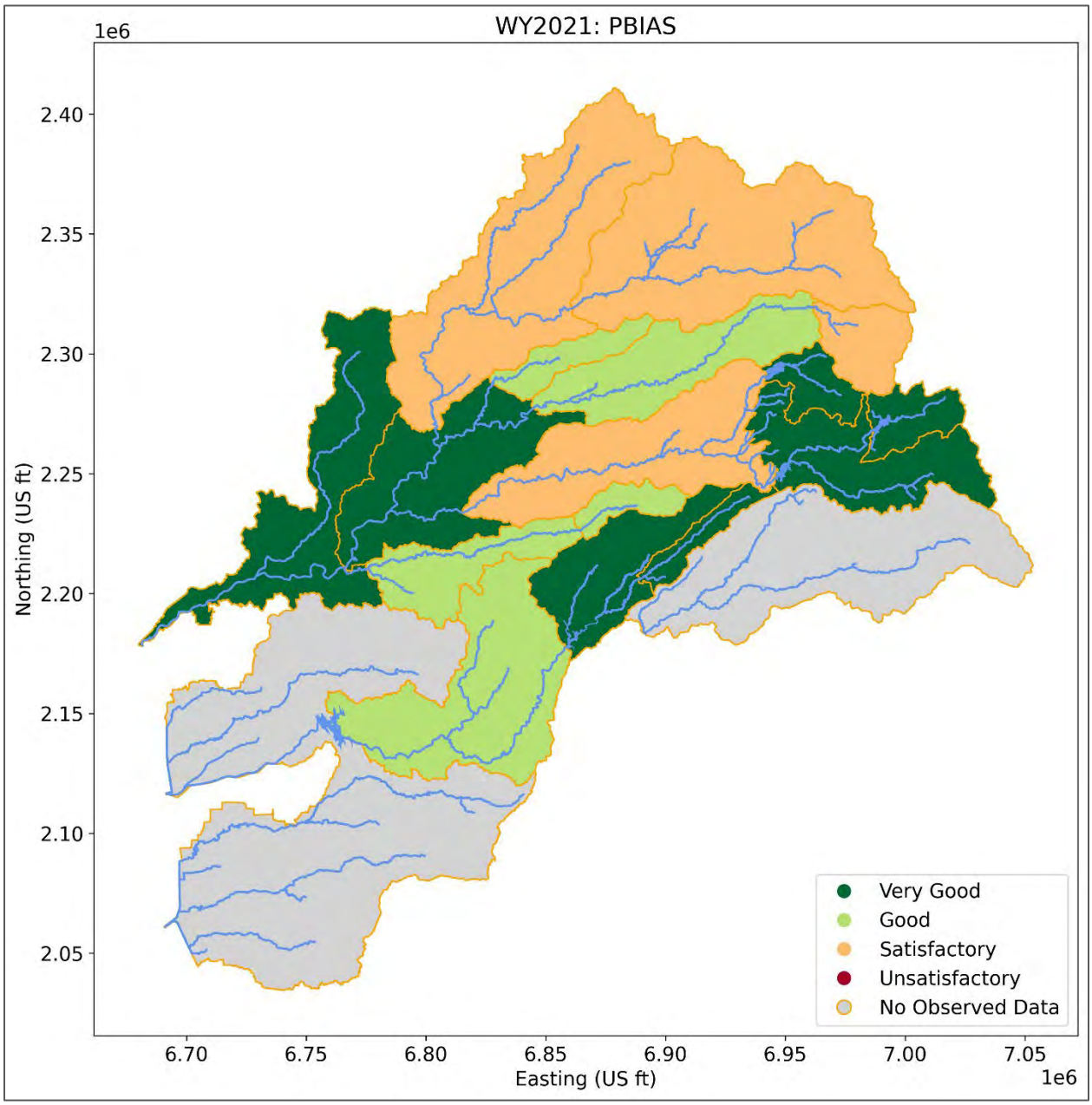


Figure A-71. WY2021 Percent Bias (PBIAS) Calibration Results for the Entire Calibrated Watersheds

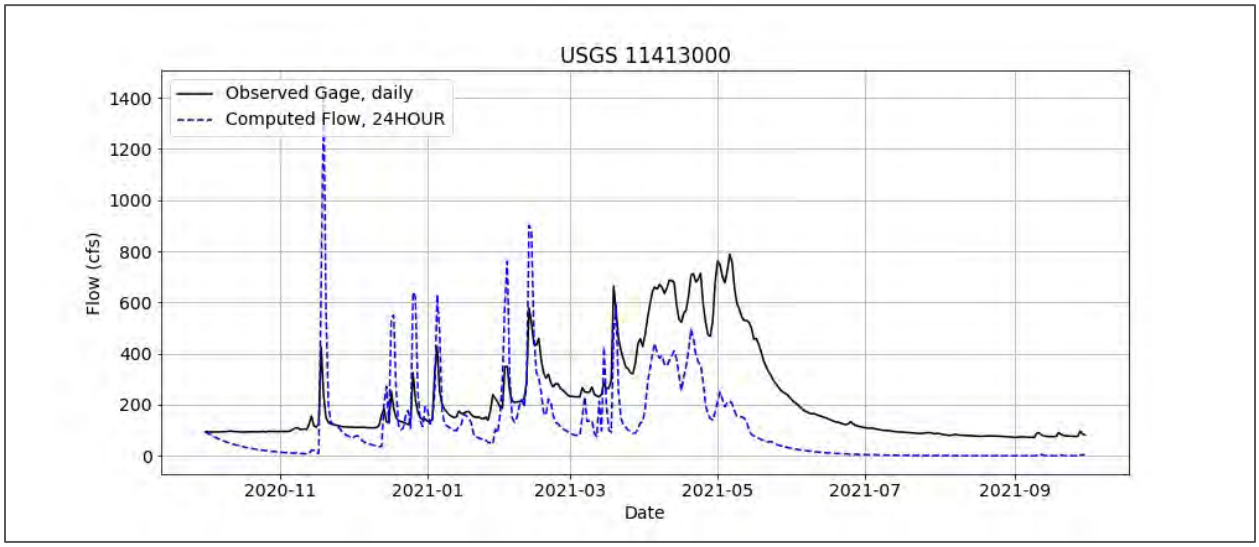


Figure A-72. WY2021 Calibration Results for Calibration Location USGS Gage 11413000

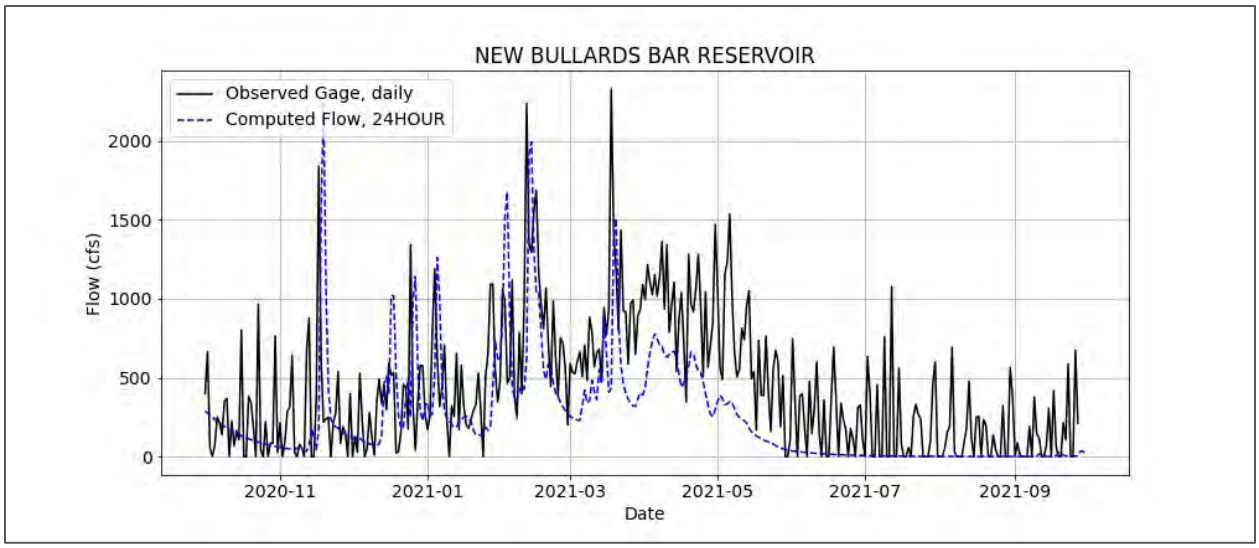


Figure A-73. WY2021 Calibration Results for Calibration Location New Bullards Bar Reservoir

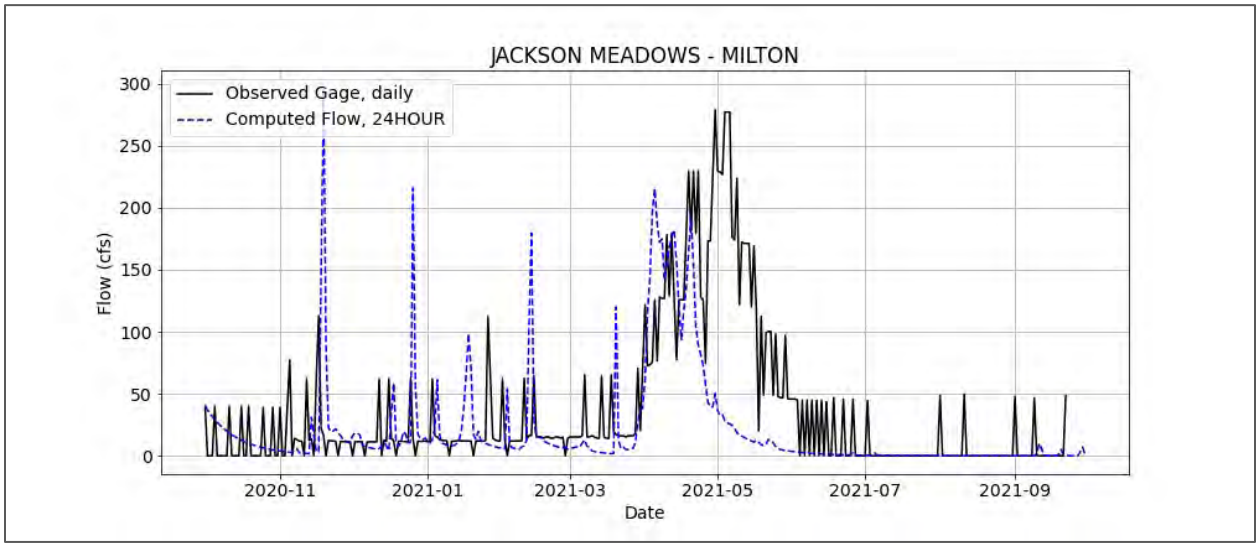


Figure A-74. WY2021 Calibration Results for Calibration Location Jackson Meadows and Milton Reservoirs

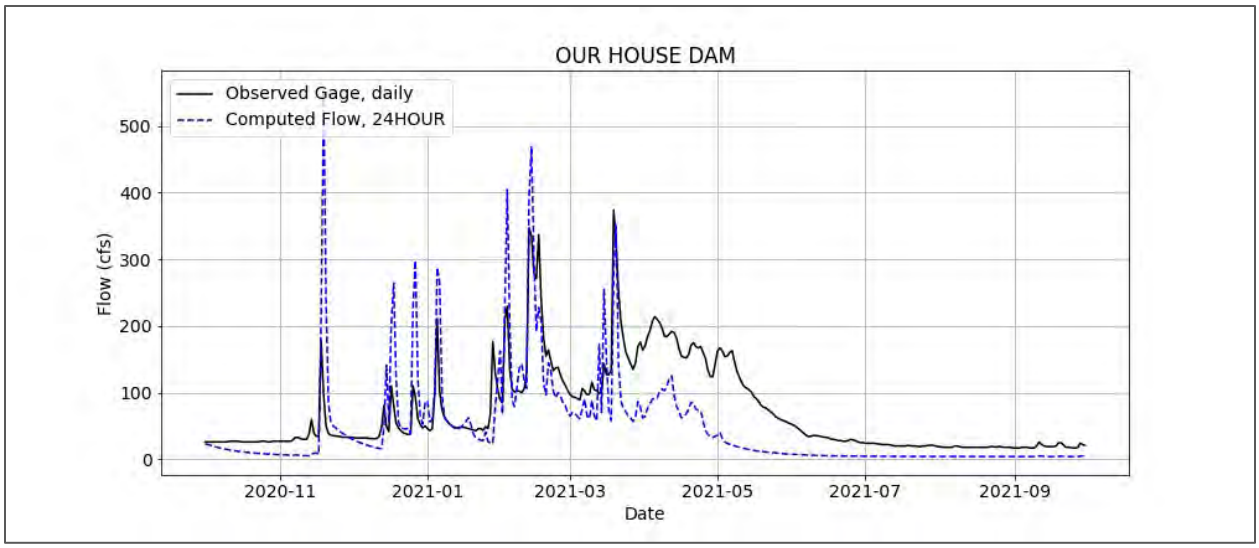


Figure A-75. WY2021 Calibration Results for Calibration Location Our House Dam

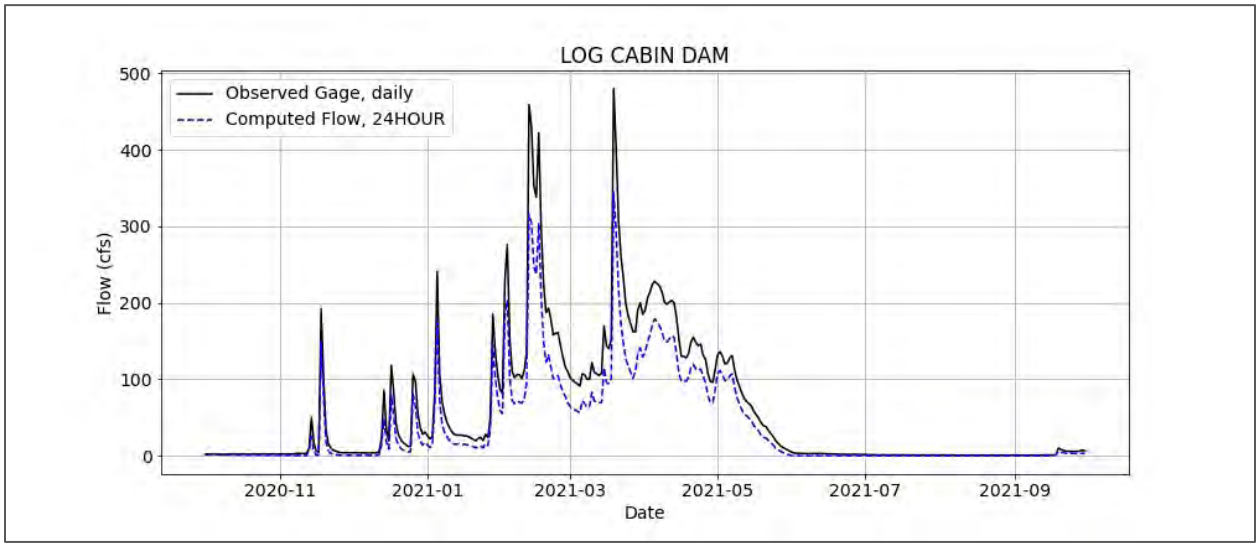


Figure A-76. WY2021 Calibration Results for Calibration Location Log Cabin Dam

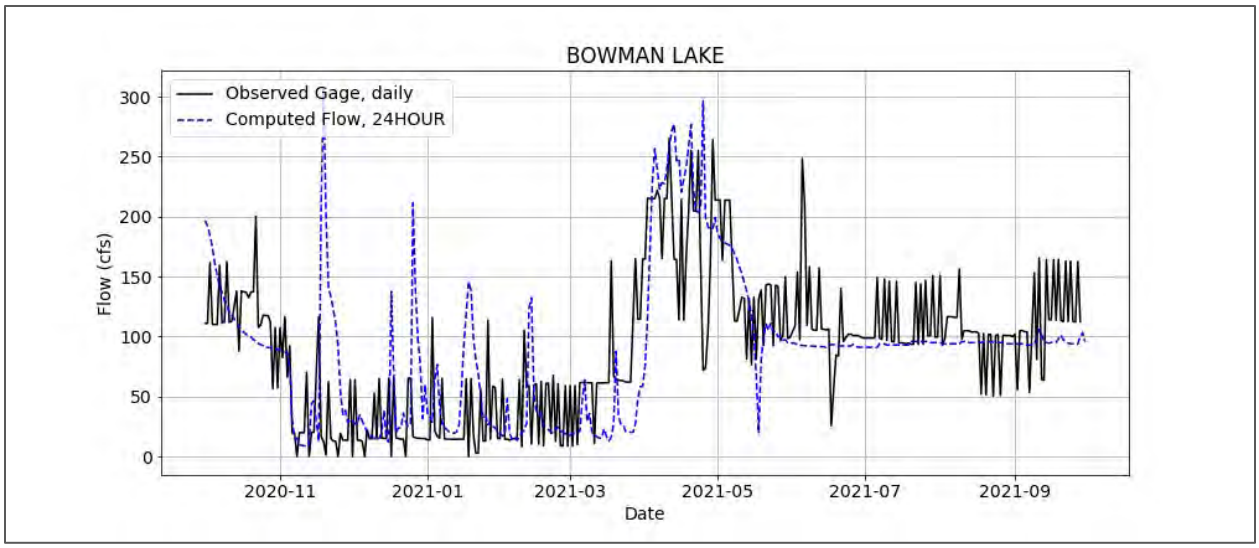


Figure A-77. WY2021 Calibration Results for Calibration Location Bowman Lake

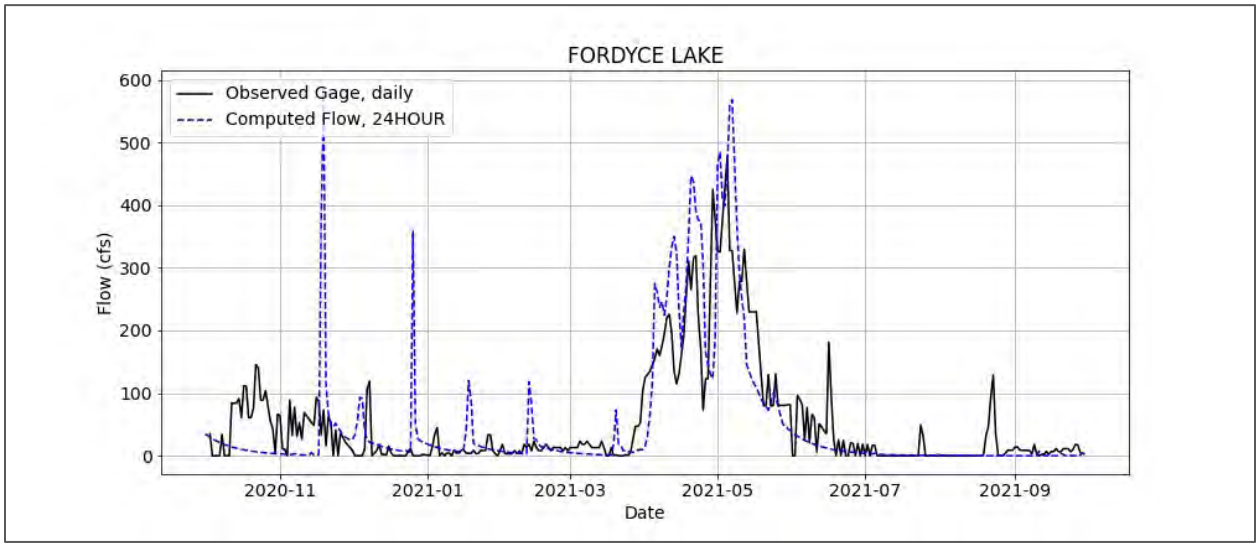


Figure A-78. WY2021 Calibration Results for Calibration Location Fordyce Lake

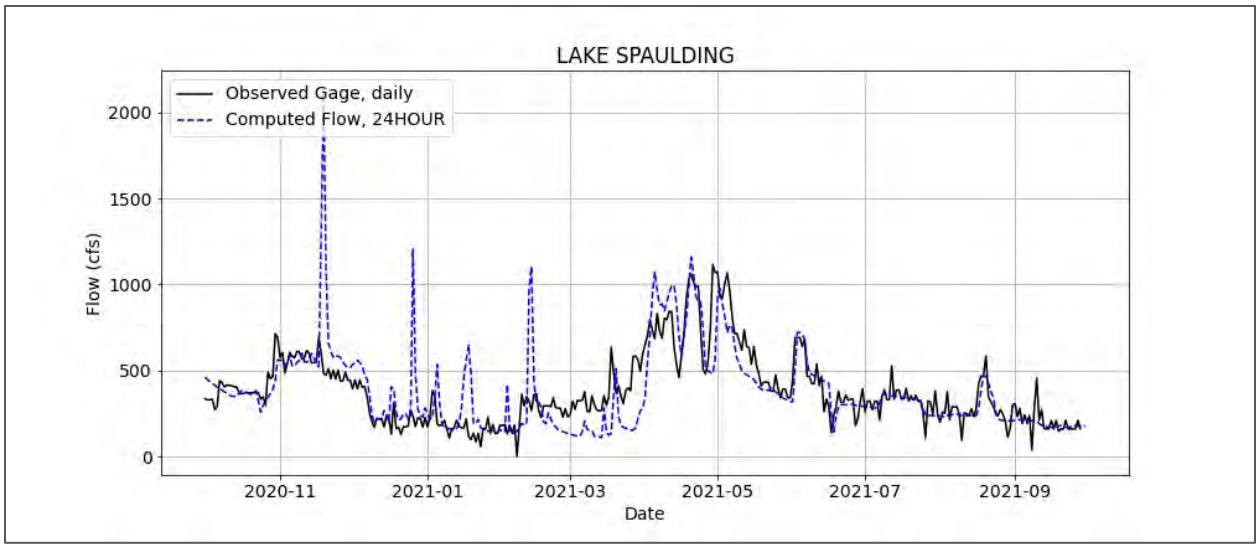


Figure A-79. WY2021 Calibration Results for Calibration Location Lake Spaulding

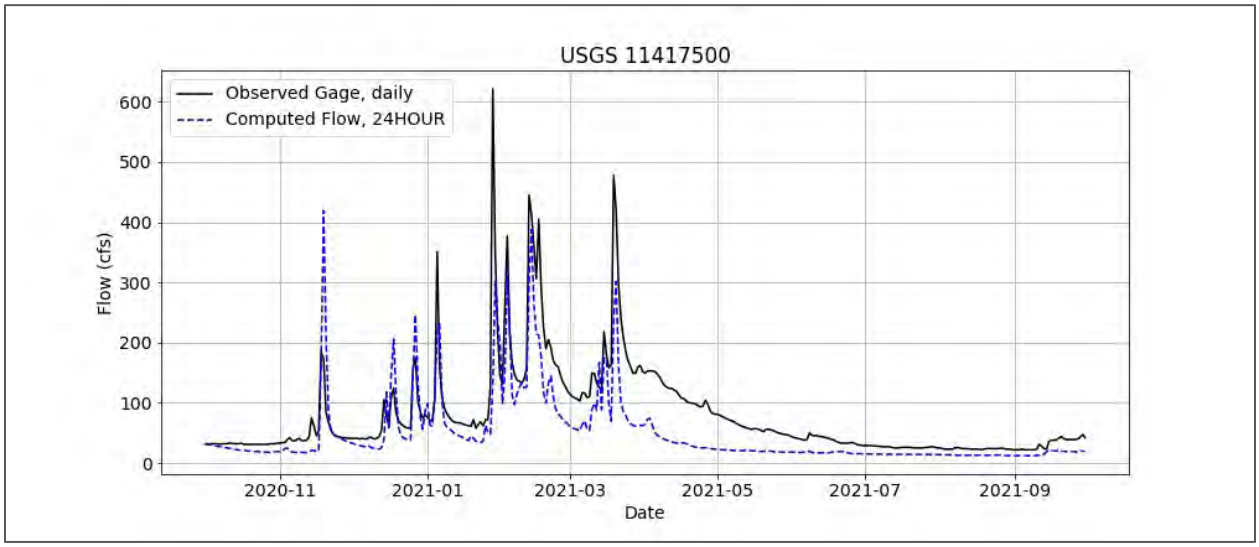


Figure A-80. WY2021 Calibration Results for Calibration Location USGS Gage 11417500

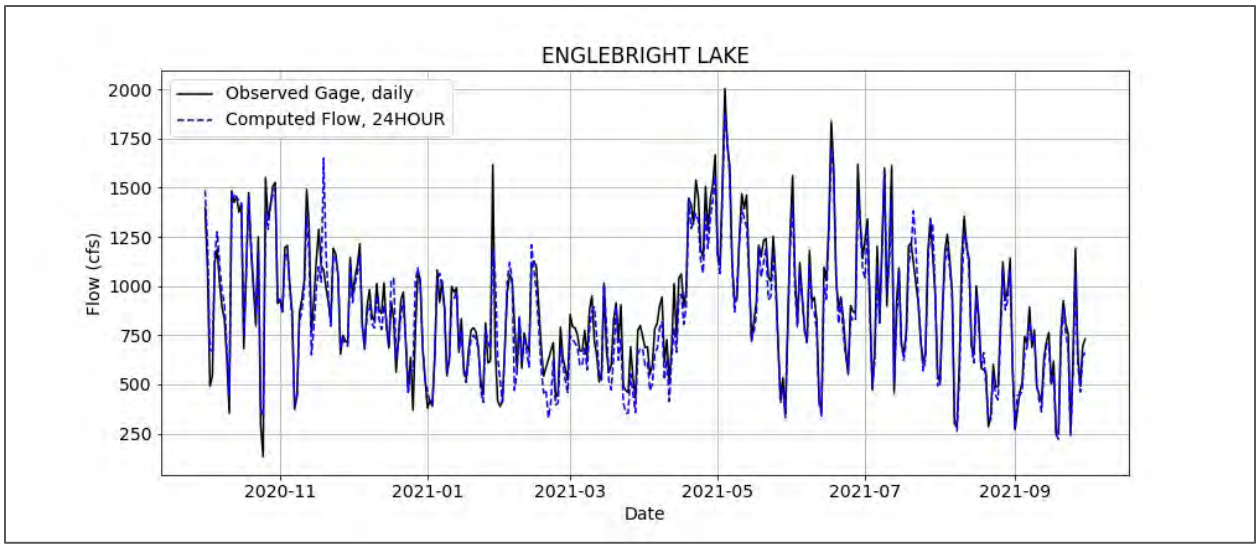


Figure A-81. WY2021 Calibration Results for Calibration Location Englebright Lake

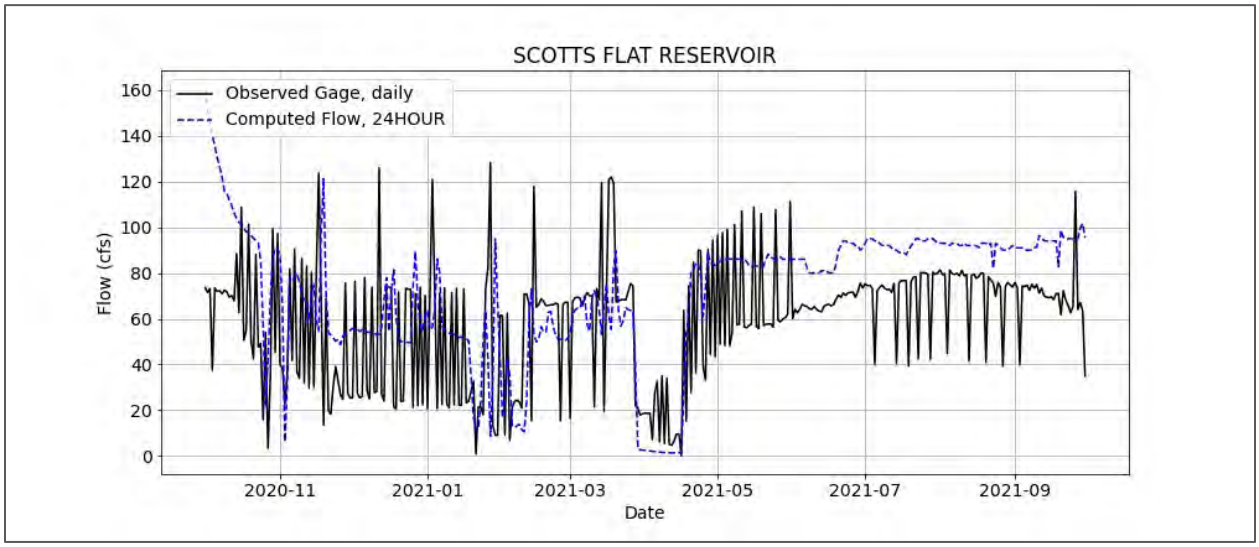


Figure A-82. WY2021 Calibration Results for Calibration Location Scotts Flat Reservoir

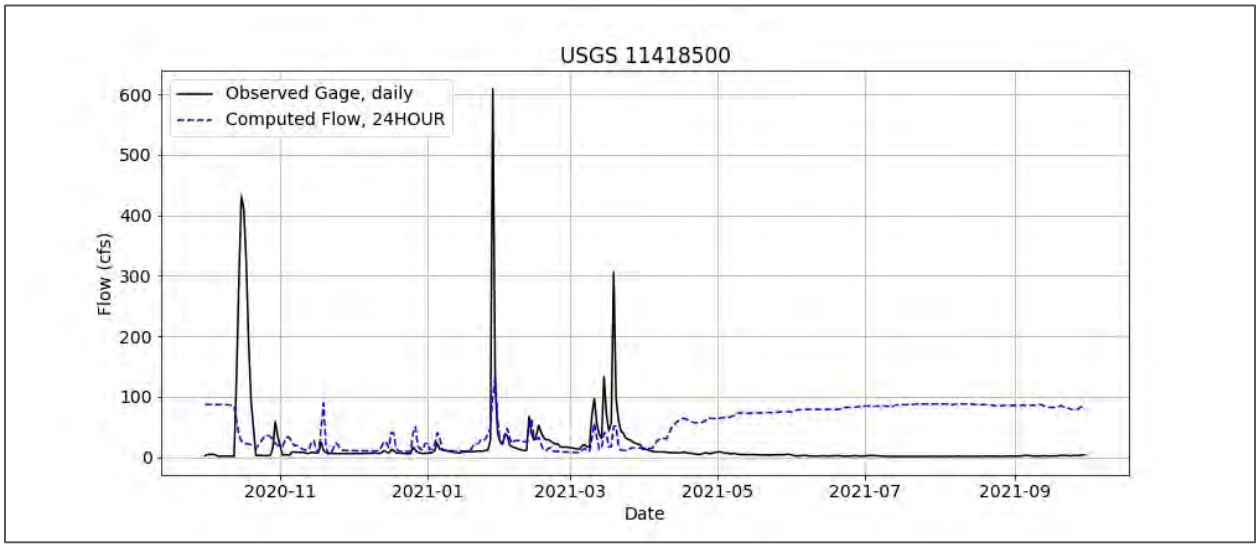


Figure A-83. WY2021 Calibration Results for Calibration Location USGS Gage 11418500

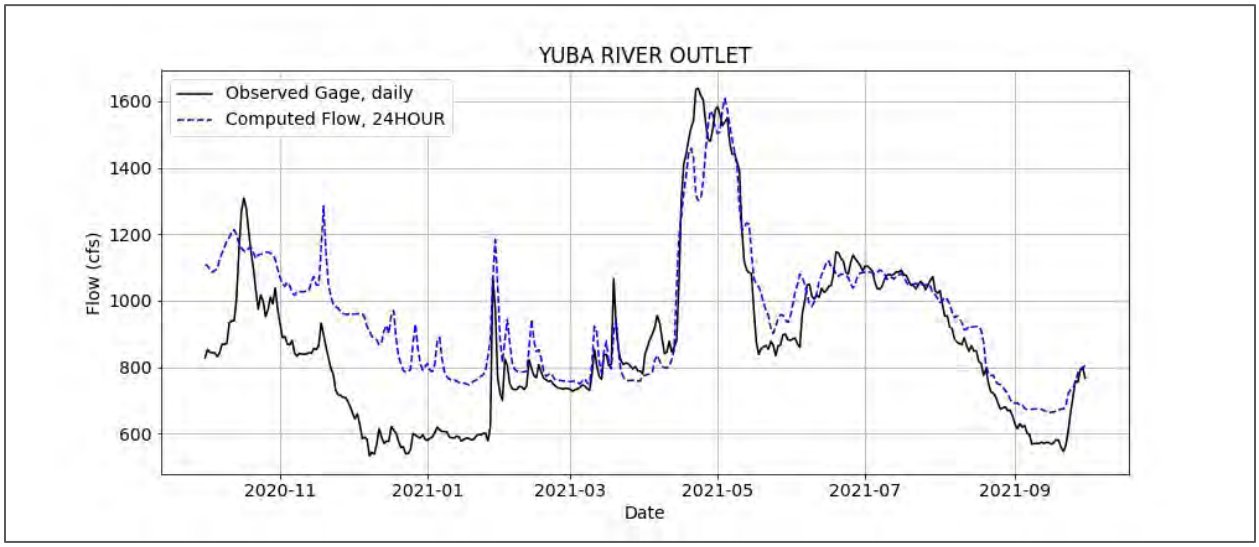


Figure A-84. WY2021 Calibration Results for Calibration Location Yuba River Outlet

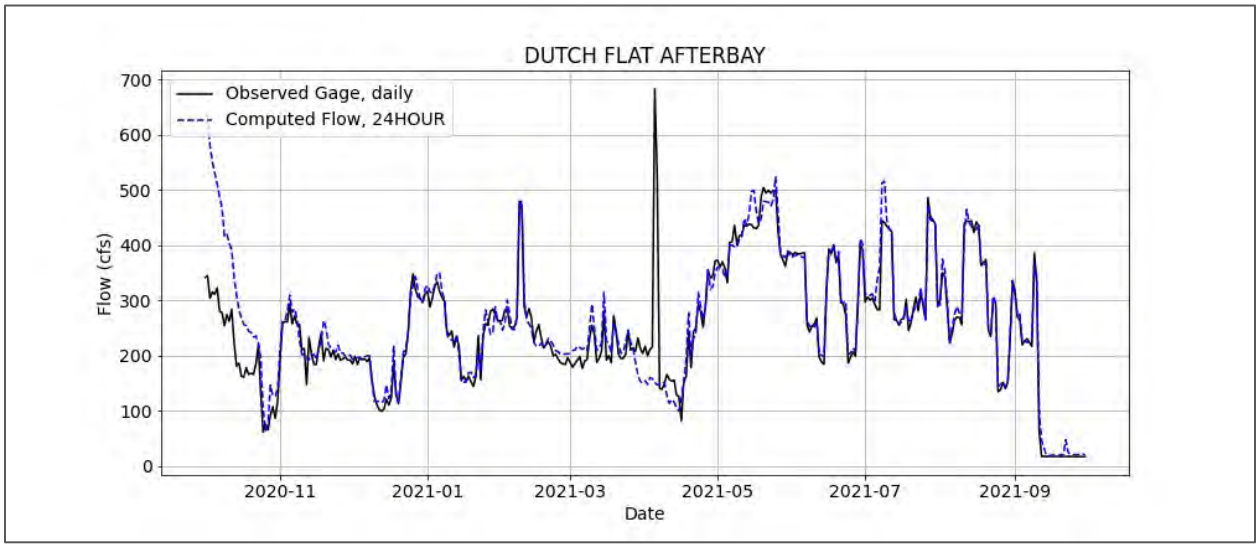


Figure A-85. WY2021 Calibration Results for Calibration Location Dutch Flat Afterbay

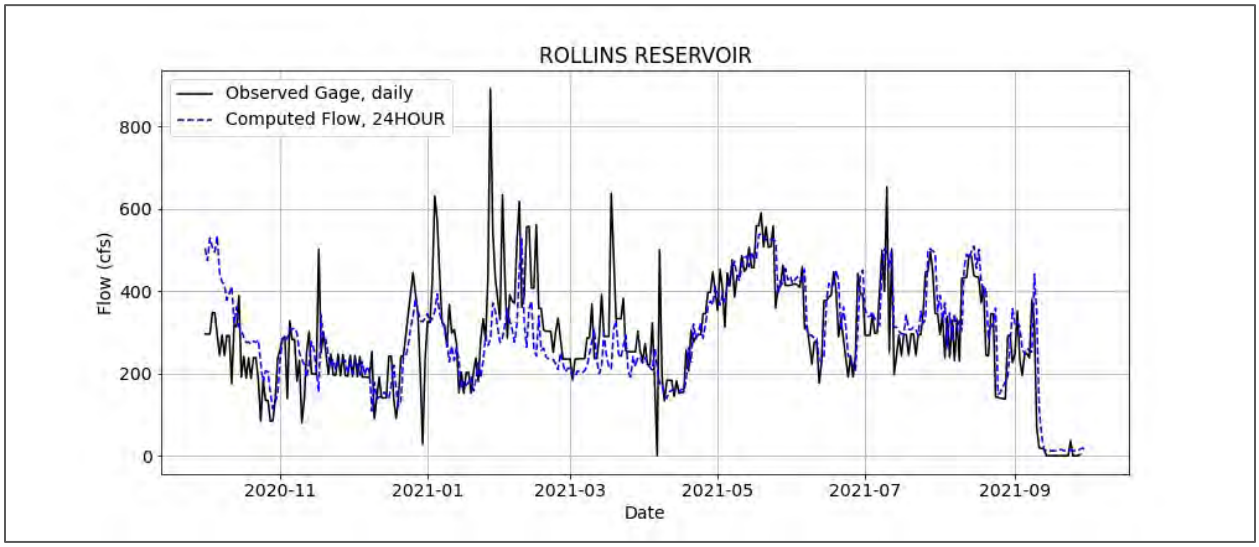


Figure A-86. WY2021 Calibration Results for Calibration Location Rollins Reservoir

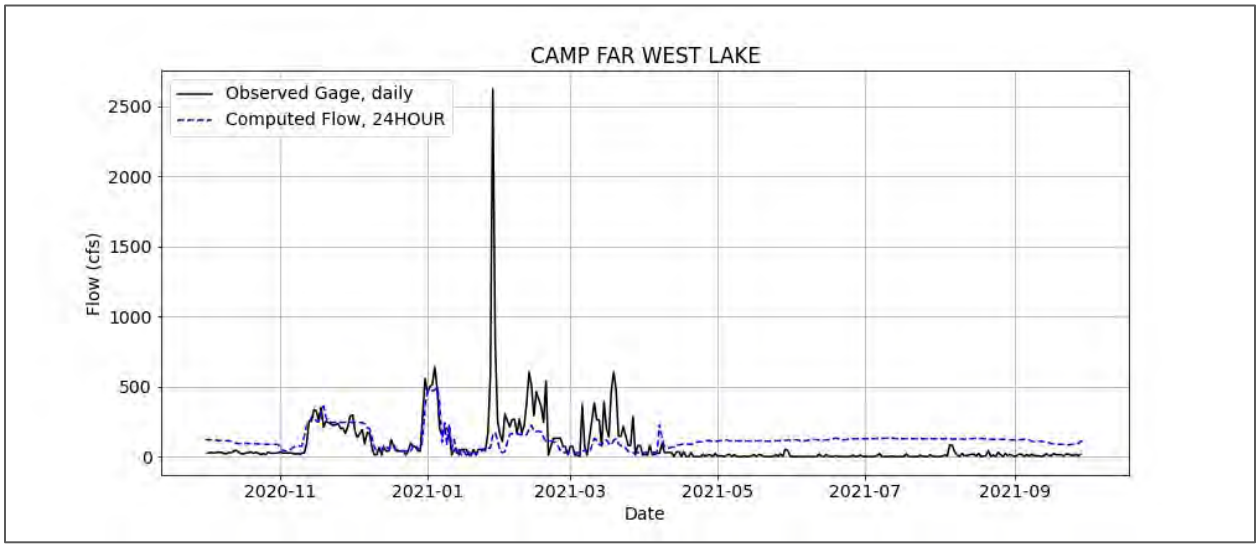


Figure A-87. WY2021 Calibration Results for Calibration Location Camp Far West Lake

A.5. Calibration Refinements Results for Other Water Years

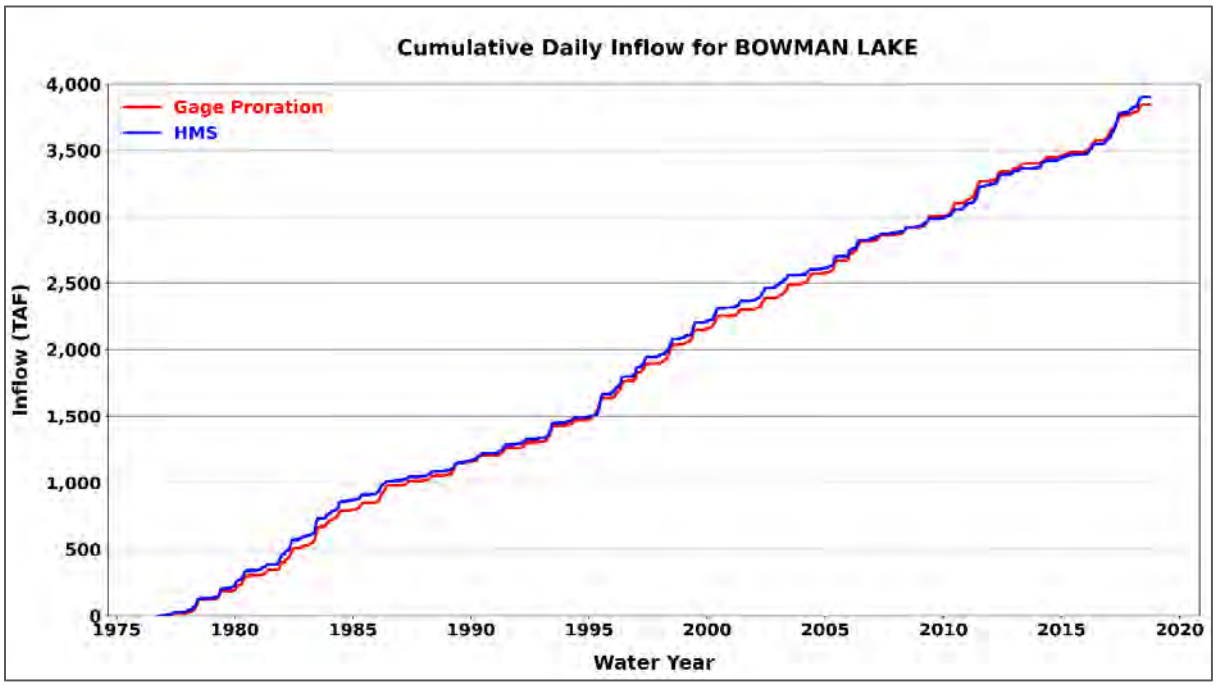


Figure A-88. Cumulative Daily Inflow (1975–2018) for Bowman Lake After Calibration Refinements

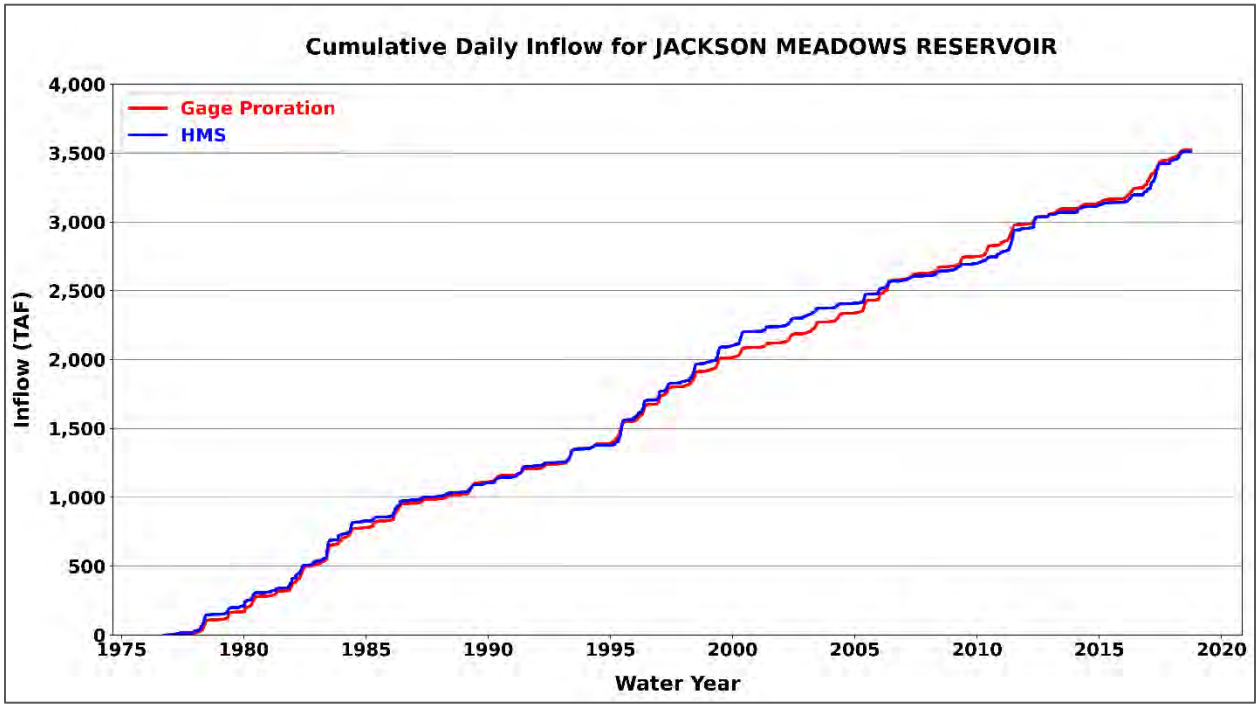


Figure A-89. Cumulative Daily Inflow (1975–2018) for Jackson Meadow Reservoir After Calibration Refinements

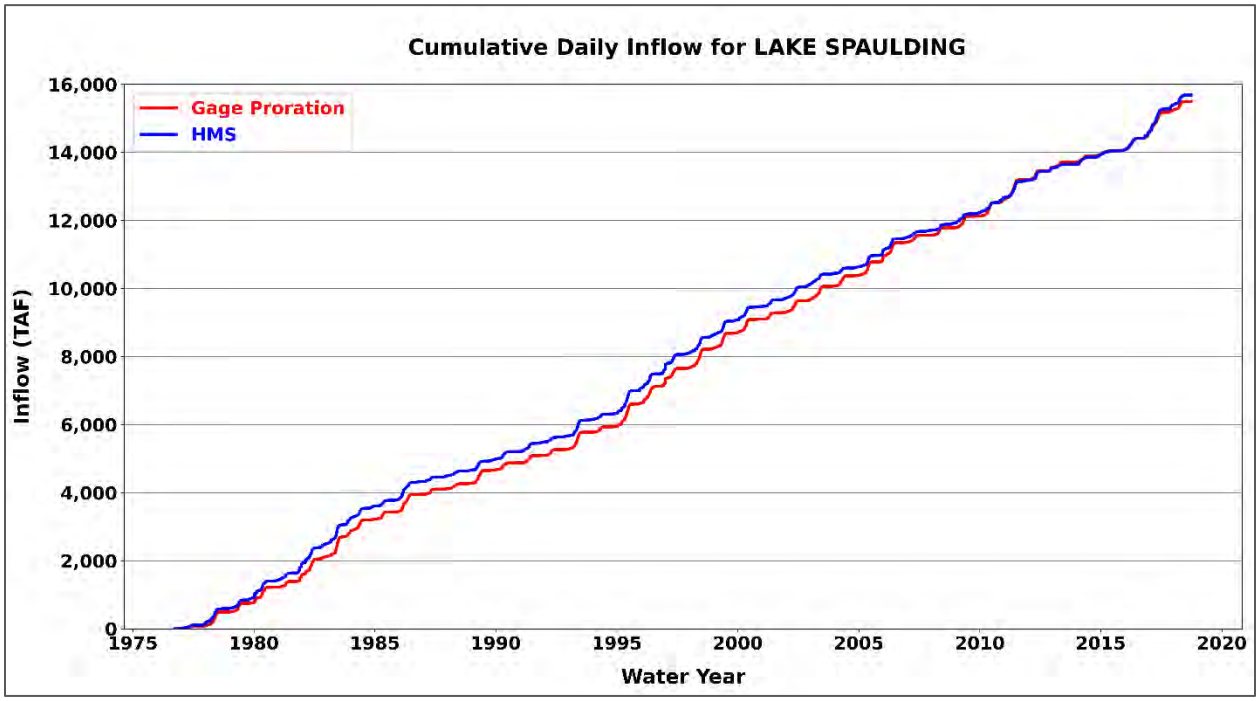


Figure A-90. Cumulative Daily Inflow (1975–2018) for Lake Spaulding After Calibration Refinements

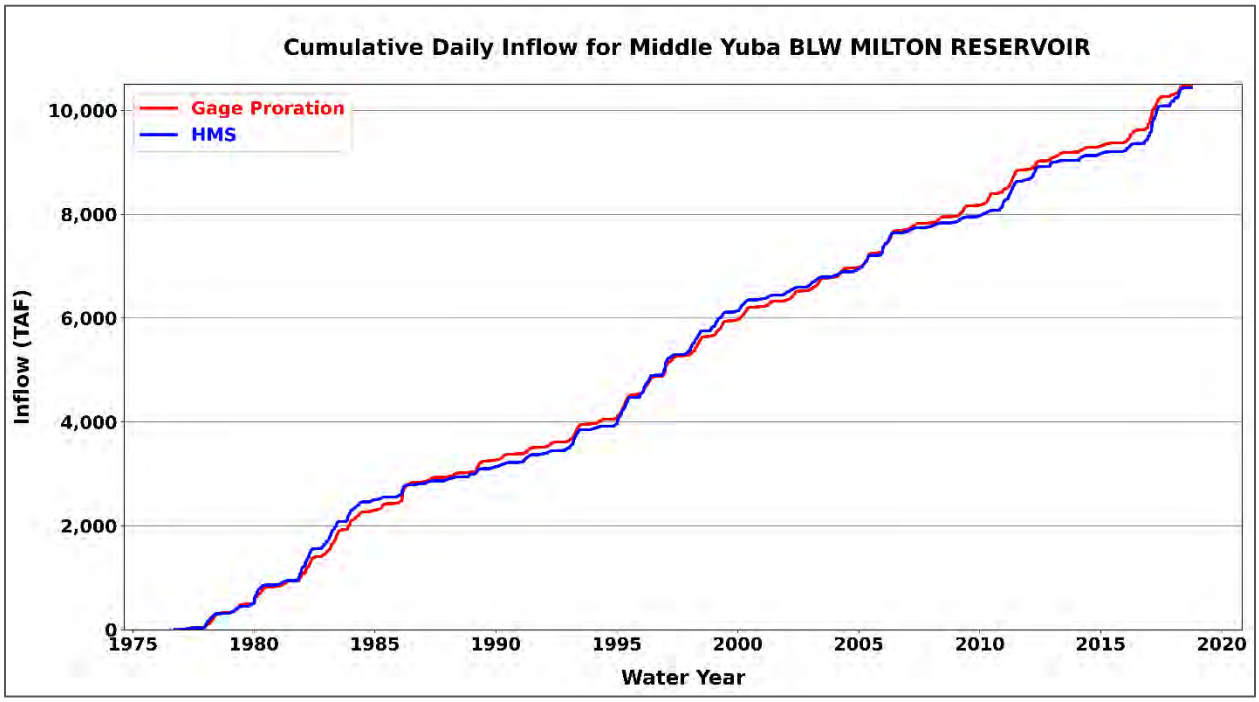


Figure A-91. Cumulative Daily Inflow (1975–2018) for Middle Yuba-Below Milton Reservoir After Calibration Refinements

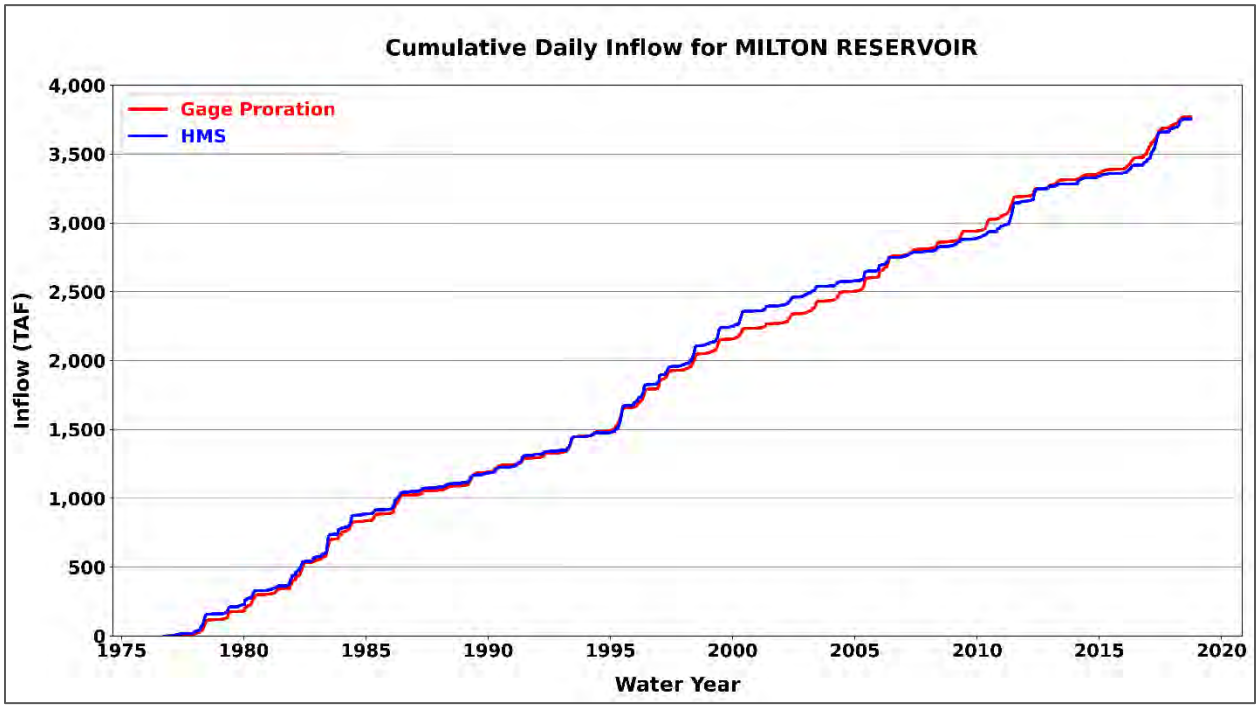


Figure A-92. Cumulative Daily Inflow (1975–2018) for Middle Yuba- Milton Reservoir After Calibration Refinements

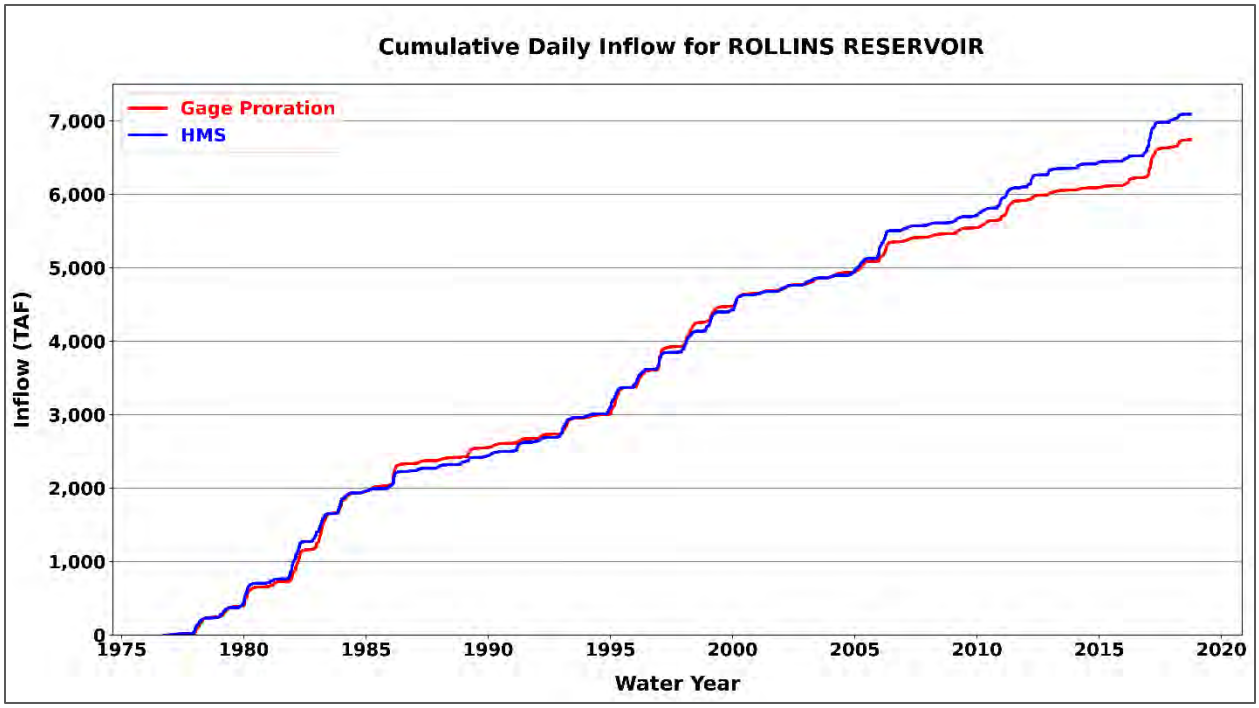


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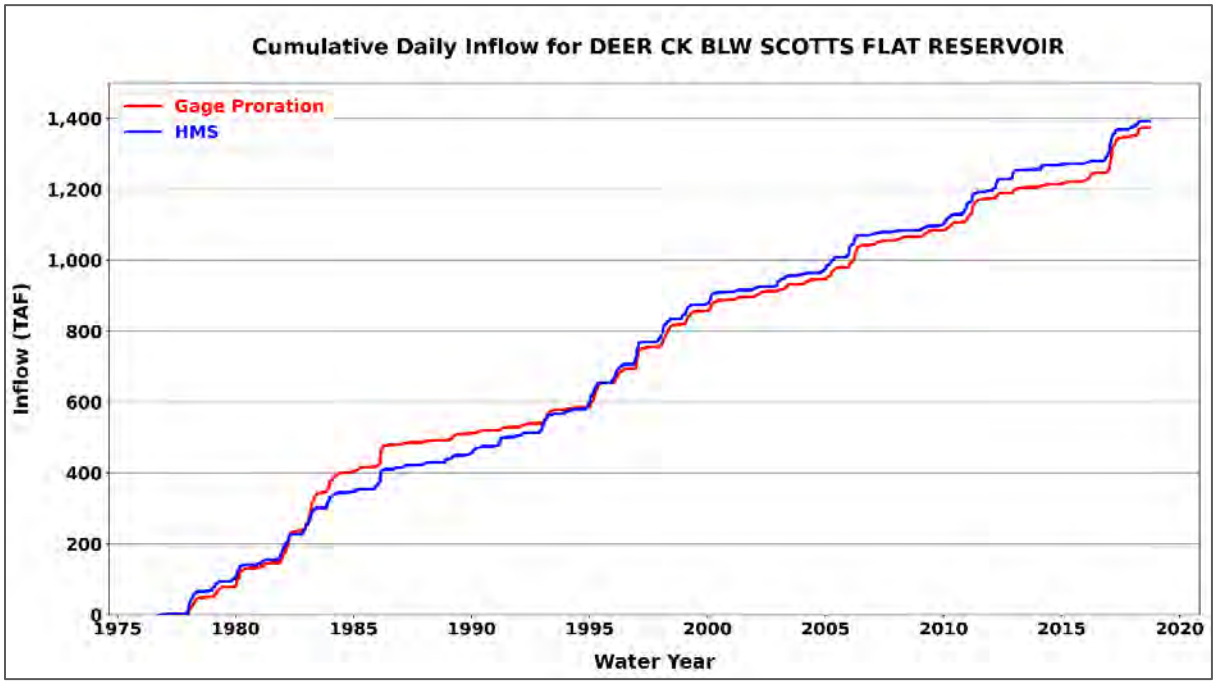


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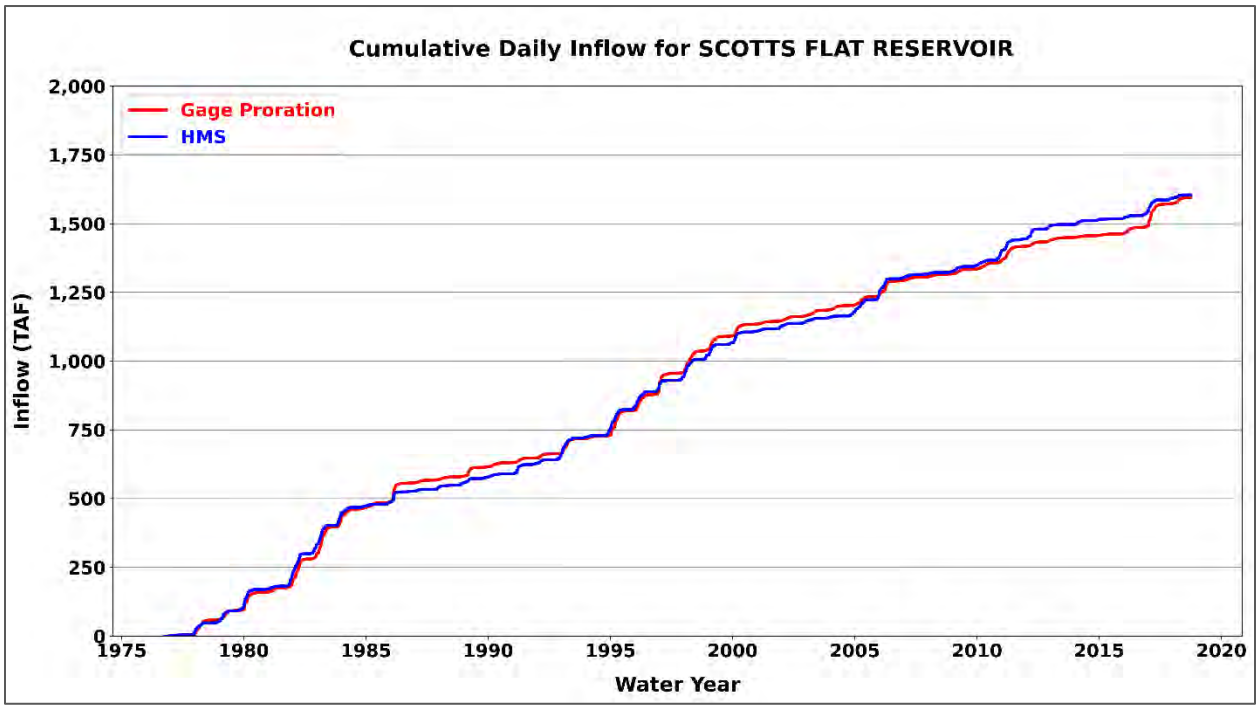


Figure A-95. Cumulative Daily Inflow (1975–2018) for Scott Flat Reservoir After Calibration Refinements

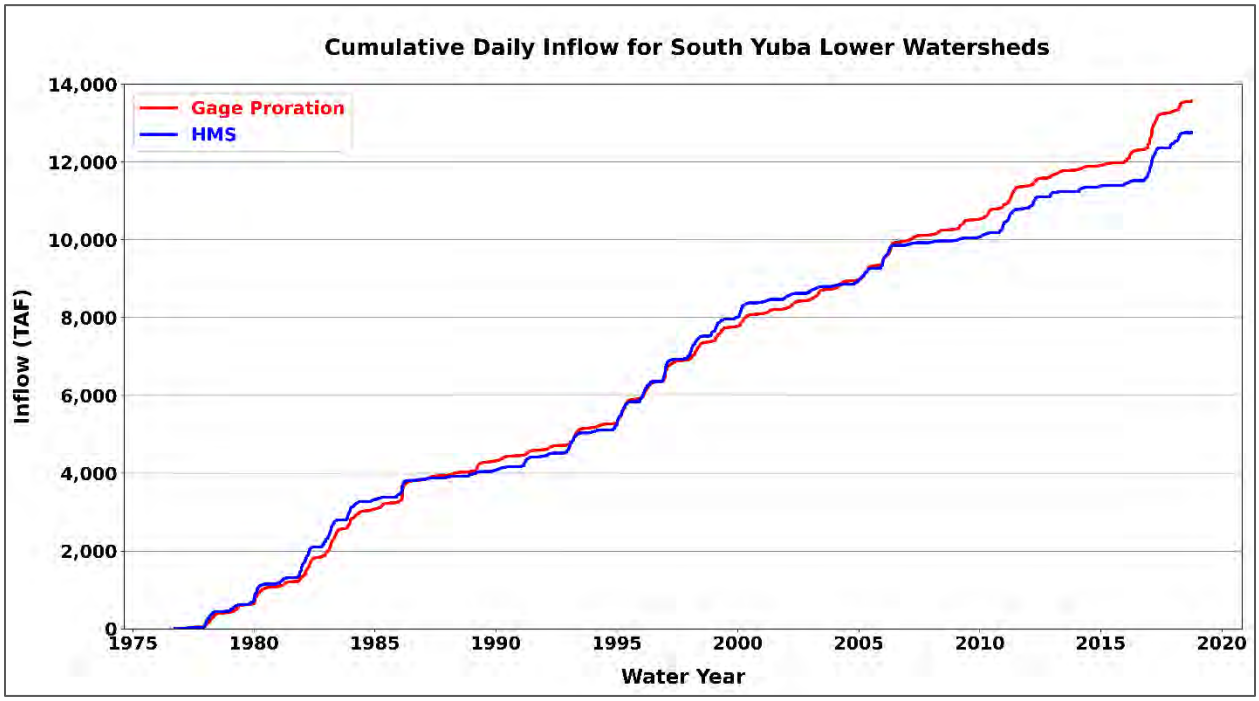


Figure A-96. Cumulative Daily Inflow (1975–2018) for South Yuba Lower Watersheds After Calibration Refinements

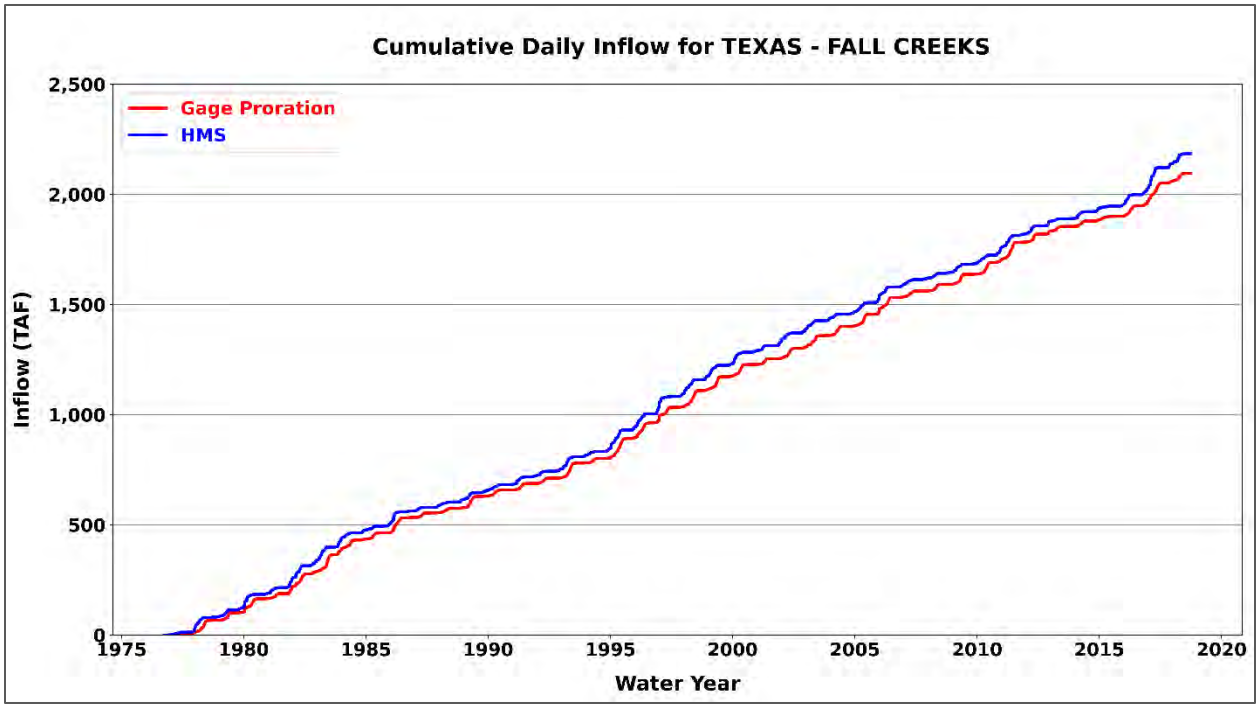


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Appendix B. Chapter 4 Supplemental Information

B.1. Assumptions Used to Develop the Model

Table B-1. General Data Sources and Assumptions

Category	Parameter	Current Scenario (Recent Historical) Data Sources, Assumptions	Projected Scenario General Data Sources, Assumptions	Additional Details	References
Demand Model Setup	Demand model platform	Integrated Water Flow Model Demand Calculator (IDC) demand model, linked to a canal system balance model.	Same platform as current scenario.	An IDC demand model was used to quantify treated and raw water demand in NID. Results were linked by parcels to canals to quantify upstream demand at NID's water supply sources (factoring in conveyance system losses and municipal purchases).	[1]
Demand Model Setup	Demand model time step	Monthly	Monthly	IDC was used to simulate demand on a monthly time step. A monthly time step captures intra-annual conditions and interdependencies among different factors that influence demand.	[2] (Section 2.7)
Demand Model Setup	Demand model grid	Unitized grid, results linked to parcels.	Same approach as current scenario.	Demand was simulated in IDC for different combinations of land use, soil, and climate zone characteristics found in NID that impact demand. The IDC results were calculated first on a "unit" depth basis (e.g., feet/month) and were then linked to parcels that most closely matched those combinations of characteristics to quantify the demand "volume" (e.g., acre-feet/month).	[3]
Land Use	Land use types and areas	Summarized from available spatial land use mapping data (DWR, Land IQ, USDA) and survey or crop report data (DWR, counties, NID).	Land use area changes estimated based on county general plan and zoning information, NID "soft service areas" (i.e., areas of potential growth), and recent historical trends (methodologies and/or results verified with counties and NID staff).	Recent historical land use was summarized from available spatial data sources and linked to specific parcels in NID. Projected land use was developed based on recent historical trends in land use, with spatial land use changes informed by county general plan and zoning data and fill in of "soft service areas" where growth opportunities exist within NID. The effects of potential alternate projected scenarios on demand were evaluated through sensitivity analyses to identify "bookend" projected scenarios.	[4]-[17]
Precipitation Simulation	Precipitation	PRISM gridded historical precipitation data, consistent with HEC-HMS model.	Climate change-adjusted precipitation projections, consistent with HEC-HMS model.	Precipitation was simulated for climate zones in NID that share similar historical precipitation rates. Data sources used for the current and projected scenarios were consistent with the data sources used to simulate precipitation in the HEC-HMS model.	[2] (Section 9) [18]-[19]
Precipitation Simulation	Precipitation runoff	Calculated using the modified Soil Conservation Service (SCS) curve number method, routing runoff to the nearest waterway.	Same approach as current scenario, but assuming projected precipitation and projected land use changes.	IDC was used to simulate precipitation runoff using a modification of the United States Department of Agriculture (USDA) SCS curve number method. Curve numbers were derived from technical literature, depending on land use types, soil textures, and typical hydrologic conditions.	[20]
Evapotranspiration	Evapotranspiration (ET)	Calculated from spatial OpenET data, summarized by land use type and climate zones in NID. OpenET data was evaluated in comparison to other technical literature and ET data sources and was used to develop local crop coefficients (Kc) to facilitate estimation of ET in the projected scenarios.	Calculated from reference ET (ETo) and crop coefficients (Kc) following the FAO 56 guidelines. Kc for different land uses was calculated from historical OpenET ETc and spatial CIMIS ETo. Projected ETo was estimated through climate change adjustments, consistent with the climate change scenarios used in the HEC-HMS model.	ET was simulated for different land uses across climate zones in NID that share similar historical ETo rates. The industry-standard crop coefficient approach, documented in FAO 56, was used to estimate ET due to land use characteristics (captured in Kc) and climate effects (captured in ETo). Local Kc values were developed using the available information about local ET and crop water use (e.g., satellite-based ET information from OpenET) to provide locally-accurate representations of ET that account for deficit irrigation or other local factors that impact water needs for different land uses in NID.	[21]-[24], [38]-[39]
Soil Moisture Simulation	Soil textures and soil parameters (wilting point, field capacity, total porosity, pore size distribution, saturated hydraulic conductivity)	Summarized from SSURGO and STATSGO soil data and technical literature. Soil parameters were evaluated and calibrated using industry-standard approaches (e.g., pedotransfer functions) to ensure physically realistic soil water characteristics.	Same approach as current scenario.	Simulated soil textures in NID were classified from USDA National Cooperative Soil Survey (NCSS) SSURGO/STATSGO data. Initial soil parameters were assigned from SSURGO/STATSGO data. Final soil parameters were refined through calibration using pedotransfer functions (standard, predictive methods for translating raw soil data into soil water characteristics that are physically realistic) and were compared with values from technical literature.	[25]-[27]
Soil Moisture Simulation	Initial soil moisture (i.e., soil moisture at the first model time step)	Estimated to be equal to the soil field capacity.	Same approach as current scenario.	Initial soil moisture simulated in IDC depends on irrigation and hydrologic conditions preceding the simulation period. The first model time step was initiated more than one year prior to the current and projected scenario analysis period. This allowed sufficient time for IDC to simulate soil moisture with respect to irrigation and hydrologic conditions preceding the analysis period.	[25]-[26]
Soil Moisture Simulation	Minimum soil moisture (i.e., soil moisture at which irrigation is triggered)	Estimated to be equal to 50% of the available soil moisture.	Same approach as current scenario.	IDC simulates irrigation once the minimum soil moisture is reached. The minimum soil moisture was set to 50% of the available soil moisture to represent typical conditions in California and to avoid simulation of additional water stress within IDC (local Kc values already account for typical water stress, as applicable; see parameter "Evapotranspiration").	[25]-[26]
Agricultural Water Use Inputs	Root depth	Defined for each simulated land use type based on representative values in technical literature.	Same approach as current scenario.	Different land use types have different characteristic root depths, determining where in the soil vegetation can extract moisture. Typical root depths for different land use types are documented in technical literature.	[28]
Agricultural Water Use Inputs	Irrigation period (i.e., months when irrigation occurs)	Defined based on NID's historical irrigation delivery records.	Estimated based on recent historical information with consideration for potential future changes to the irrigation season start/end.	Typical irrigation periods were identified from NID delivery records and through discussion with NID staff.	[29]
Agricultural Water Use Inputs	Tailwater (i.e., runoff of irrigation applied water)	Tailwater for each irrigated land use was simulated as a fraction of the total irrigation applied water (approximately 5% for irrigated land uses in NID).	Estimated to be similar to the current scenario.	Tailwater depends mainly on customer irrigation practices and irrigation methods for different crops and field conditions. Model inputs were set at levels typical of land uses and irrigation methods in NID, with comparison of recent historical demands simulated in IDC to NID delivery records.	
Urban Water Use Inputs	Population	Estimated from California Department of Finance (DOF) population estimates for cities, counties.	Estimated with respect to California DOF population projections for counties, county General Plan information and transportation studies, and NID's projected connections for treated water customers (e.g., from NID's 2020 Urban Water Management Plan).	California DOF population estimates and projections were consistent with methods used to evaluate projected water demands in NID's 2020 Urban Water Management Plan and in county transportation studies.	[30]-[31]

Category	Parameter	Current Scenario (Recent Historical) Data Sources, Assumptions	Projected Scenario General Data Sources, Assumptions	Additional Details	References
Urban Water Use Inputs	Per capita water use	Estimated based on population estimates and potable water production data from NID, cities, and the State Water Resources Control Board (SWRCB).	Estimated to be similar to the current scenario (changes to urban demand were simulated through changes to population and other inputs).	Per capita water use (together with population) drives the IDC simulation of urban demand. Estimates and trends were derived from NID, state, and city data.	[32]-[34]
Urban Water Use Inputs	Urban indoor water use fraction	Estimated based on urban water production and deliveries during winter months, assuming that the minimum monthly use (typically February) is primarily used indoors.	Estimated to be similar to the current scenario.	The urban indoor water use fraction is the fraction of treated water that is assumed to be used indoors (i.e., for drinking water, sanitation, etc.). Urban indoor water use is simulated in IDC separately from urban outdoor water use (i.e., for landscape irrigation).	[32]-[33]
Urban Water Use Inputs	Urban return flow fraction (i.e., urban wastewater and runoff of applied water)	Indoor use is assumed to be approximately 100% return flow (i.e., 100% wastewater inflow). Outdoor use is assumed to have approximately 5% return flow (i.e., tailwater), typical of landscape irrigation.	Estimated to be similar to the current scenario.	Return flow is simulated in IDC as a fraction of the total urban water use. Model inputs were set at levels typical of urban water use, land uses, and irrigation methods in NID.	[1], [35]
Raw Water Demand	Raw water demand	Calculated using IDC as the amount of water needed to meet irrigation demand, after accounting for soil moisture, precipitation, tailwater, ET, etc.	Same approach as current scenario but calculated with projection scenario information.	Irrigation applied water was adaptively calculated using the IDC model, based in part on local land use in NID in conjunction with local ET information and other IDC input data described above. IDC inputs were defined unique to specific, local characteristics observed in NID, to the extent possible. Model inputs were refined to provide for consistency between model results and recent historical delivery records.	[36]
Treated Water Demand	Treated water demand	Calculated as the amount of water needed to meet urban water use requirements, after accounting for population, per capita water use, return flow, etc.	Same approach as current scenario but calculated with projection scenario information.	Urban water demand was adaptively calculated using the IDC model. Model inputs were refined to provide for consistency between model results and recent historical delivery records.	[36]
Municipal Water Demand	Municipal water demand	Summarized from historical municipal purchase records from NID.	Estimated consistent with other NID projections.	Future projections of municipal water purchases from NID were defined consistent with projections in NID's 2020 Urban Water Management Plan.	[36]
Environmental Flows	Environmental flows	*Simulated as part of the ResSim reservoir operations model.*	*Simulated as part of the ResSim reservoir operations model.*	Environmental flows are NID's in-stream flow requirements, as specified in the FERC Final Environmental Impact Statement for Hydropower License. Environmental flows are simulated as part of the ResSim reservoir operations model.	[36]
Conveyance System Losses (Below NID Reservoirs)	Conveyance system losses (below NID reservoirs)	Estimated as a fraction of canal inflows, based on NID operations data.	Same approach as current scenario, with adjustment for different projected scenarios.	System losses from NID conveyance infrastructure (below NID's reservoirs) was estimated as a fraction of NID's canal inflows. Estimates were consistent with previous NID analyses based on NID operations data, calculated from inflows and outflows. These losses include all evaporation, seepage, and other losses from the conveyance system below NID's reservoirs. Evaporation from NID's reservoirs are simulated as part of the ResSim reservoir operations model.	[25]-[26], [36]-[39]

Reference Source

[1] California Department of Water Resources (DWR), 2022c. IDC: Integrated Water Flow Model Demand Calculator. Available at: https://water.ca.gov/Library/Modeling-and-Analysis/Modeling-Platforms/Integrated-Water-Flow-Model-Demand-Calculator
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B.2. Evapotranspiration and Crop Coefficient Development Process

B.2.1. Introduction

Evapotranspiration (ET), or consumptive water use, is the major driver of agricultural water use, and is impacted by many factors, including:

- The types of crops and vegetation that are grown (reflecting the inherent differences in water needs of different crops and vegetation);
- The quality of crops, vegetation, and land use (including water availability, nutrient and pest management, and other factors); and
- Environment-driven demand for evaporation (related to weather and climate parameters, as a function of temperature, solar radiation, wind speed, and humidity).

Each of these factors are accounted for in the methods used to quantify ET.

In the Nevada Irrigation District (NID) Plan for Water (PFW) demand model, ET was quantified for different land uses and different climate zones in NID for each of the demand model scenarios using the best available local information and standard technical approaches (ASCE 2016). Two key approaches used to quantify ET were:

- Open ET data: In the current demand scenario, ET was quantified based on representative ET curves developed for different land uses and climate zones in NID using OpenET data.
- Crop coefficient approach: In the projected demand scenarios, ET was calculated following the standard crop coefficient approach described in the United Nations Food and Agriculture Organization (FAO) Irrigation and Drainage Paper 56 (Allen et al. 1998). In this approach, ET is calculated by multiplying a reference evapotranspiration (ETo) value by a crop coefficient (Kc) as seen in Equation 1. ETo captures the environment-driven demand for evaporation, while Kc represents the unique properties of crops and vegetation to accurately estimate the specific crop water use characteristics. Kc thus serves as a scaling factor for modifying ETo, tailoring ET calculations to the unique demands of different land uses under specific climatic and environmental conditions.

$$\mathbf{ET} = \mathbf{Kc} \times \mathbf{ETo} \quad [1]$$

The purpose of this appendix is to document the processes used in analyzing OpenET data and developing Kc values specific to the local conditions within NID. NID covers a diverse landscape, necessitating approaches for quantifying ET that account for local conditions within NID with respect to climate and crop water use characteristics. The approaches described in this appendix aim to provide accurate estimates of crop water use in the NID PFW demand model.

B.2.2. Data Sources

Accurate estimation of crop water use in NID requires comprehensive and reliable data sources that reflect the diverse landscape within the NID service area. This section outlines the primary data sources used in the ET analysis and Kc development process.

B.2.2.1 OpenET

OpenET is a multi-agency web-based geospatial utility that leverages satellite-based remote-sensing technology to provide spatially distributed and continuous ET estimates over vast, diverse regions. While OpenET is a new utility, the underlying methodologies to quantify ET apply a variety of well-established modeling approaches that are widely used in local, state, and Federal government and research applications. Additional information about the OpenET team, data sources, and methodologies are available at: https://openetdata.org/.

The capability of OpenET to deliver timely and large-scale ET datasets played a crucial role in developing ET and Kc estimates that capture the unique crop water use conditions observed within NID in recent years. OpenET information is available in raster coverages of the NID service area with a spatial resolution of 30 meters (m) x 30 m (approximately 0.22 acres). Data is available on both a daily and monthly timestep from 2016 through present. Monthly ensemble mean ET data for the entire NID service area in 2016–2022 was extracted from OpenET and analyzed to support development of the NID PFW demand model.

B.2.2.2 Spatial California Irrigation Management Information System (CIMIS)

Spatial CIMIS is a geospatial data product produced and released by the CIMIS. CIMIS operates an extensive network of weather stations strategically distributed across California that collect and report weather and climate parameters, including ETo estimates. Spatial CIMIS provides spatially continuous ETo estimates throughout California, which are calculated based on available quality-controlled CIMIS station data using advanced interpolation techniques with reference to topography and other factors that impact climate conditions. This approach enables the creation of ETo estimates throughout California, even where direct measurement may not exist. Additional information about the spatial CIMIS data sources and methodologies is available at: https://cimis.water.ca.gov/SpatialData.aspx.

Spatial CIMIS data was used together with OpenET data to calculate Kc curves representing specific land uses and climate conditions within NID. Spatial CIMIS ETo information is available in raster coverages of the NID service area with a spatial resolution of 2 km x 2 km. ETo estimates were extracted from spatial CIMIS on a daily timestep from 2016–2022 and were aggregated to monthly ETo totals to support development of monthly Kc curves.

B.2.3. Methods

B.2.3.1 Representative ET Curves

OpenET data was used to observe recent historical ET trends and develop representative ET curves for each land use category in each climate zone simulated in the demand model. Additional information about the land use categories and climate zones simulated in the demand model are discussed in Chapter 4 of the NID PFW report. The representative ET curves are meant to capture the range of observed ET rates across all pixels (i.e., 30 m x 30 m areas) within each climate zone that correspond to each respective land

use category. The representative ET curves were used to determine the average ET and ET percentiles across tens to thousands of pixels in NID, depending on the distribution of each land use within each climate zone in NID. Importantly, OpenET data was not used to directly assign an ET value representing any single point within NID in the demand model, but rather to identify and simulate ET trends.

The development of representative ET curves involved a series of geographic information system (GIS) analyses. The following steps were taken to calculate the representative ET curves:

- Data Collection:
  - ET: Ensemble mean ET data was downloaded from OpenET for the entire NID service area (monthly timestep, 2016–2022).
  - Land use: Spatial land use information was summarized for the entire NID service area (annual timestep, 2016–2022). This information was developed through a land use analysis process based on:
    - Statewide land use mapping, available from the California Department of Water Resources (DWR) (DWR 2023)
    - CropScape Cropland Data Layer coverage, available from the U.S. Department of Agriculture (USDA 2023)

    In total, 11 land use categories were simulated in the demand model. The land use analysis and land use categories are discussed in Chapter 4 of the NID PFW report.
  - Climate zones: Climate zones delineated based on analyses of climate-related data to identify regions with similar precipitation and ETo characteristics within the NID service area. In total, three climate zones were simulated in the demand model. The climate zones are discussed in the Chapter 4 of the NID PFW report.
- ET Summary by Land Use and Climate Zone:
  - The ET data, land use data, and climate zone boundaries were imported into the same GIS analysis process and were scaled, as necessary, to 30 m x 30 m.
  - Through a month-by-month process, the ET, land use, and climate zones were spatially linked together by location to create a compiled ET dataset containing the monthly ET rate within each 30 m x 30 m pixel, with indicators of the land use and climate zone corresponding to that pixel.
  - An array was created of all ET rates within all pixels, summarized by:
    - Land use
    - Climate zone
    - Year and month
- Representative ET Curve Calculation and Use in the Demand Model:

- Representative ET curves (ET rates per month, from 2016–2022) were calculated for each land use and climate zone by calculating the following summary statistics from all pixels linked to each land use and climate zone:
  - 10th percentile
  - 25th percentile
  - 50th percentile (median)
  - 75th percentile
  - 90th percentile
  - Mean
- The representative ET curve for each land use and climate zone was compared against other representative ET curves reported from other sources – including DWR's Cal-SIMETAW (DWR 2022a) and the Irrigation Training and Research Center (ITRC) at California Polytechnic State University – San Luis Obispo (ITRC 2023) – to verify their general consistency with ET trends reported in technical literature.
- The representative ET curve for each land use and climate zone was used within the demand model to represent the monthly ET rates for all areas corresponding to that land use and climate zone between 2016–2022. In earlier years, monthly ET rates from the same month in a hydrologically similar year were used in lieu of available data from OpenET. The 50th percentile (median) ET curve was used in the current demand scenario, and the relative impacts of other percentile curves on demand were evaluated through sensitivity analyses (discussed in the NID PFW report).

B.2.3.2 Representative Kc Curves

OpenET and spatial CIMIS data were combined and used to develop representative Kc curves for each land use category in all climate zones in the demand model. Additional information about the land use categories and climate zones simulated in the demand model are discussed in Chapter 4 of the NID PFW report. The representative Kc curves were developed to capture the range of observed crop-related water use requirements within NID. The representative Kc curves were used to estimate future crop water use requirements for each land use category in NID in the projected demand scenarios.

The development of representative Kc curves involved a series of GIS analyses, building off those used to develop the representative ET curves. The following steps were taken to calculate representative Kc curves:

- Data Collection:
  - ETo: ETo data was downloaded from spatial CIMIS for the entire NID service area (daily timestep aggregated to monthly values, 2016–2022)
  - ET: Ensemble mean ET data was downloaded from OpenET for the entire NID service area (monthly timestep, 2016–2022). See Section B.2.3.1.

- Land use and climate zones: Spatial land use information was summarized (annual timestep, 2016–2022), and climate zones were delineated for the entire NID service area. See Section B.2.3.1.

- Kc Summary by Land Use and Climate Zone:
  - The ETo data was imported into a GIS analysis process and was downscaled to 30 m x 30 m, consistent with the ET data. Units were converted, as needed, for consistency.
  - The compiled ET data containing monthly ET rates with indicators of the land use and climate zone (developed through the process described in Section B.2.3.1) was imported into the same GIS analysis process.
  - An array was created containing Kc values for each pixel in the NID service area, calculated based on the ratio of ET to ETo (rearranging Equation 1 to solve for Kc). Kc values within all pixels were summarized by:
    - Land use
    - Climate zone
    - Year and month

- Representative Kc Curve Calculation and Use in the Demand Model:
  - Representative Kc curves (Kc values each month, summarized across 2016–2022) were calculated for each land use across all climate zones by calculating the following summary statistics from all pixels linked to the corresponding land use:
    - 25th percentile
    - 50th percentile (median)
    - 75th percentile
  - The representative Kc curves for each land use in water year 2022 (October 2021 through September 2022) were used together with projected monthly ETo estimates to calculate monthly ET estimates for all projected demand scenarios following Equation 1. Projected monthly ETo estimates were estimated following the standard Hargreaves-Samani approach (Hargreaves and Samani 1985, Allen et al. 1998), based on spatial projected temperature information in the NID service area derived from the climate change analyses used in the hydrology scenarios (see Chapter 4 of the NID PFW report for more information).

    The following Kc curves were used within each projected demand scenario:
    - Low Demand: 25th percentile
    - Baseline Demand: 50th percentile (median)
    - High Demand: 75th percentile

    The selection of these percentiles is discussed in Section B.2.4.3.

B.2.4. Results and Conclusions

These analyses of representative ET curves and representative Kc curves provide valuable insights into local water use requirements within the NID service area and serve as a solid foundation for water

management planning in the NID PFW process. The subsections below present and discuss results of the ET and Kc development process.

B.2.4.1 ET and Representative ET Curves

Figure 1 presents the spatial distribution of ET within NID in July 2022, as an example. The ET values were derived from OpenET data, which provides spatially distributed and continuous ET estimates. The map highlights the diverse consumptive water use patterns across different areas in NID. ET values reflect both the variability in climate conditions across NID as well as the monthly water needs of crops and vegetation, accounting for differences in inherent characteristics, growth stages, agronomic and irrigation practices, and environments across NID. Accurate representation of these qualities is crucial for accurately simulating demand within NID with respect to local, observed conditions.

Figure 2 presents a sample, representative ET curve developed for pasture in climate zone 3 (the lowest elevation zone). As discussed above, the representative ET curves were compared to other representative ET curves reported from other sources (e.g., Cal-SIMETAW, ITRC) to verify their general consistency with ET trends reported in technical literature. In contrast with OpenET, many ET estimation approaches do not directly account for crop stress, which is caused by a variety of factors, and if present, will reduce ET. Consequently, many ET approaches and estimates in technical literature overestimate actual ET. One benefit of using OpenET data to quantify ET is that it captures the variability of ET observed within NID for each land use category, including those factors that may lead to differences in ET values compared to those reported in technical literature. The ET curves from other sources (e.g., Cal-SIMETAW, ITRC) tend to be higher than the OpenET results, especially in the mid- to late-summer period when evaporative demand is highest and when crop stress, if present, will be most noticeable. Differences observed between other sources and OpenET are influenced by those factors, which are captured within this ET analysis.

B.2.4.2 ETo

As described above, ETo serves as a critical parameter for estimating crop water use requirements. Figure 3 shows the spatial distribution of ETo from spatial CIMIS within NID in July 2022, as an example, revealing significant spatial variability in ETo across the NID service area. Differences in ETo across the landscape are influenced by climate and weather-related parameters, as a function of temperature, solar radiation, wind speed, and humidity. Regions with higher ETo values indicate areas with relatively higher consumptive water use requirements (all else equal), whereas lower ETo values correspond to relatively lower consumptive water use requirements. Factoring spatial estimates of ETo into the development of representative ET curves helps to capture these differences across the NID service area.

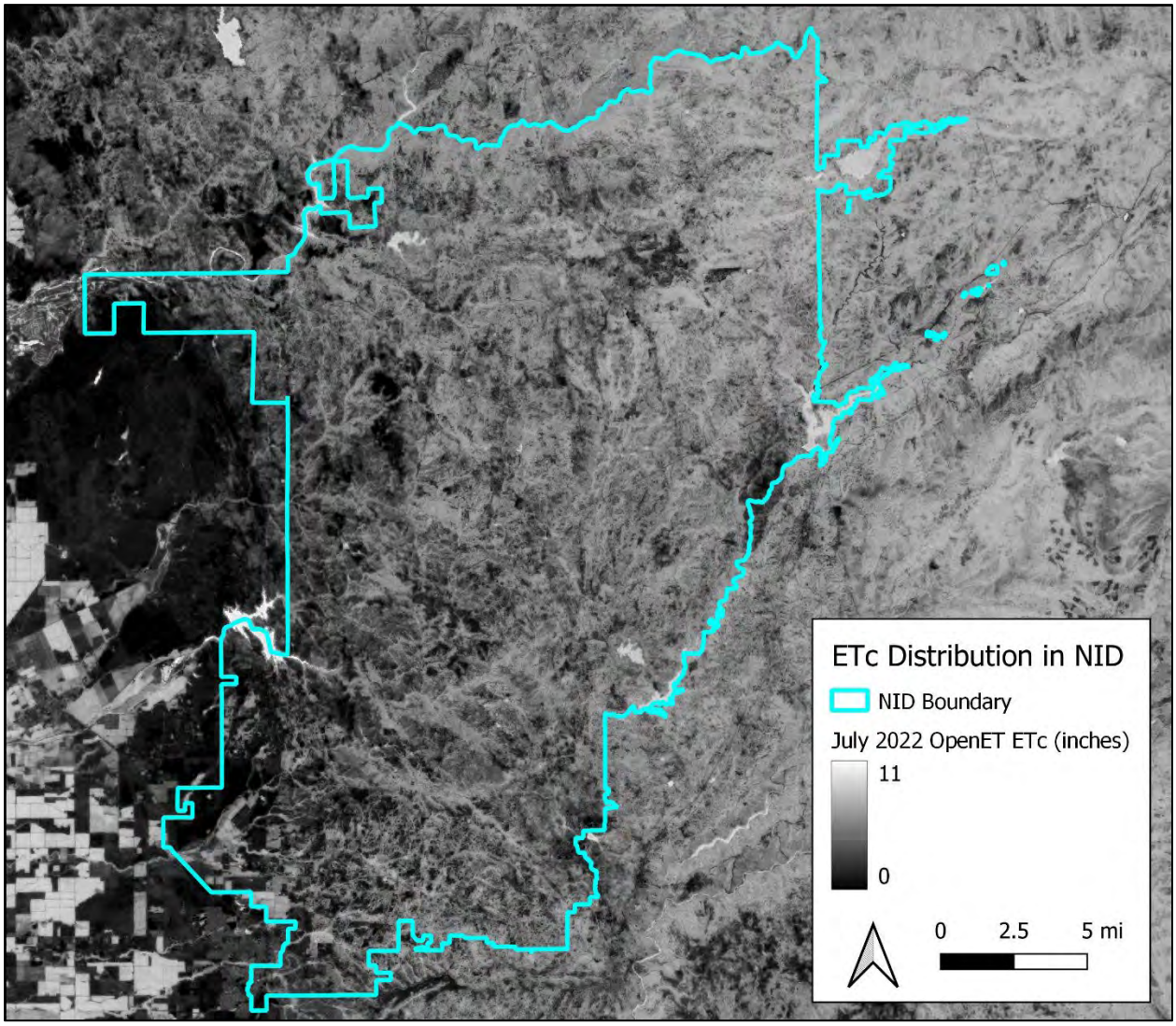


Figure B-1. Crop Evapotranspiration (ET) in July 2022 from OpenET.

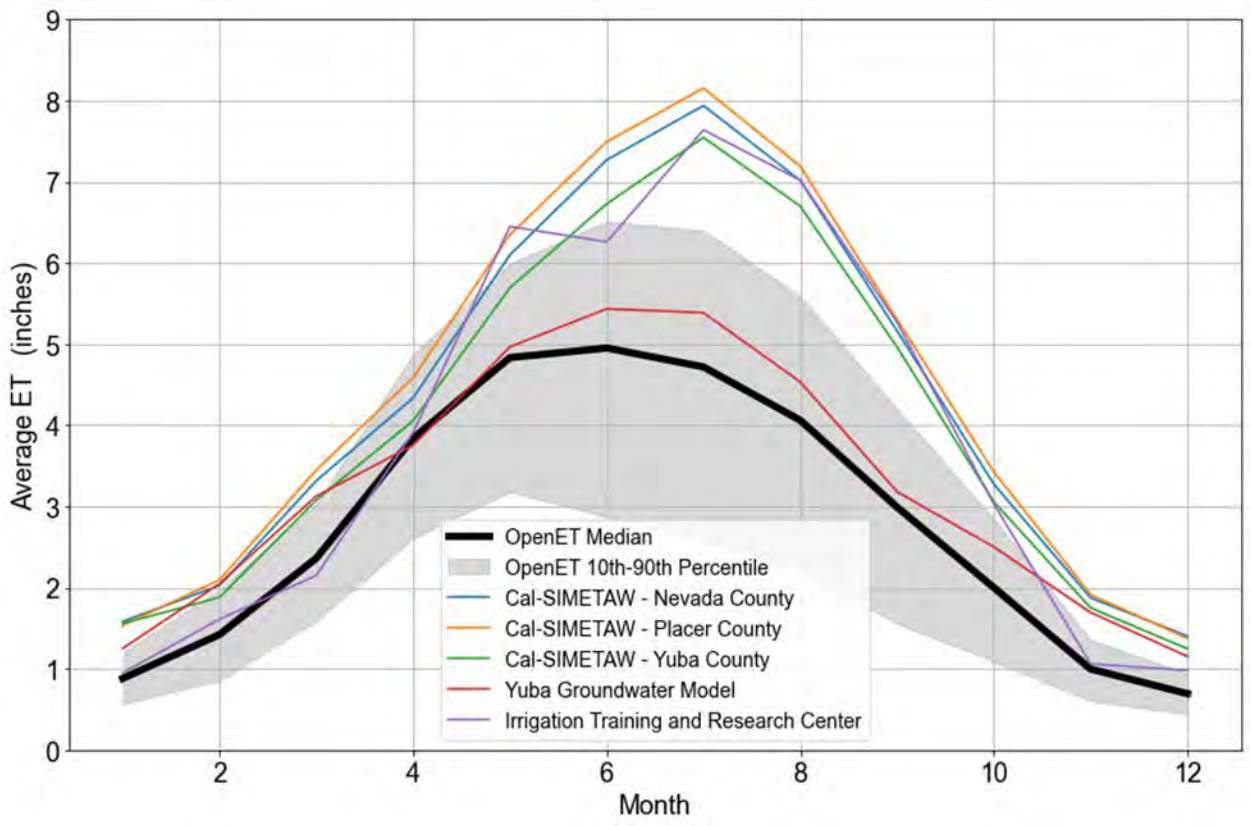


Figure B-2. Sample ET Curve Summarized for all Parcels Categorized as Pasture in Climate Zone 3 (2021), with Comparisons to Other Representative ET Estimates for Pasture from Cal-SIMETAW (DWR 2022a), the Yuba Groundwater Model (YWA 2019), and the Irrigation Training and Research Center ET Data for Water Budget Applications (ITRC 2023).

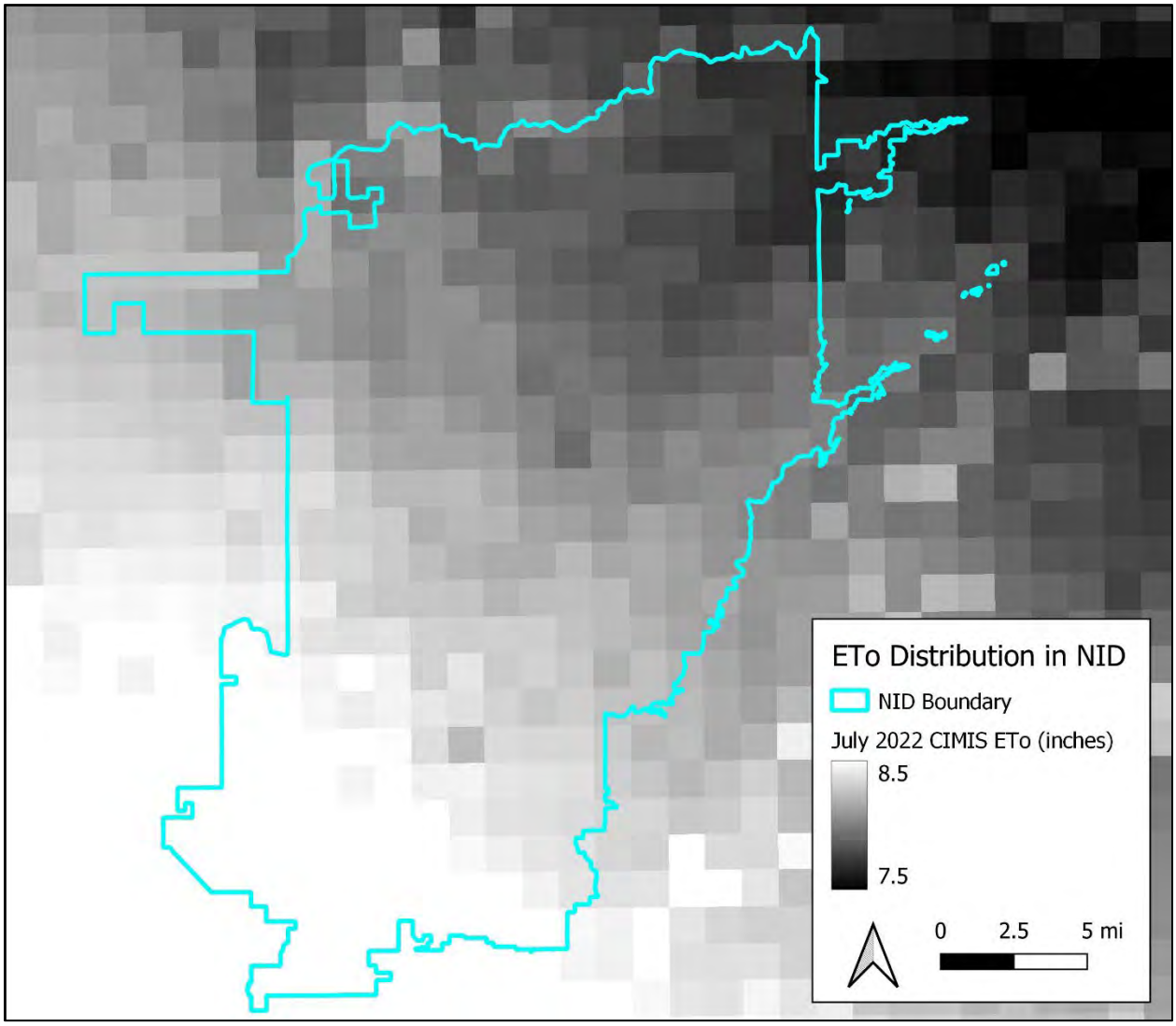


Figure B-3. Reference Evapotranspiration (ETo) in July 2022 from Spatial CIMIS.

B.2.4.3 Representative Kc Curves

Figure 4 illustrates the median Kc values for various land use categories within the NID service area in water year 2022 (October 2021 through September 2022), summarized across all climate zones. The figure showcases the variations in Kc values for different land use categories over the course of the year, as well as relative differences between land use categories. The representative Kc values, such as those depicted in Figure 4, were considered in the demand model development process to quantify ET in the projected scenarios.

Figure 5 provides a comparison of ET values calculated for pasture using the representative Kc curves, versus ET values summarized from OpenET data for pixels representing pasture. The comparison is made for 2016–2022, a period when OpenET data is available, although it is noted that the representative Kc curves shown are those that are also used in the projected demand scenarios:

- Low Demand: 25th percentile (ET in Figure 5 is calculated using ETo summarized from the wet hydrology scenario)
- Baseline Demand: 50th percentile, or median (ET in Figure 5 is calculated using ETo summarized from the median hydrology scenario)
- High Demand: 75th percentile (ET in Figure 5 is calculated using ETo summarized from the dry hydrology scenario)

The comparison in Figure 5 indicates that ET estimates generated by the representative Kc curves are within the range of ET estimates observed from OpenET data during the irrigation season (generally March-October). Additionally, ET estimates calculated using the 25th and 75th percentile Kc curves reflect a reasonable range within the upper and lower bounds of the 25th and 75th percentile ET values observed from OpenET data.

Table 1 summarizes the relative changes in total annual ET from the median Kc for different land use categories if the 25th percentile or 75th percentile Kc curves are used. As compared to ET generated using the median Kc values, these percentiles result in an average change of approximately -18% of total ET (using the 25th percentile Kc values) or +15% of total ET (using the 75th percentile Kc values) overall.

The selection of the 25th percentile and 75th percentile for the “low” and “high” projected demand scenarios was informed by comparison of these ET changes to typical differences in ET under reasonable changes in cultivation and irrigation practices where ET is reduced (in the low bookend scenario) or ET is increased (in the high bookend scenario). Typical differences range from +/-15% or more, depending on conditions. A sample of references considered in this comparison is provided below. Many of the references provided evaluate ET of alfalfa, which serves as a proxy for evaluating ET of pasture – the primary agricultural land use in NID.

- Sanden et al. 2011: Review of alfalfa water requirements and recommendations for irrigation planning from the University of California Cooperative Extension. Normal year ET is considered a good guideline for planning irrigations, but actual ET can be +/-15% of that.
- Andales et al. 2010: ~12% decrease in ET observed between two growing seasons (2008–2009) for alfalfa cultivated under similar conditions each year, but with water stress early in the season when the decrease in ET was observed. ET differences were measured using weighing lysimeters, which are considered to be one of the most accurate ways to measure ET over a small area (ASCE 2016).
- Hunsaker et al. 2002: ~10-30% difference in ET observed between well-watered and water-stressed treatment conditions during the same growing season (1985) for alfalfa cultivated under otherwise similar conditions. A 30% difference in ET from well-watered to water-stressed conditions likely represents +/-15% difference from a "median" condition between those bookend conditions. ET differences were measured using weighing lysimeters.
- Djaman and Irmak 2013: ~5-10% change in ET observed between full irrigation and 50% reduced irrigation conditions during two growing seasons (2009–2010) for corn cultivated under otherwise similar conditions. ET differences were estimated using a soil water balance.
- Tasumi et al. 2005: +/- 10-20% difference in daily Kc values during peak-season irrigation of beans and corn under different cloud cover conditions (higher values in clear sky, lower values in cloudy

conditions). ET differences used to calculate the Kc values were measured using weighing lysimeters.

- Samani et al. 2013: ET was quantified for 751 alfalfa fields in New Mexico using a remote-sensing approach (similar to OpenET) and the range of total ET was observed between ~700-1200 mm/year (27.6-47.2 inches/year, with some outliers). This range translates to a difference in ET of approximately +/- 20-30% around the average, and the 25th and 75th percentiles are approximately 10-15% around the average. Potential reasons cited for ET and Kc variability was determined to include "irrigation methods and technology, lack of knowledge of irrigation scheduling, limited water supply, interference of harvesting schedule with irrigation, cultural practices, and economic factors."

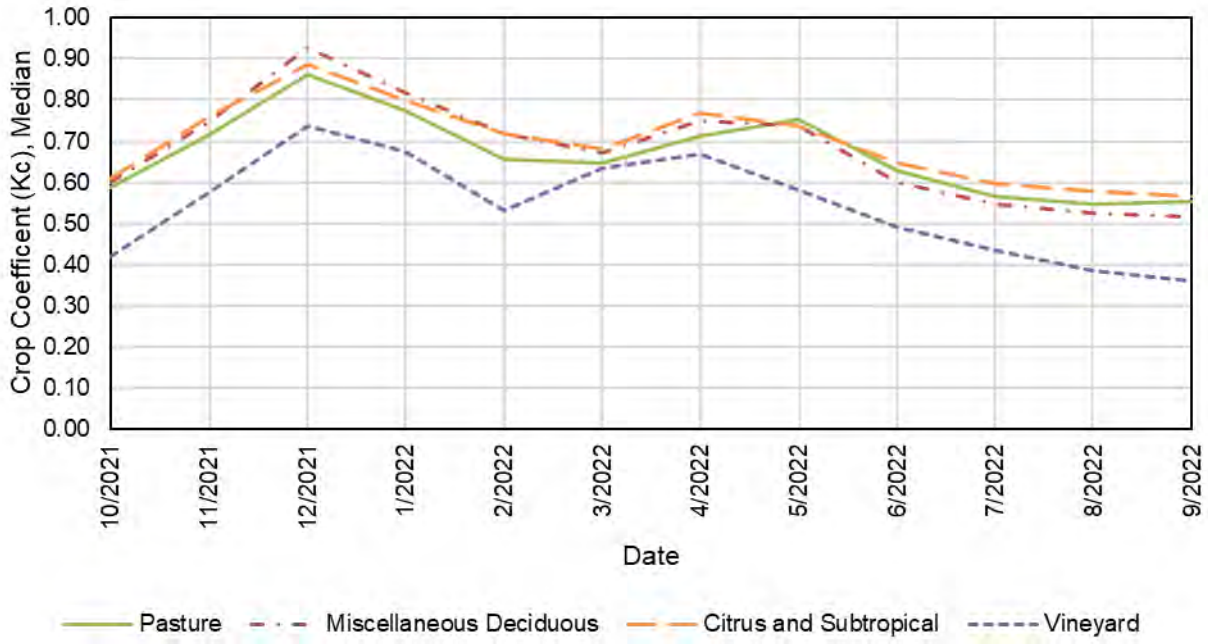


Figure B-4. Median Crop Coefficients for Various Land Use Categories in Water Year 2022, Summarized Across all Climate Zones.

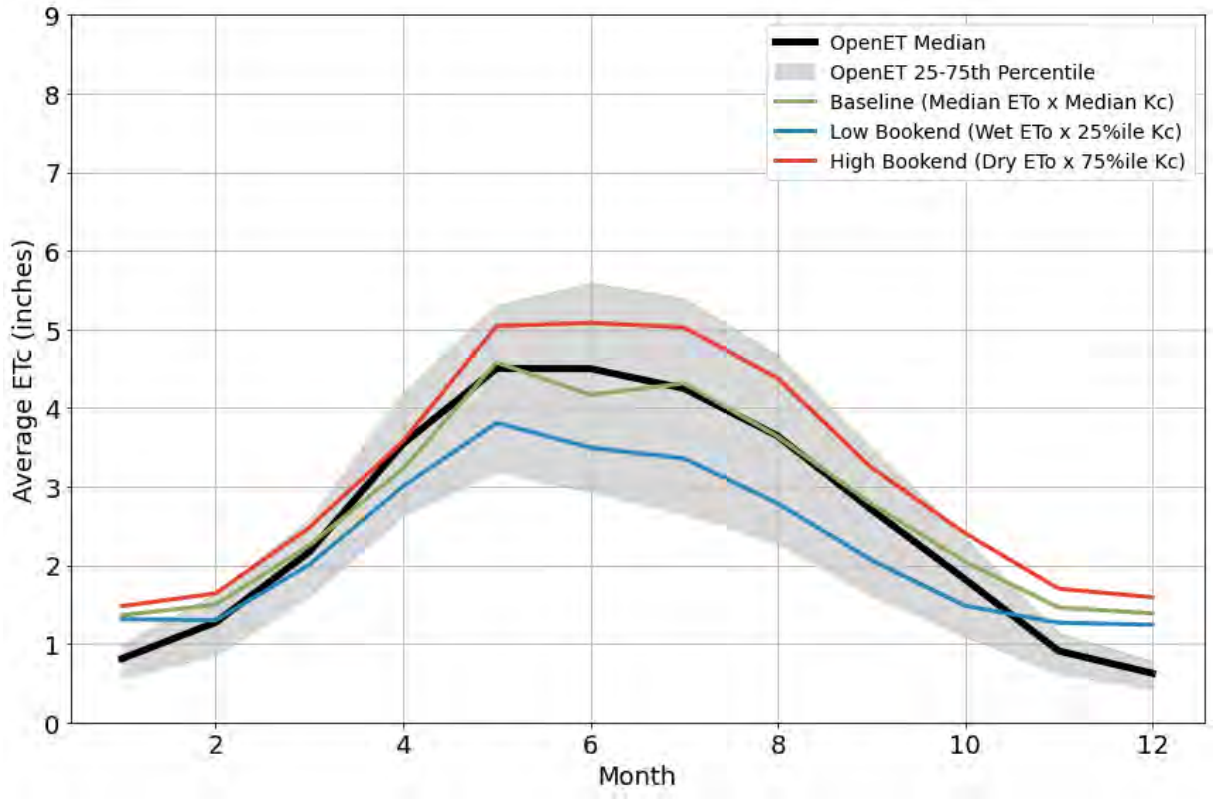


Figure B-5. Comparison of ET Calculated from Representative Kc Curves with OpenET ET for Pasture (2016–2022).

Table B-2. Percent Difference from Median ET Calculated Using the 25th Percentile and 75th Percentile Kc Values for Agricultural Land Use Categories in NID.

Agricultural Land Use Category	Fraction of Total Agricultural Land Use Area Evaluated	Percent Difference in ET in Water Year 2022 (%)	
		25th Percentile Kc vs Median Kc	75th Percentile Kc vs Median Kc
Pasture	88%	-17%	14%
Vineyard	6%	-16%	16%
Misc. Deciduous	3%	-18%	14%
Misc. Truck Crops	2%	-27%	30%
Citrus and Subtropical	1%	-15%	12%
Average (Area-Weighted)		-18%	15%

B.3. Land Use Analysis Process

B.3.1. Introduction

The purpose of this appendix is to document the process used to analyze and summarize spatial land use information for the NID service area. This information was used to assemble an annual spatial land use and

land cover (LULC) dataset for use in the NID PFW demand model. The spatial LULC dataset was used for a variety of purposes in the demand model, including identifying typical land uses within NID to simulate in the demand model, and identifying where those land uses occur. This spatial representation and understanding of land use provides a crucial linkage between the demand model results and the locations within NID where demand occurs.

B.3.2. Data Sources

The annual spatial LULC dataset was developed primarily using geospatial land use information obtained from the California DWR and the USDA. Both data sources are described below.

B.3.2.1 DWR Statewide Land Use Mapping

DWR provides a statewide land use mapping dataset covering all developed land in California, including cultivated agricultural land, idle agricultural land, and urban areas (DWR 2023). The dataset is generated by Land IQ, in cooperation with DWR, using remotely-sensed imagery and associated analytical techniques. The data is provided in vector-based GIS formats with field-by-field classification of each appropriate land use. The data does not generally include non-developed land (e.g., native vegetation), and leaves gaps outside of areas where developed land uses exist. Currently, statewide land use mapping data is available in 2014, 2016, 2018, 2019, 2020, 2021 and provisionally for 2022. The statewide land use mapping dataset undergoes extensive quality assurance, quality control, and validation processes by Land IQ and DWR to ensure that there is appropriate classification of different land uses throughout California. Additional information about the DWR statewide land use mapping dataset is available online at: https://data.cnra.ca.gov/dataset/statewide-crop-mapping.

B.3.2.2 USDA CropScape Cropland Data Layer

The USDA's CropScape Cropland Data Layer (CDL) is a raster-based data product that allows visualization of land uses throughout the United States (USDA 2023). The CDL dataset is generated using remotely-sensed imagery and analytical methodologies to provide a continuous nationwide land use coverage. Updates are released annually, with new CDL data becoming available each spring for the preceding year. Although validation of the CDL data does occur at the national level, issues have been identified in agricultural land use designations in California through independent, local checks. For this reason, the CDL data is used primarily for identifying non-developed land uses where gaps exist in the DWR statewide land use mapping dataset. Additional information about the USDA CDL data is available online at: https://nassgeodata.gmu.edu/CropScape/.

B.3.3. Methods

The DWR and USDA data were combined through an analysis process to develop the spatial LULC dataset used in the NID PFW demand model. The result was a spatially continuous annual representation of land use in the NID service area for 2013–2022, during the current demand scenario simulation period. As the DWR data is considered the most accurate spatial data source available within the NID service area, the DWR data was prioritized in development of the spatial LULC dataset, while the USDA data was used to fill in gaps in the DWR dataset.

The general process used to create the combined spatial LULC dataset was as follows:

1. The DWR data was rasterized and reprojected to match the USDA data projection and spatial resolution (30 meters (m) x 30 m).
2. The USDA data was masked to exclude any values where DWR data was available (i.e., to include only gaps within the DWR data).
3. For each year of available data, the DWR data and USDA data were combined to create one continuous raster coverage of NID, using:
4. The DWR data for that year (if available), or the DWR data for the most recent or hydrologically similar year (if data for that year was not available).
5. The USDA data for that year, filling in gaps in the DWR data.
6. Land uses in the combined spatial LULC dataset were linked to the appropriate land uses simulated in the demand model.
7. Land use areas (acres) were summarized from the spatial LULC dataset by converting the area of each pixel in continuous raster (30 m x 30 m) to acres.

Results of this analysis process were summarized and used in both raster and tabular format.

B.3.4. Results

Sample results of the land use analysis process are provided in Figure 1 and Table 1 for 2019 and 2022, respectively. Based on this analysis, the majority of land within the NID service area is categorized as either native vegetation or urban (Figure 1). In 2022, pasture was the predominant agricultural land use, encompassing 67% of all agricultural land (Table 1).

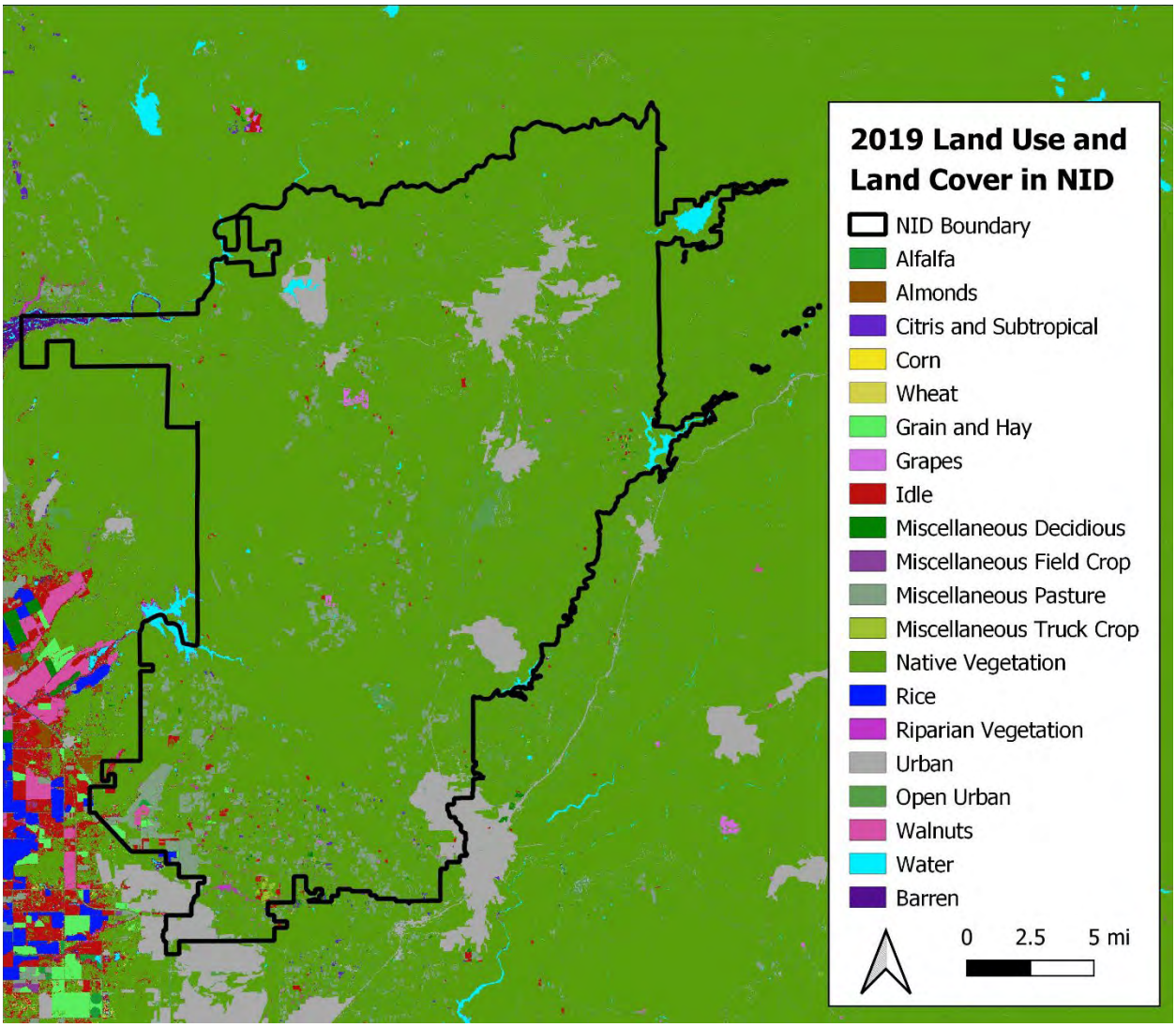


Figure B-6. Land Use Class in the LULC Dataset in 2019

Table B-3. Average Land Use Acreage in NID in Water Year 2022.

Land Use Sector in the Demand Model	Land Use Category in the Demand Model	Land Use Class in the Spatial LULC Dataset	Acres
Agricultural	Citrus and Subtropical	Citrus and Subtropical	68
	Idle	Idle and Barren	804
	Miscellaneous Deciduous	Almond	59
		Miscellaneous Deciduous	144
		Walnuts	115
	Miscellaneous Truck and Nursery	Miscellaneous Field Crops	24
		Miscellaneous Truck Crops	95
		Other Crops	570
	Pasture	Alfalfa	39
		Miscellaneous Pasture	4,432
	Vineyard	Grapes	297
Native and Riparian Vegetation	Native and Riparian Vegetation	Native and Riparian Vegetation	104,933
	Water	Water	1,663
Urban	Urban and Residential	Urban	16,771
		Total	130,014

B.4. Demand Model Input Parameter Sensitivity Analyses

B.4.1. Introduction

The purpose of this appendix is to document the sensitivity analyses that were conducted to test the relative impacts of different input parameters within the demand model that was developed and used to support the NID PFW process. The NID PFW is a public collaboration process to determine the best ways to meet the NID community's demand for water over the coming 50 years and involves a review of NID's available water supply and the long-term impacts on varying water demands. As part of the NID PFW process, a demand model was developed to simulate and test the water demands experienced under potential future demand scenarios – referred to as projected demand scenarios. The projected demand scenarios were developed to simulate a range of high and low demand conditions that may be experienced within the NID service area over the next 50 years.

The objectives of the sensitivity analyses documented in this appendix were to:

- Identify which factors most significantly impact demand, and should be considered in the development of the projected demand scenarios, and to
- Evaluate potential demand changes from current conditions in different "bookend" scenarios (i.e., a potential future range of high demand and low demand conditions), helping to identify reasonable bounds for developing input parameters in the projected demand scenarios.

The input parameters considered in the sensitivity analyses included:

- Raw water customers (with respect to changes in NID's customer base and areas receiving raw water)
- Treated water customers (with respect to changes in NID's customer base and parcels receiving treated water)
- Evapotranspiration (ET), with respect to changes in:
  - Climate-related impacts to environment-driven demand for evaporation
  - Crop cultivation practices and environmental stresses
- System losses (in NID's canals and distribution system downstream of NID's reservoirs)

In total, five levels of demand conditions were considered in each sensitivity analysis, with incrementally higher and lower demand conditions simulated around a baseline current demand condition (Figure B-7). The baseline current demand condition was developed starting from a historical demand model calibrated within approximately two percent, on average, of recent historical demand (2013–2022) across the NID service area, and was then refined for current conditions assuming: continuation of current land use (2022), current population and urban water use (2022), recent average precipitation (2013–2022) and ET (2016–2022), and 15% system losses (representing NID's current estimate of canal system losses based on findings from NID's Raw Water Master Plan and associated analyses by NID of water that is released into NID canals that is not delivered to NID customers).

The sections below identify the assumptions that were used to develop each level of demand conditions in each sensitivity analysis and the equivalent results for each. Results of the sensitivity analyses reported below are the "average water requirement" of NID's customers, which includes the sum of raw water demand and treated water demand, as well as the system losses in NID's canals and distribution system downstream of NID's reservoirs that occur delivering water to NID's customers (Figure B-7). These sensitivity analysis results do not include municipal water demand or environmental flows. Changes to municipal water demand were included in the projected demand scenarios based on five-year projected changes to municipal water use (2020–2040) from NID's Urban Water Management Plan, with interpolation or extrapolation in the intervening and following years through the end of the projected period. Regulatory-required environmental flows were included in the reservoir operations model (i.e., the ResSim model) that was developed and used in coordination with the demand model to simulate water supply versus demand and conditions of unmet demand under potential projected scenarios. Additional information about the projected demand scenarios and demand model is provided in the NID PFW report.

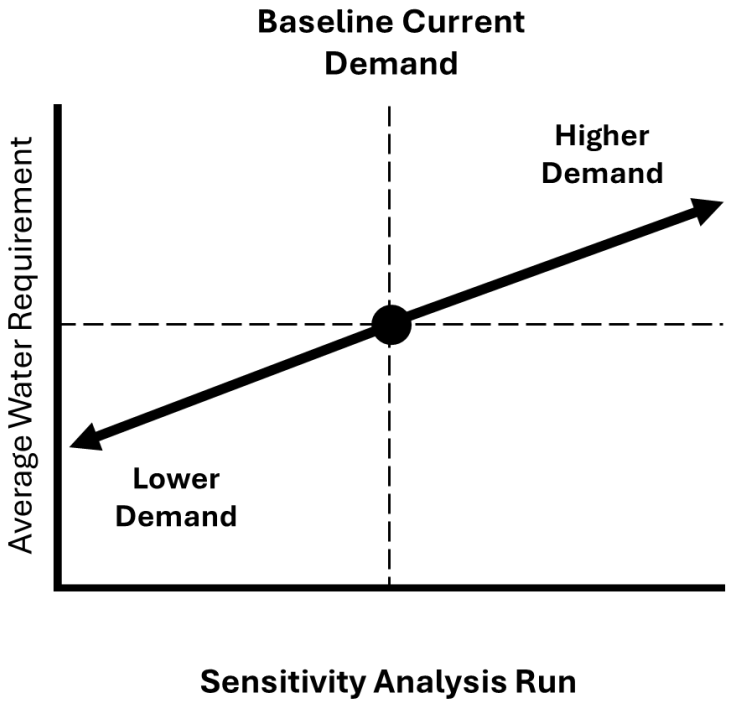


Figure B-7. Layout of Sensitivity Analysis Runs and Results Summaries.

B.4.2. Sensitivity Analyses

B.4.2.1 Raw Water Customers

The first analysis was conducted to evaluate the sensitivity of the demand model to changes in NID's raw water customers, as related to changes in NID's customer base and areas receiving raw water. Around the baseline current demand condition (analysis run 3):

- Higher demand conditions were evaluated through expansion of raw water customers into parcels within 1,000 feet of NID canals that (1) were not already NID customers, per NID delivery records, and (2) have historically been associated with agriculture or irrigated land uses, as identified from land use analyses. Expansion was tested through 50% fill-in to those areas (analysis run 4) and through 100% fill-in to those areas (analysis run 5). These levels of expansion were selected to test potential high-demand bookend scenarios, although actual future growth of NID's raw water customer base is likely to be less than this.
- Lower demand conditions were evaluated through reduction of land irrigated by raw water customers, with no fill-in to additional parcels in the NID service area. The analysis tested 25% reduction (analysis run 2) and 50% reduction (analysis run 1) of non-permanent crop areas. These reductions were selected to test the demand model sensitivity to potential low-demand bookend scenarios. However, potential future reductions in irrigated areas are likely to be less than these changes.

Changes in the average water requirement resulting from this analysis ranged between approximately -55,000 acre-feet per year (AF/yr) and +52,000 AF/yr, as compared to the baseline current demand condition (Figure B-8 and Table B-4).

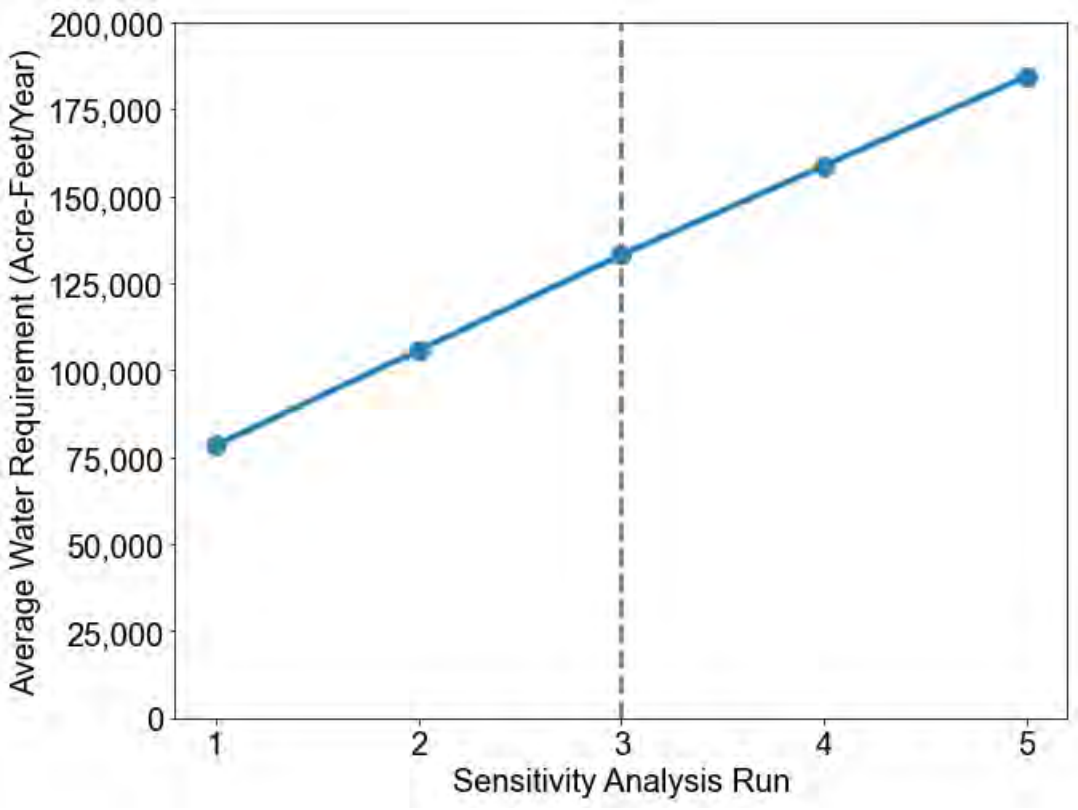


Figure B-8. Sensitivity Analysis Summary: Raw Water Customers.

Table B-4. Sensitivity Analysis Summary: Raw Water Customers.

Sensitivity Analysis Run	Change from Baseline	Average Water Requirement (AF/yr)	Difference from Baseline (AF/yr)
1	50% reduction in non-permanent crop areas, no fill-in to additional parcels	78,000	-55,000
2	25% reduction in non-permanent crop areas, no fill-in to additional parcels	106,000	-27,000
3 (Baseline)	No change (2022 land use)	133,000	--
4	Land use in 2022, plus fill-in to 50% parcels within 1000 feet of NID canals	159,000	26,000
5	Land use in 2022, plus fill-in to 100% parcels within 1000 feet of NID canals	185,000	52,000

B.4.2.2 Treated Water Customers

The second analysis was conducted to evaluate the sensitivity of the demand model to changes in NID's treated water customers, as related to changes in NID's customer base and parcels receiving treated water. Around the baseline current demand condition (analysis run 3):

- Higher demand conditions were evaluated through expansion of treated water customers into soft service areas (i.e., areas where NID has identified potential future growth opportunities for treated water customer service). Expansion was confined to parcels that were not already associated with NID customers, per NID delivery records. Expansion was tested through 50% fill-in (analysis run 4) and 100% fill-in (analysis run 5) to the soft service areas. These levels of expansion were selected to test potential high-demand bookend scenarios, although actual future growth of NID's treated water customer base is likely to be less than this.
- Lower demand conditions were evaluated through population decline in the NID service area, resulting in reduction in NID's treated water customers. The analysis tested population decline to the 2015–2019 average, representing the average population prior to the COVID-19 pandemic (analysis run 2), as well as population decline to the minimum population in the NID service area since 2000 (analysis run 1). These reductions were selected to test the demand model sensitivity to potential low-demand bookend scenarios. However, potential future reductions in NID's treated water customer base is likely to be less than these changes.

This analysis resulted in minimal changes to the average water requirement in NID, representing +/-3,000 AF/yr or less as compared to the baseline current demand condition (Figure B-9 and Table B-5).

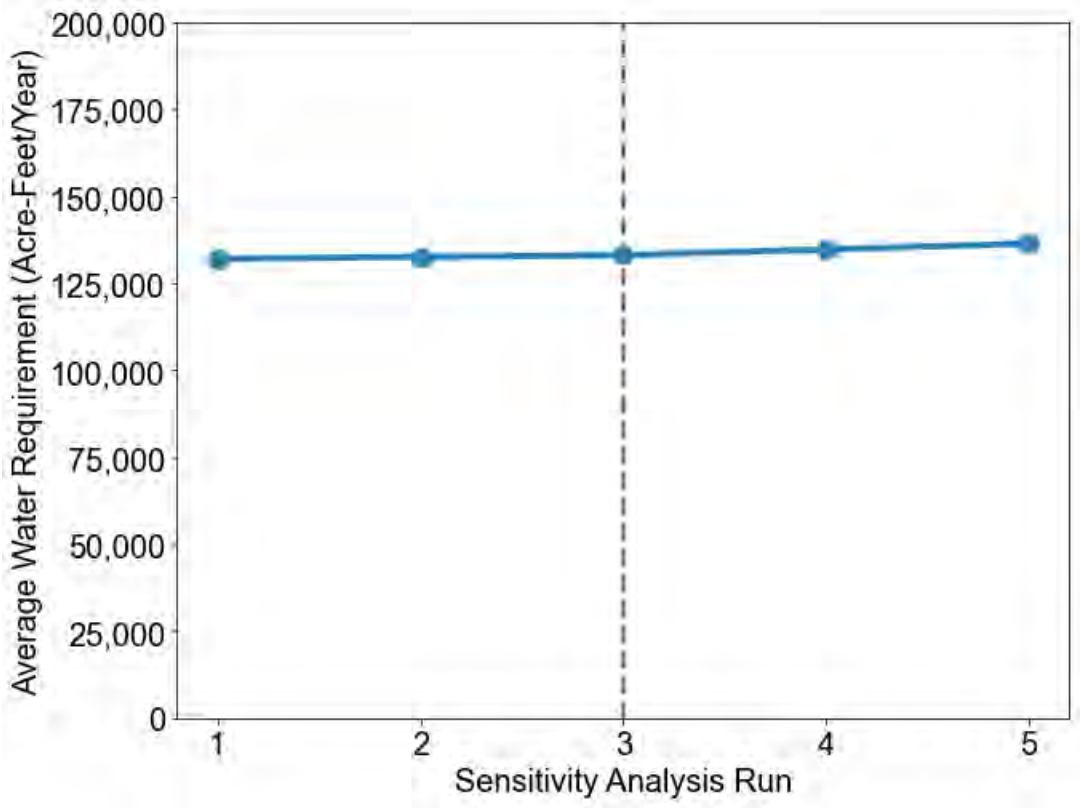


Figure B-9. Sensitivity Analysis Summary: Treated Water Customers.

Table B-5. Sensitivity Analysis Summary: Treated Water Customers.

Sensitivity Analysis Run	Change from Baseline	Average Water Requirement (AF/yr)	Difference from Baseline (AF/yr)
1	Population decline to minimum since 2000 (depending on location, ~80-90% of current)	132,000	-1,000
2	Population decline to 2015–2019 average (pre-pandemic average, ~95% of current)	133,000	0
3 (Baseline)	No change (2022 population)	133,000	--
4	Expansion to fill 50% of soft service areas (~ +20% of current treated water customers)	135,000	2,000
5	Expansion to fill 100% of soft service areas (~ +40% of current treated water customers)	136,000	3,000

B.4.2.3 Evapotranspiration with Changes to Climate

The third analysis was conducted to evaluate the sensitivity of the demand model to changes in ET, as related to potential changes in climate (specifically temperature) within the NID service area. ET and its relationship to climate parameters is described further in Chapter 4 of the NID PFW report. Around the baseline current demand condition (analysis run 2), higher and lower demand conditions were evaluated through increases or decreases (respectively) in the average daily temperature in the NID service area. Temperature changes were used to adjust the median historical ET in the NID service area based on the relationship between ET and temperature described by Hargreaves and Samani. Additional information about the Hargreaves-Samani approach is described in the NID PFW report. The following temperature changes were tested:

- Lower demand:
  - Adjusted for an average -2.2°F (-1.2°C) temperature change (analysis run 1)
- Higher demand:
  - Adjusted for an average +2.2°F (+1.2°C) temperature change (analysis run 3)
  - Adjusted for an average +4.3°F (+2.4°C) temperature change (analysis run 4)
  - Adjusted for an average +6.5°F (+3.6°C) temperature change (analysis run 5)

These changes were selected to test the demand model sensitivity to potential temperature changes in bookend climate change scenarios. However, potential future changes in temperature may be greater or less than these changes. This analysis resulted in changes in the average water requirement ranging between approximately -4,000 AF/yr to +16,000 AF/yr, as compared to the baseline current demand condition (Figure B-10 and Table B-6).

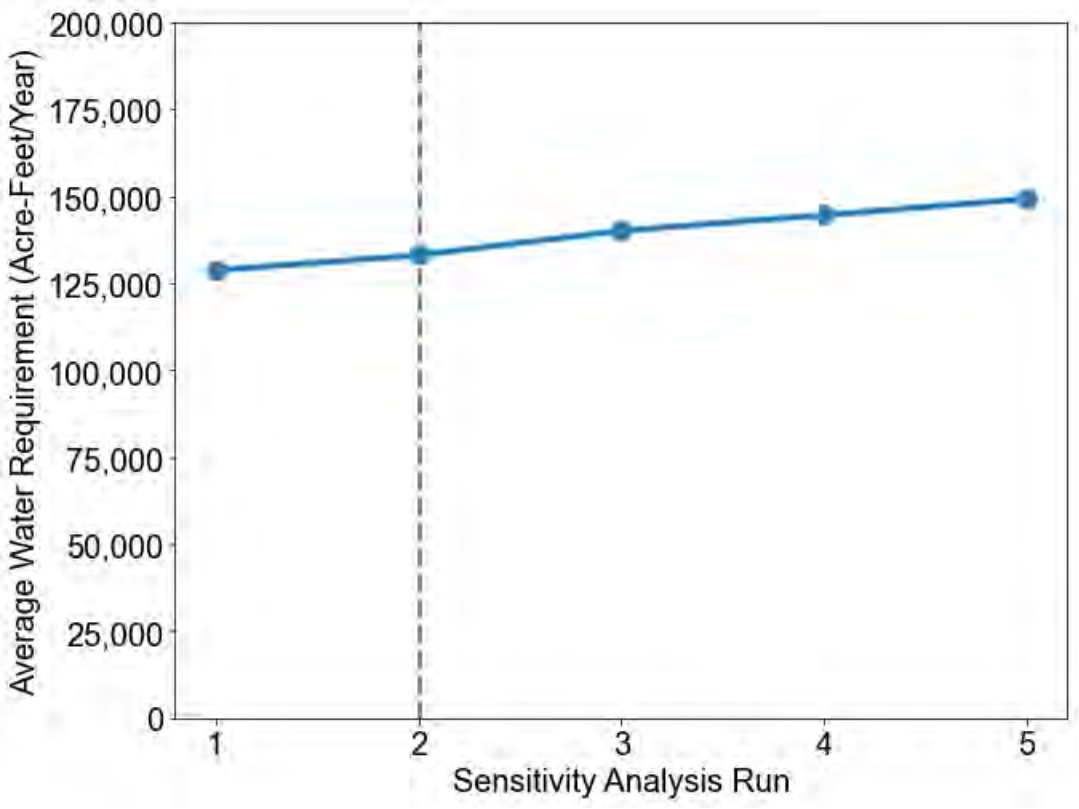


Figure B-10. Sensitivity Analysis Summary: Evapotranspiration with Changes to Climate.

Table B-6. Sensitivity Analysis Summary: Evapotranspiration with Changes to Climate.

Sensitivity Analysis Run	Change from Baseline	Average Water Requirement (AF/yr)	Difference from Baseline (AF/yr)
1	Median historical ET adjusted for -2.2°F (-1.2°C)	129,000	-4,000
2 (Baseline)	No change (median historical ET)	133,000	--
3	Median historical ET adjusted for +2.2°F (+1.2°C)	140,000	7,000
4	Median historical ET adjusted for +4.3°F (+2.4°C)	145,000	12,000
5	Median historical ET adjusted for +6.5°F (+3.6°C)	149,000	16,000

B.4.2.4 Total Evapotranspiration

The fourth analysis was conducted to evaluate the sensitivity of the demand model to changes in total ET. ET is impacted by:

- the types of crops or vegetation that are grown (reflecting the inherent differences in water needs of different crops and vegetation);
- the quality of crops, vegetation, or land use, including water availability, nutrient and pest management, and other factors; and
- the environmental demand for evaporation related to weather and climate parameters, as a function of temperature, solar radiation, wind speed, and humidity.

Each of these factors is accounted for in the methods used to quantify ET in the demand model. Changes in total ET in this analysis were determined through ET data summarized from OpenET. OpenET is a multi-agency web-based geospatial utility that uses satellite imagery to quantify ET over time with a spatial resolution of 30 meters x 30 meters (approximately 0.22 acres). For the NID demand model, OpenET data was used to observe recent historical ET trends and evaluate representative ET rates for land uses in NID (e.g., average ET and percentiles across tens to thousands of pixels in NID). Additional information about OpenET and its application in the demand model is described in the NID PFW report.

Around the baseline current demand condition (analysis run 3), higher and lower demand conditions were evaluated through increases or decreases (respectively) in the average ET value simulated in NID. Potential high and low demand conditions were determined from OpenET data as follows:

- Lower demand:
  - 10th percentile ET from OpenET analyses (analysis run 1)
  - 25th percentile ET from OpenET analyses (analysis run 2)
- Higher demand:
  - 75th percentile ET from OpenET analyses (analysis run 4)
  - 90th percentile ET from OpenET analyses (analysis run 5)

These changes were selected to test the demand model sensitivity to potential ET changes over the range of conditions experienced in NID historically. However, potential future ET changes may be less than these changes. This analysis resulted in changes in the average water requirement ranging between approximately -40,000 AF/yr to +42,000 AF/yr, as compared to the baseline current demand condition (Figure B-11 and Table B-7).

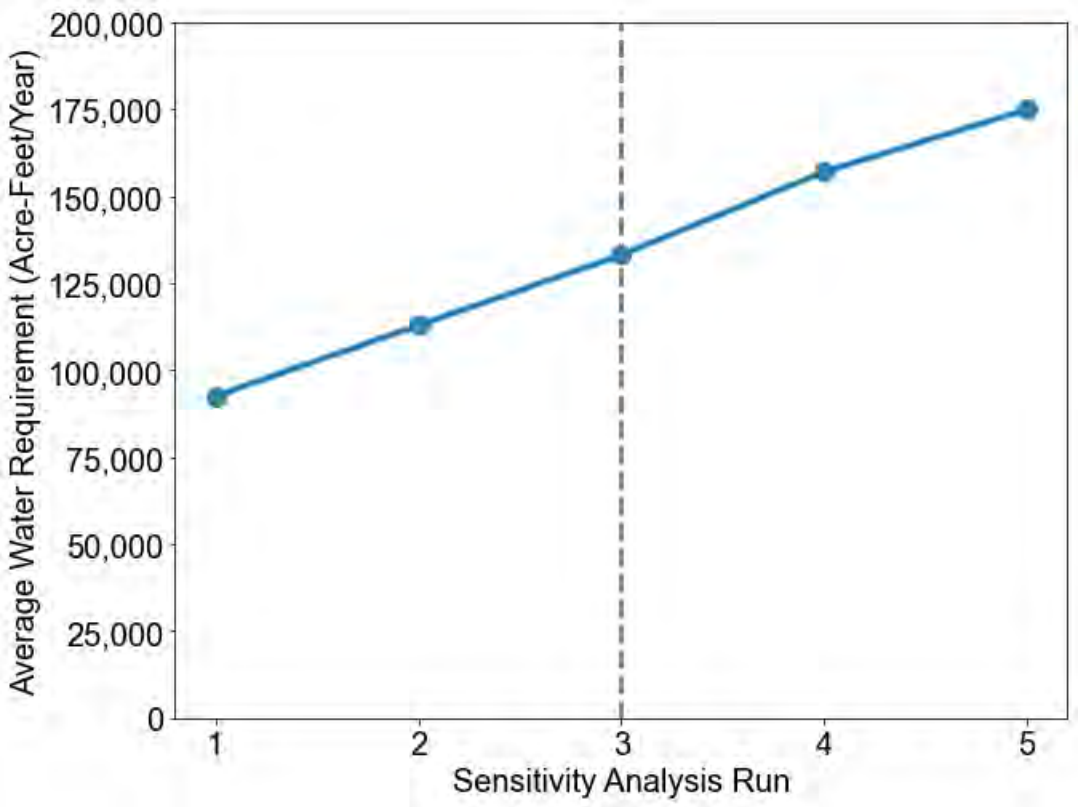


Figure B-11. Sensitivity Analysis Summary: Total Evapotranspiration.

Table B-7. Sensitivity Analysis Summary: Total Evapotranspiration.

Sensitivity Analysis Run	Change from Baseline[1]	Average Water Requirement (AF/yr)	Difference from Baseline (AF/yr)
1	10th percentile ET	93,000	-40,000
2	25th percentile ET	113,000	-20,000
3 (Baseline)	No change (50th percentile ET)	133,000	--
4	75th percentile ET	157,000	24,000
5	90th percentile ET	175,000	42,000

[1]By percent of parcels, by land use category and climate zone.

B.4.2.5 System Losses

The fifth analysis was conducted to evaluate the sensitivity of the demand model to changes in system losses. In this context, system losses represent water that is lost (whether through seepage, evaporation, or other outflows) from NID's canals and distribution system downstream of NID's reservoirs that occur delivering water to NID's customers.

Around the baseline current demand condition (analysis run 2), higher and lower demand conditions were evaluated through increases or decreases (respectively) in average system losses. The following system losses were tested:

- Lower demand:
  - System losses representing 10% of canal inflows (analysis run 1)
- Higher demand:
  - System losses representing 20% of canal inflows (analysis run 3)
  - System losses representing 30% of canal inflows (analysis run 4)
  - System losses representing 40% of canal inflows (analysis run 5)

These changes were selected to test the demand model sensitivity to uncertainties and potential changes in system losses across a range of conditions. The actual system losses likely differ from these conditions but are expected to generally fall within this range. This analysis resulted in changes in the average water requirement ranging between approximately -7,000 AF/yr to +56,000 AF/yr, as compared to the baseline current demand condition (Figure B-12 and Table B-8).

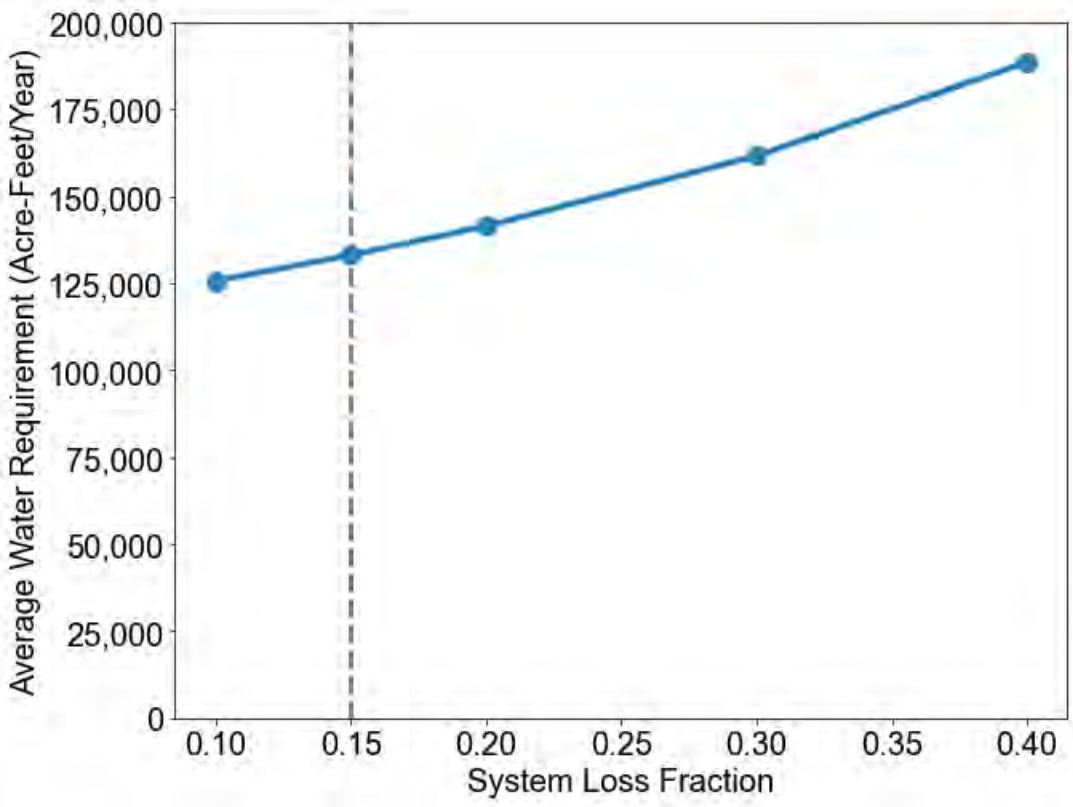


Figure B-12. Sensitivity Analysis Summary: System Losses.

Table B-8. Sensitivity Analysis Summary: System Losses.

Sensitivity Analysis Run	Change from Baseline	Average Water Requirement (AF/yr)	Difference from Baseline (AF/yr)
1	10% system losses	126,000	-7,000
2 (Baseline)	No change (15% system losses)	133,000	--
3	20% system losses	141,000	8,000
4	30% system losses	162,000	29,000
5	40% system losses	189,000	56,000

B.4.3. Comparison of Sensitivity Analyses

Figure B-13 provides a comparison of the results across all five sensitivity analyses, sorted generally from the greatest sensitivity and potential impacts to average water requirements in NID to the lowest sensitivity and potential impacts. This comparison indicates that changes to the raw water customer demand in NID (under those conditions tested) have the most significant potential impacts to the average water requirement. This reflects the significance of raw water use in NID, which represents approximately 90% of NID's annual demand. Following raw water customers, other factors with potentially significant impacts to the average water requirement include system losses and total ET changes. System losses are currently calculated in NID (and in the NID demand model) as a fraction of the total canal inflows, based on the best information currently available. Thus, significant changes to the estimated system losses have widespread effects on the water required in the NID system. Total ET changes are also impactful, mirroring the model sensitivity to raw water customer demand, which is primarily driven by ET. In contrast, temperature-related impacts to ET alone are less impactful than considering the effects of all factors that impact total ET. Treated water customer demand has the lowest potential impact to the demand model results among those parameters tested, as treated water use represents a much smaller portion of NID's demand.

The results of these sensitivity analyses were considered in the development of the projected demand scenarios. Please see Chapter 4 of the NID PFW report for more information about the projected demand scenarios and the assumptions and data sources that were used to develop those.

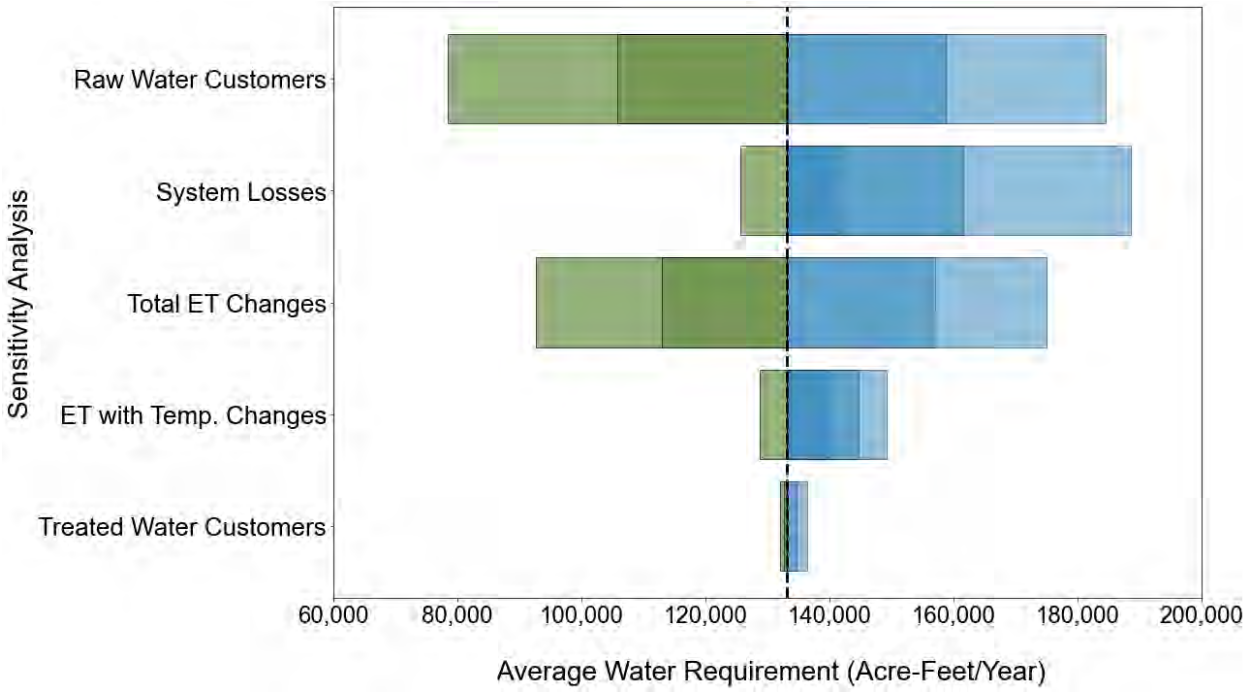


Figure B-13. Comparison of Sensitivity Analyses.

B.5. References

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Appendix C:

Chapter 5 Supplemental Information

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Appendix C. Chapter 5 Supplemental Information

C.1. Middle Yuba River

C.1.1. Jackson Meadows Reservoir

Jackson Meadows Reservoir daily storage matches historical storage well over the calibration period, as shown in Figure C-1. Releases from Milton Reservoir to the Middle Yuba River are shown in Figure C-2 and to the Milton-Bowman Conduit in Figure C-3.

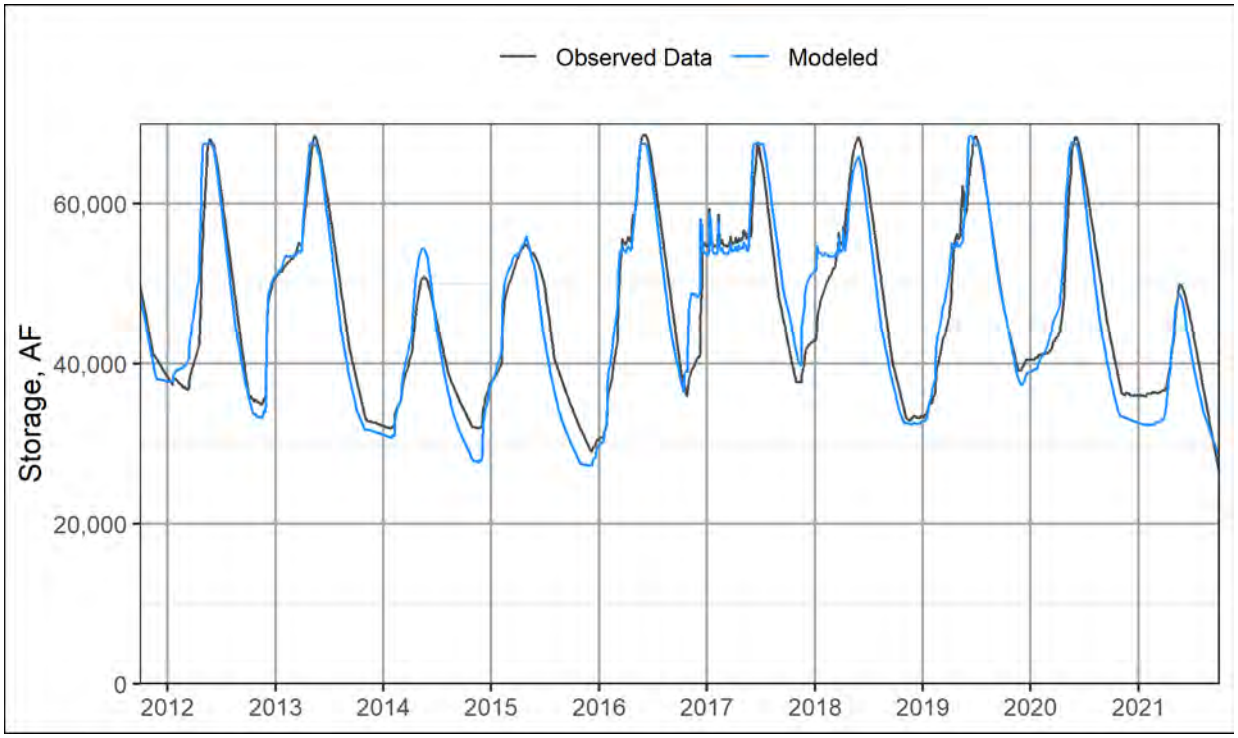


Figure C-1. Jackson Meadows Reservoir Storage, Water Years 2012–2021

C.1.2. Milton Reservoir

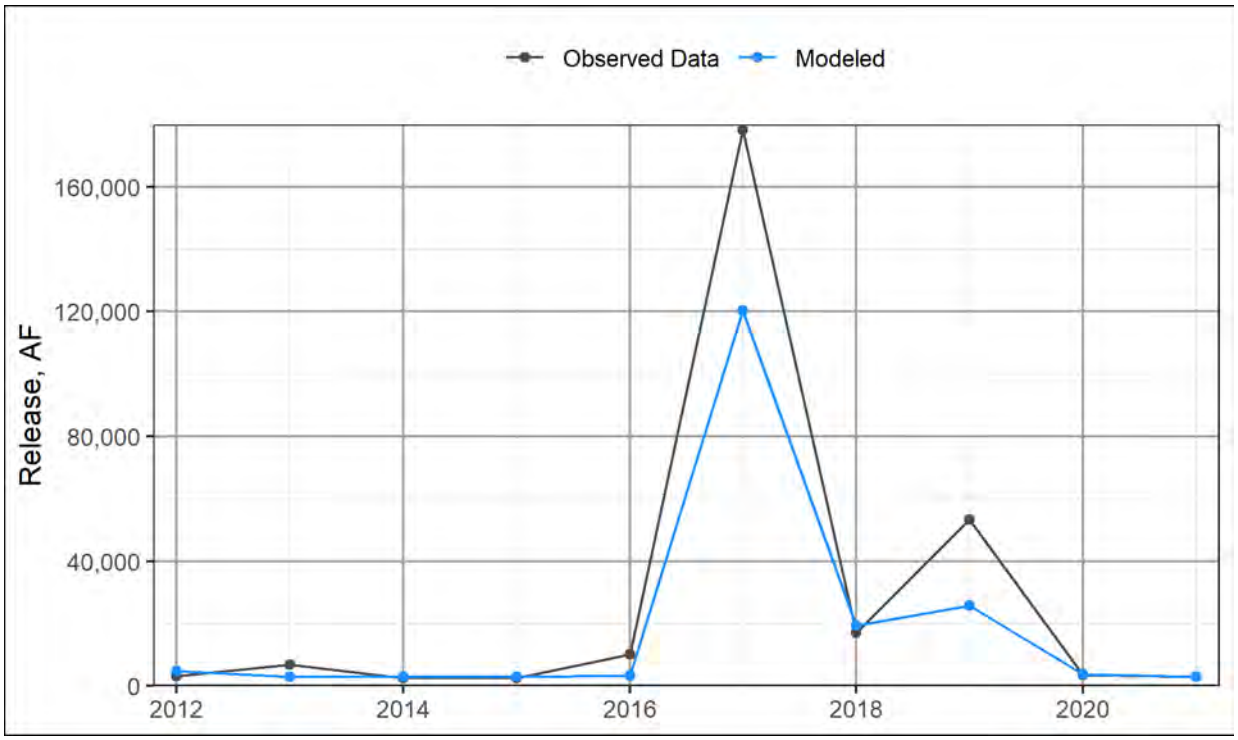


Figure C-2. Release from Milton Reservoir to Middle Yuba River, Water Years 2012–2021

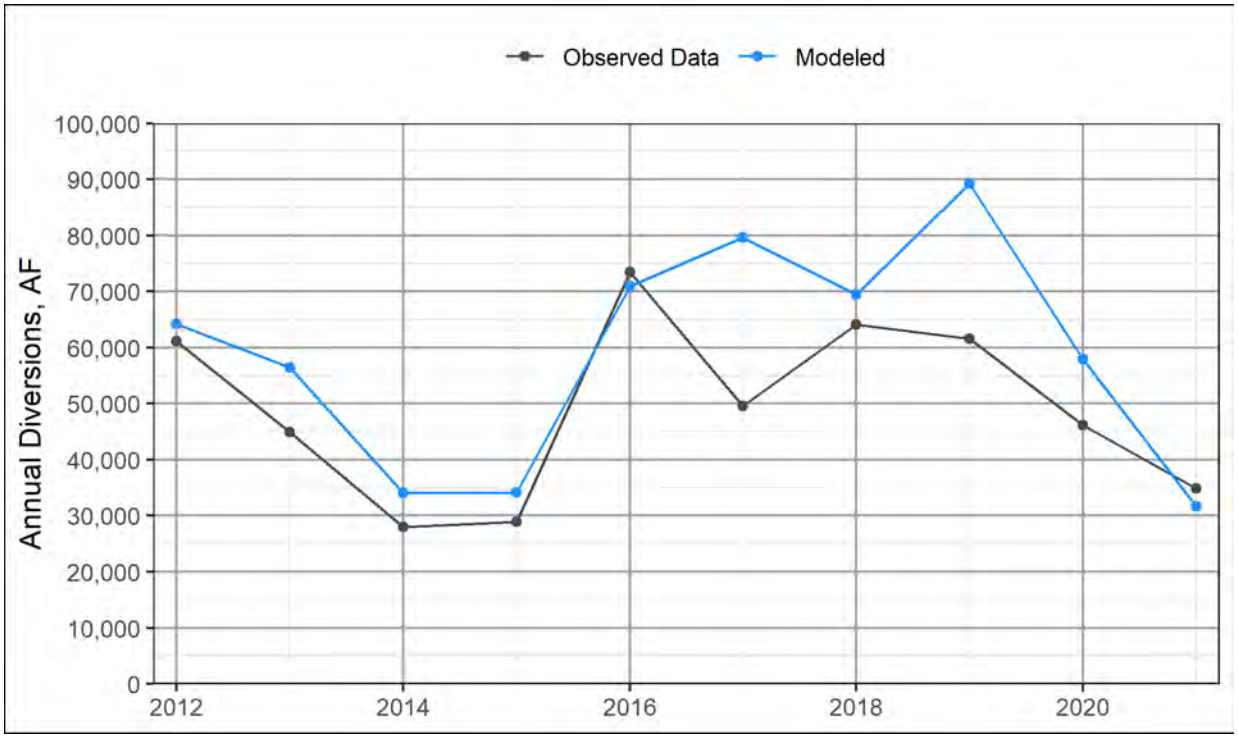


Figure C-3. Diversions to Milton-Bowman Conduit, Water Years 2012–2021

C.2. Canyon Creek

Reservoirs upstream of Bowman Reservoir have daily storage traces that match recent observed data fairly well, as shown in Figure C-4 through Figure C-7. Releases from these reservoirs have limited gauge data with all reservoirs' spills not included in the recorded observed data; therefore, it is not possible to compare reservoir release volumes.

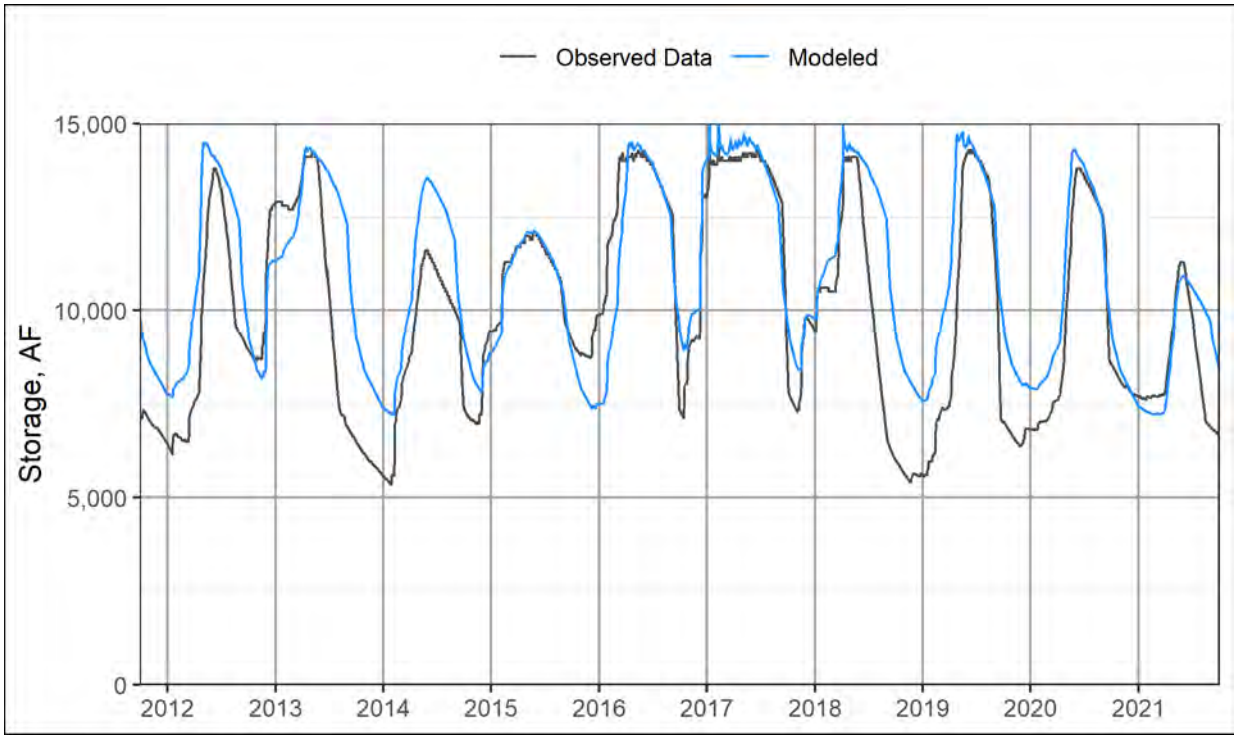


Figure C-4. French Lake Storage, Water Years 2012–2021

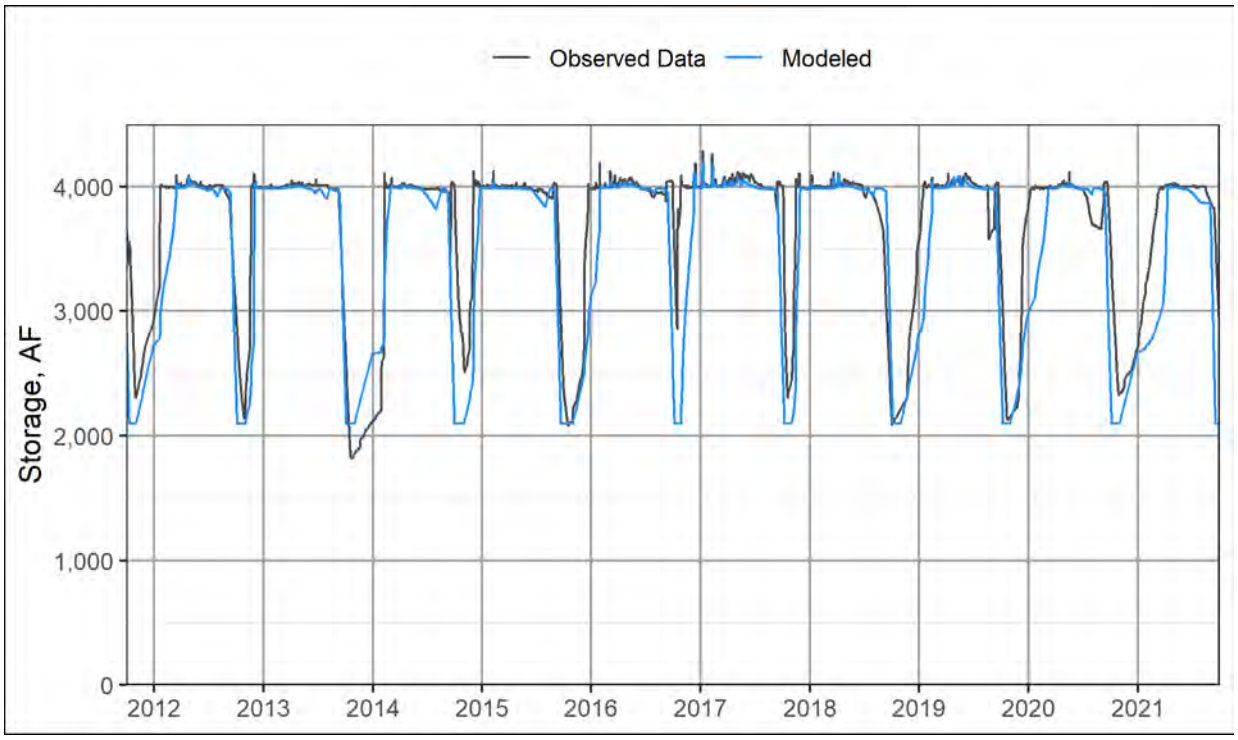


Figure C-5. Faucherie Lake Storage, Water Years 2012–2021

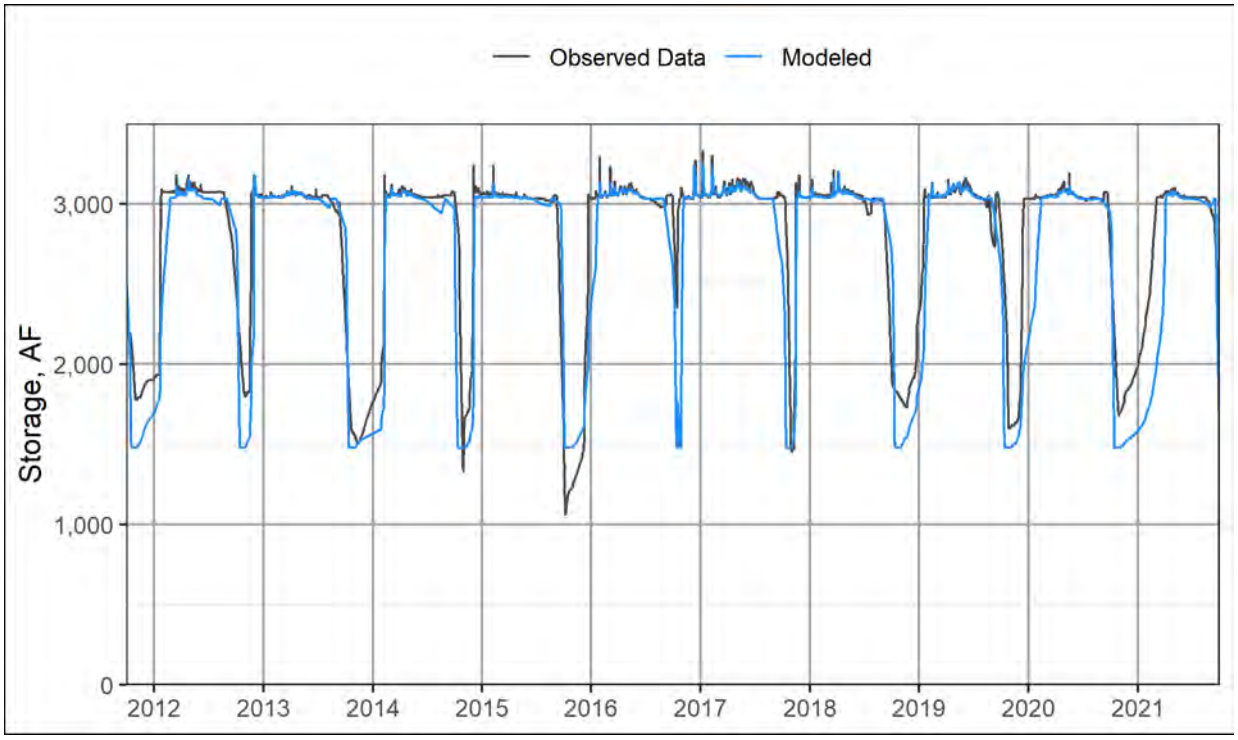


Figure C-6. Sawmill Lake Storage, Water Years 2012–2021

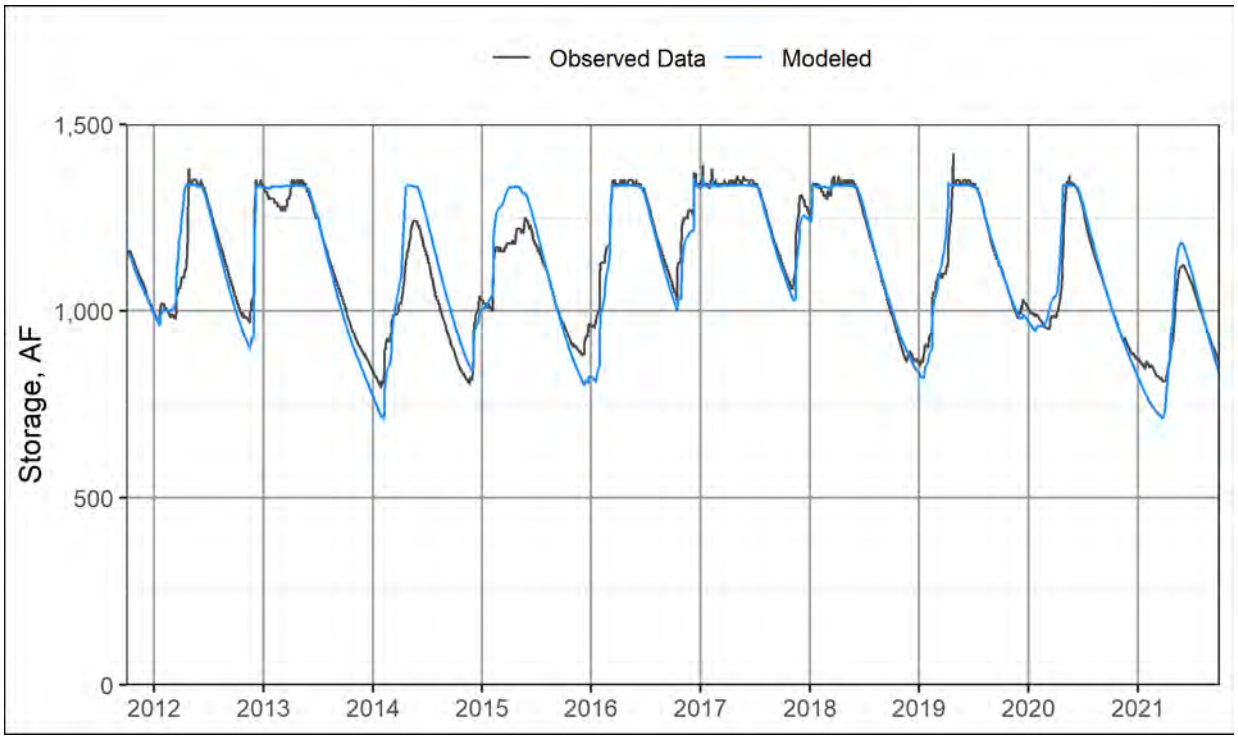


Figure C-7. Jackson Lake Storage, Water Years 2012–2021

Daily storage at Bowman Reservoir matches the recent observed data over the validation period fairly well, as shown in Figure C-8. Releases to Canyon Creek are shown in Figure C-9, and diversions to the Bowman-Spaulding Conduit are shown in Figure C-10.

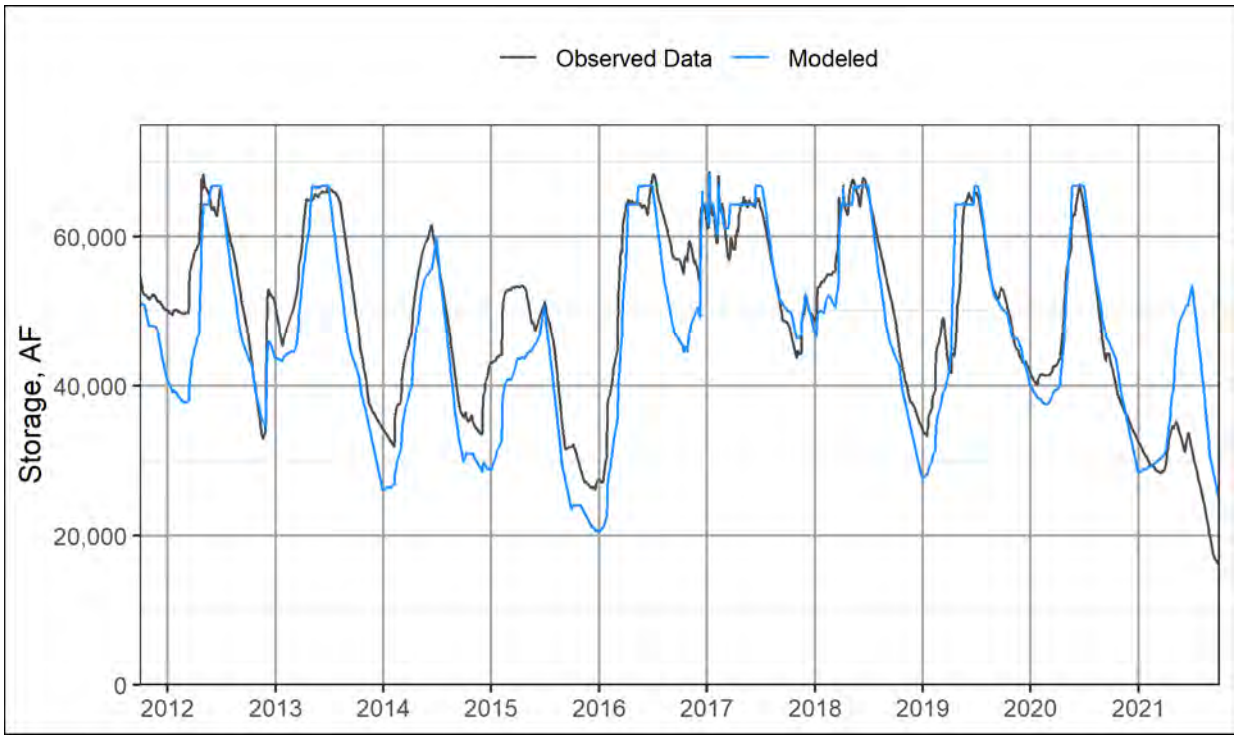


Figure C-8. Bowman Reservoir Storage, Water Years 2012–2021

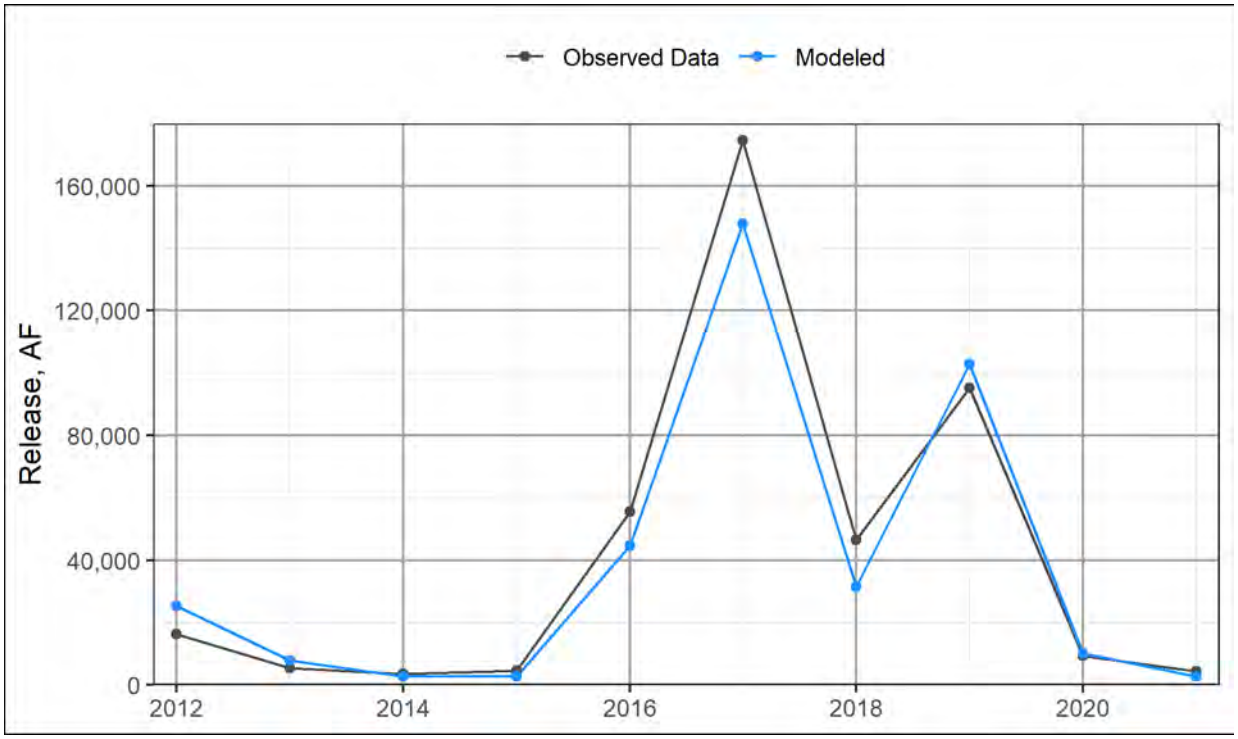


Figure C-9. Bowman Reservoir releases to Canyon Creek, Water Years 2012–2021

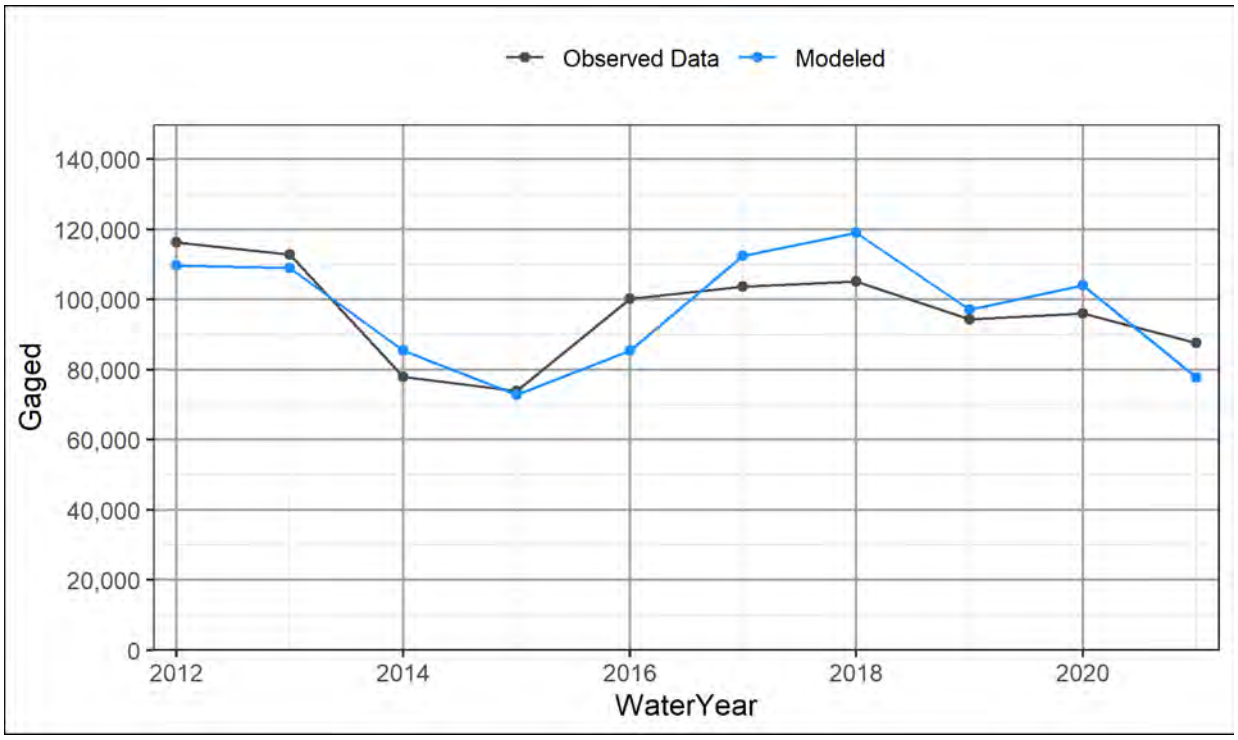


Figure C-10. Bowman Reservoir Diversions to Bowman-Spaulding Conduit, Water Years 2012–2021

C.3. Texas Fall Creeks

C.3.1. PG&E Reservoirs

Many PG&E Reservoirs upstream of the diversions along the Bowman-Spaulding conduit on the collection of streams referred to as the Texas-Fall Creeks are not gauged throughout the year or are not gauged at all. Comparisons to historical observed data are shown where possible. Most reservoirs match the observed data reasonably well, with the exception of Blue Lake. The simple nature of Blue Lake operations, in which the lake only releases discretionary water in wet years and can go 10 years between discretionary releases, suggests that the storage discrepancy is due to the unimpaired hydrology and not reservoir operations. Blue Lake has a very small watershed area, and its unimpaired hydrology could be affected by precision in its estimation parameters.

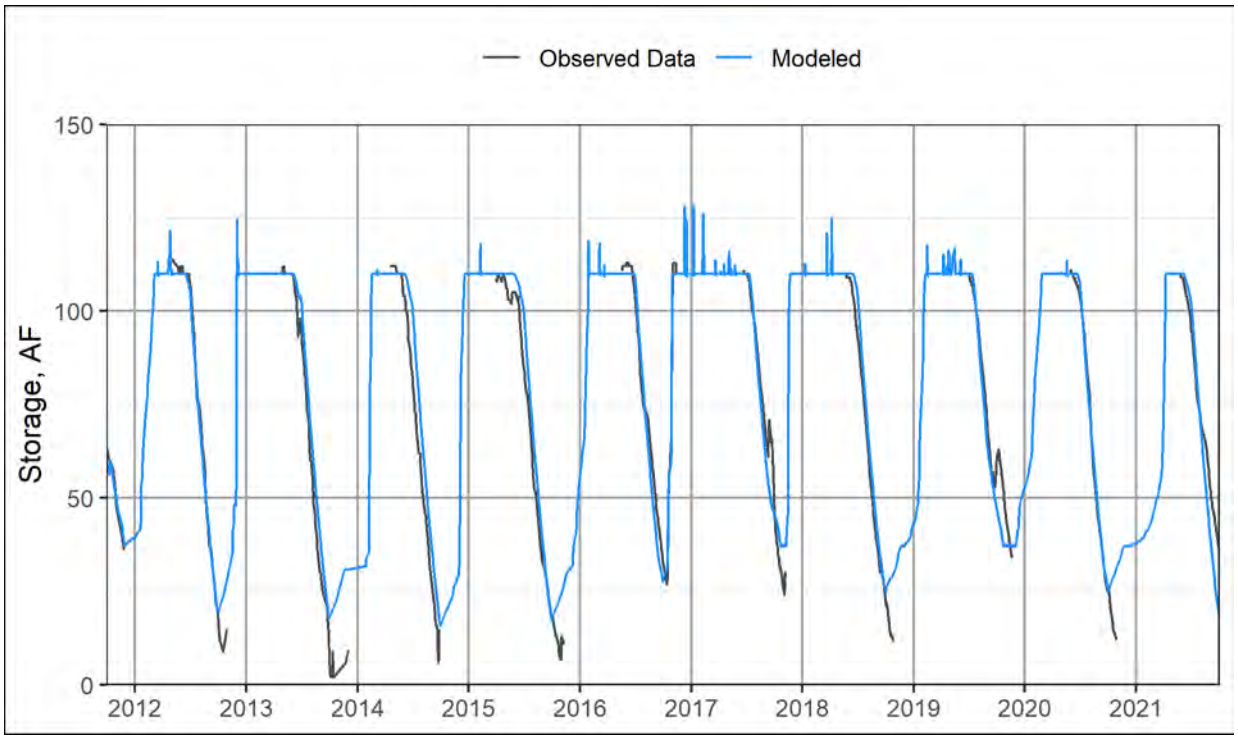


Figure C-11. Middle Lindsey Lake Storage, Water Years 2012–2021

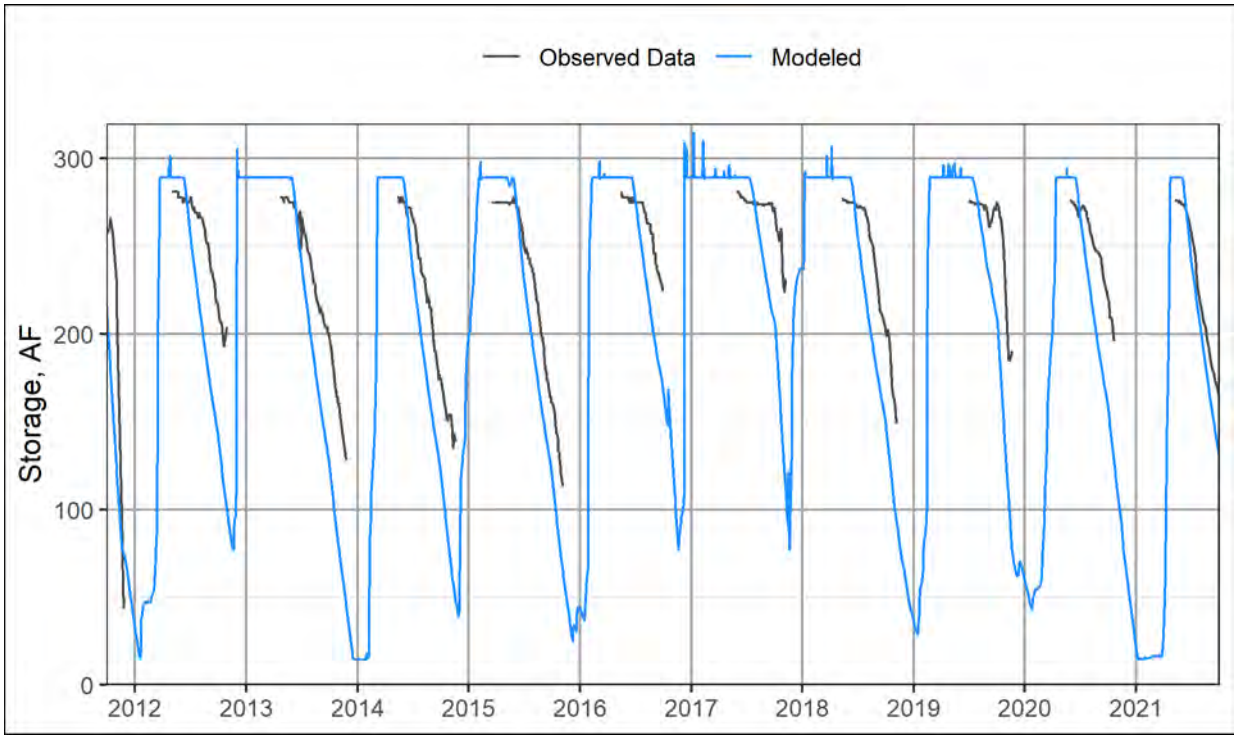


Figure C-12. Lower Lindsey Lake Storage, Water Years 2012–2021

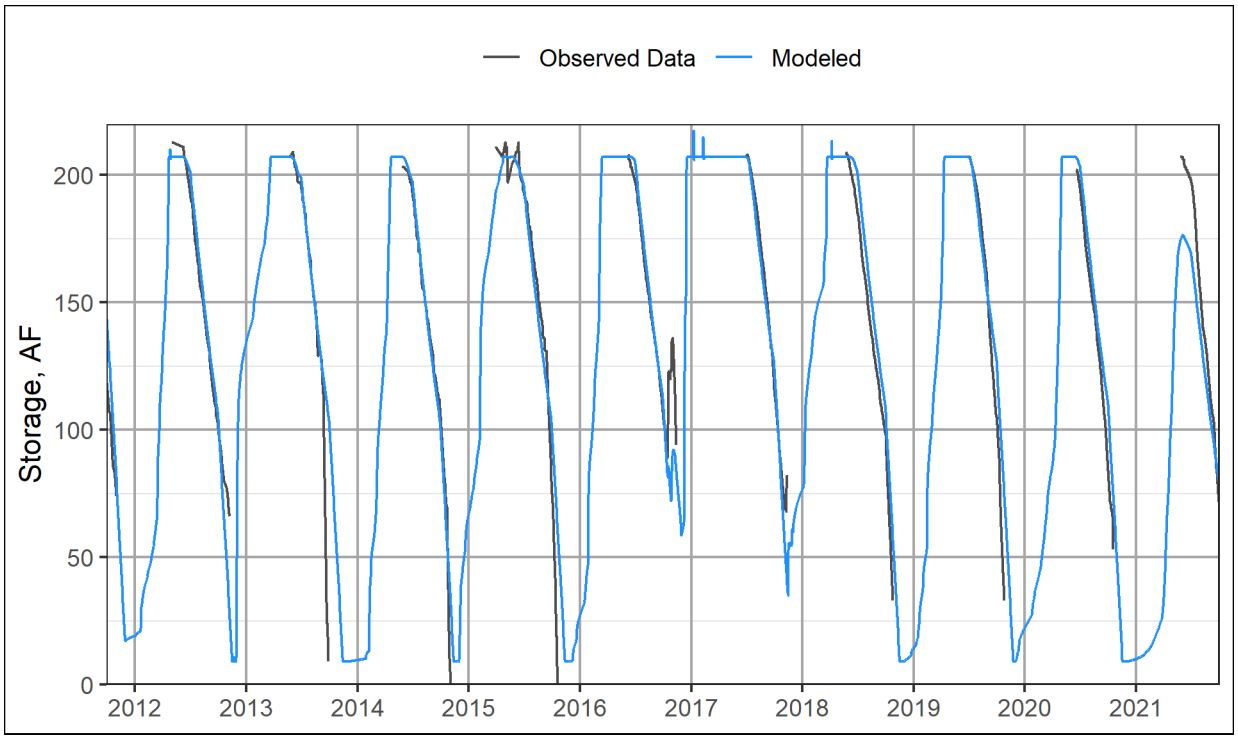


Figure C-13. Upper Rock Lake Storage, Water Years 2012–2021

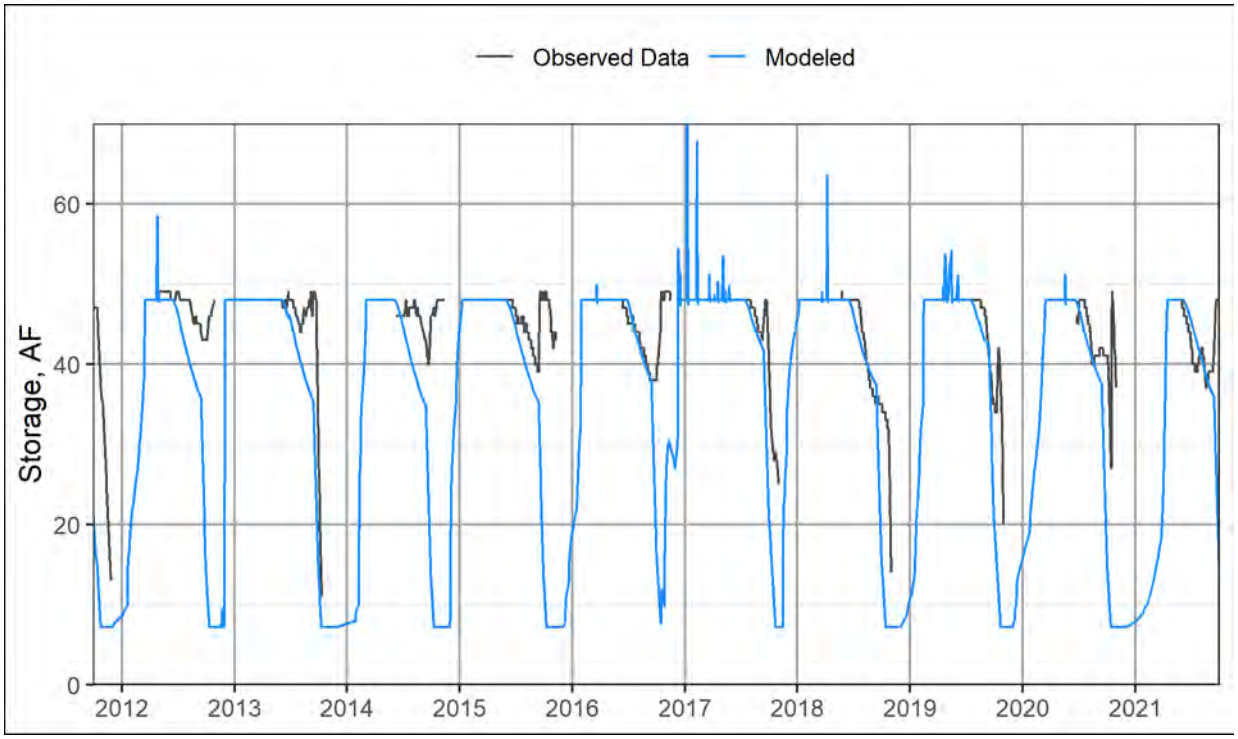


Figure C-14. Lower Rock Lake Storage, Water Years 2012–2021

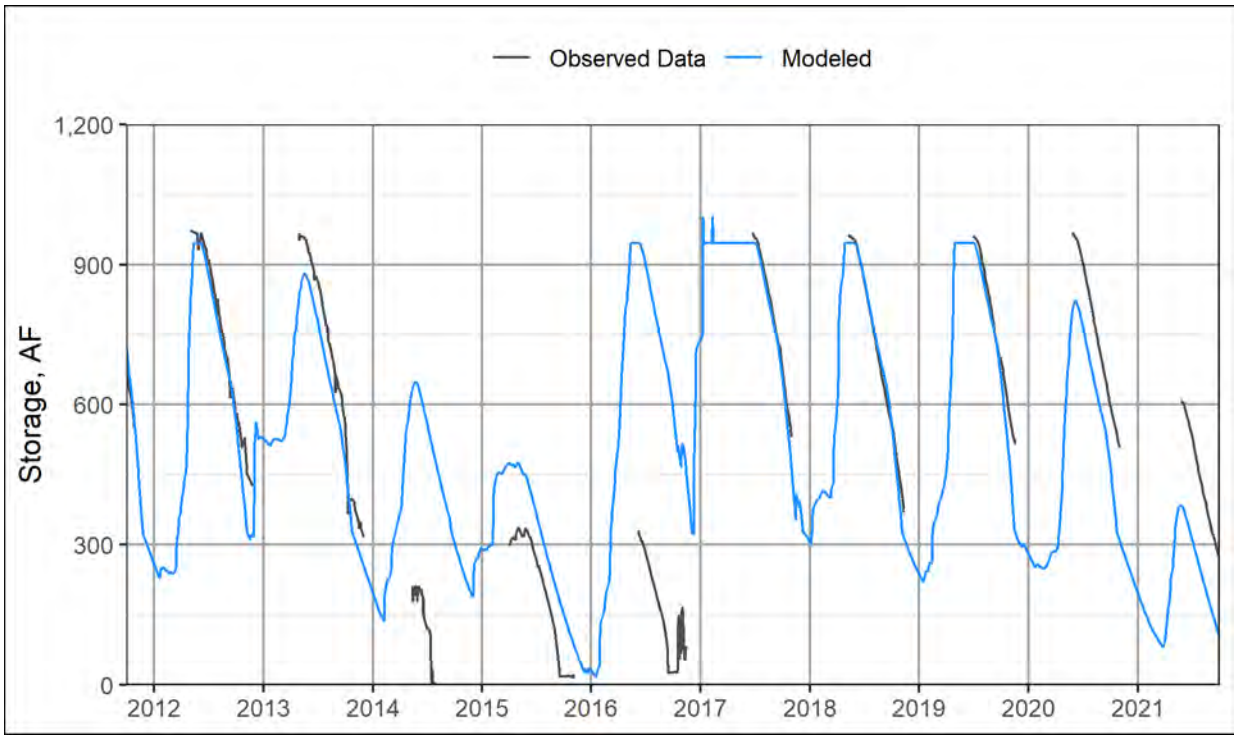


Figure C-15. Culbertson Lake Storage, Water Years 2012–2021

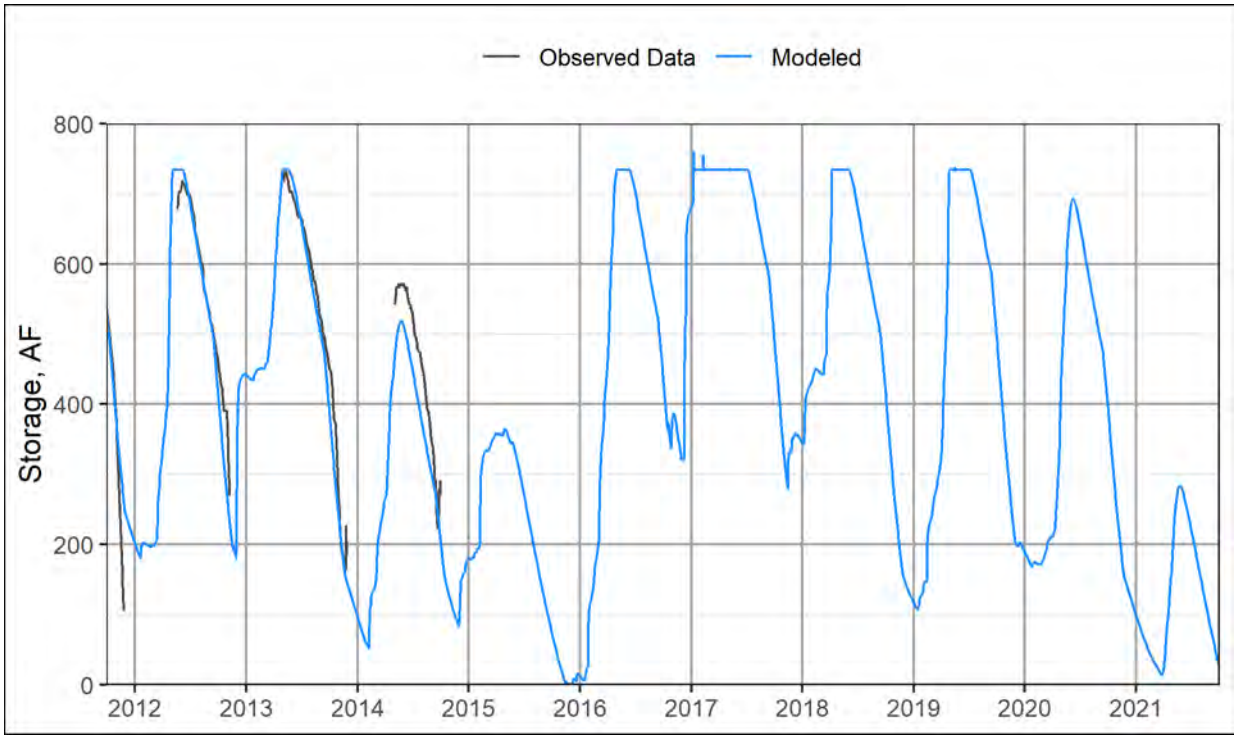


Figure C-16. Feely Lake Storage, Water Years 2012–2021

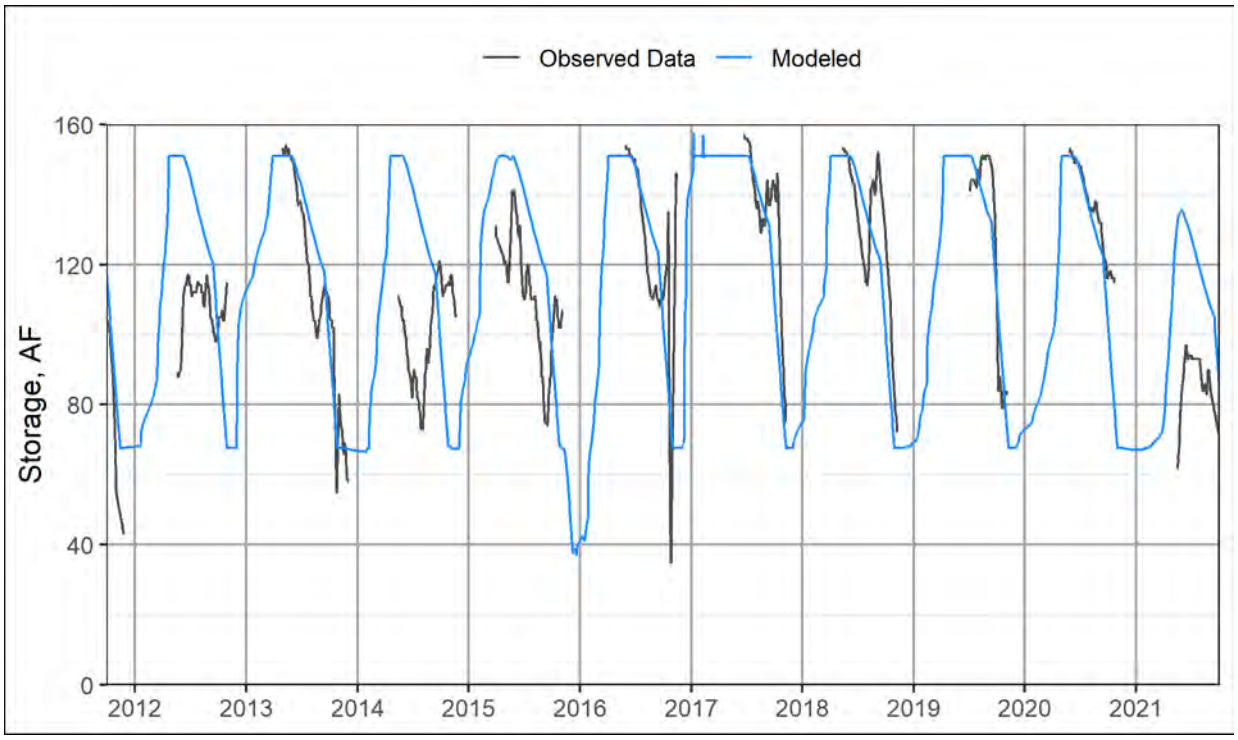


Figure C-17. Carr Lake Storage, Water Years 2012–2021

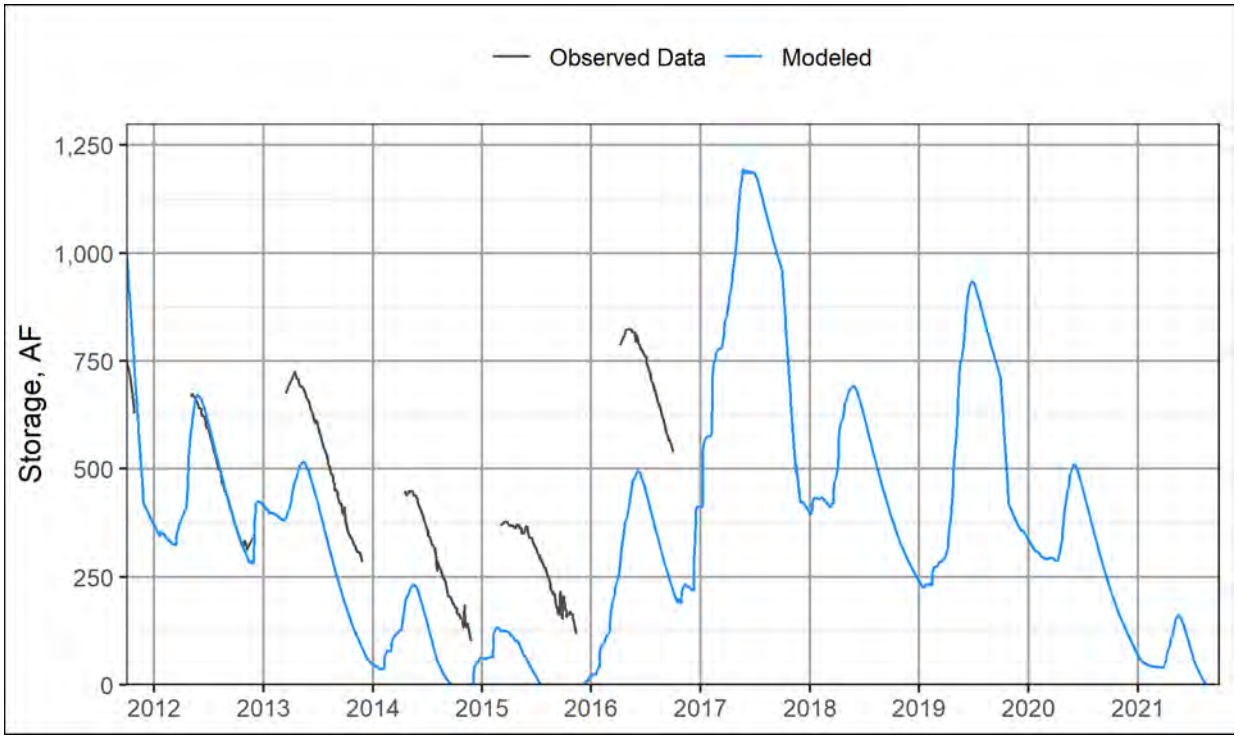


Figure C-18. Blue Lake Storage, Water Years 2012–2021

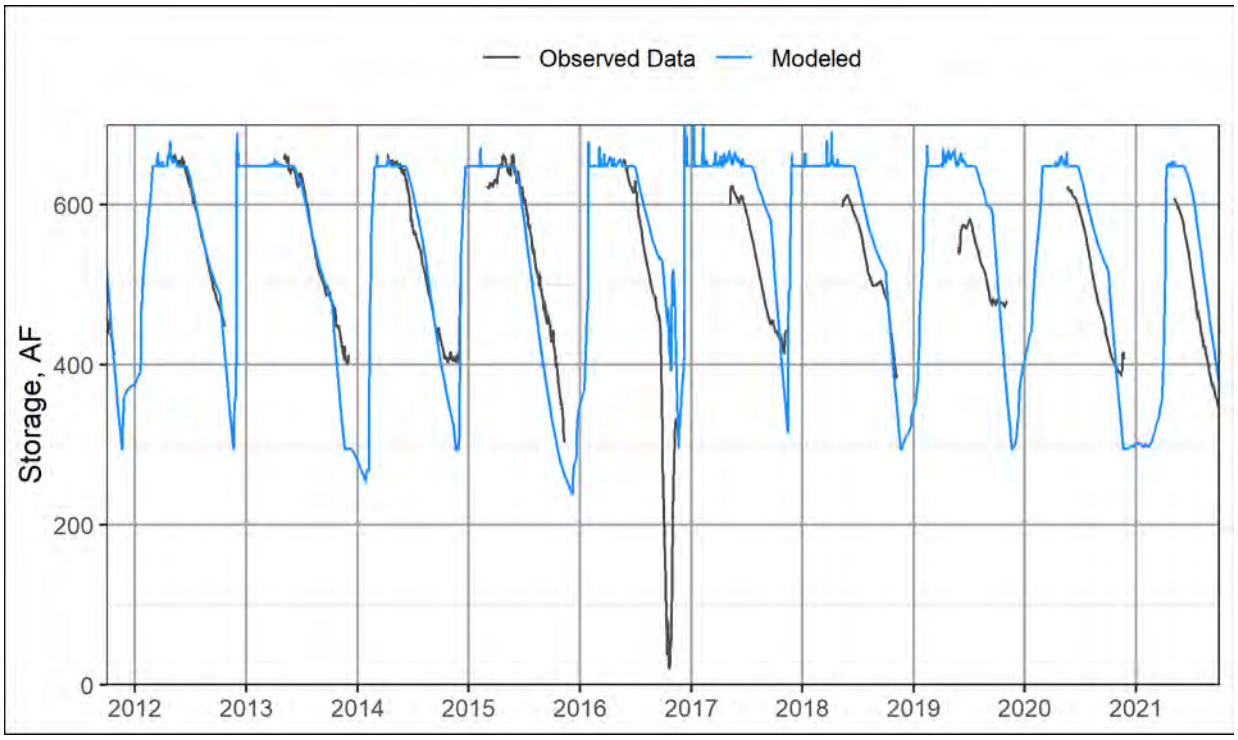


Figure C-19. Rucker Lake Storage, Water Years 2012–2021

Fuller Lake does not have available observed storage, but the reservoir must generally be kept full to maintain head on Spaulding PH No 3.

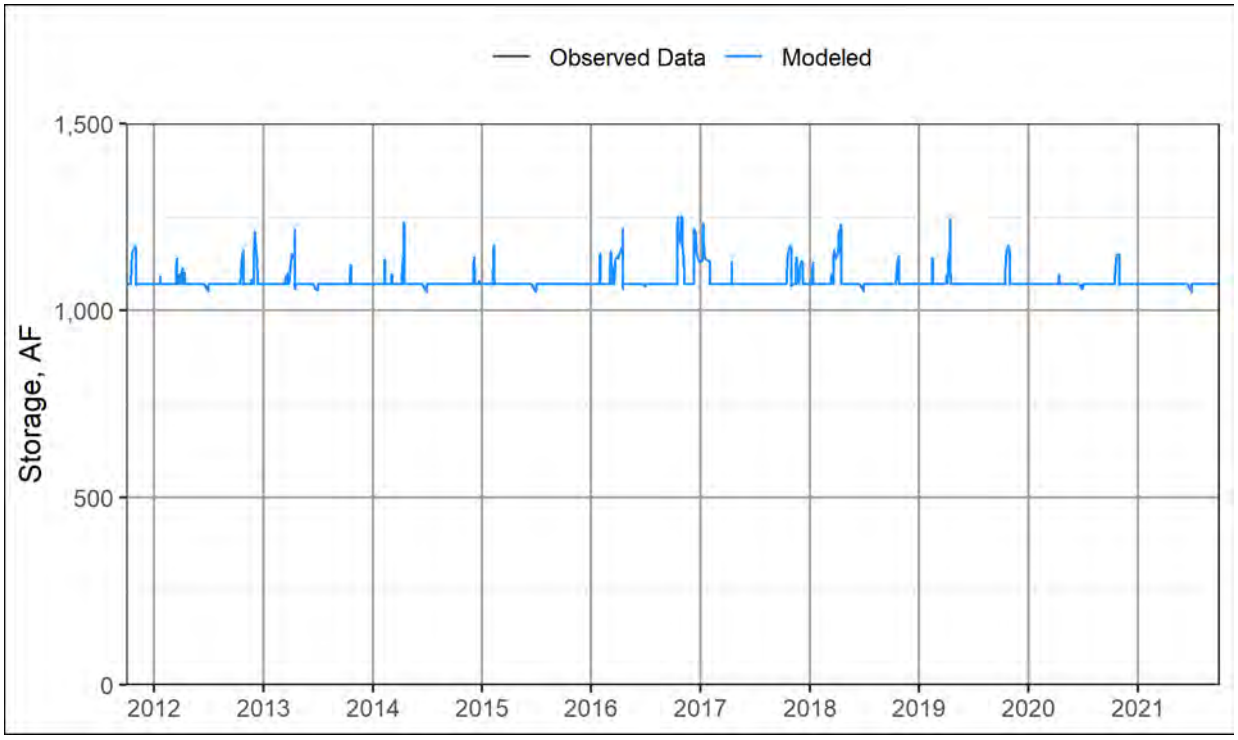


Figure C-20. Fuller Lake Storage, Water Years 2012–2021

C.3.2. Spaulding Powerhouse No. 3

Annual diversions into Spaulding at the end of the Bowman-Spaulding Conduit through Spaulding Powerhouse No 3 are shown in Figure C-21 and Figure C-22.

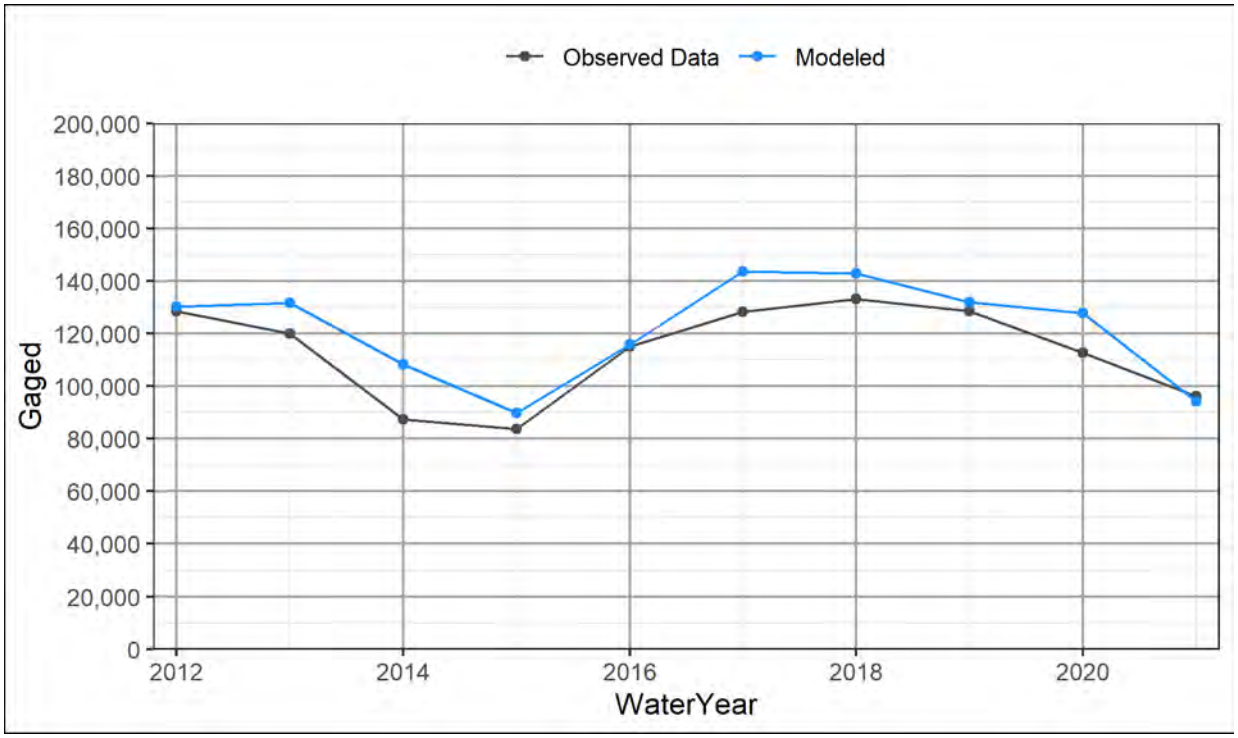


Figure C-21. Annual Flows through Spaulding Powerhouse No. 3, Water Years 2012–2021

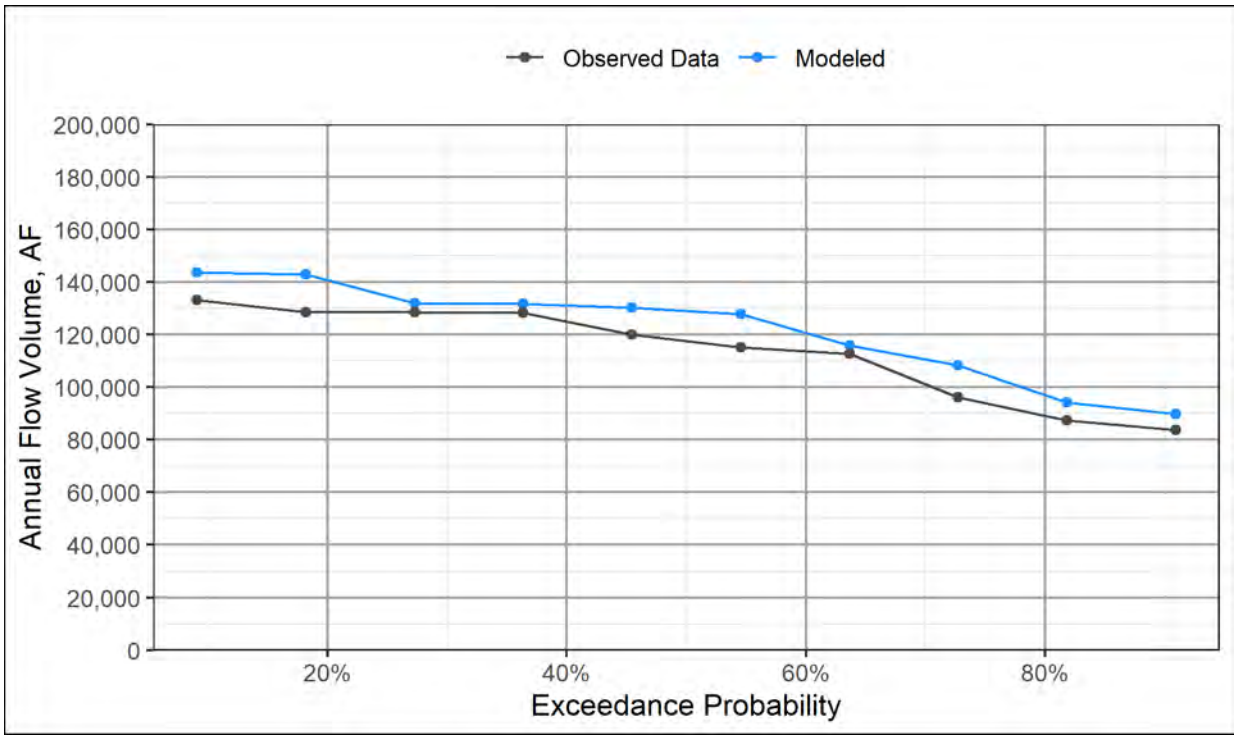


Figure C-22. Annual Flow Exceedance through Spaulding Powerhouse No. 3, Water Years 2012–2021

C.4. South Yuba River

C.4.1. Upstream of Fordyce Lake

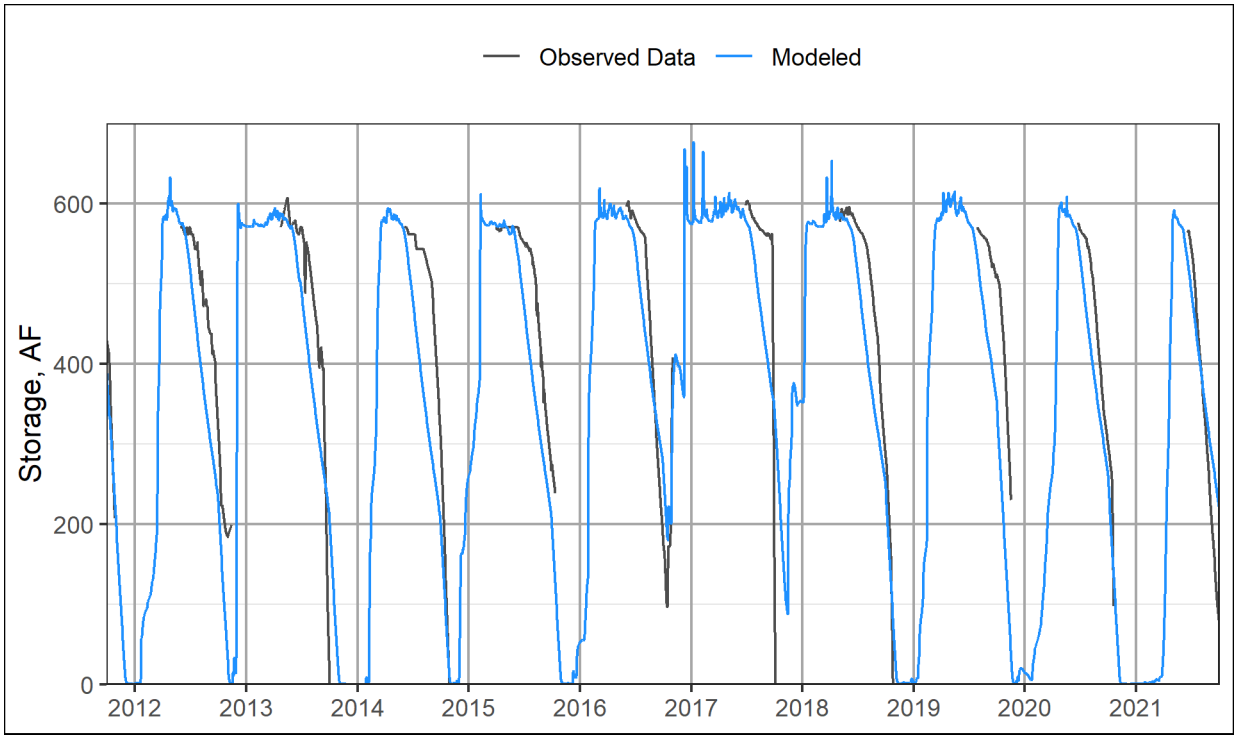


Figure C-23. White Rock Lake Storage, Water Years 2012–2021

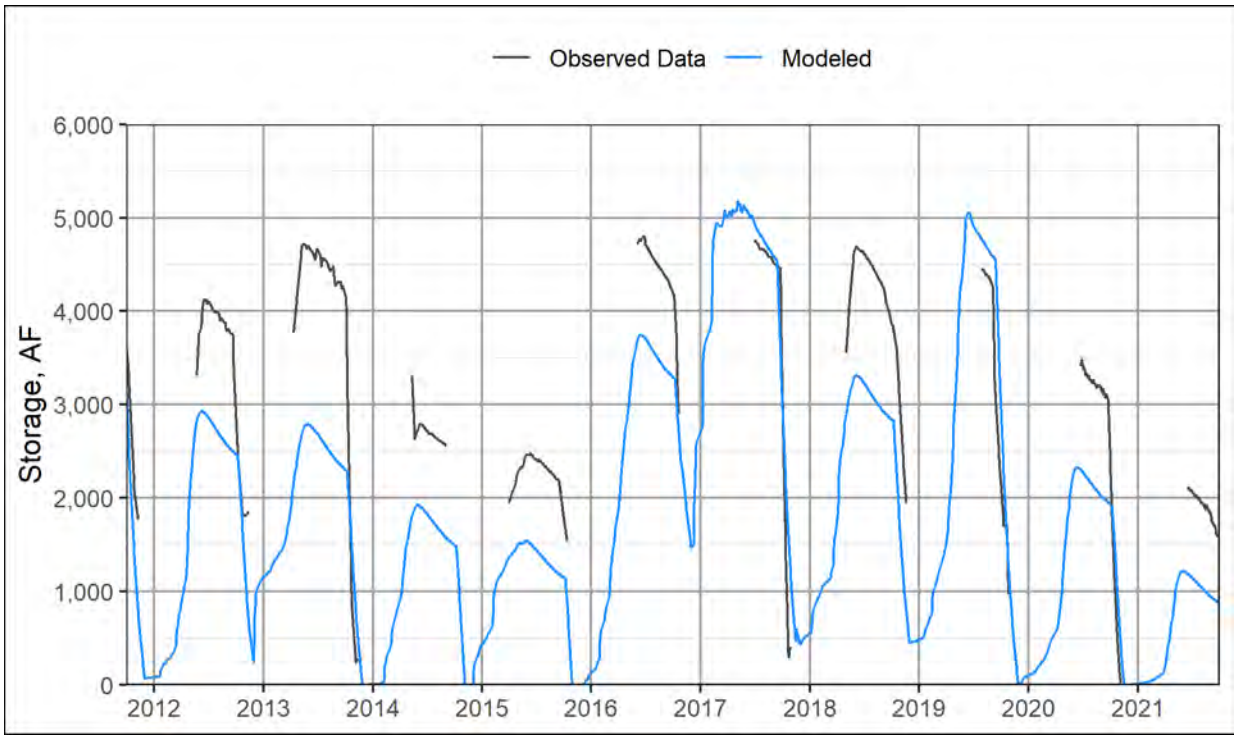


Figure C-24. Meadow Lake Storage, Water Years 2012–2021

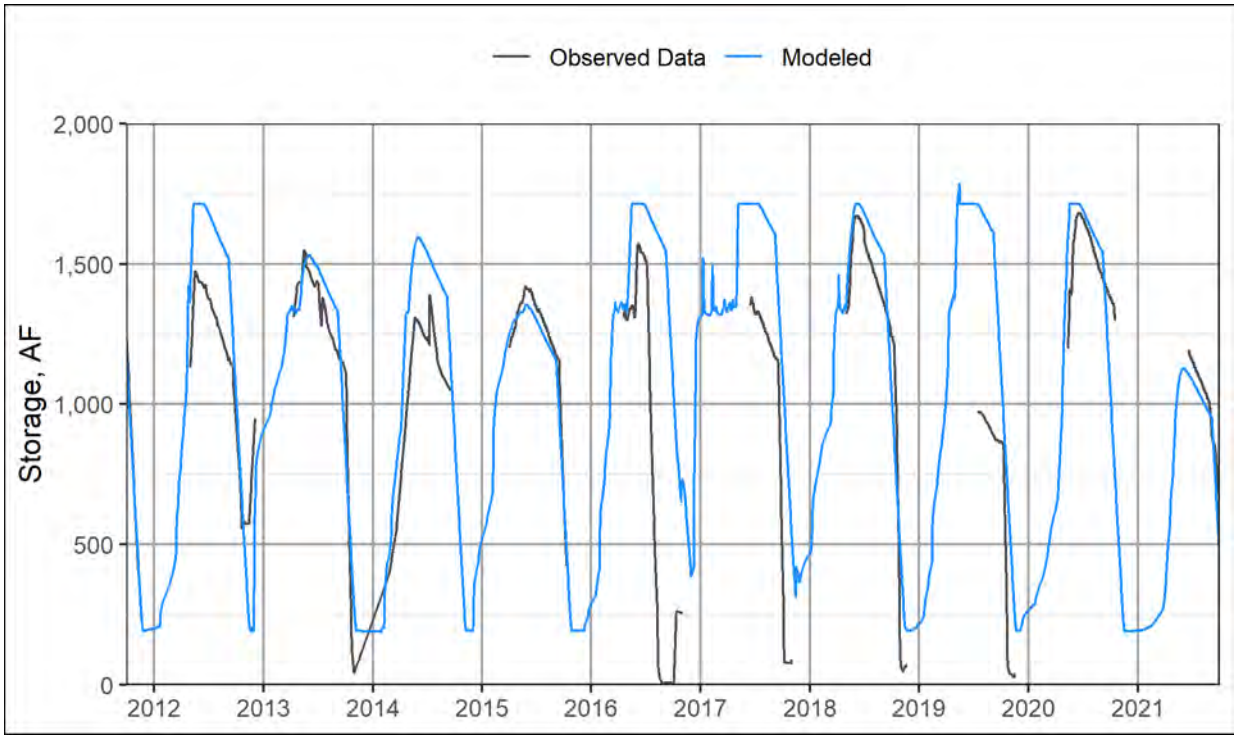


Figure C-25. Lake Sterling Storage, Water Years 2012–2021

C.4.2. Fordyce Lake

Fordyce Lake Operations are difficult to capture. Historical carryover ranges from 4–20 TAF, with no consistency regarding year type. Reservoir fill levels generally match observed values with the notable exception of 2021.

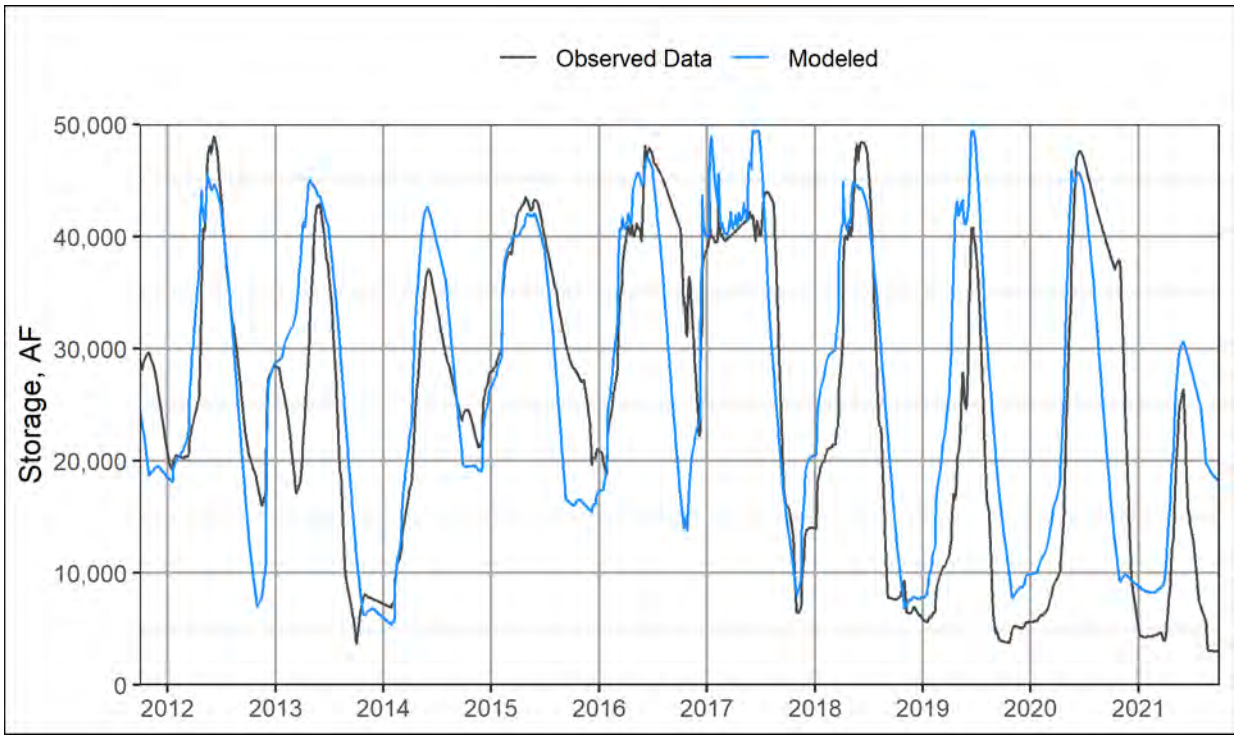


Figure C-26. Fordyce Lake Storage, Water Years 2012–2021

C.4.3. Lake Spaulding

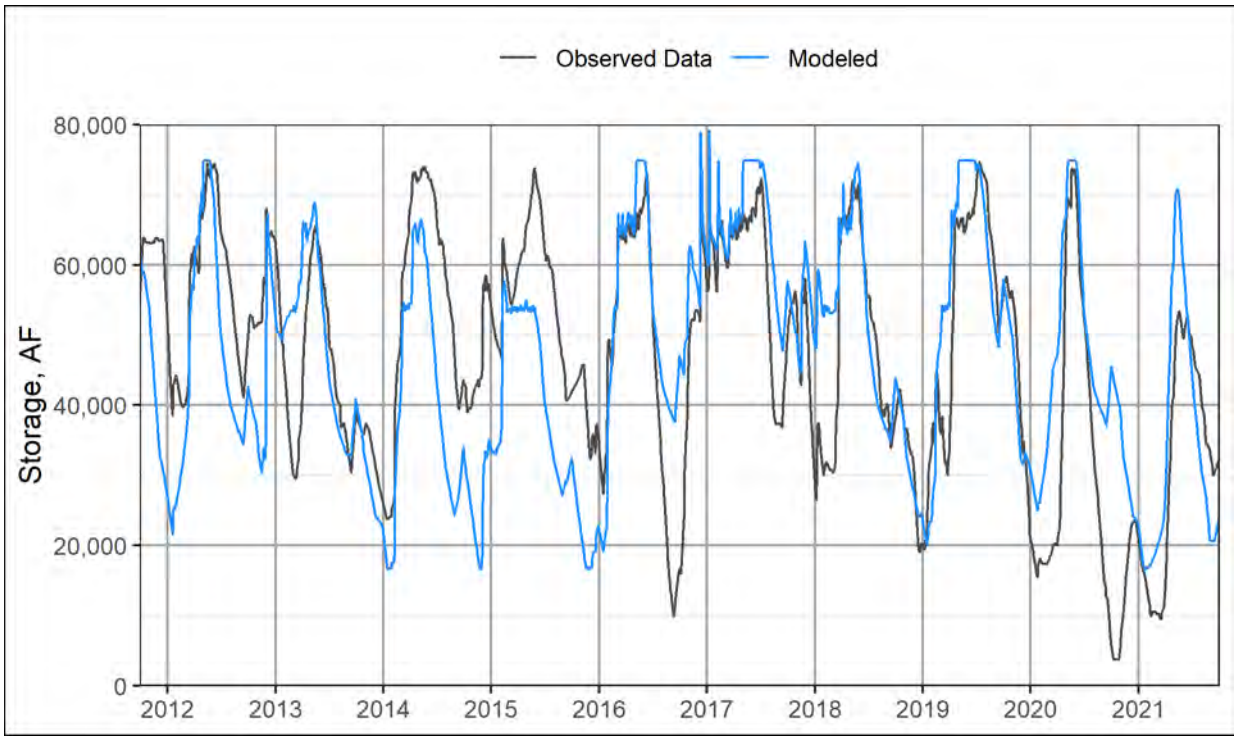


Figure C-27. Lake Spaulding Storage, Water Years 2012–2021

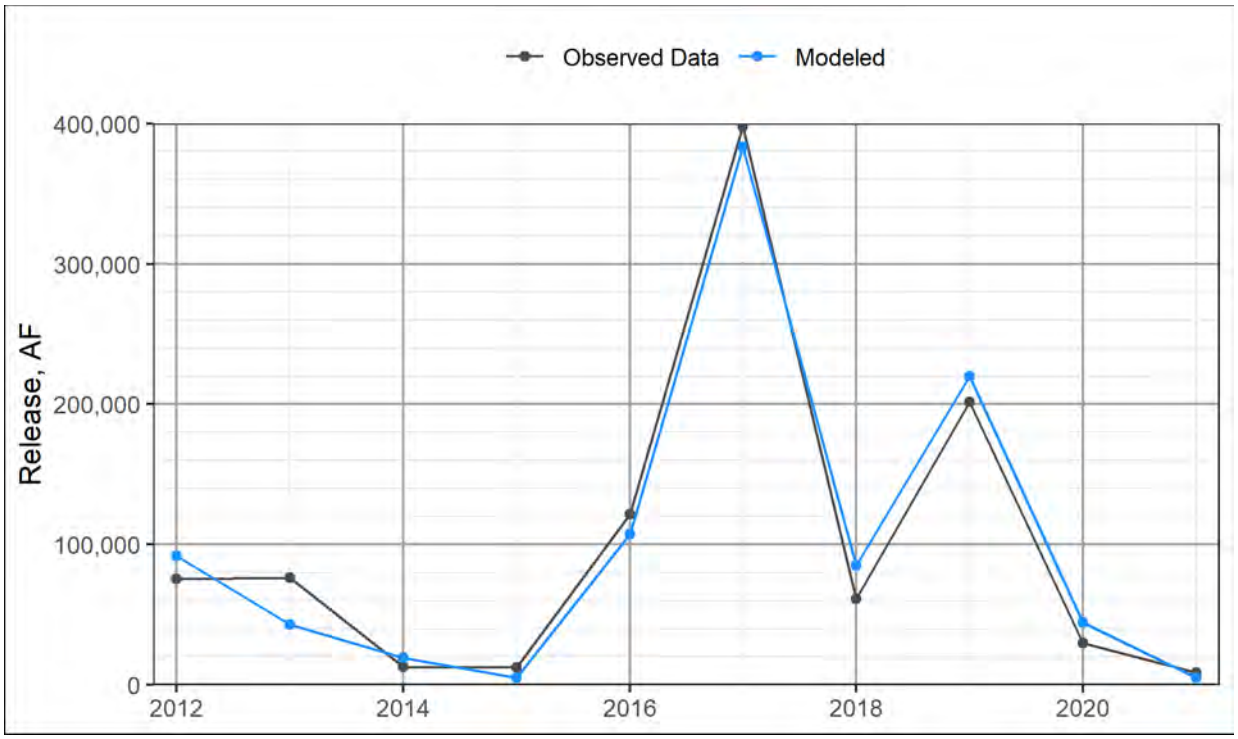


Figure C-28. Release from Lake Spaulding to South Yuba River, Water Years 2012–2021

Annual diversions into Spaulding Powerhouse No. 1 are shown in Figure C-29 and Figure C-30. Annual diversions into Spaulding Powerhouse No. 2 are shown in Figure C-31 and Figure C-32.

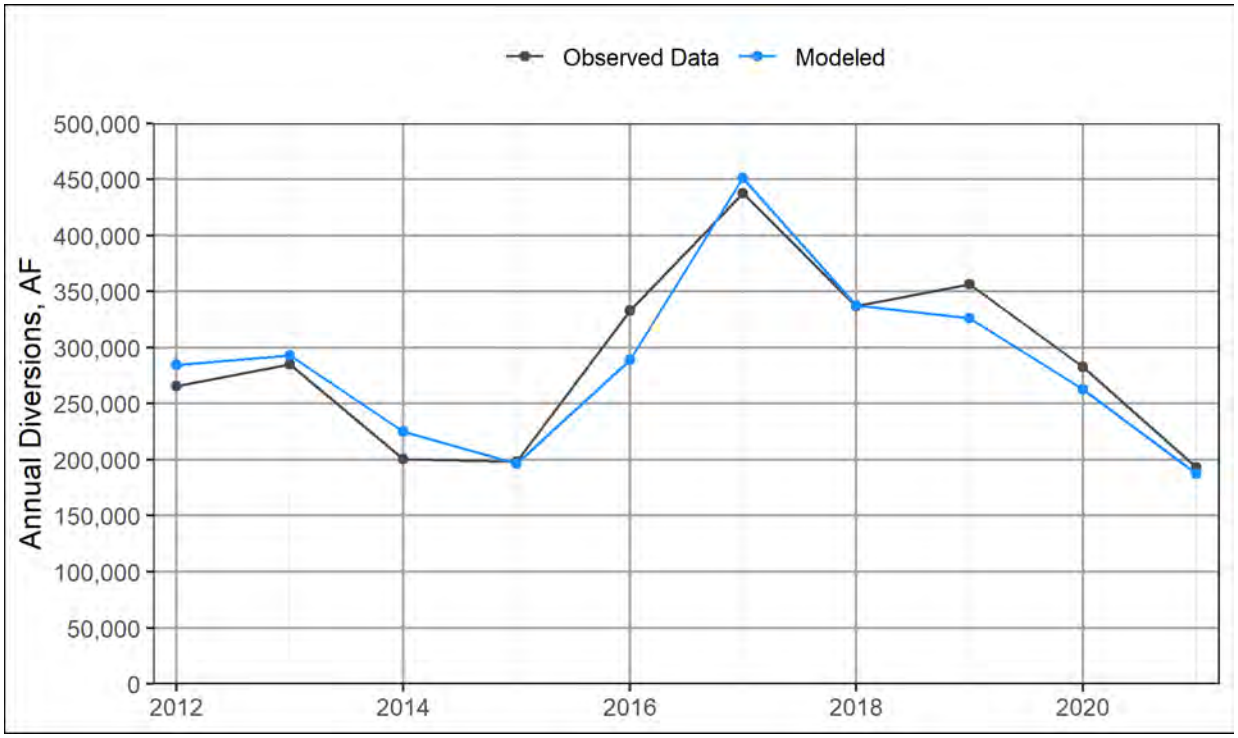


Figure C-29. Annual Flows through Spaulding Powerhouse No. 1, Water Years 2012–2021

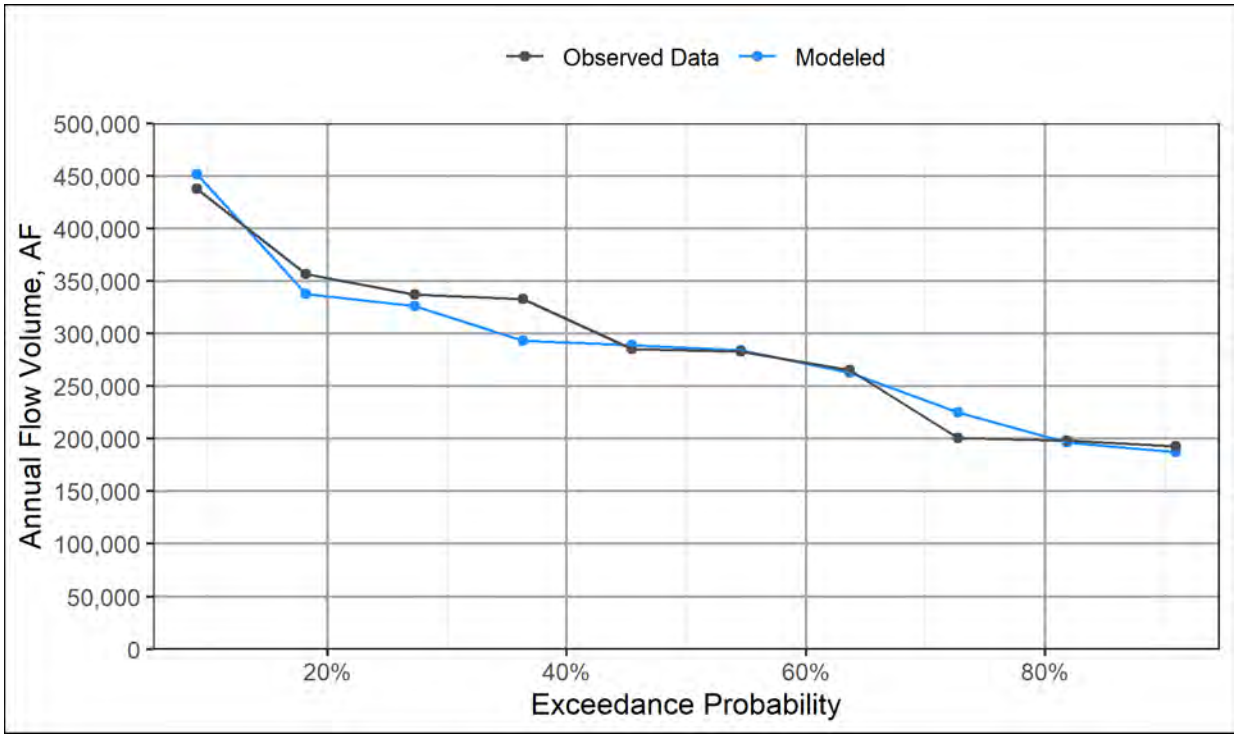


Figure C-30. Annual Flow Exceedance through Spaulding Powerhouse No. 1, Water Years 2012–2021

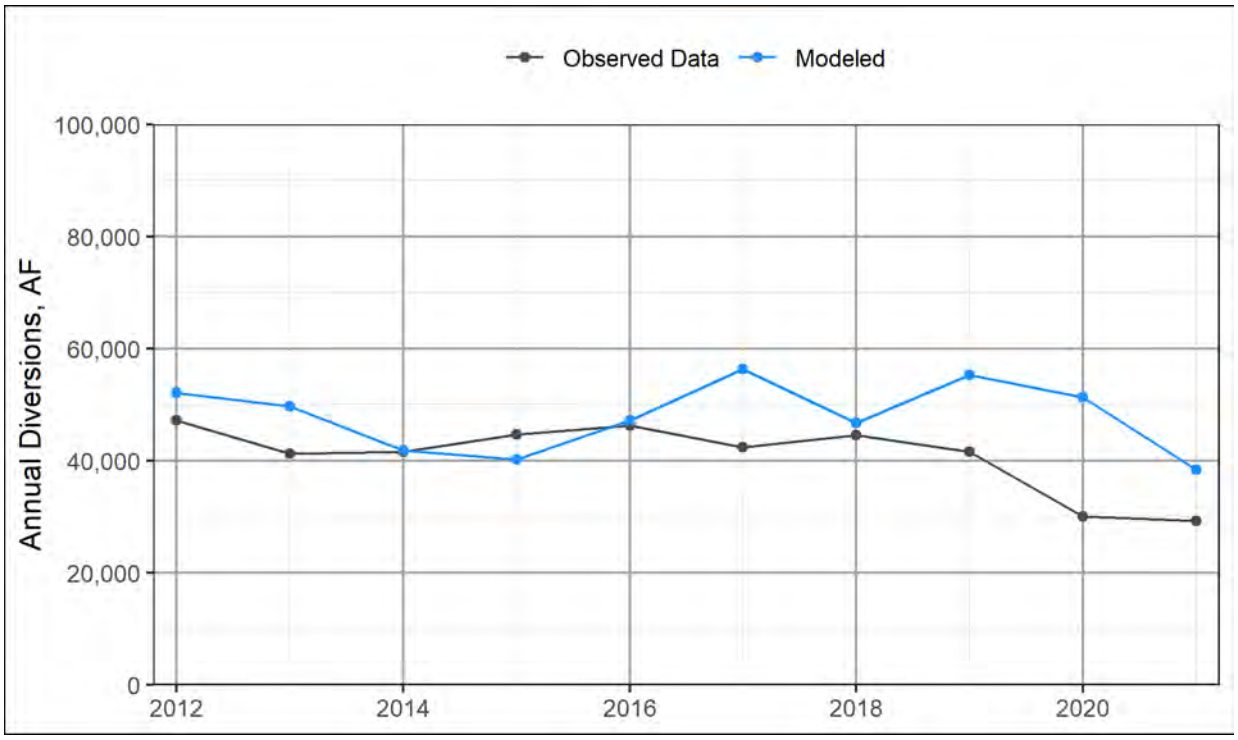


Figure C-31. Annual Flows through Spaulding Powerhouse No. 2, Water Years 2012–2021

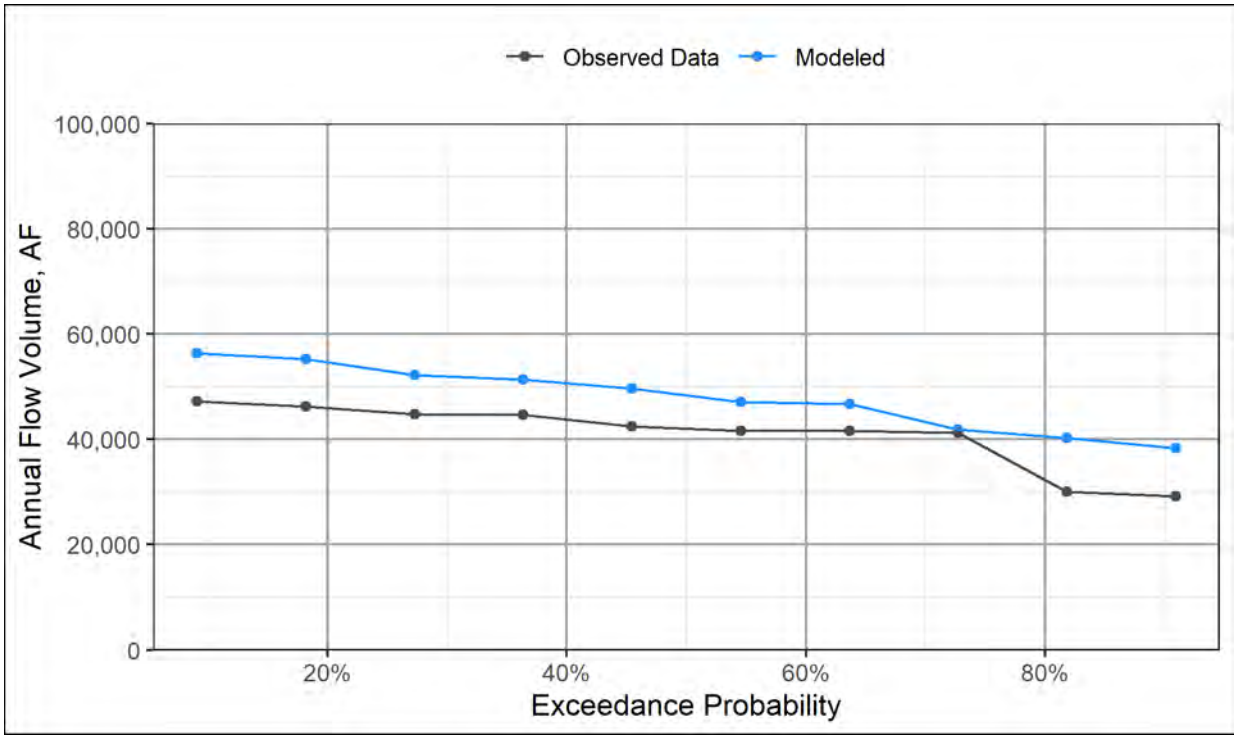


Figure C-32. Annual Flow Exceedance through Spaulding Powerhouse No. 2, Water Years 2012–2021

C.5. North Fork American River

C.5.1. Lake Valley Reservoir

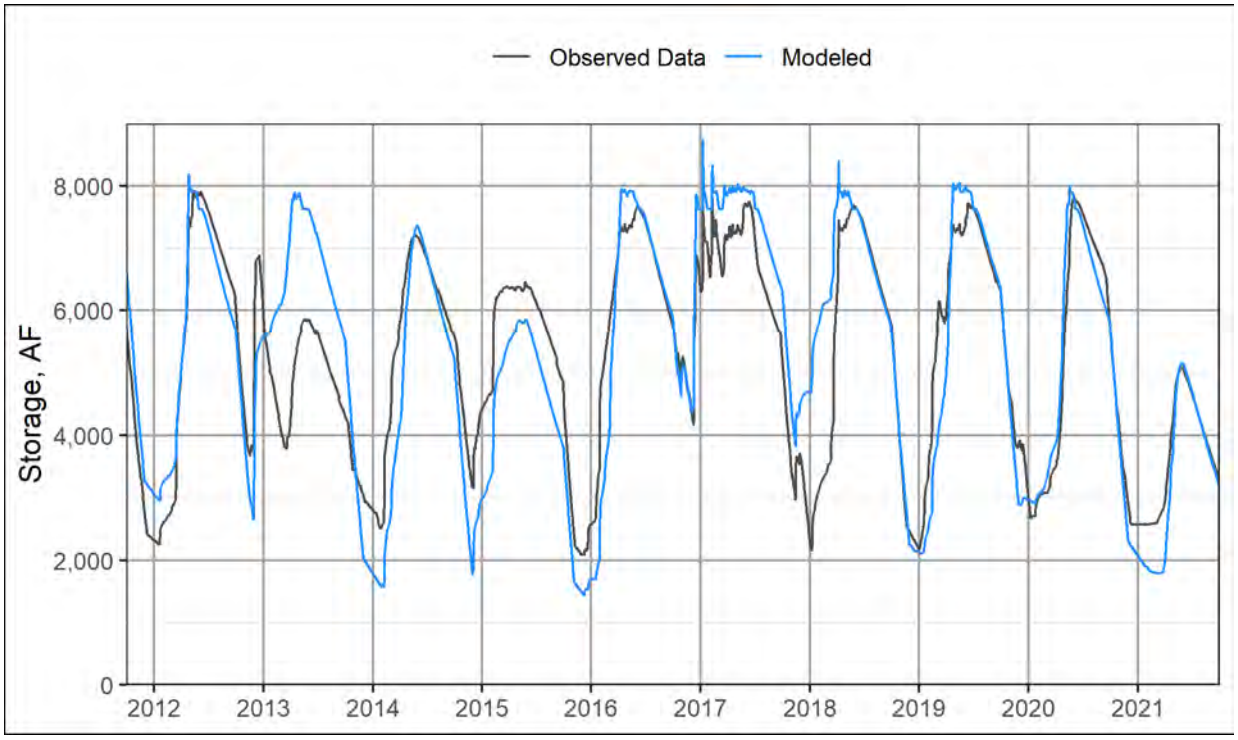


Figure C-33. Lake Valley Reservoir Storage, Water Years 2012–2021

C.5.2. Kelly Lake

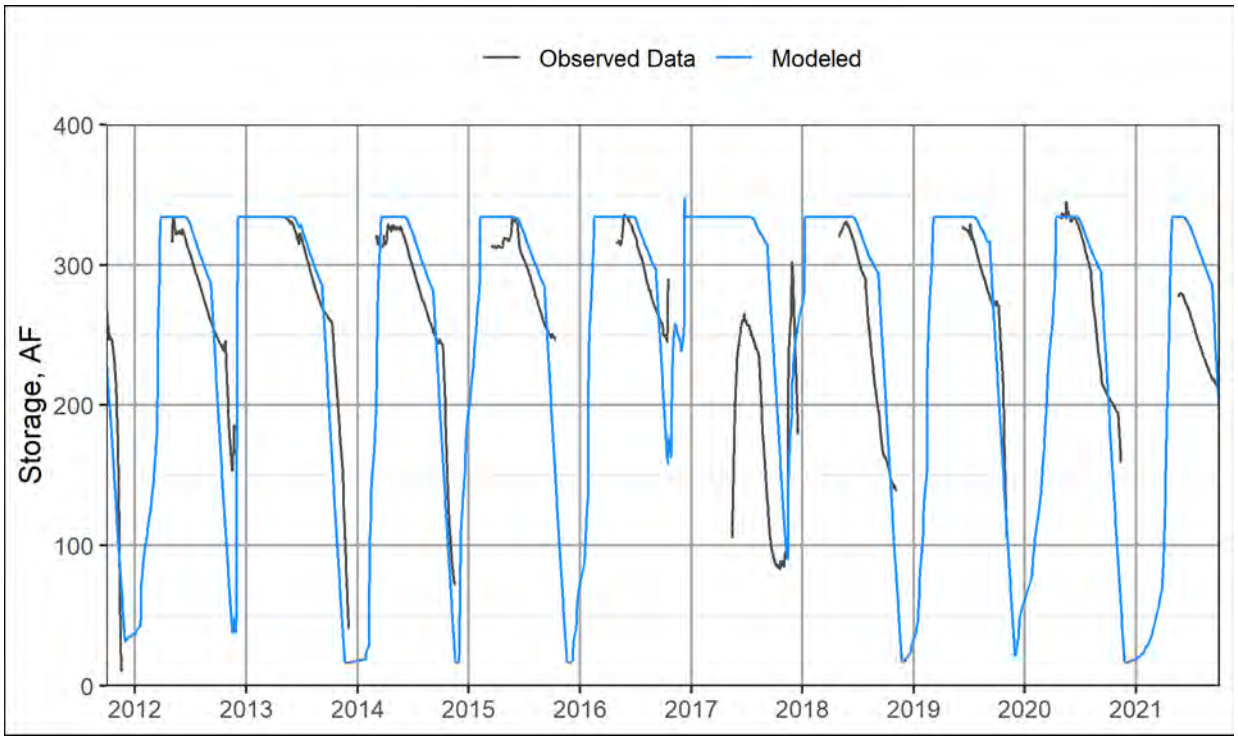


Figure C-34. Kelly Lake Storage, Water Years 2012–2021

C.5.3. Lake Valley Canal Flows

The Lake Valley Canal was piped in 2014, which resulted in a reduced capacity for the conduit. The model reflects the current capacity of the conduit and does not match flows pre-canal piping. For this reason, flows in the Lake Valley Canal are only compared for the period of water years 2015–2021.

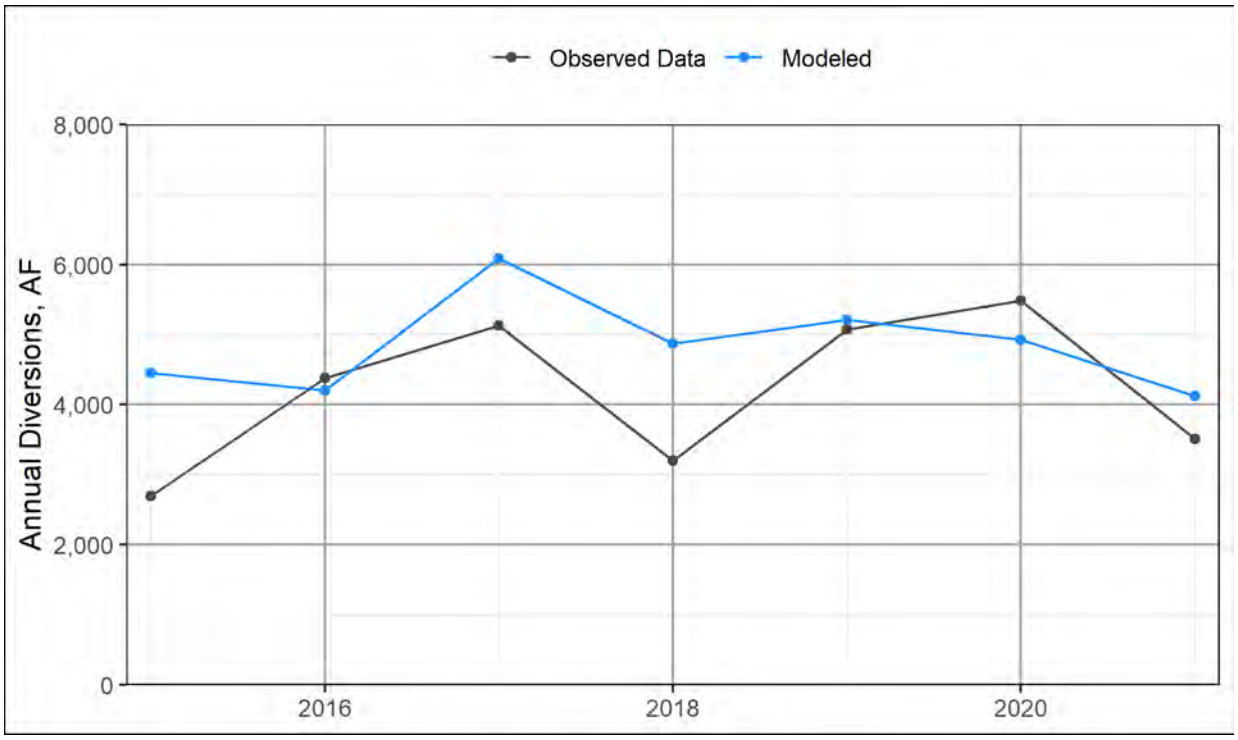


Figure C-35. Annual Diversions into Lake Valley Canal, Water Years 2015–2021

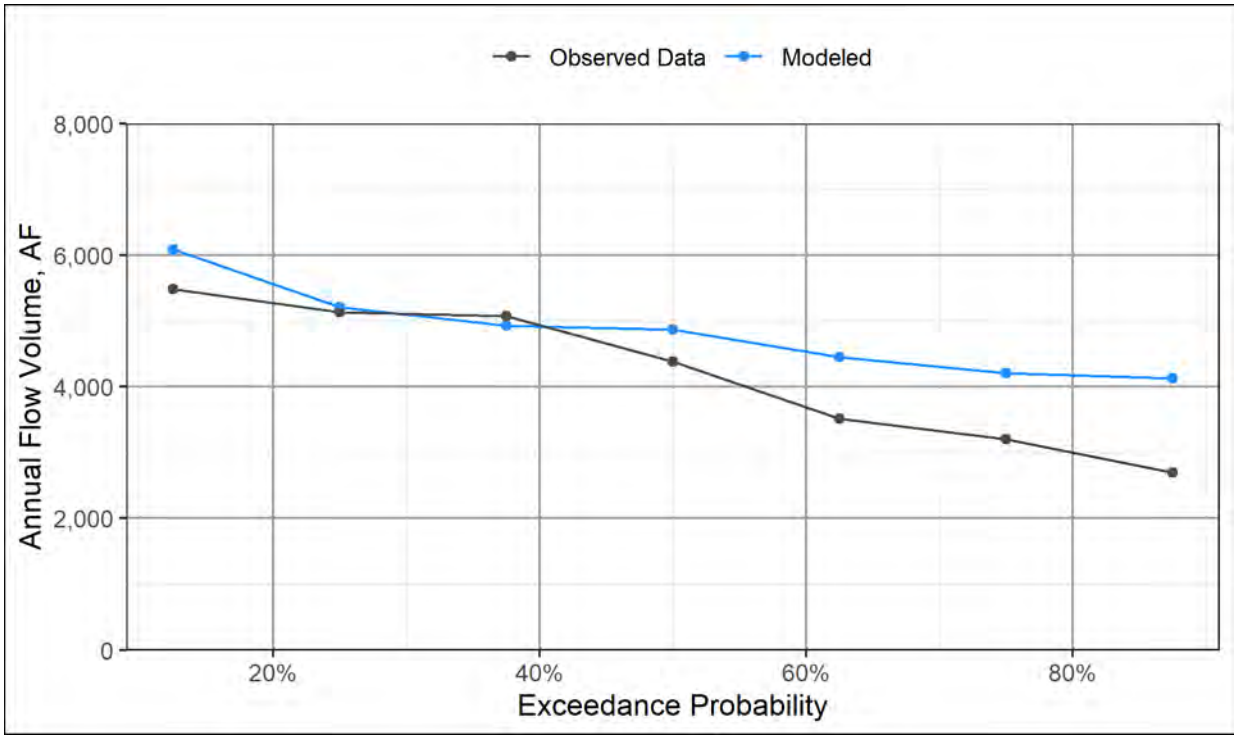


Figure C-36. Annual Diversions into Lake Valley Canal Exceedance, Water Years 2015–2021

C.5.4. Diversions from Canyon Creek into the Towle Canal

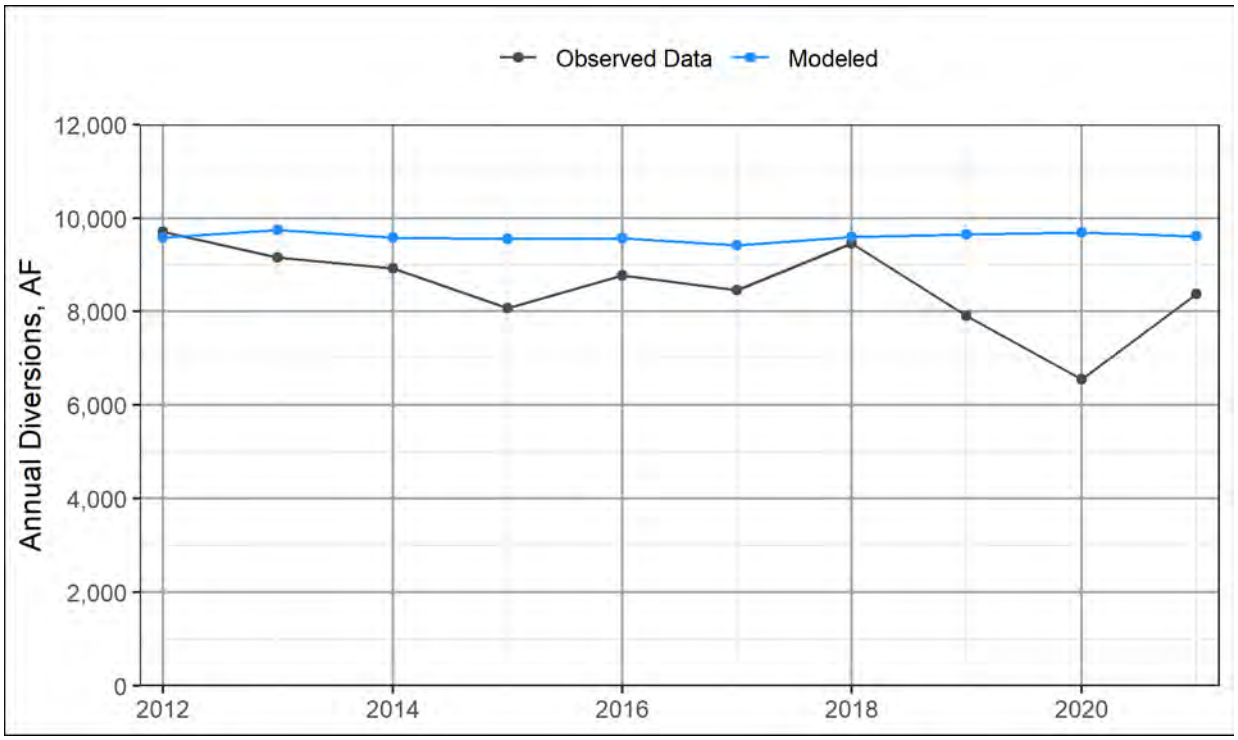


Figure C-37. Annual Diversions into Towle Canal, Water Years 2012–2021

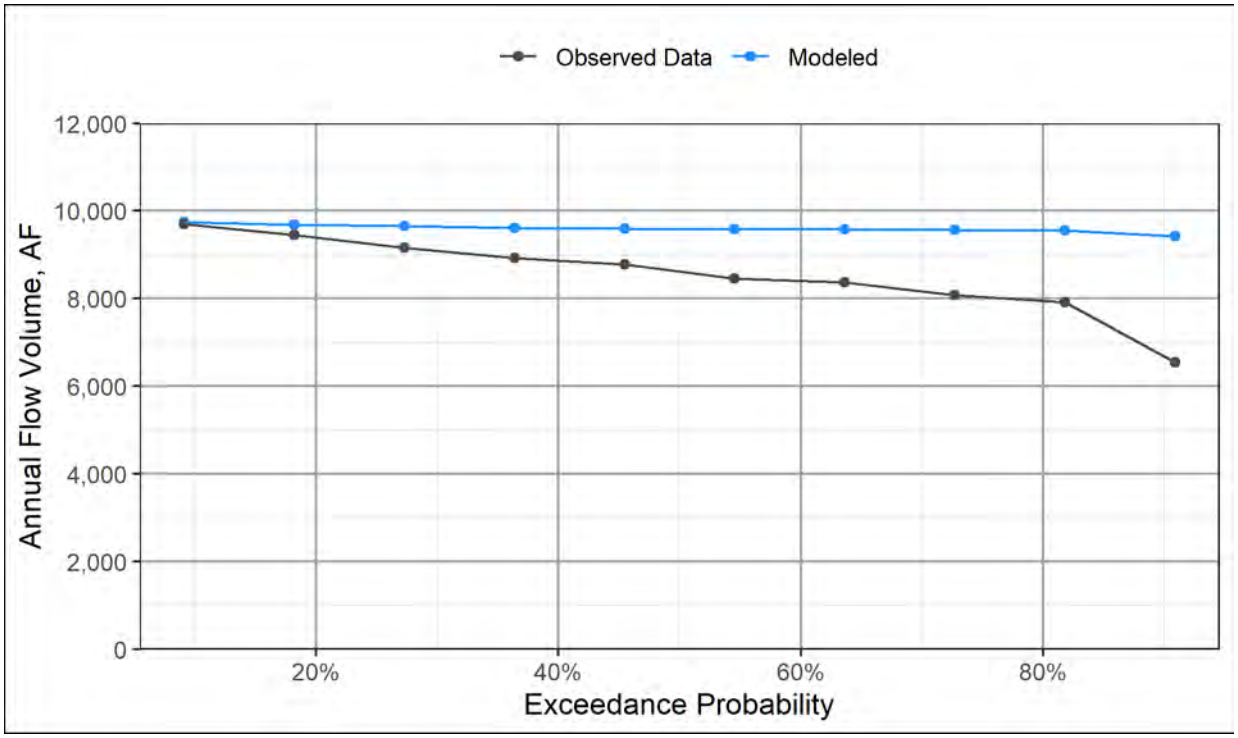


Figure C-38. Annual Diversions into Towle Canal Exceedance, Water Years 2012–2021

C.6. Bear River

C.6.1. Drum Forebay

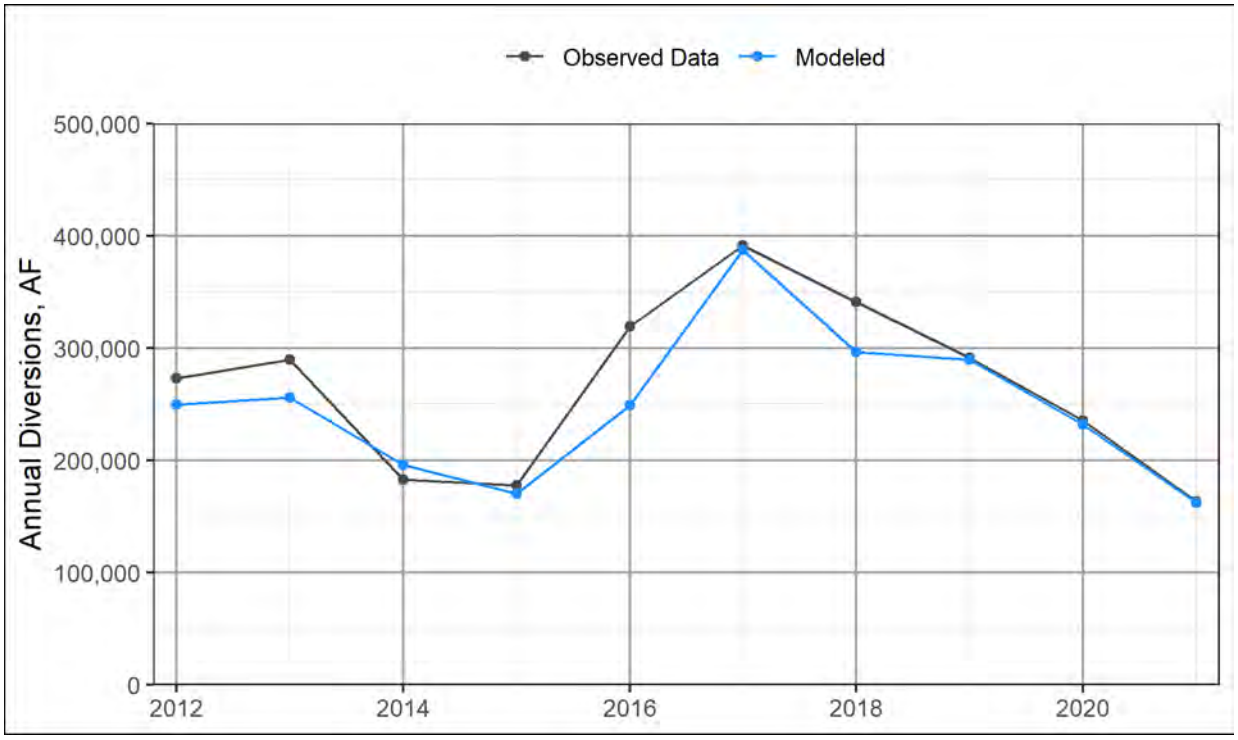


Figure C-39. Annual Flows through Combined Drum Powerhouses, Water Years 2012–2021

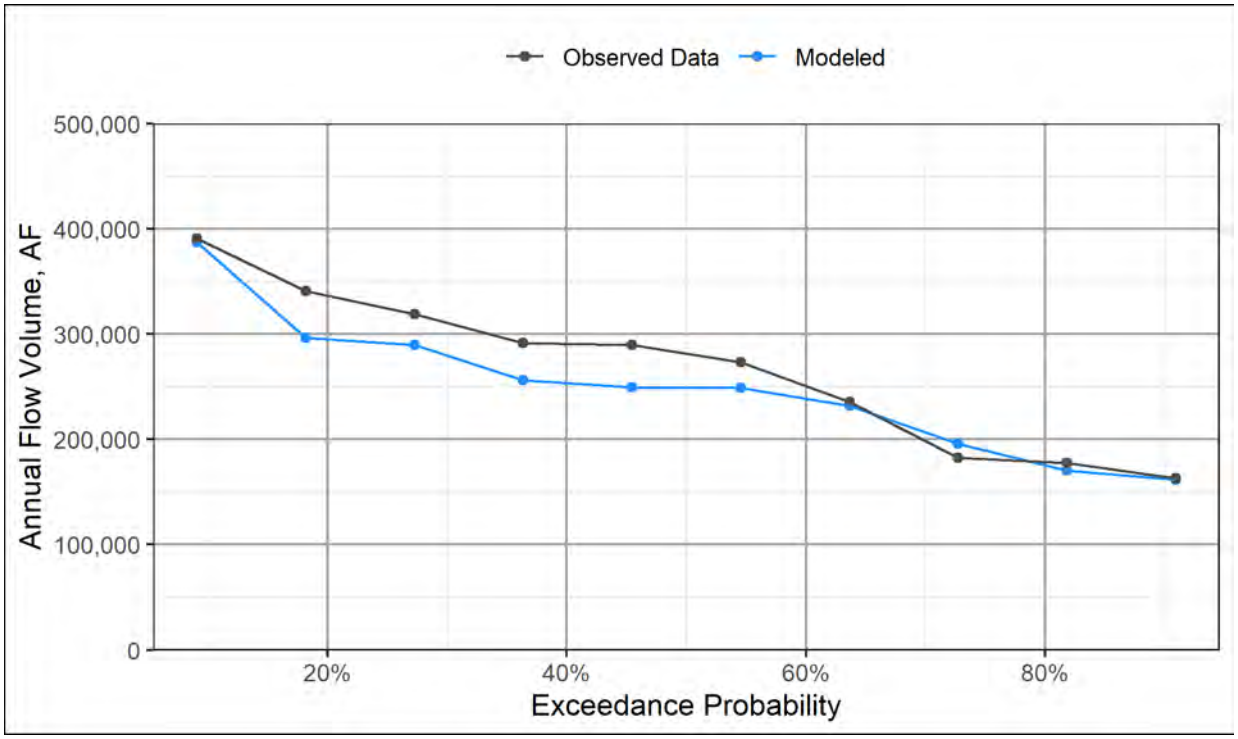


Figure C-40. Annual Flow Exceedance through Combined Drum Powerhouses, Water Years 2012–2021

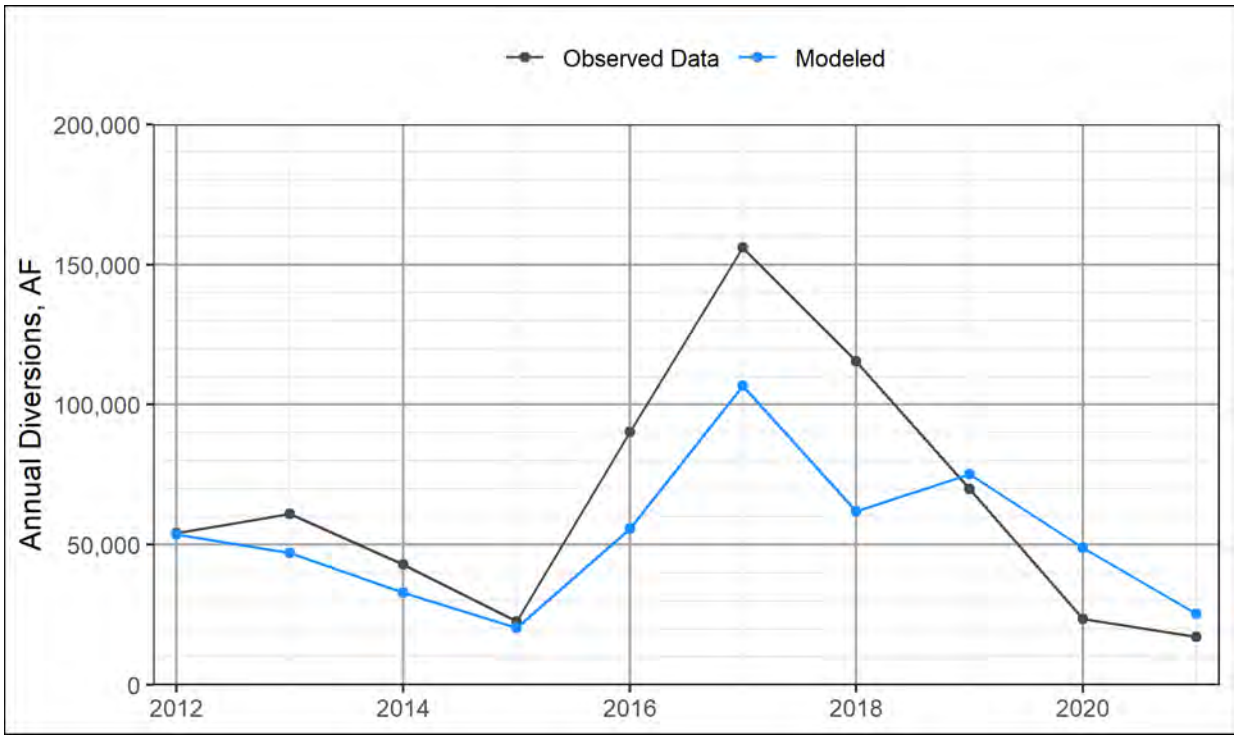


Figure C-41. Annual Flows through Drum Powerhouse No. 1, Water Years 2012–2021

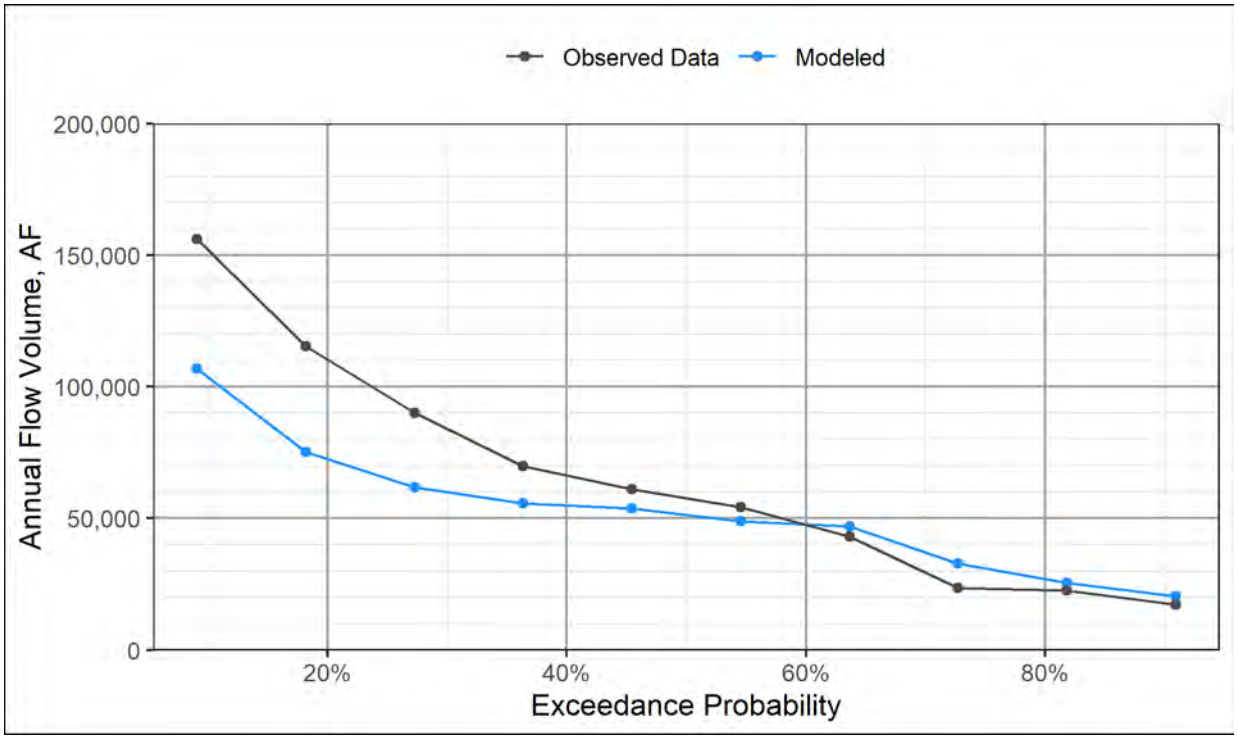


Figure C-42. Annual Flow Exceedance through Drum Powerhouse No. 1, Water Years 2012–2021

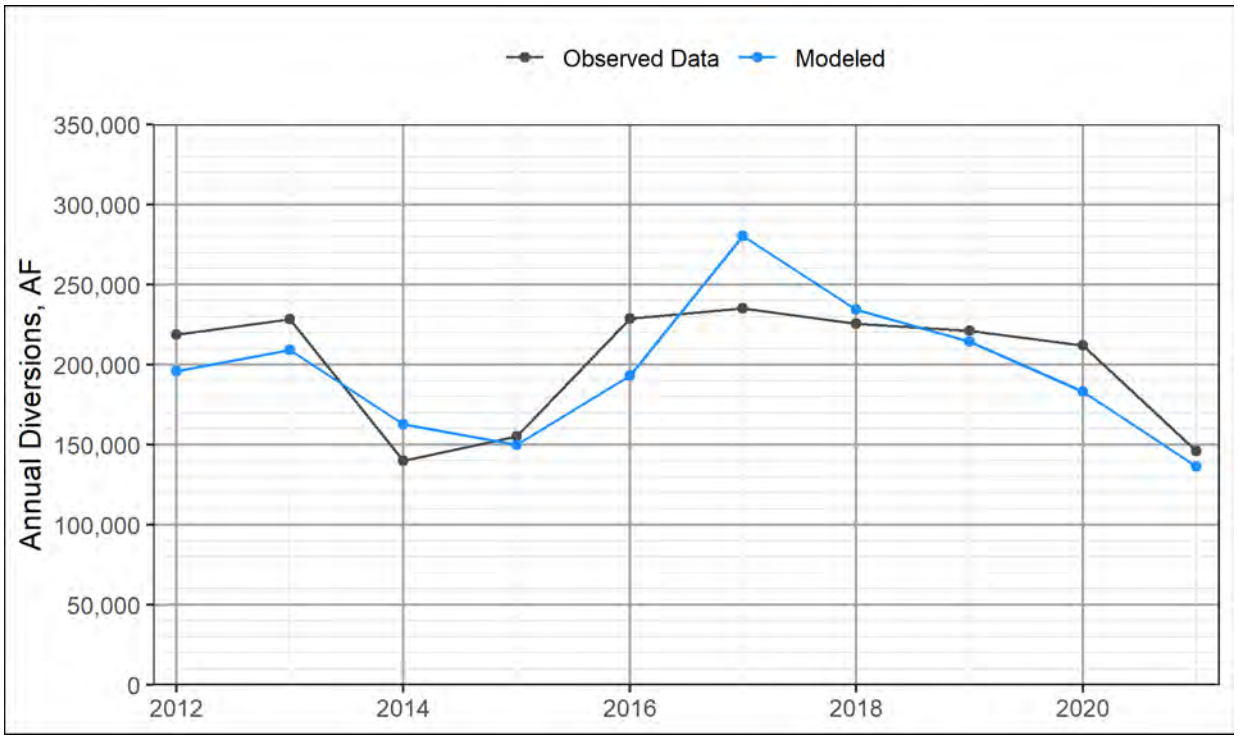


Figure C-43. Annual Flows through Drum Powerhouse No. 2, Water Years 2012–2021

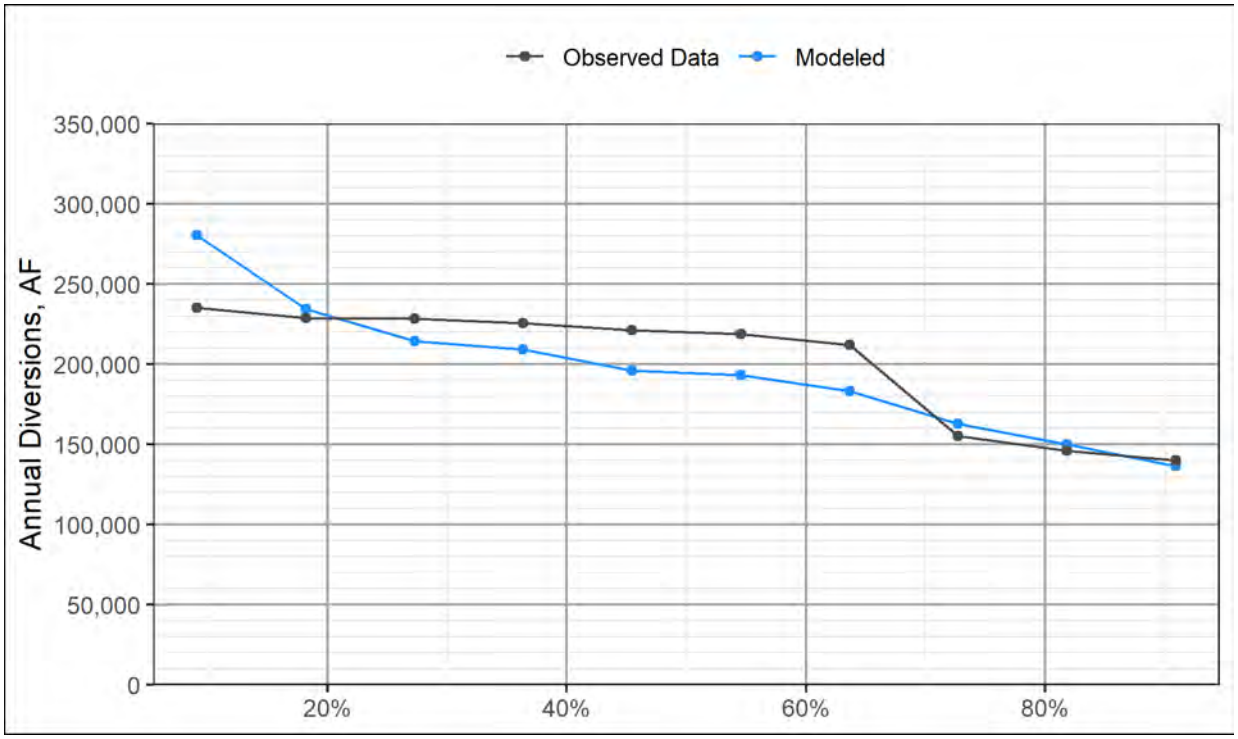


Figure C-44. Annual Flow Exceedance through Drum Powerhouse No. 2, Water Years 2012–2021

C.6.2. Drum Afterbay

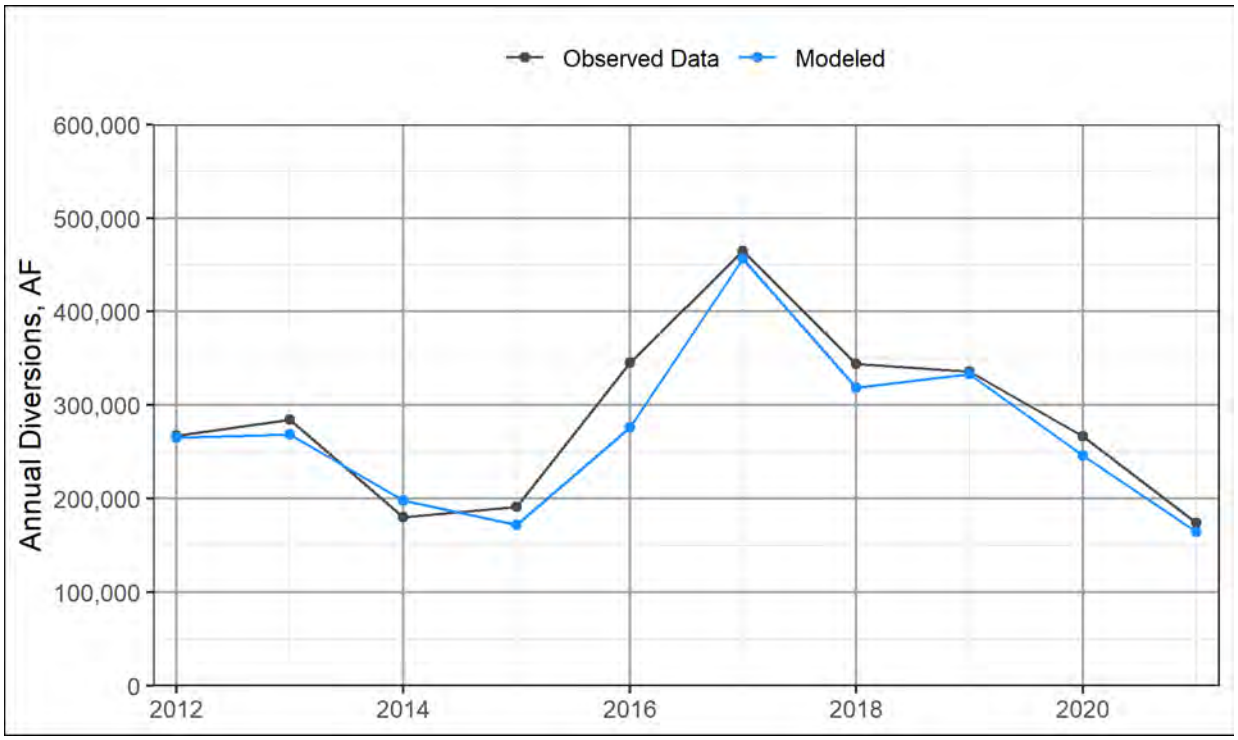


Figure C-45. Annual Flows through Combined Dutch Flat Powerhouses, Water Years 2012–2021

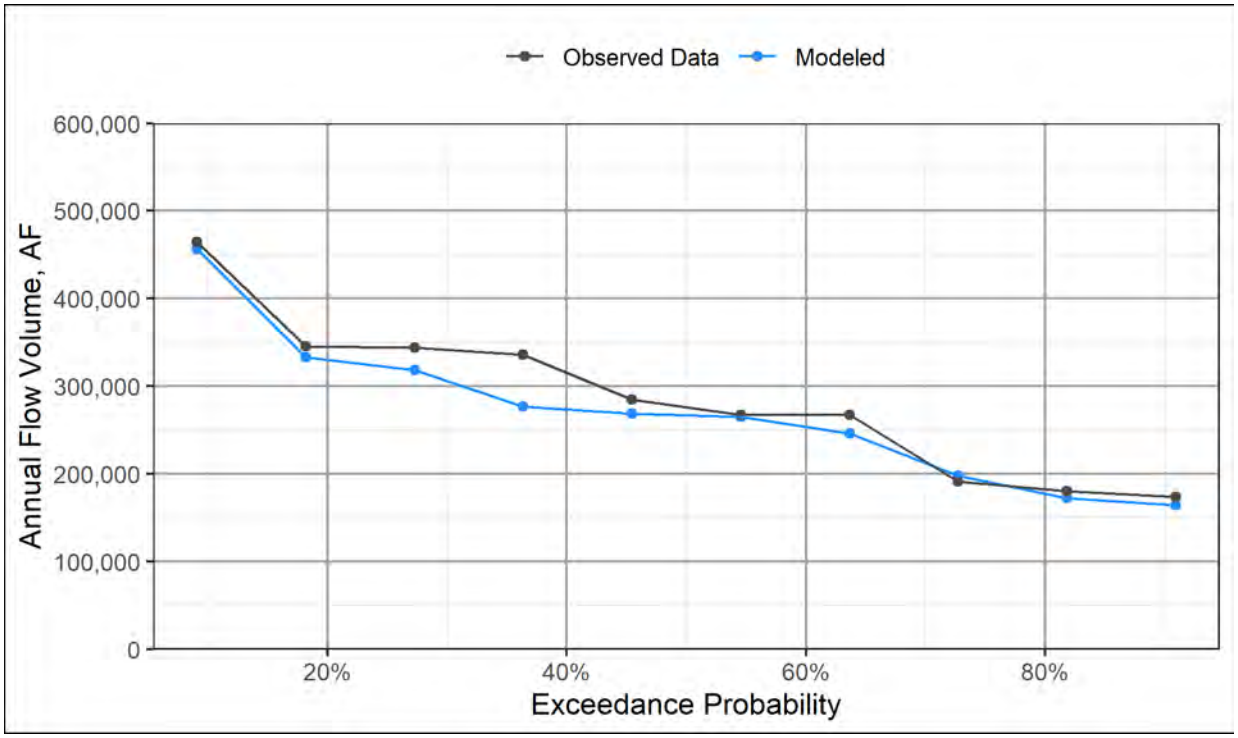


Figure C-46. Annual Flow Exceedance through Combined Dutch Flat Powerhouses, Water Years 2012–2021

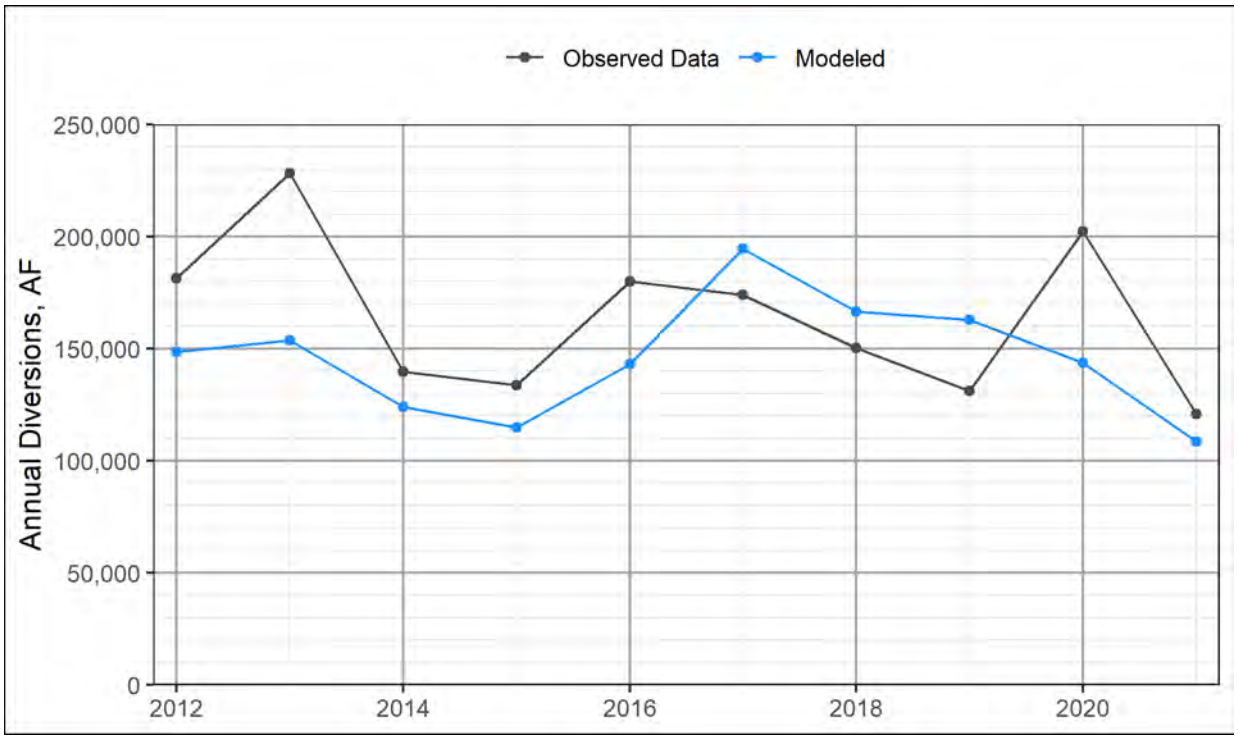


Figure C-47. Annual Flows through Dutch Flat Powerhouse No. 1, Water Years 2012–2021

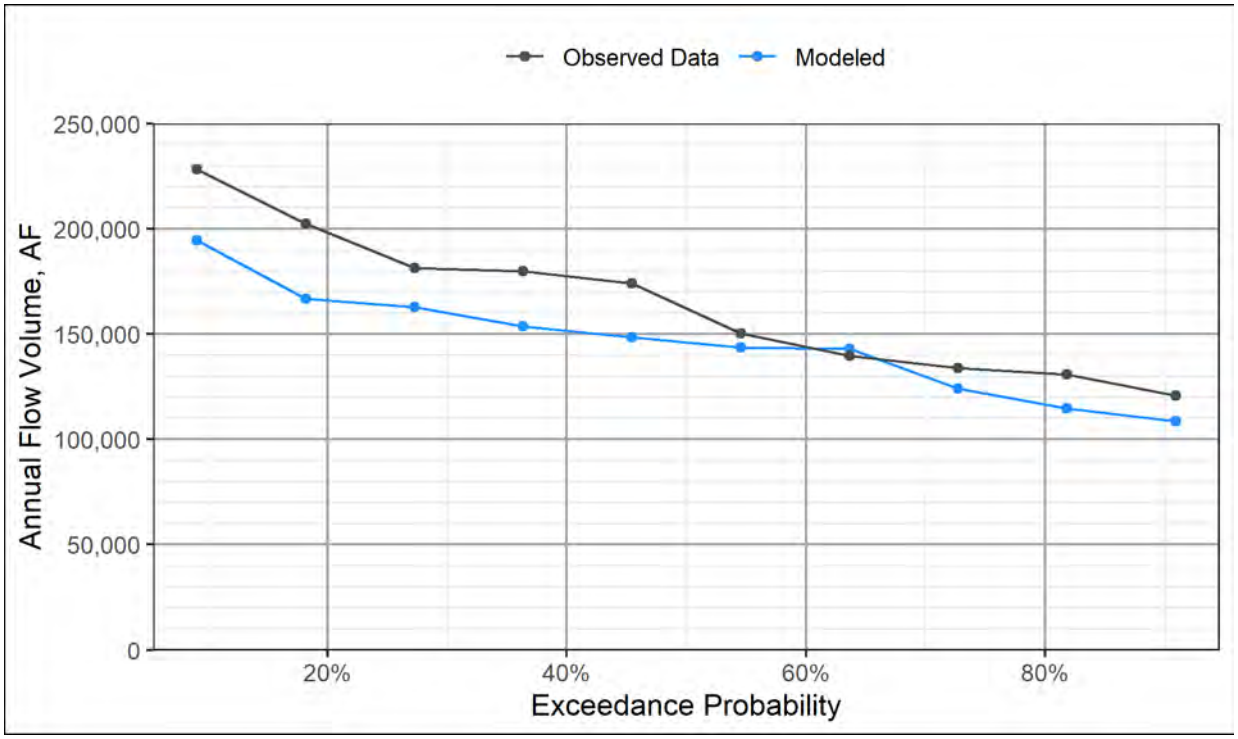


Figure C-48. Annual Flow Exceedance through Dutch Flat Powerhouse No. 1, Water Years 2012–2021

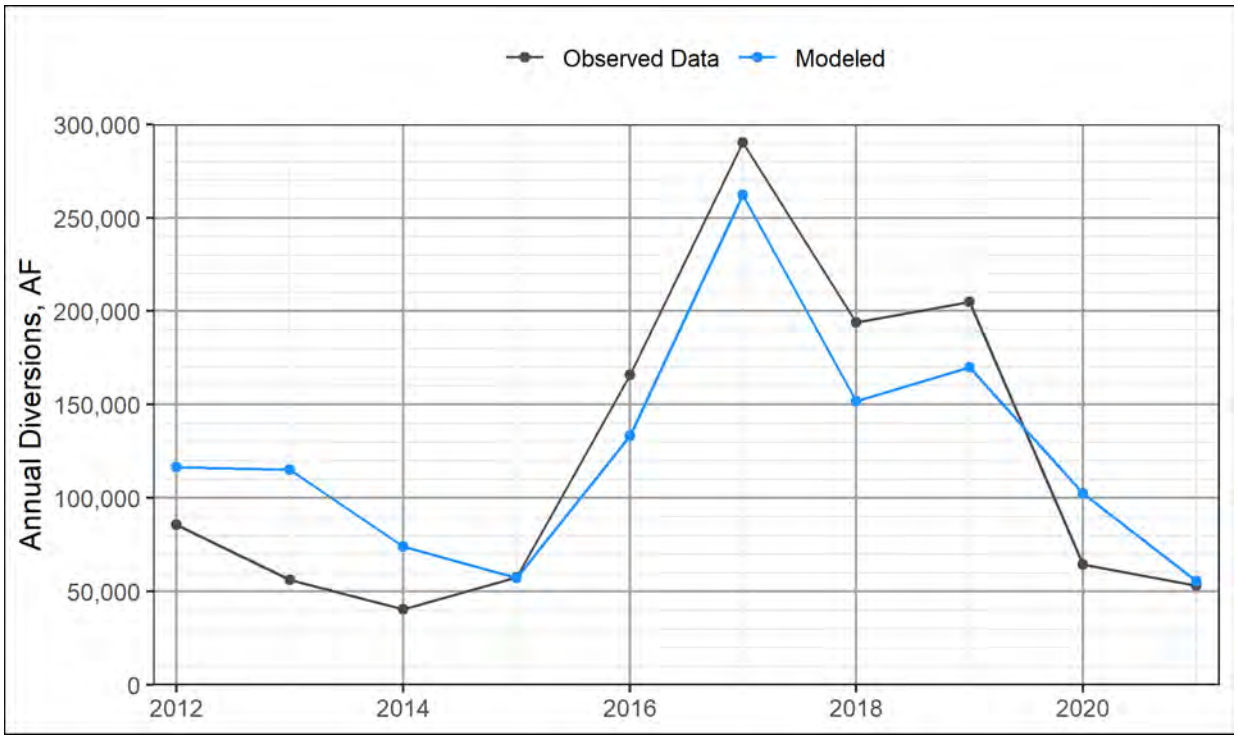


Figure C-49. Annual Flows through Dutch Flat Powerhouse No. 2, Water Years 2012–2021

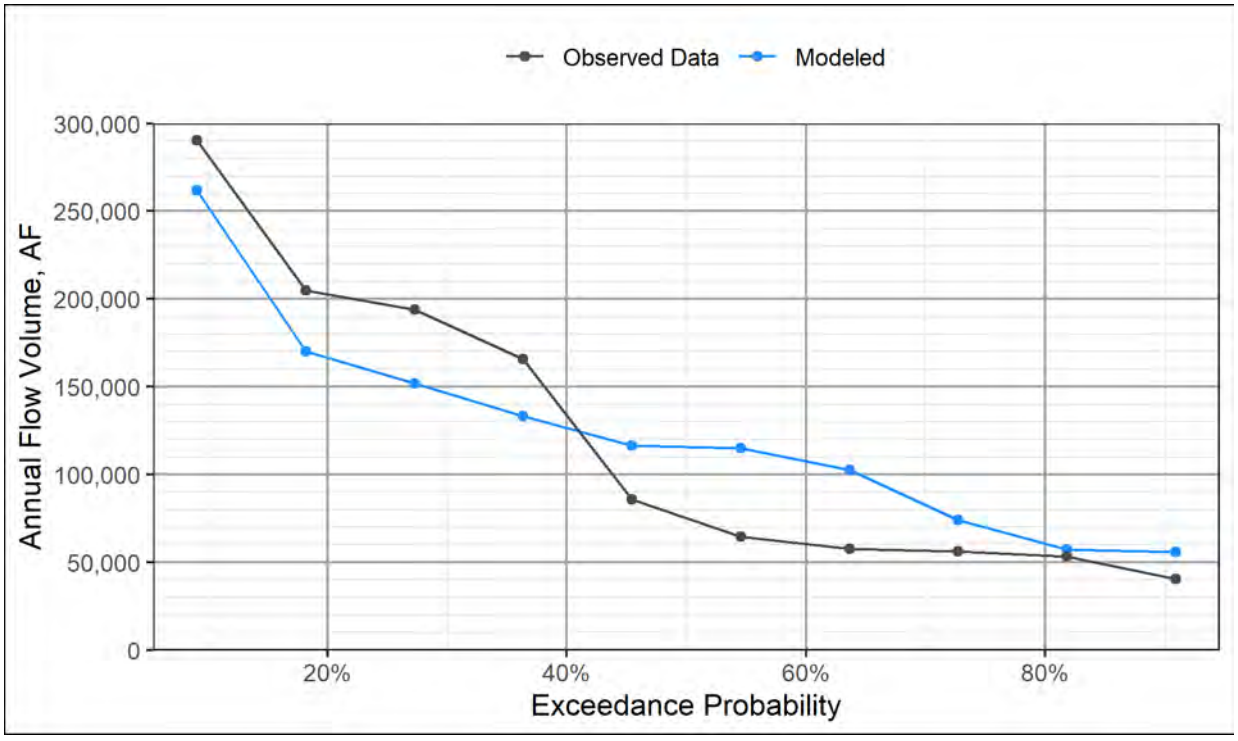


Figure C-50. Annual Flow Exceedance through Dutch Flat Powerhouse No. 2, Water Years 2012–2021

C.6.3. Dutch Flat Afterbay

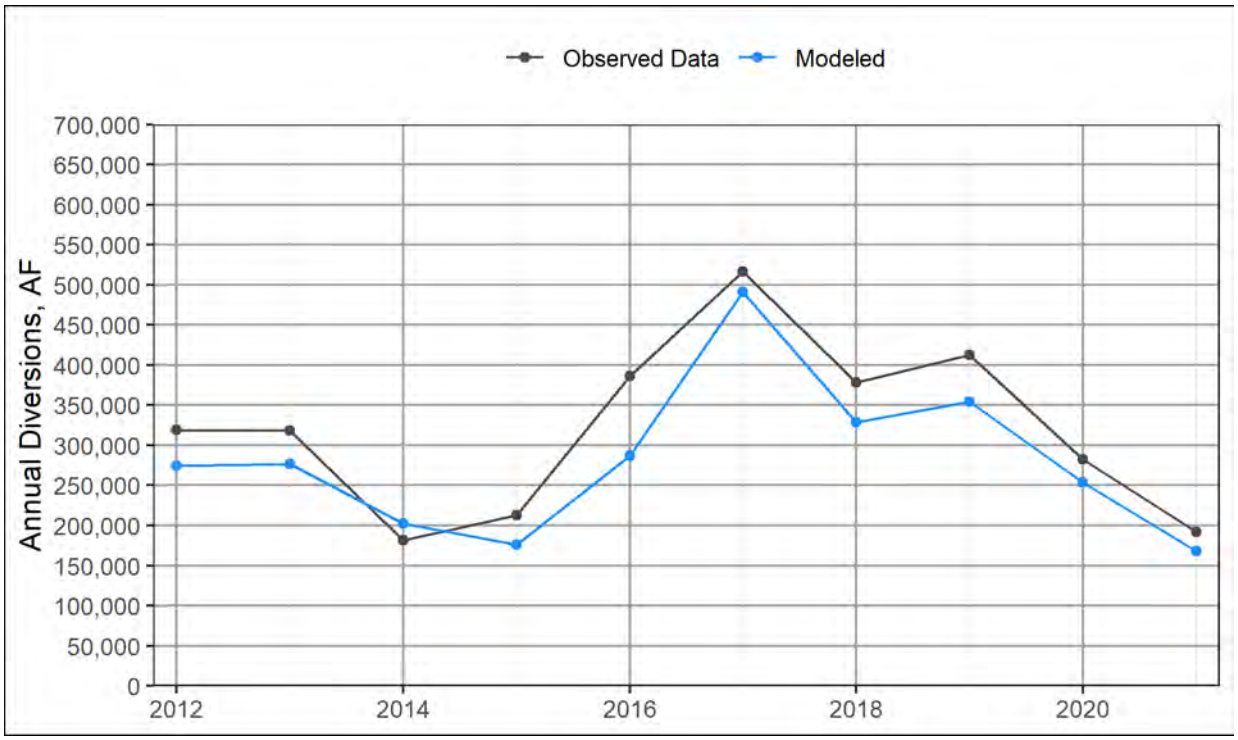


Figure C-51. Annual Flows through Chicago Park Powerhouse, Water Years 2012–2021

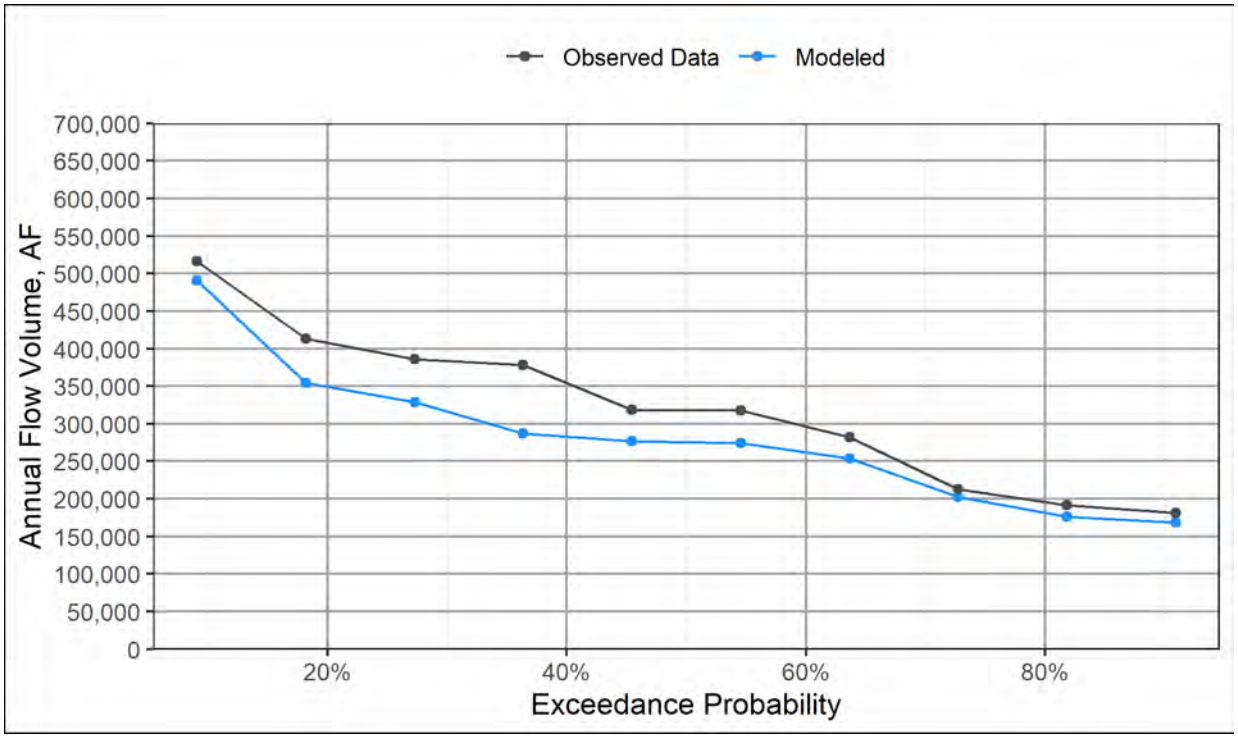


Figure C-52. Annual Flow Exceedance through Chicago Park Powerhouse, Water Years 2012–2021

C.6.4. Rollins Lake

Rollins Lake had a bathymetric survey in 2021, which changed the estimate of storage capacity of the Reservoir. The model uses the new storage-elevation relationship from the updated bathymetric survey, while USGS storage data before 2021 uses the previous storage-elevation relationship. For this reason, Rollins Lake validation uses reservoir elevation rather than storage.

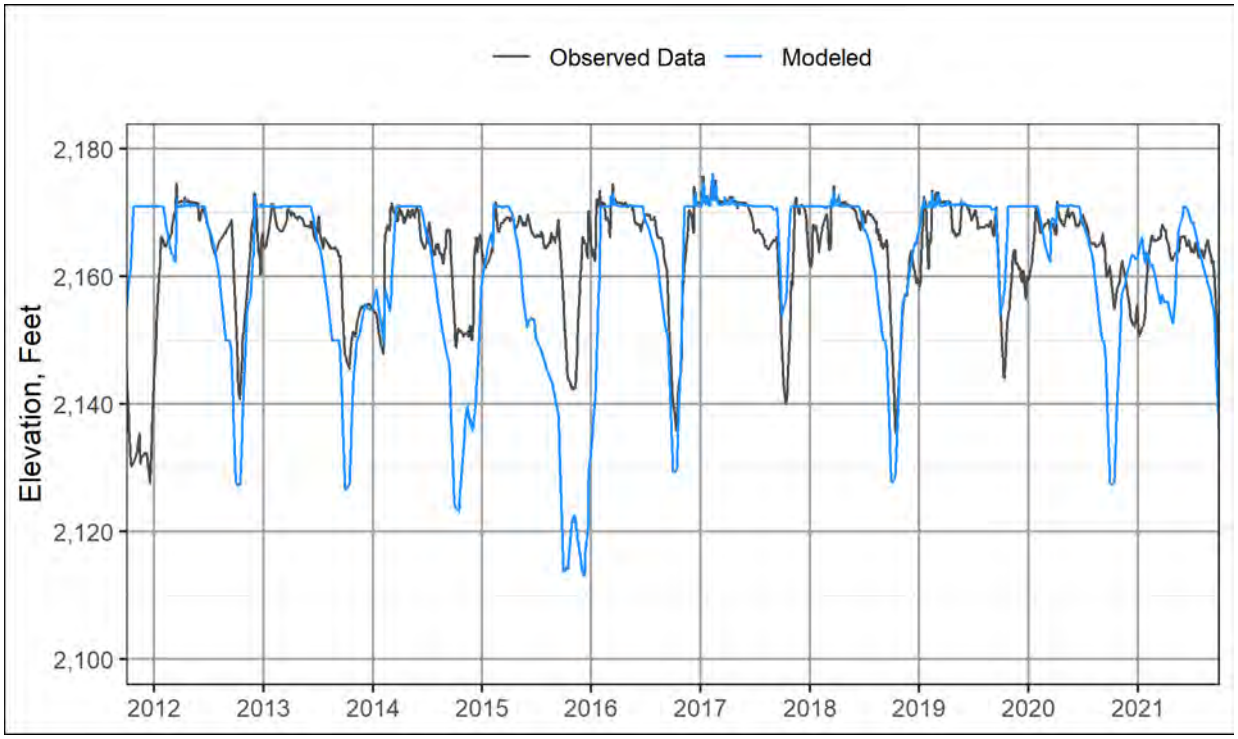


Figure C-53. Rollins Lake Elevation, Water Years 2012–2021

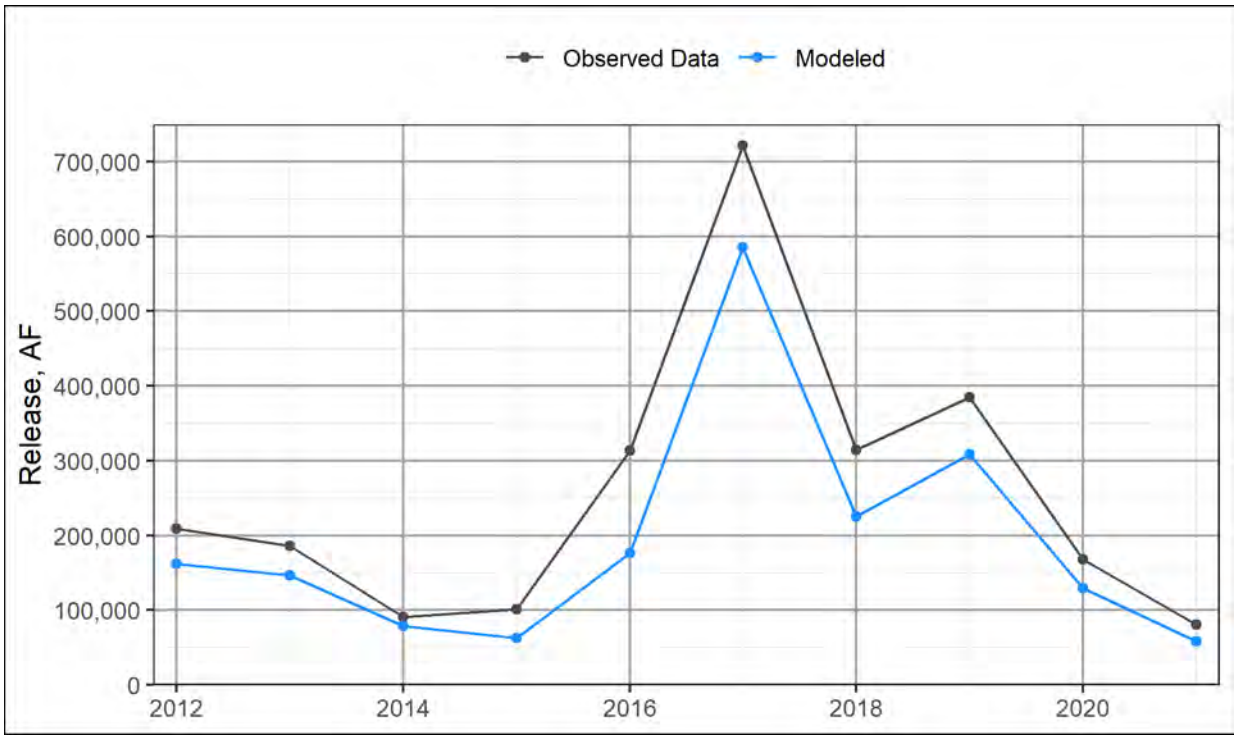


Figure C-54. Rollins Lake releases to Bear River, Water Years 2012–2021

C.6.5. Bear River Canal

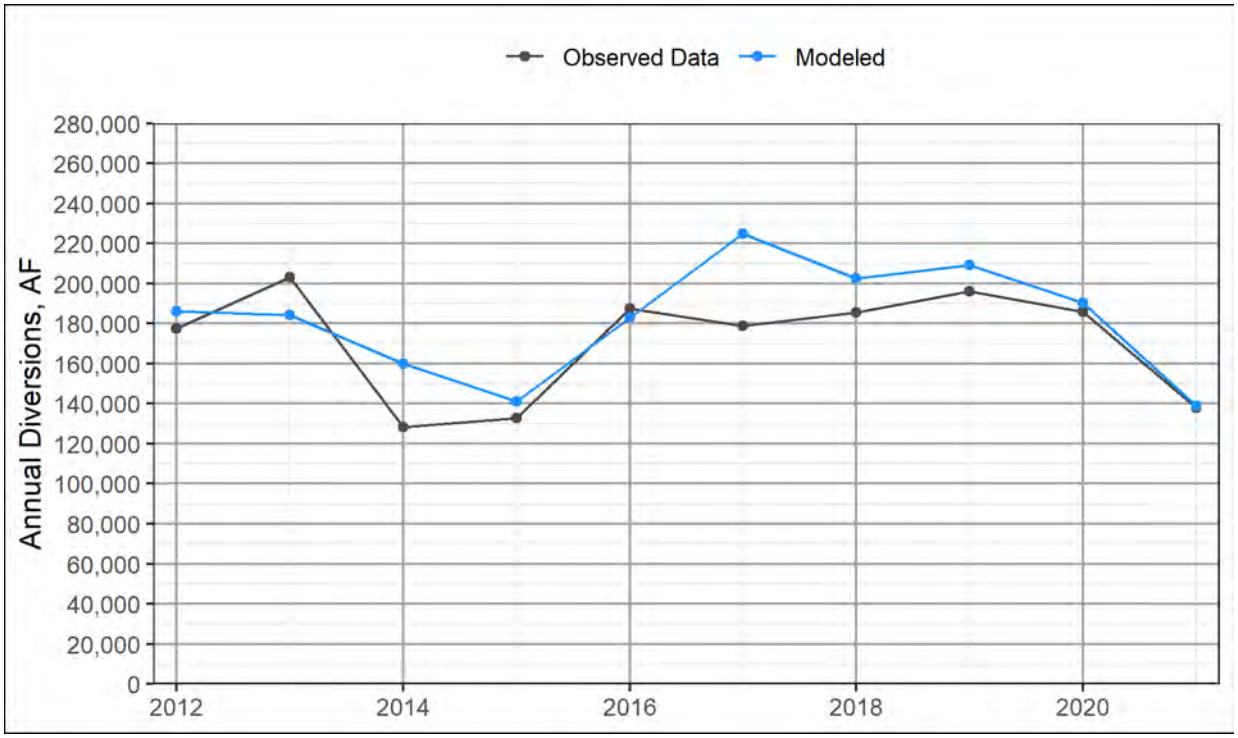


Figure C-55. Rollins Lake Diversions to Bear River Canal, Water Years 2012–2021

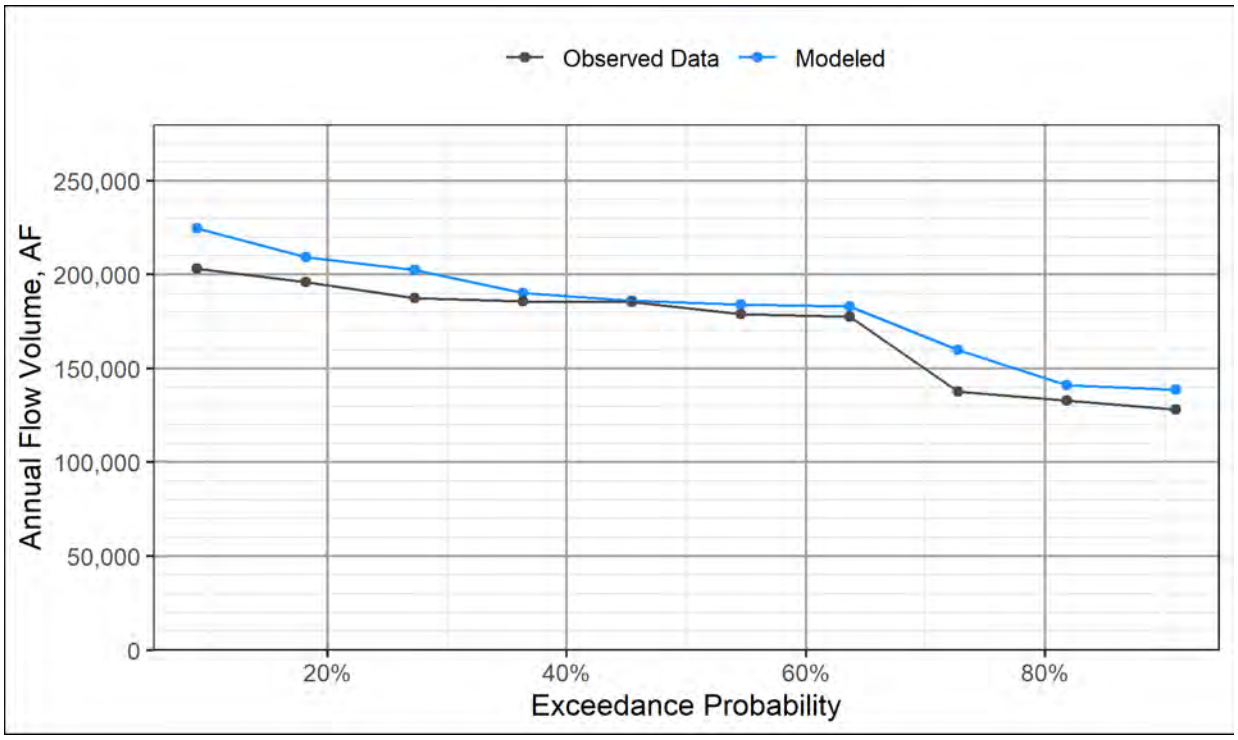


Figure C-56. Annual Diversion Exceedance to Bear River Canal, Water Years 2012–2021

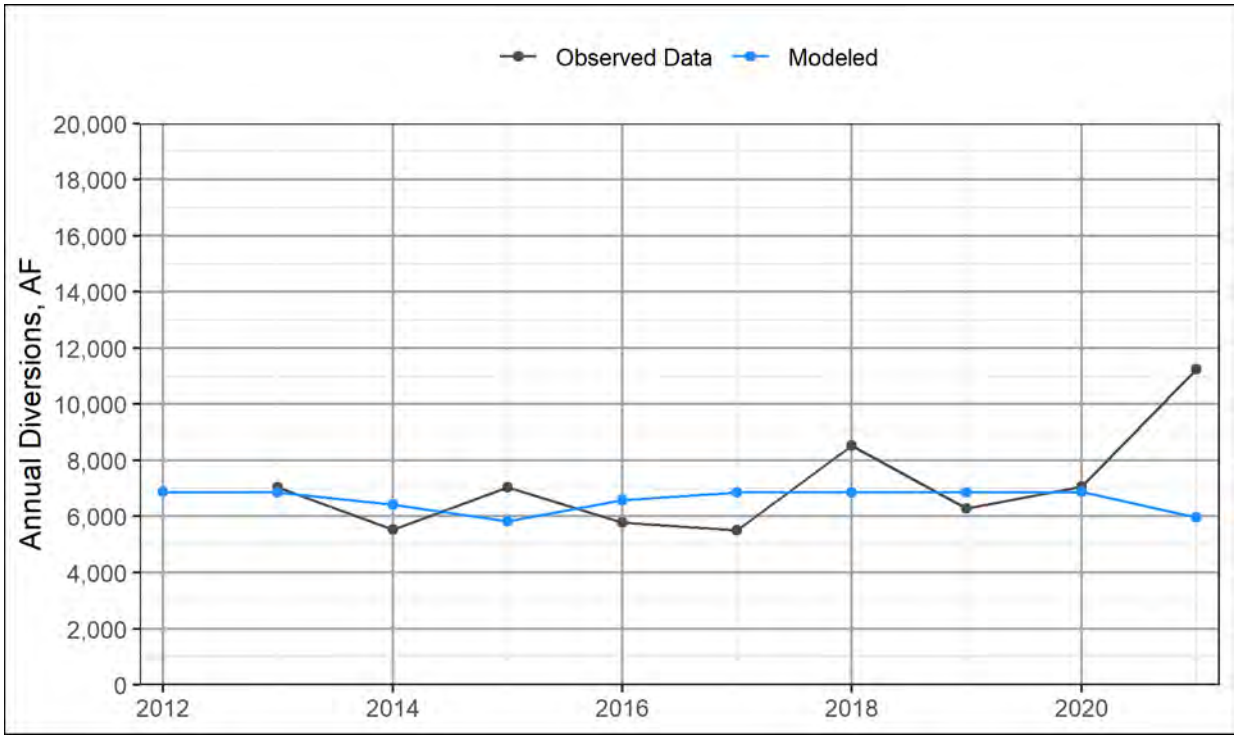


Figure C-57. NID Diversions from Rock Creek Reservoir, Water Years 2012–2021

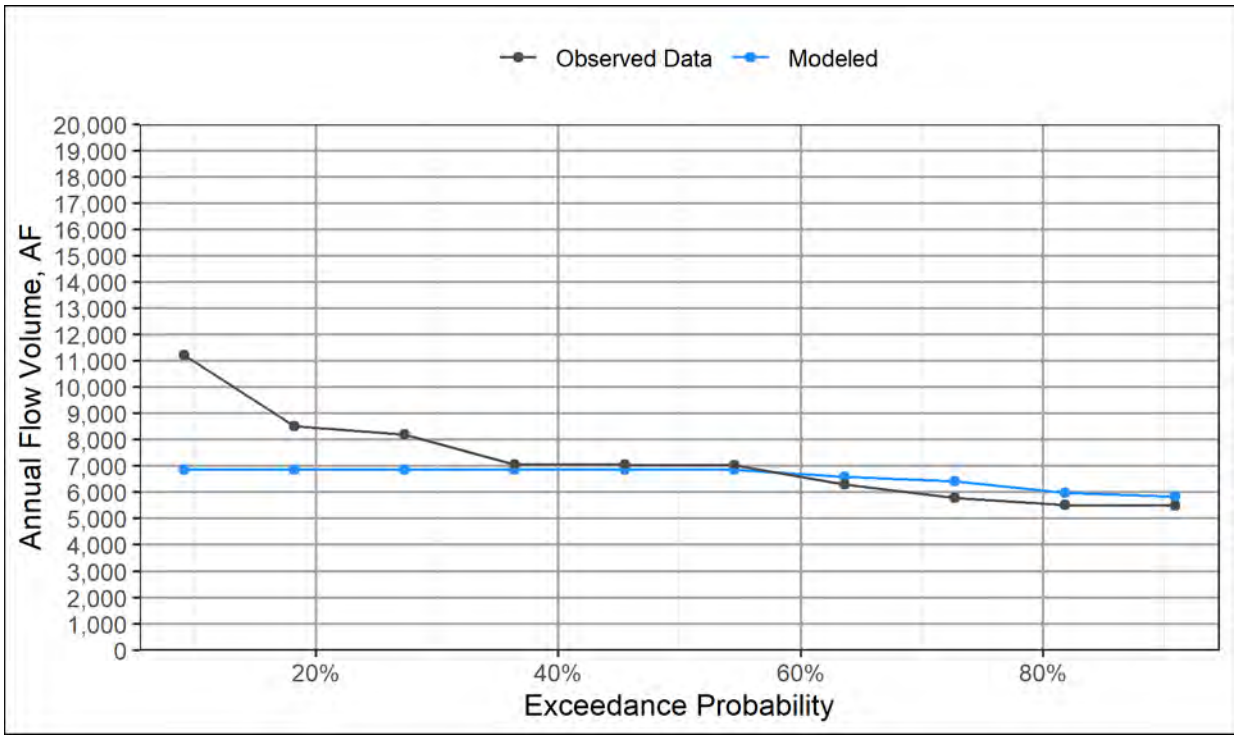


Figure C-58. Annual Diversion Exceedance to NID from Rock Creek Reservoir, Water Years 2012–2021

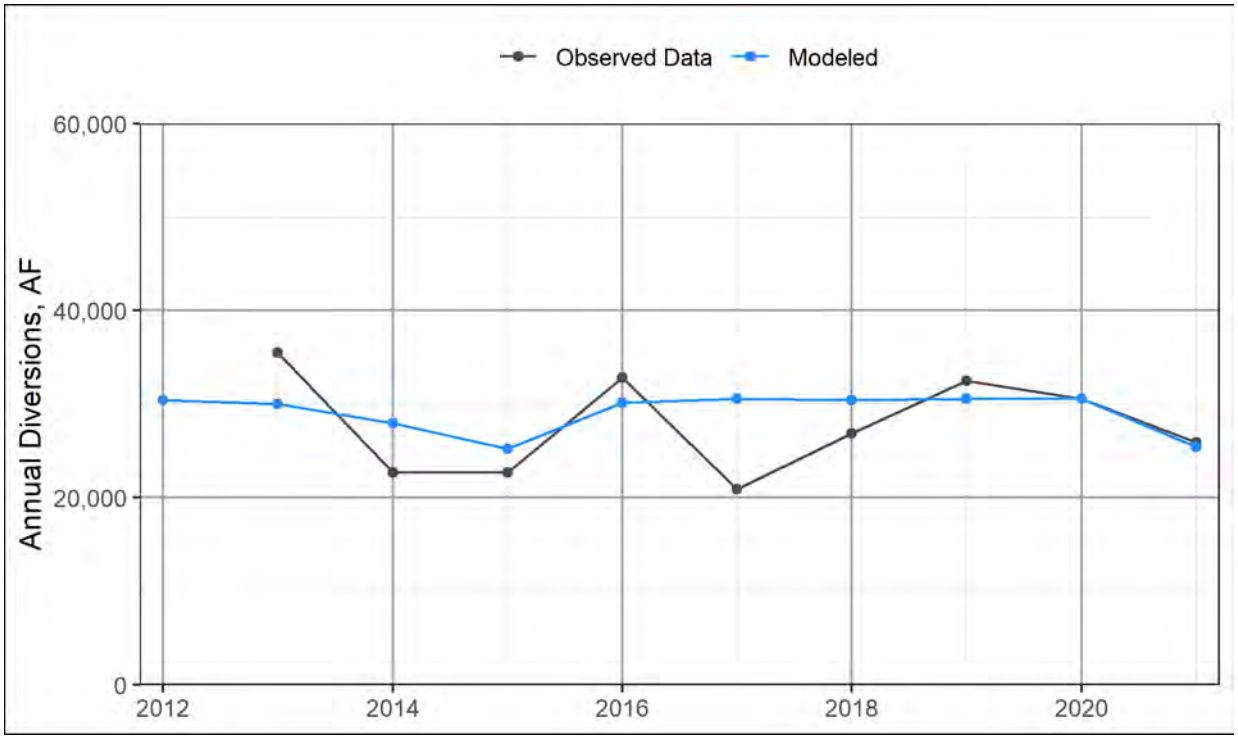


Figure C-59. NID Diversions into Auburn Ravine, Water Years 2012–2021

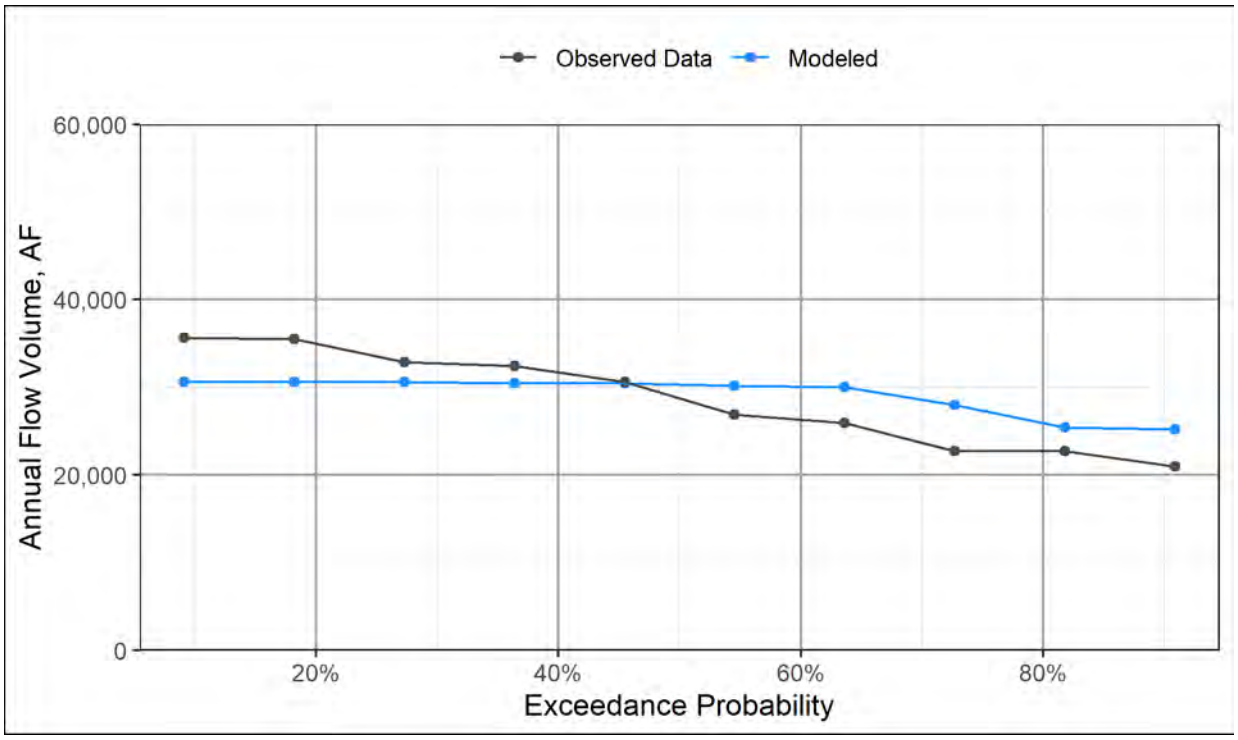


Figure C-60. Annual Diversion Exceedance NID into Auburn Ravine, Water Years 2012–2021

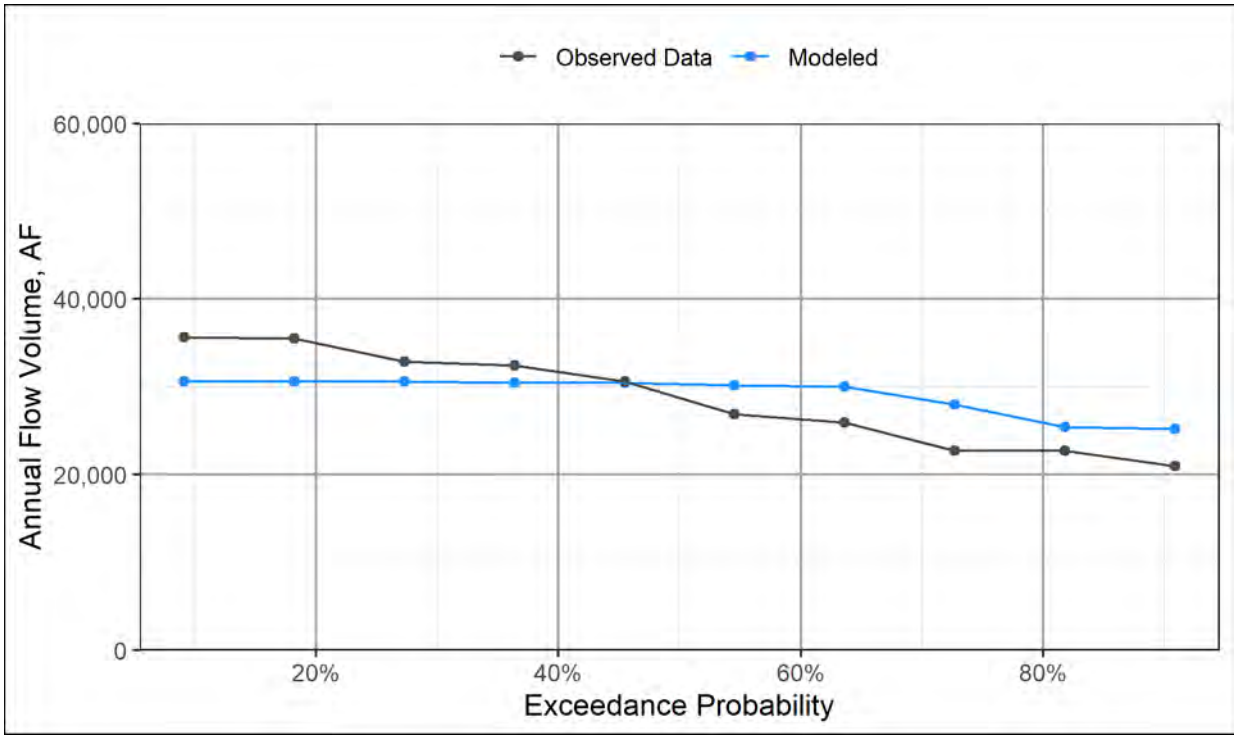


Figure C-61. Annual Diversion Exceedance NID into Auburn Ravine, Water Years 2012–2021

C.6.6. Lake Combie

Lake Combie had a bathymetric survey in 2021, which changed the estimate of storage capacity of the Reservoir. The model uses the new storage-elevation relationship from the updated bathymetric survey, while USGS storage data before 2021 uses the old storage-elevation relationship. For this reason, Lake Combie validation uses reservoir elevation rather than storage.

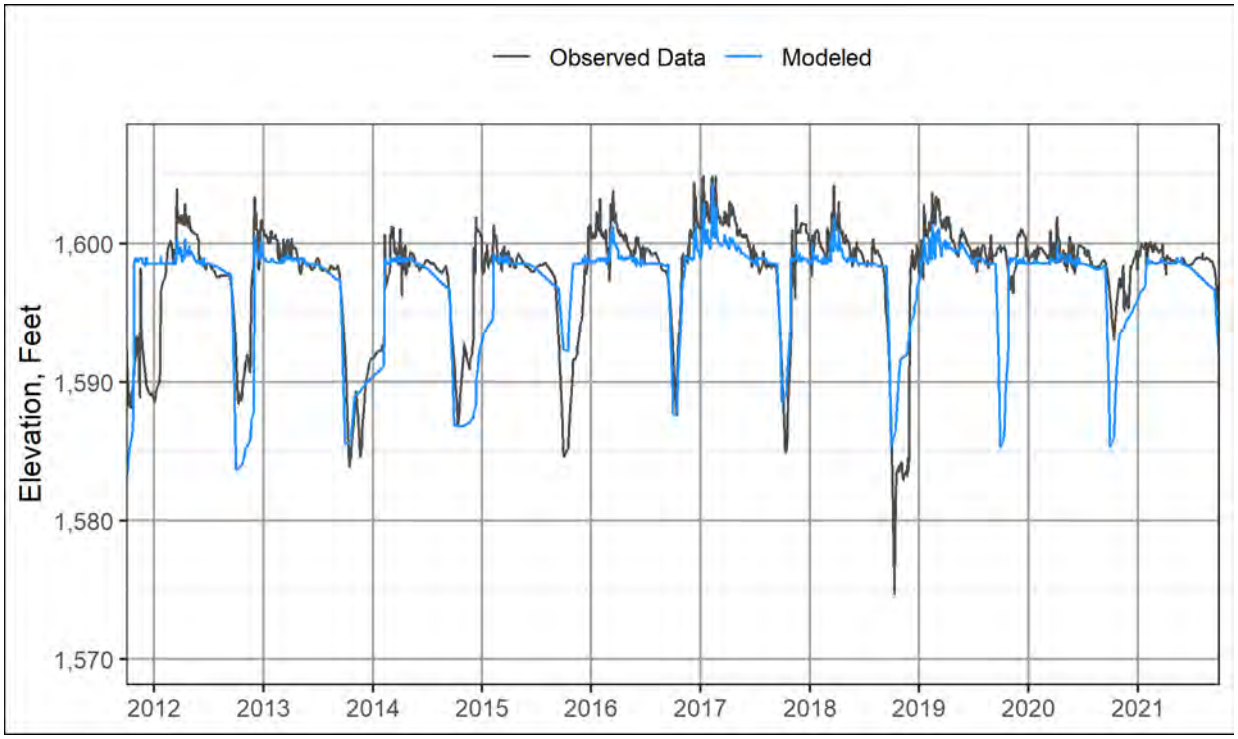


Figure C-62. Combie Lake Storage, Water Years 2012–2021

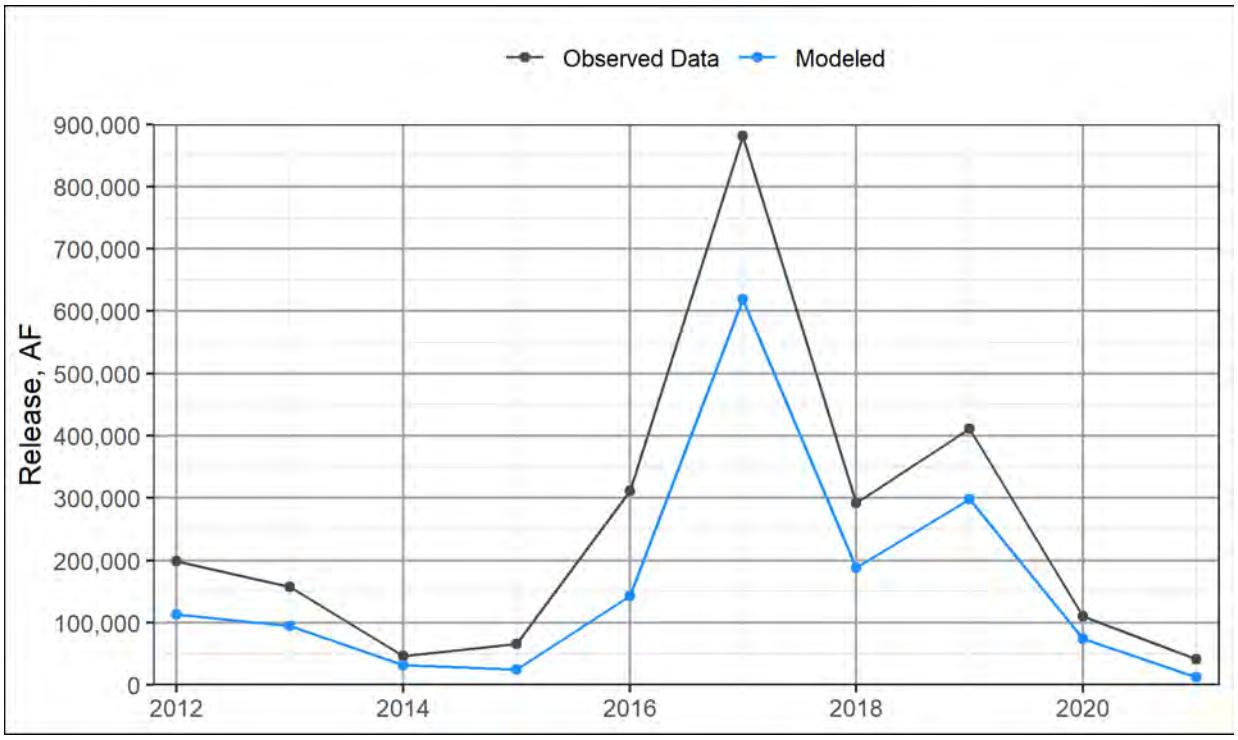


Figure C-63. Combie Lake releases to Bear River, Water Years 2012–2021

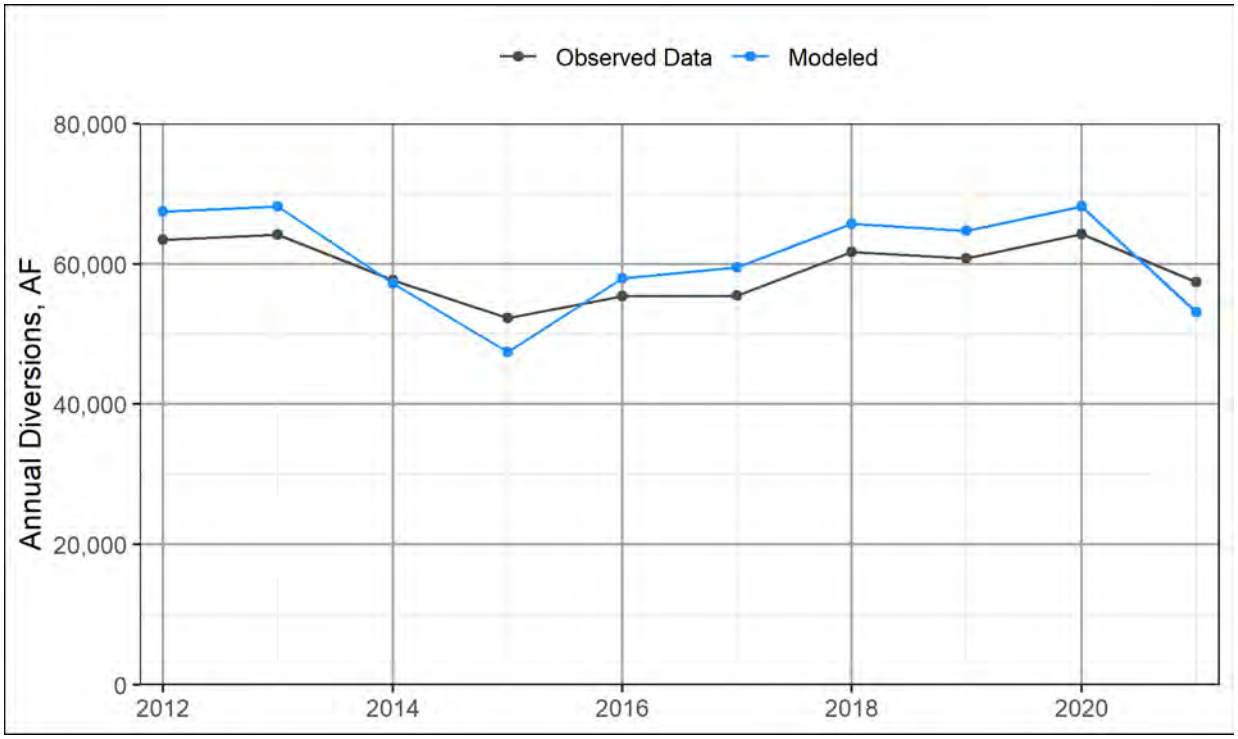


Figure C-64. Combie Lake Diversions to Phase I Canal and Magnolia III Canal, Water Years 2012–2021

C.7. Deer Creek

C.7.1. Deer Creek Powerhouse

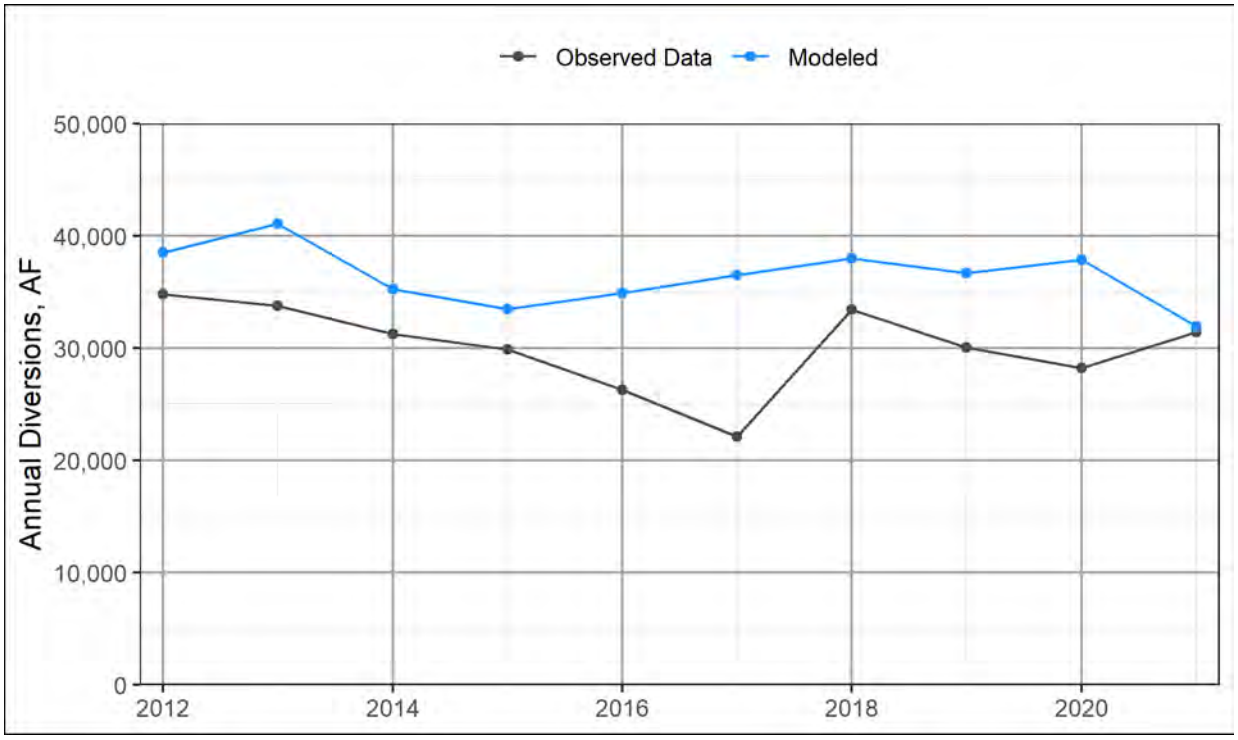


Figure C-65. Annual Flow through Deer Creek Powerhouse, Water Years 2012–2021

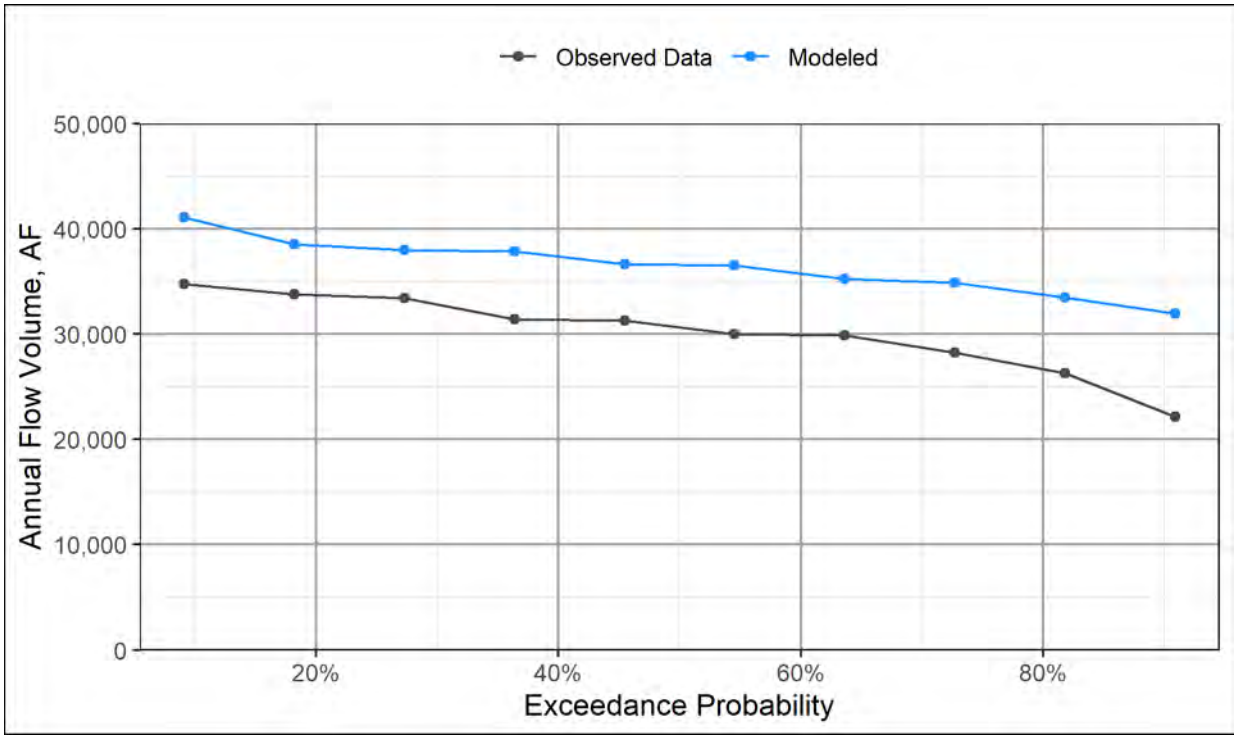


Figure C-66. Annual Flow Exceedance through Deer Creek Powerhouse, Water Years 2012–2021

C.7.2. Scotts Flat Reservoir

Scotts Flat Reservoir had a bathymetric survey in 2021, which changed the estimate of storage capacity of the Reservoir. The model uses the new storage-elevation relationship from the updated bathymetric survey, while USGS storage data before 2021 uses the old storage-elevation relationship. For this reason, Scotts Flat Reservoir validation uses reservoir elevation rather than storage.

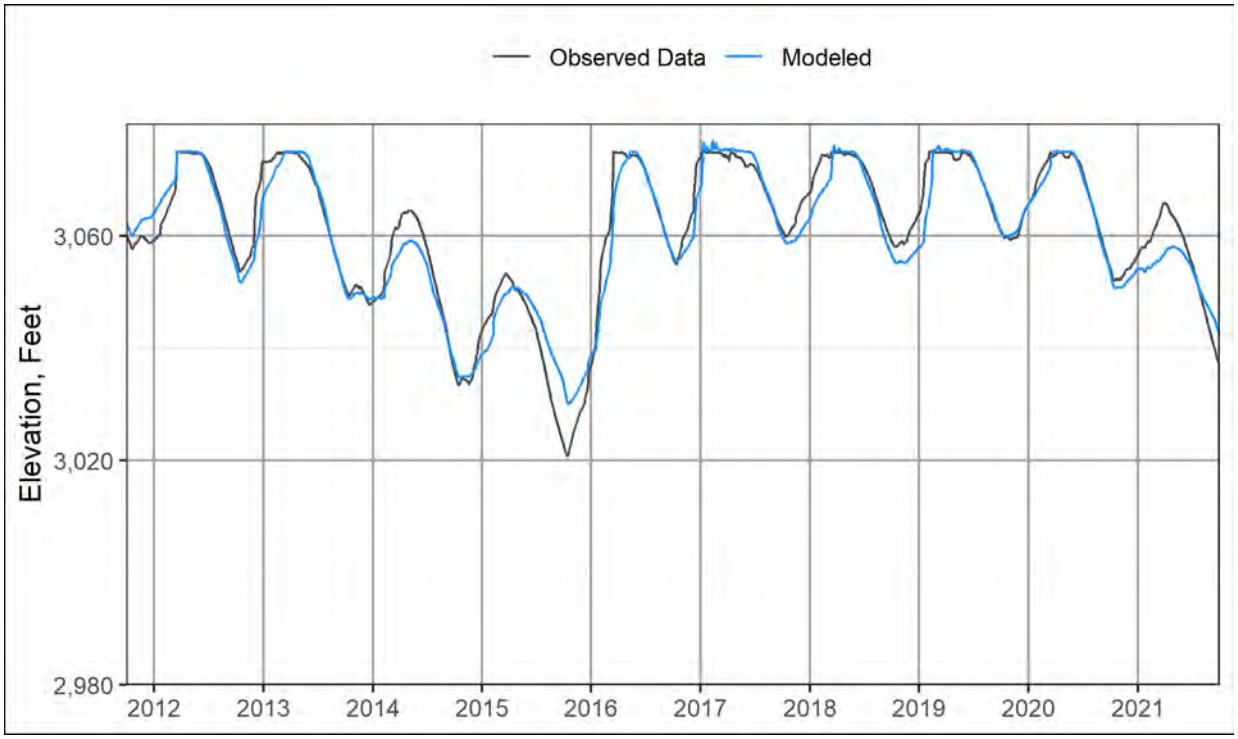


Figure C-67. Scotts Flat Reservoir Elevation, Water Years 2012–2021

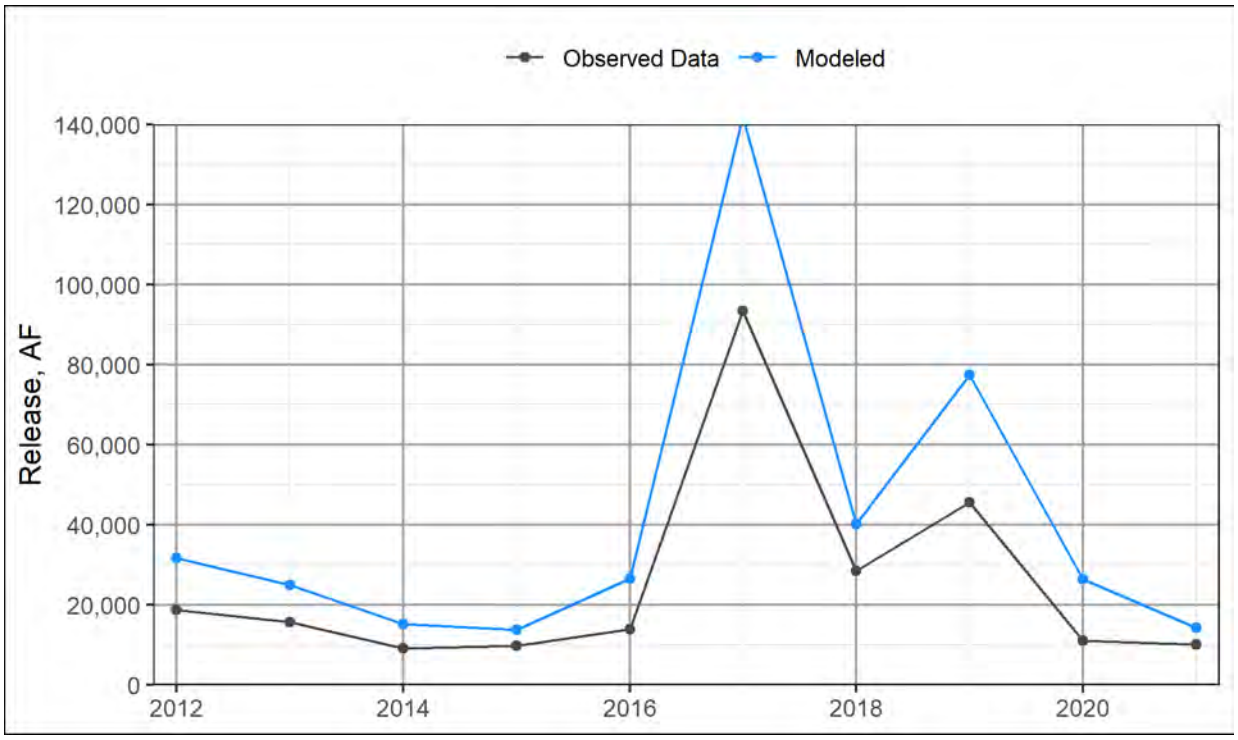


Figure C-68. Scotts Flat releases to Deer Creek, Water Years 2012–2021

C.7.3. Cascade Canal

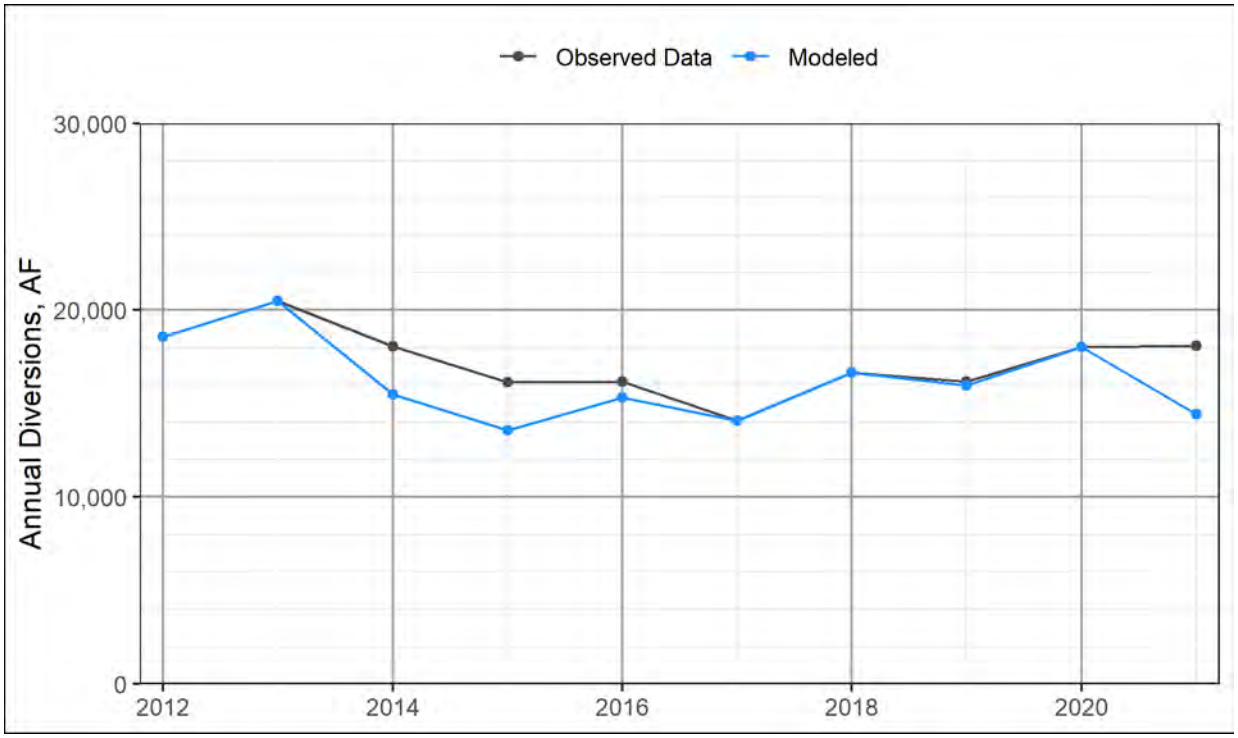


Figure C-69. Diversions to Cascade Canal, Water Years 2012–2021

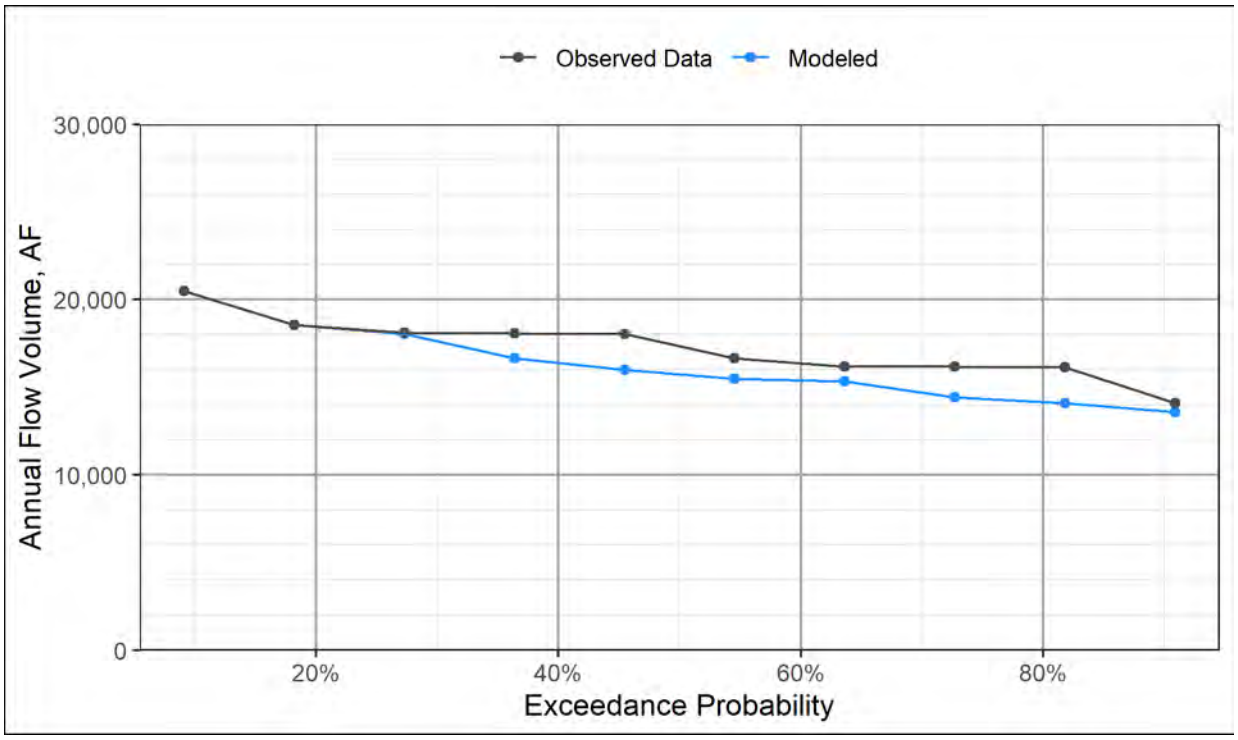


Figure C-70. Annual Diversion Exceedance to Cascade Canal, Water Years 2012–2021

C.7.4. DS Canal

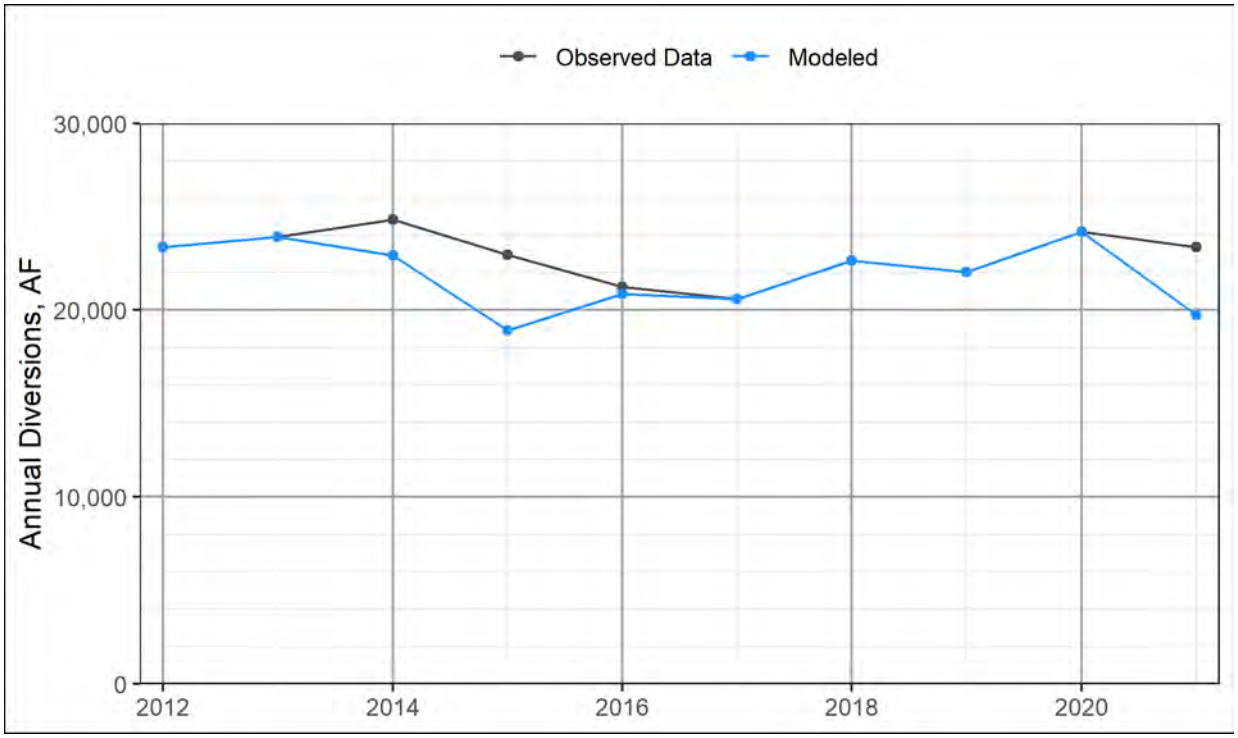


Figure C-71. Diversions to DS Canal, Water Years 2012–2021

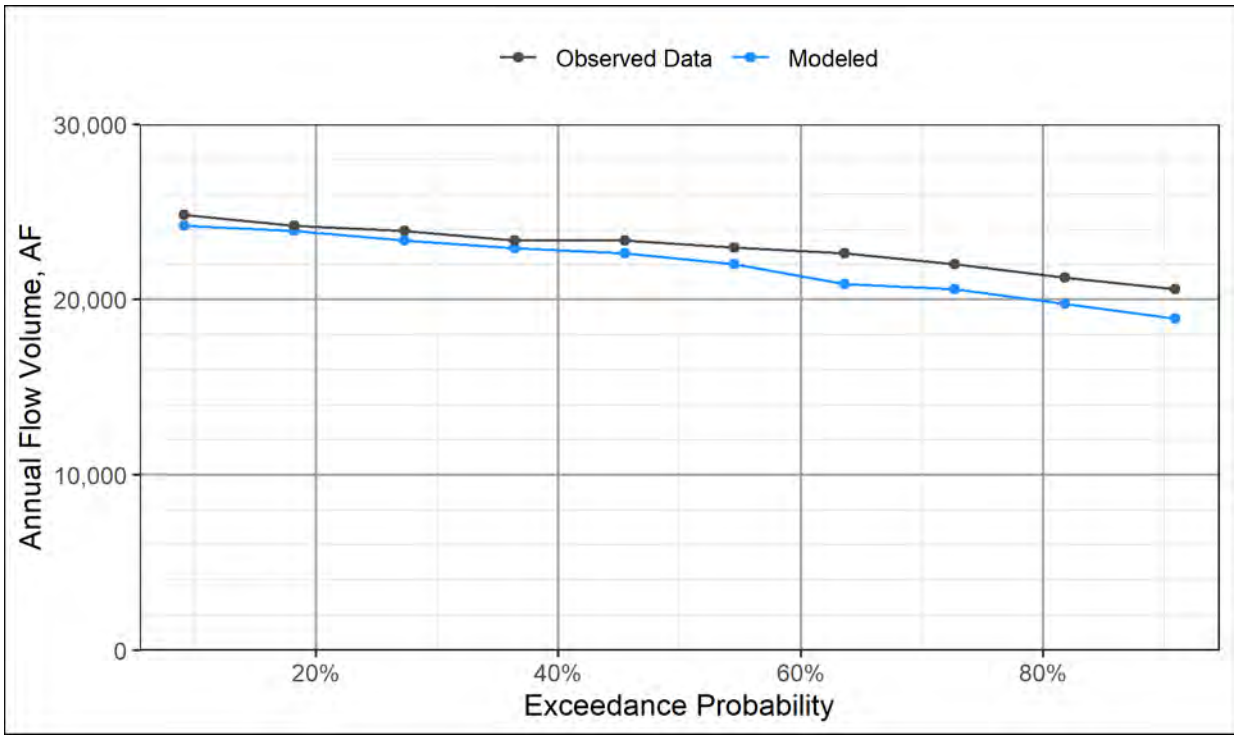


Figure C-72. Annual Diversion Exceedance to DS Canal, Water Years 2012–2021

C.7.5. Newtown Canal

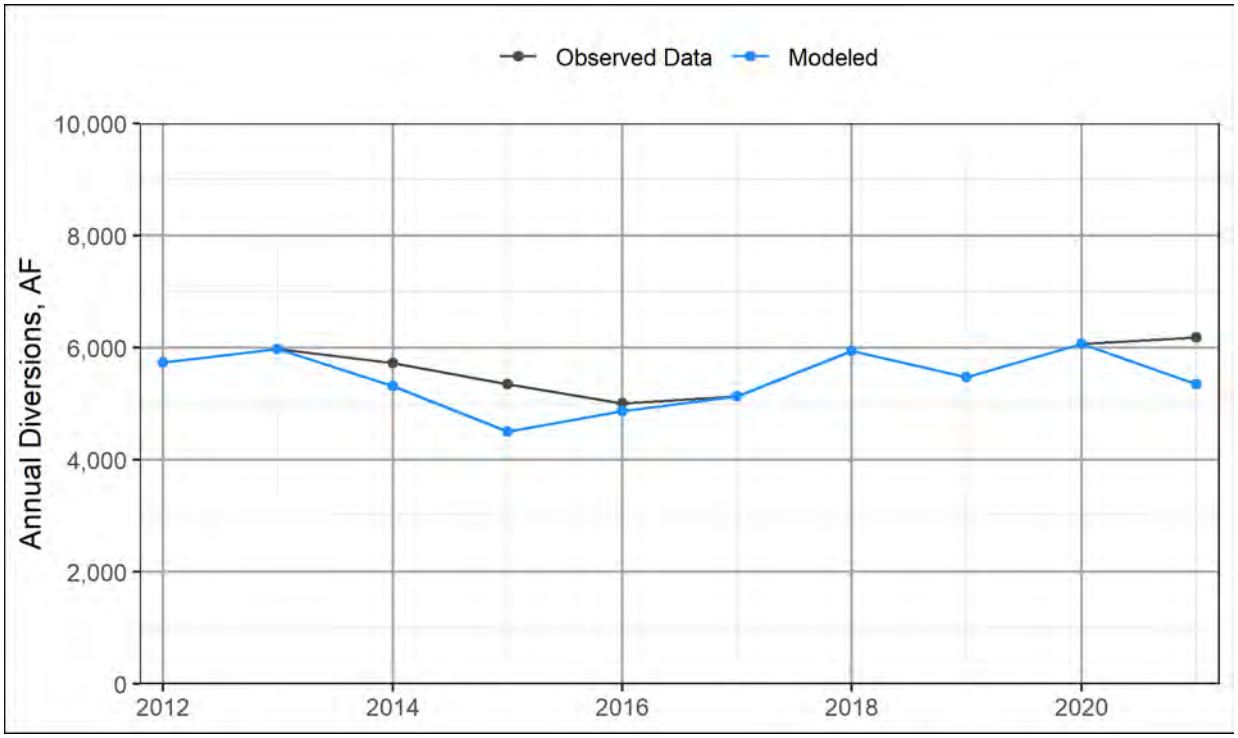


Figure C-73. Diversions to Newtown Canal, Water Years 2012–2021

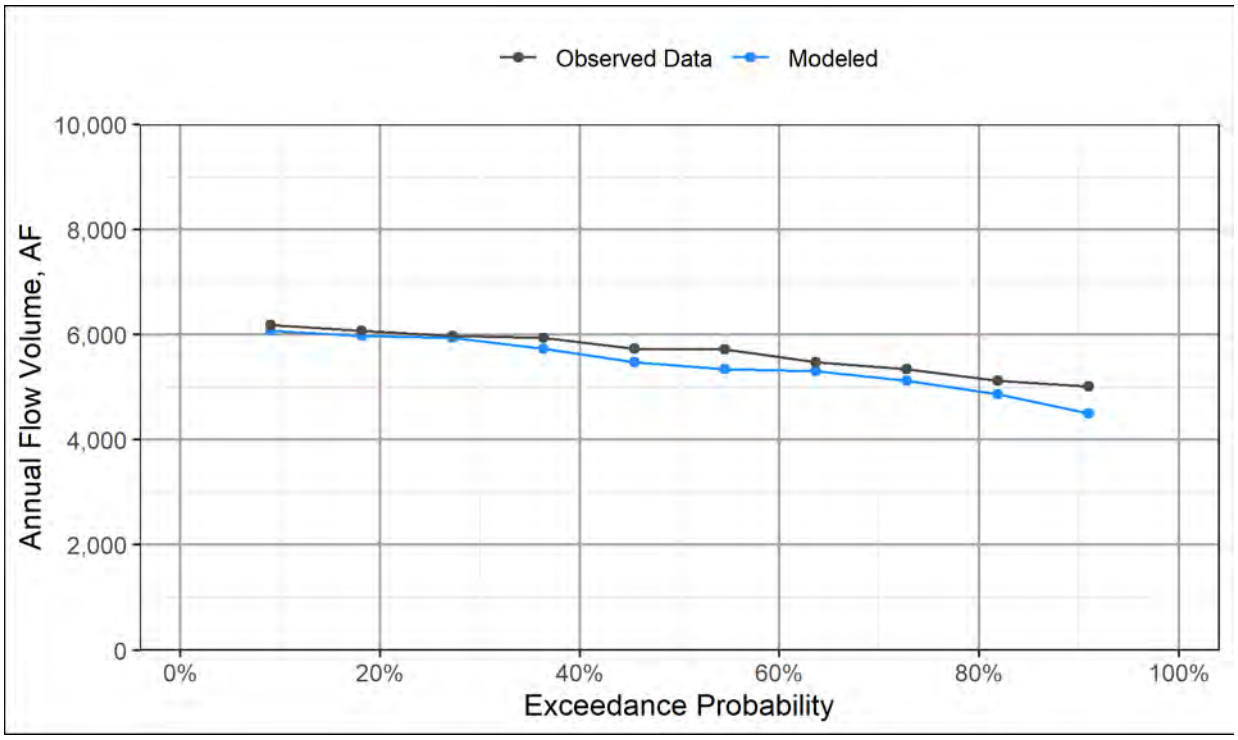


Figure C-74. Annual Diversion Exceedance to Newtown Canal, Water Years 2012–2021

C.7.6. Tunnel Canal

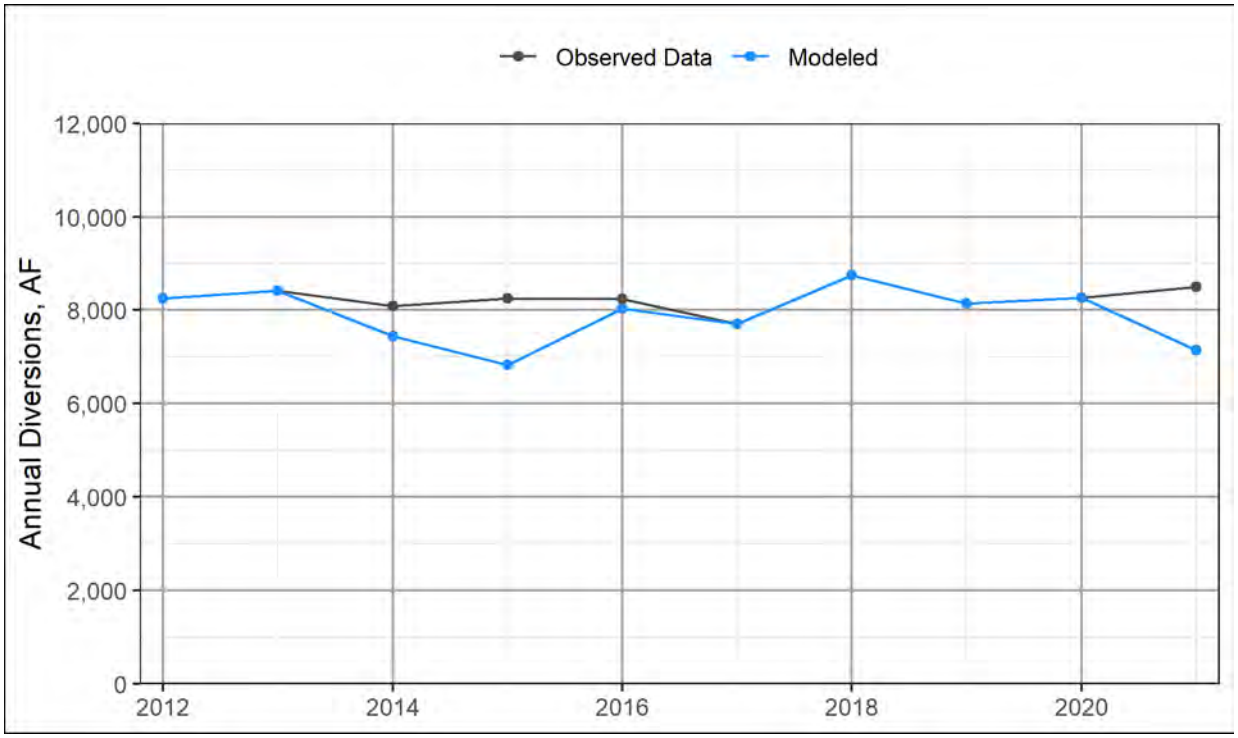


Figure C-75. Diversions to Tunnel Canal, Water Years 2012–2021

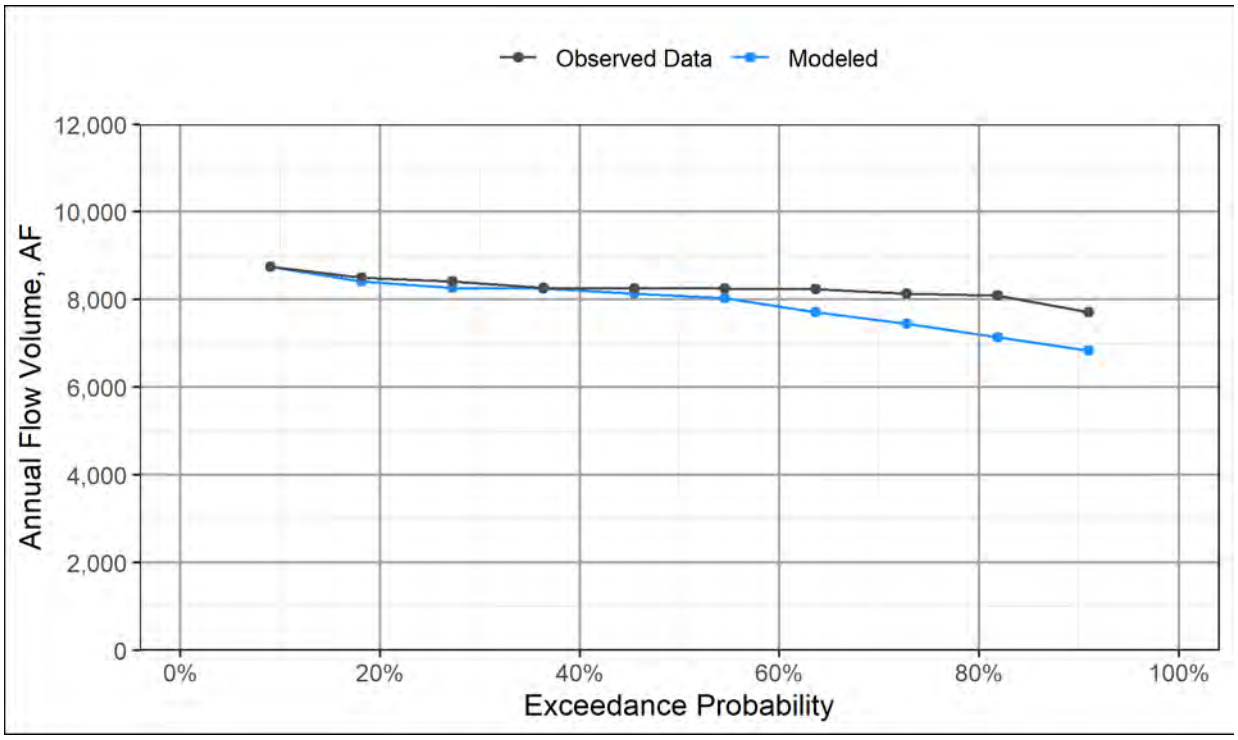


Figure C-76. Annual Diversion Exceedance to Tunnel Canal, Water Years 2012–2021

CASE STUDY: 2020 INTEGRATED WATER RESOURCES PLAN – REGIONAL NEEDS ASSESSMENT



2020 Integrated Water Resources Plan (IRP) – Regional Needs Assessment

Adopted April 12, 2022

Executive Summary

Southern California's water future in a word — uncertain.

Higher temperatures in the Southwest have led to a dramatic reduction in Colorado River runoff this century. Variable weather in Northern California and stressed ecosystems have resulted in unprecedented low imports from the State Water Project (SWP). Likewise, in Southern California itself, less stormwater is percolating into groundwater basins, both from too much rain at times or not enough.

As a regional planner for water supply reliability for Southern California, the Metropolitan Water District relied on single, mid-range forecasts during planning efforts for over a generation. At this moment, with so many questions about what lies ahead, planning that narrows in on a single forecast does not capture the breadth of uncertainties.

Scenario Planning: A Fresh Approach

In collaboration with its 26 member agencies, other interested parties, and its Board of Directors, Metropolitan has broadened its perspectives with scenario planning and thoroughly analyzing four potential futures – all different, all plausible. In the scenarios, demands on Metropolitan's imported supplies varied due to different weather and demographic patterns, among other factors. Supplies varied as well, due to reasons such as climate change severity and regulatory impacts.

After analyzing these futures, a potential for water shortages emerged. The planning revealed that a large portion of Metropolitan's service area is vulnerable to Northern California drought and regulatory restrictions. At present, Metropolitan has limited capacity to move Colorado River water to the northern portions of the district's service area served by the SWP.

The member agencies in this area are the City of Burbank, Calleguas MWD, Eastern MWD, Inland Empire Utility Agency, Las Virgenes MWD, City of Los Angeles, City of San Fernando, Three Valleys MWD, Upper San Gabriel Valley MWD, and Western MWD. About a third of Metropolitan's six-county service area lives within the boundaries of this SWP Dependent Area.

As the scenario planning process identified the potential of water shortages for these communities, the threat began to play out in real life.

The 2020 and 2021 water years experienced record low supply from Northern California due to the drought – a 20 percent SWP allocation in 2020 followed by a historically low 5 percent last year. Metropolitan declared a drought emergency in 2021 because the Dependent Areas were approaching shortage conditions.

With experience confirming analysis, Metropolitan found the possibility of shortage in three of the four scenarios, after exhausting available and accessible supplies. Only in a future with low demands and stable imported supplies would Southern California avoid shortage without additional water supply and system reliability investments. The record low supplies so far this decade from Northern California, coupled with the first-ever shortage declaration for the lower Colorado River in August 2021, suggest the region may not be so fortunate.

Scenario planning led to the following findings:

SWP Dependent Areas

- Vulnerabilities in the SWP Dependent Areas are more severe given reduced reliability of SWP supplies and Metropolitan distribution system constraints. Actions identified in the implementation phase must prioritize addressing the SWP Dependent Area's reliability challenge.
- New core[1] supplies must be accessible to the SWP Dependent Areas. Greater access to existing core supplies can also increase SWP Dependent Area reliability.
- Enhanced accessibility to core supplies and storage, both existing and new, will improve SWP Dependent Area and overall reliability. This includes improvements to Metropolitan's distribution system and capacity to deliver non-SWP supply and storage.
- Storage capacity, put/take capabilities, and accessibility are critical considerations for the SWP Dependent Area. New storage capacity and put/take capabilities should be consistent with the portfolio analysis. New storage must be accessible to the SWP Dependent Areas.

Storage

- Storage capacity, put/take capabilities, and accessibility are critical considerations in maintaining reliability under the region's current and future conditions, especially for SWP Dependent Areas.
- Maintaining Metropolitan's existing storage portfolio is critical, including the consideration of re-negotiating contracts when they expire.
- Expanding existing or developing new storage programs and investments in Metropolitan's distribution system can reduce the need for new core supply development to meet potential future shortages and adapt to climate change.
- When evaluating storage options, put/take capabilities are essential; even storage programs with modest put/take capabilities help reduce the need for flexible supply[2].

Retail Demand/Demand Management

- Metropolitan's future supply reliability may fluctuate based on demand increases and decreases.
- Variability in retail demand largely comes from changes in outdoor water use. Outdoor water use behavior is complex, influenced by weather and climate and by awareness of water scarcity and other conservation measures.
- It is important to pay attention to demand rebound, demand growth, and demand reductions, and take appropriate regional measures as necessary.
- Managing long-term demands through the efficient use of water reduces dependency on supplies, helps preserve storage, and helps reduce the need for extraordinary conservation measures.

[1] Core supplies are resource management actions that augment supply or reduce Metropolitan demand and remain available each year.

[2] Flexible supplies are implemented as needed and include savings from deliberate efforts to change water use behavior

Metropolitan Imported Supplies

- Existing imported supplies are at risk from various drivers of uncertainty.
- Maintaining existing imported supply reliability reduces the need for new core supply development and leverages years of investments.
- SWP supplies are highly susceptible to varying hydrologic conditions, climate change, and regulatory restrictions.
- Variability and capacity in SWP supplies provide opportunities to store water during wet periods for use in dry years, including Colorado River storage. Metropolitan's ability to distribute or store SWP supplies when they materialize will enhance the region's reliability, particularly the SWP Dependent Areas. The Colorado River system and Colorado River Aqueduct capacity do not offer the same opportunities concerning SWP storage.
- Shortages on the Colorado River will limit the reliability of Colorado River Aqueduct deliveries as a core supply in the future.

Local Supply

- Maintaining existing and developing new local supplies is critical in helping manage demands on Metropolitan.
- Impacts to reliability occur if local supply assumptions are not achieved; therefore, it is important to track the progress of local supply development as one of the signposts in the One Water Implementation phase.
- Additional actions may be needed should existing and future local supply levels deviate from IRP assumptions.

One Water: How a Comprehensive Solution Starts by Understanding the Need

Metropolitan's emerging One Water approach to reliability and resilience brings together all of Southern California's interests in managing finite water resources for both community and ecosystem needs. It goes beyond identifying the region's future water portfolio and embraces collaboration, diverse communities, and a unified approach to problem-solving. This 2020 IRP looks at multiple futures and builds a One Water foundation by understanding the potential needs of Southern California in the next quarter-century.

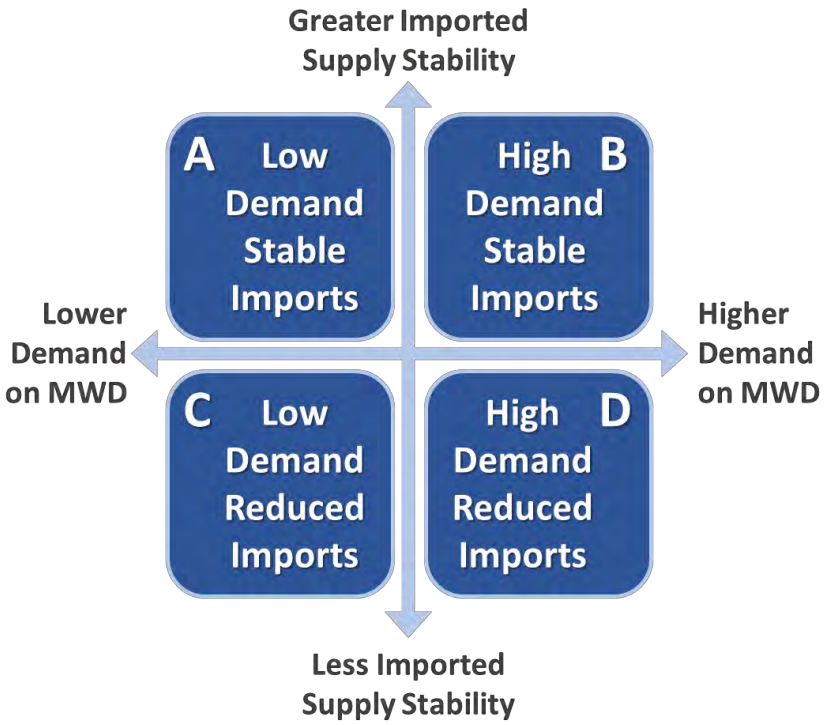
Metropolitan's stated goal is 100 percent reliability for all its Member Agencies. The first step toward achieving this goal is to identify potential shortcomings, which speaks to the wisdom of analyzing different plausible futures. The scenario analyses revealed conceivable reliability outcomes through 2045. The potential annual net shortage ranged from none under the Low Supply/Stable Imports Scenario (A) to as high as 1.2 million acre-feet (MAF) under the High Demand/Reduced Imports Scenario (D). As Metropolitan proceeds towards implementation in the next phase of the IRP, actions will address these gaps consistent with the portfolio category analysis presented in Chapter 4.

The IRP Regional Needs Assessment identifies significant threats facing Southern California's water supply reliability through successive qualitative and quantitative analysis steps. The assessment sizes up the scope of reliability challenges and the management solutions that could be in store for the region by the year 2045 under a wide range of conditions. The completion of this assessment launches the "One Water Implementation" phase, which will involve extensive collaboration among Metropolitan's Board, member agencies, and other interested parties to develop an adaptive management strategy will also establish a process for monitoring key reliability indicators and find joint approaches to the regional problems and resource needs identified in this assessment. For example, Metropolitan will continue to support the development of local supplies by Member Agencies during the One Water Implementation phase.

IRP Scenario Framework

As illustrated by **Figure ES-1**, the 2020 IRP is based on four scenarios characterized by divergent outcomes of imported supply stability and water demands on Metropolitan.

***Figure ES-1**: 2020 IRP Scenario Framework*



Key drivers of these outcomes include climate change, regulatory requirements, and the economy. These remain uncertain but significantly contribute to water supply and demands. These and other drivers of change were identified through a collaborative process. The impacts of these drivers within each scenario were quantified using Metropolitan's models.

The IRP scenarios serve as learning tools, not predictions. By contemplating four alternative but plausible outcomes, they shed light on what could happen between now and 2045. They also signal the need for future "signposts" to indicate emerging needs that may require the re-prioritization of future investments and other adaptive actions.

Technical Results

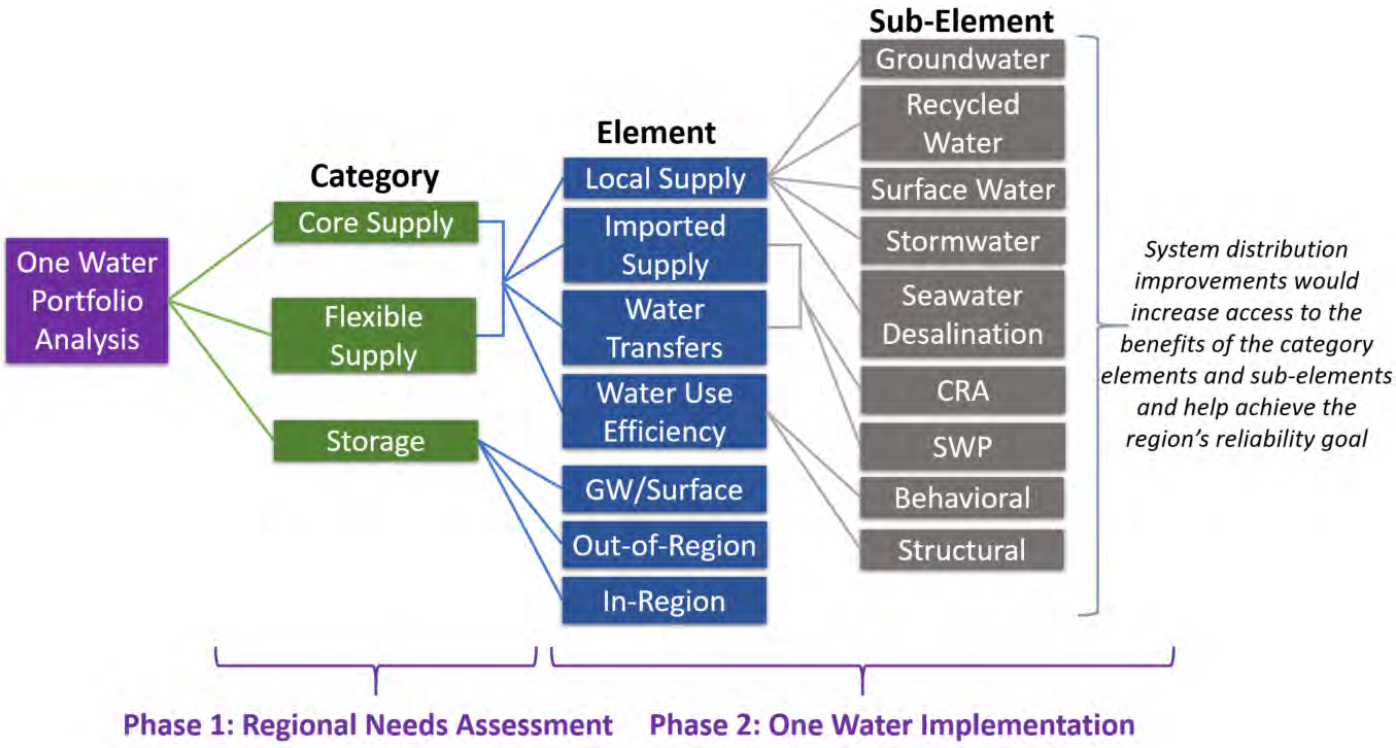
The technical results of the Regional Needs Assessment were based on two analytical processes:

- Reliability assessment to define and quantify potential "gaps" for each scenario, and
- Portfolio analyses to quantify high-level categories of actions that would be needed to achieve reliability in each scenario.

Scenario A (Low Demand/Stable Imports) posed the least challenge to reliability, Scenario D (High Demand/Reduced Imports) the greatest.

As shown in **Figure ES-2**, the portfolio analysis explored the effectiveness of supply categories to reduce or eliminate gaps. The three supply types include core, flexible, and storage. The evaluation determined an effective resource mix for each scenario at the category level.

Figure ES-2: *Levels of One Water Portfolio Analysis*



Note: The elements and sub-elements identified are examples and not meant to be an exhaustive list.

This report, which completes the IRP Regional Needs Assessment phase, offers findings, quantifies supply-demand gaps, and examines the effectiveness of generalized portfolio categories to inform implementation. The One Water Implementation phase will analyze solution portfolios at the Element and Sub-Element levels, consistent with the core supply, flexible supply, and storage configurations identified here.

These results and findings impart optimism for Southern California's water future. Metropolitan has identified the tools necessary to successfully adapt to various plausible futures using the full suite of available solutions — a comprehensive One Water approach. It is also well within Southern California's control to avoid a future with unsustainable increased per-capita water use and demands. With the

development of an adaptive management strategy, Southern California can adjust its portfolio of water actions to keep up with our changing times.

Chapter 1 - Introduction

The Evolution of Metropolitan's Integrated Water Resource Planning

The Integrated Water Resources Plan (IRP) is Metropolitan's key planning effort that establishes a long-term, comprehensive water resources strategy to provide the region with a reliable and affordable water supply. At its core, the IRP process is a collaborative effort between key interested parties – Metropolitan, its Member Agencies, other local water agencies, and community, business, environmental, and agricultural interests – to identify preferred solutions to long-term water resource reliability challenges and develop strategies to address those challenges.

The IRP is adaptive – as regional water resource issues evolve, so does the IRP. Since the inaugural IRP in 1996, Metropolitan routinely monitors conditions and measures progress in achieving the plan's objectives. As such, the IRP has been periodically updated to expand Metropolitan's strategy to address changing conditions that affect water resource reliability.

Regional Assemblies and the 1996 IRP

The 1987-1992 drought (California Department of Water Resources, 2021, pp. 4-6) exposed Southern California to significant water supply challenges across six years, prompting a change in water management, investment, and planning. In response, Metropolitan initiated regional assemblies of Metropolitan's board and senior management, member agency managers, local water agencies, and invited public officials. The assemblies established principles for agencies in the service area that would guide the development and adoption of future IRPs:

- Every water supplier, to varying degrees, relies upon the regional imported water supply distribution and storage system.
- Metropolitan is a lead agency in the region's water management.
- Every water supplier is responsible for promoting a strong water ethic to their constituents and is committed to the transparent, equitable, and fair development and implementation of water management programs to achieve regional goals.

With this foundation, Metropolitan developed the first Integrated Water Resources Plan (MWDSC, 1996). The 1996 IRP identified a "Preferred Resource Mix" based on cost-effectiveness, diversification, and reliability to supply the region through 2020. This portfolio balanced the investments between imported supply, local supply, and conservation. Additionally, the 1996 IRP emphasized the need for a coordinated network of surface and groundwater storage.

2004 IRP Update

After the 1996 IRP, drought within the Colorado River Basin resulted in the loss of surplus supplies available to Metropolitan. In 2003, the Quantification Settlement Agreement (QSA) and other related agreements established water use caps for higher-priority users in California, enabling several new water transfer programs to augment Metropolitan's basic apportionment. The 2004 IRP Update updated the original goals set in 1996, quantified the impact of changing conditions, and revised resource development targets through 2025. This first update recognized the need to adapt to changing conditions and anticipate uncertainties. These uncertainties ranged from population and economic growth, increasingly stringent water quality regulations, endangered species protections, and a shifting climate and hydrology. The update addressed these uncertainties by including a planning buffer of

10 percent of regional demands (500,000 AF) that identified additional local supplies and imported supply transfers or exchanges that could be implemented as needed.

2010 IRP Update

By 2010, the Colorado River had experienced below-average precipitation for a decade. The SWP faced new environmental and water quality protections that reduced the Sacramento-San Joaquin Delta supplies, particularly during the 2007-2009 drought. The 2010 IRP Update established adaptive management as a strategy to meet demands under observed hydrology and future uncertainty to address these changed conditions. Elements of the adaptive management strategy included:

- **Core resources.** A strategy to maintain reliability under planned conditions such as published demographic forecasts and historical hydrology.
- **Supply buffer.** This strategy expanded the earlier concept of a planning buffer to respond to shorter-term variability outside of planned conditions. This preventive action included expanding water-use efficiency and local supplies beyond the core resources.
- **Future supply actions.** This new strategy addressed long-term uncertainty by accelerating the development of new water supplies through driving feasibility studies, technological research, and regulatory review.

With the 2010 IRP Update, Metropolitan's planning efforts began to lay the foundation for a more proactive strategy to address future uncertainties.

2015 IRP Update

The 2012-2016 drought (DWR, 2021) further strained imported supplies and local groundwater basins that were already in decline from extended dry conditions and regulatory constraints. However, the region entered this drought with a record quantity of water stored within Metropolitan's network of reservoirs and groundwater banks at the time, highlighting the success of Metropolitan's investments in storage guided by the IRP. These critically dry years acted as both a stress test for Metropolitan's adaptive management strategy and a further indication of the severe challenges the future could hold. The 2015 IRP Update revised resource targets, identified transfers and exchanges to address short-term risk, and reaffirmed the importance of taking action today to accelerate the development of new water supplies through future supply actions. As such, the 2015 IRP Update developed approaches for how Metropolitan could advance conservation and local resources development and maximize its storage reserves in a future that may see more severe and frequent drought.

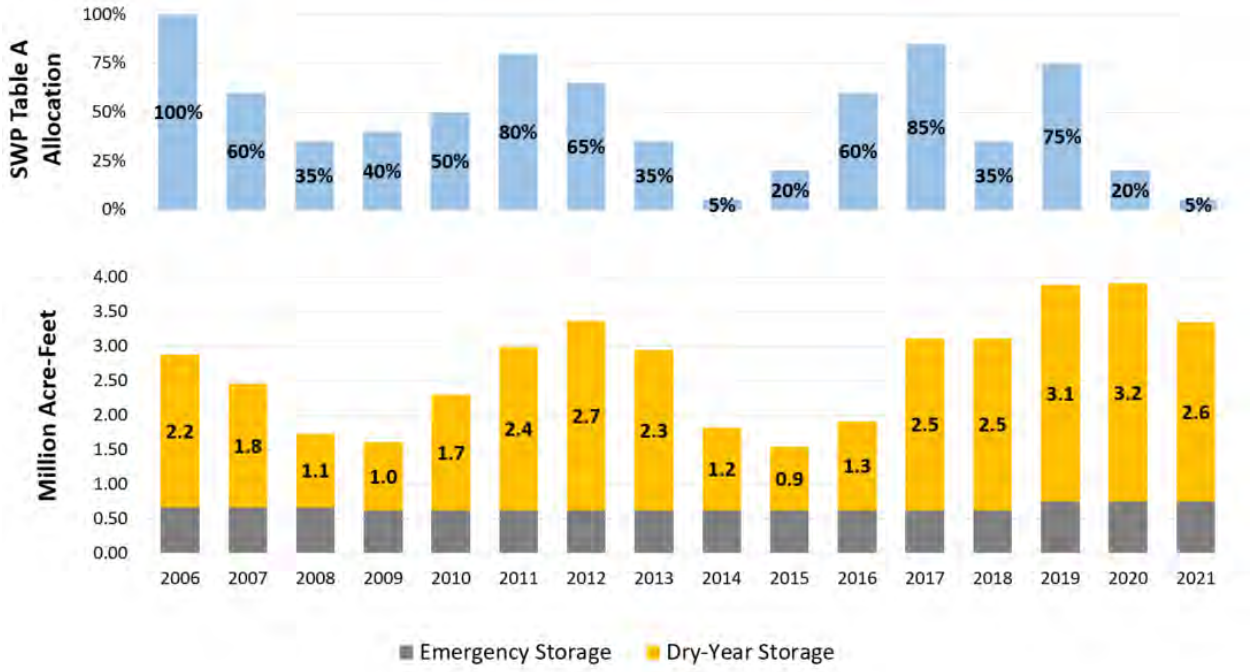
Conditions Underlying the 2020 IRP and Future Uncertainty

After the 2015 IRP Update, the region received a brief respite from drought. From 2016 to 2020, Metropolitan leveraged its prior investments in conservation, local projects, regional storage, distribution, and treatment infrastructure to rapidly improve its water supply position. Metropolitan moved a record amount of water into storage in 2017 and reached a record-high storage balance by the end of 2020 as shown in **Figure 1-1**. This figure also illustrates that Metropolitan has, through these investments, stored water in wet years when the SWP allocation was higher (2010-2012, and 2016-2017, and 2019) for use in drought years when the SWP

Metropolitan Imported Supplies Finding: *SWP supplies are highly susceptible to varying hydrologic conditions, climate change, and regulatory restrictions.*

allocation was lower (2008-2009, 2013-2015, and 2020-2021). Metropolitan's diverse portfolio investments guided by the IRP made this management of wetter hydrologic conditions possible. The region's ability to continue to effectively manage surplus water during wet years to quickly recover from dry conditions will prove vital for managing through future droughts.

Figure 1-1: *SWP Allocation and End of Year Storage Balance*



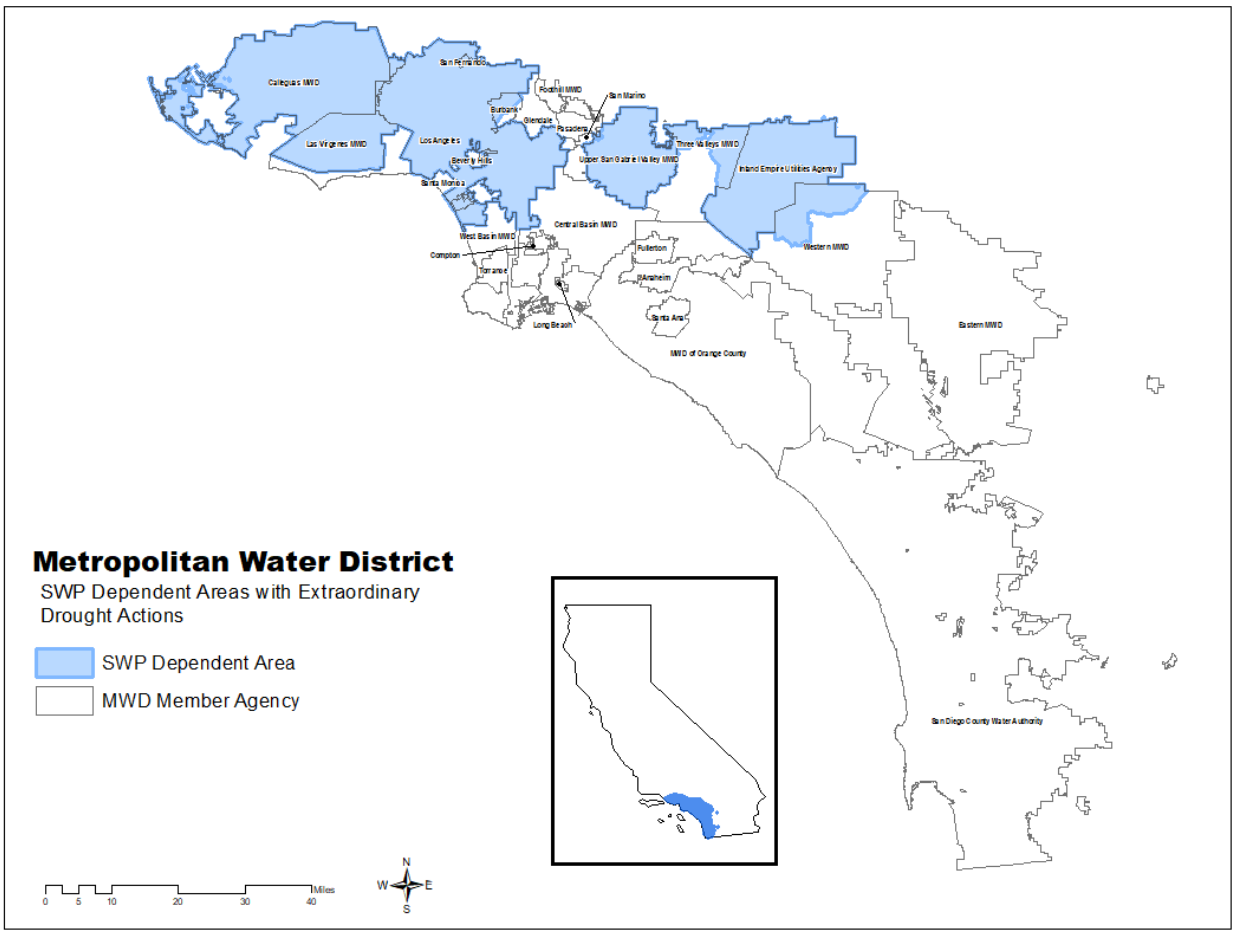
Note: End of year 2021 balance subject to DWR adjustments and USBR final accounting.

The current drought once again brought the need for regional planning sharply into focus. Despite the record amounts of water in storage at the end of 2020, consecutive low SWP allocations in 2020 (20 percent) and 2021 (5 percent) highlighted a critical vulnerability within Metropolitan's existing distribution system. Colorado River supplies cannot serve some parts of the service area that are not otherwise self-sufficient with local supplies. A key challenge for Metropolitan in 2021 was in meeting water demands in these "SWP Dependent Areas," shown in **Figure 1-2**. The very low SWP allocation of 5 percent made it imperative to safeguard the limited SWP supplies. A combination of storage withdrawals, voluntary conservation efforts, and expanded access to Colorado River supplies through extraordinary drought actions preserved SWP Table A supplies and SWP storage to meet SWP Dependent Area demands in 2021.

Vulnerability of the SWP Dependent Areas is both a near-term and long-term concern, as the findings of this 2020 IRP Regional Needs Assessment Report will emphasize. As of the writing of this report, ensuring water reliability for the SWP Dependent Areas continues to be a challenge. Metropolitan declared a regional drought emergency in November 2021 because the SWP Dependent Areas were approaching shortage. On December 1, 2021, the California Department of Water Resources (DWR) announced a zero percent initial SWP Table A allocation for 2022 based on low reservoir levels and dry hydrologic conditions; DWR later increased the 2022 SWP allocation to 15 percent in January 2022 after

favorable precipitation events in December[3]. Under a zero percent SWP allocation, there would have been insufficient SWP supplies to fully meet consumptive demands not deemed essential to human health and safety needs in the SWP Dependent Areas. Additionally, Metropolitan would be unable to replenish its regional storage in Diamond Valley Lake. As such, it is vital to maintain and preserve SWP deliveries to ensure reliability throughout Metropolitan's service area. If conditions for Metropolitan's crucial imported supply systems continue to worsen, then the region may increasingly face similar prospects in the future.

Figure 1-2: *State Water Project Dependent Areas with Extraordinary Drought Actions*



The extreme changes in hydrologic conditions since the 2015 IRP Update underscore why it is vital that the IRP evolves. While past investments have played a key role in managing through the changing conditions experienced over the past 25 years, the continued evolution of the IRP will be essential for guiding the next 25 years of investments. Today, as the forecasts of past IRPs draw inevitable comparisons to present conditions, there is a growing appreciation of the limitations inherent to any projection based on a single set of assumptions. An array of factors shaped water supply and demand trends between then and now, and many uncertainties out of Metropolitan's control loom on the

[3] As of this writing, the SWP allocation of 15 percent is not finalized for 2022. Continued dry conditions may result in a lowering of the allocation.

horizon. Mounting evidence of an increasingly varied climate and a proliferation of other external uncertainties suggest that previous IRPs may have relied on too narrow of a range of outcomes to ensure the avoidance of shortages in the future.

Figure 1-3: *Evolution of IRP Retail M&I Demand Forecast Range and Observed Historical Demand*

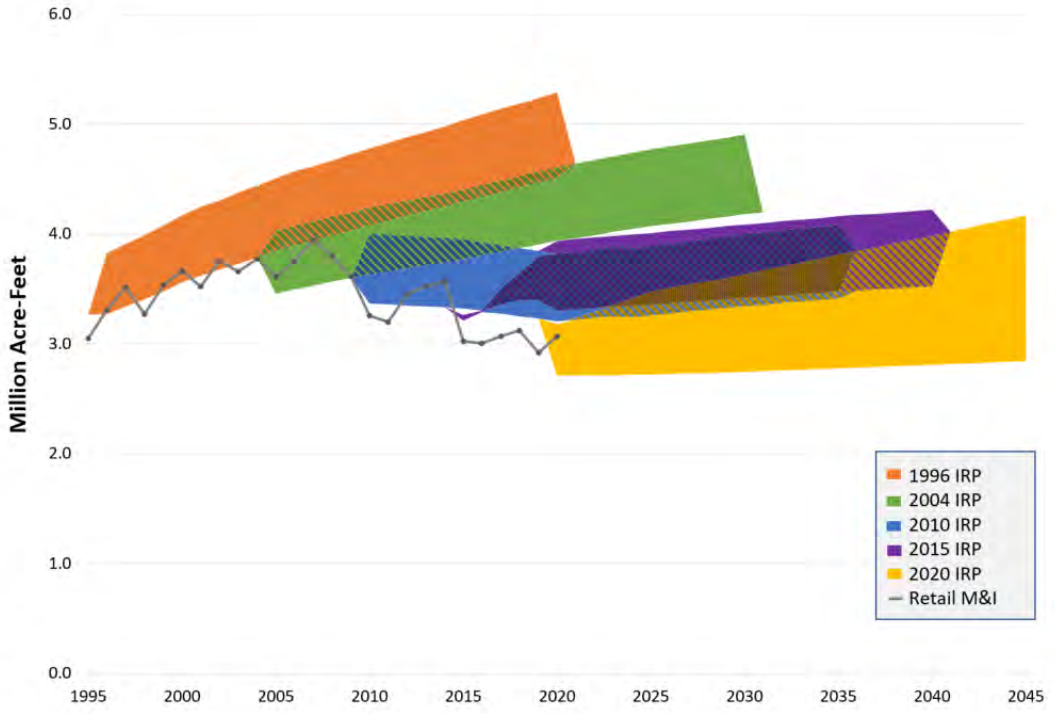


Figure 1-3 illustrates that Metropolitan recalibrated to current conditions as a baseline for each IRP update. Additionally, each IRP update incorporated new knowledge on uncertainties in the forecasts. The 2020 IRP in the yellow shaded area of the chart offers a wider range of retail demand forecasts than previous IRPs. It encompasses a range of assumptions comprising four distinct scenarios. It also takes a step forward from prior IRPs by examining a broader range of outcomes for these uncertainties, rather than just one set of assumptions as in past IRPs. For the 2020 IRP, all four scenarios launch and diverge over time from a common baseline of observed conditions leading up to the year 2020.

The 2020 Integrated Water Resource planning process features a regional needs assessment, as its first phase, that evaluates the impacts of future uncertainties on water resource reliability. This effort resulted in a comprehensive list of findings, the focus of this report, to help guide actions to address those uncertainties. Going forward, Metropolitan has the process and tools to evaluate specific investments and program actions under a range of future scenarios — developing an adaptive management strategy through the One Water Implementation that can guide implementation.

Chapter 2 – IRP Scenario Process

Planning for an Uncertain Future

It is increasingly clear that the underlying mechanisms and assumptions used to make past IRP projections are unpredictable. This means that a single long-term prediction on Southern California's water supplies and demands will provide an underestimation of the uncertainties and overconfidence in a specific presumed future. In this light, being aware of the range of alternative prospects is more useful than relying on a single projection. Thus, a new analytical framework was developed to:

- Define and account for uncertainties affecting water reliability
- Develop a method to assess and communicate the impacts of those uncertainties
- Explain the uncertainties and their relevance in a clear and transparent way
- Allow integration with an adaptive management strategy that will provide ongoing decision support, information generation, and reporting as essential components

Early on, scenario planning was selected to fulfill these objectives (Metropolitan Water District of Southern California, 2020g). Scenario building involves creativity, imagination, introspection, and reality checks based on political, economic, and scientific reasoning. To come up with a broad view of water-related uncertainties and plausible outcomes, Metropolitan undertook a comprehensive engagement process with its Board, member agency staff, other interested parties, and expert consultants.

In shaping the region's long-term water reliability, Metropolitan understood the importance of consensus on uncertainties and evaluating their impact. Public outreach and involvement for the 2020 IRP followed a different approach than before. Due to the onset of the COVID-19 pandemic in 2020, public outreach events pivoted to online presentations and workshops with additional information and public comment opportunities at IRP Committee meetings. The IRP microsite on Metropolitan's website provided access to expert panel discussions, data and analysis, presentations, and white papers. The online outreach broadened the opportunities for interested parties to engage throughout the IRP process.

Reliability Goal

Metropolitan's Board established the Integrated Resources Plan Special Committee (IRP Committee) to provide oversight and input during the development of the 2020 IRP. Early in the process, the IRP Committee reaffirmed a goal to provide 100 percent water supply reliability for the service area. This overarching goal set the tone for the IRP planning process and the basis for the subsequent analyses.

Given the Board's commitment to avoid shortages, scenario planning helped identify critical vulnerabilities and patterns that can mitigate potential shortages with timely interventions. The One Water Implementation phase will be designed to consider reliability measures under multiple scenarios.

Why Scenario Planning?

A look back since the previous 2015 IRP Update validated the collective, integrated efforts to secure water reliability for the 19 million people of Southern California (MWDSC, 2020e). When developing the 2015 IRP Update, California was enduring a historic drought, and the Colorado River watershed moved into its second decade of drought. But with a concerted drought response consistent with

Governor Brown's and the State Water Board's imposed mandatory conservation and Metropolitan's planning and policy efforts, the collective actions of water agencies throughout the region reduced per-capita water demands to historic lows. Combined with decades of planning and infrastructure investment since the original 1996 IRP, the area experienced a remarkable turnaround in water supply reliability. The efforts of individual consumers, local retail agencies, member agencies, and Metropolitan all contributed (MWDSC, 2020e).

Despite this success, long-term threats remain. Although persistently low demands since 2015 allowed storage to recover quickly, questions remain about whether per-capita demand will continue its downward trend. Further, the implication of continuing low demands on Metropolitan and the region's other potable and recycled water suppliers must be considered. For example, lower indoor use results in less wastewater with more highly concentrated effluent. This potentially increases the cost of recycling. Coming full circle, California again faces severe drought, conditions on the Colorado River worsen, and the disruption of the COVID-19 global pandemic has shaken society's conceptions of normality, perhaps causing yet unseen ripple effects in water-using behavior trends (AWWA and AMWA, 2020; MWDSC, 2020f; Smull et al., 2021).

The future can quickly move in unexpected directions. Reliability is a constant concern, both today and over the long term. Financial advisors warn investors that past performance is no guarantee of future results. Even the best-laid plans based on past and recent experience may not be resilient in a highly uncertain future. Because interventions to increase reliability come with different costs and benefits, decision-makers must consider affordability, environmental, and equity tradeoffs when deciding upon the timing and scale of those investments. Within this backdrop of emerging and unpredictable threats to water supply reliability and affordability, Metropolitan has considered the potential effects of major drivers and long-term threats as it moves into the IRP's One Water Implementation phase. Scenario planning offers a powerful tool to address these uncertainties.

With scenario planning, plausible futures are envisioned and explored. As described by Varum and Melo (2010), scenario planning helps one "gain confidence by 'pre-experiencing' future scenarios" (p. 361). This approach improves understanding of a broader range of potential outcomes. In turn, those outcomes allow a greater understanding of potential challenges to water supply reliability and the impacts of possible policy direction, helping to inform actions.

Throughout 2020 IRP's scenario planning process, the following points should be considered:

- Scenarios represent outcomes resulting from groupings of drivers of change, which are selected to be internally consistent and whose outcomes are outside of Metropolitan's control
- No scenario should be regarded as "most likely" or "preferred" as each scenario has outcomes that are entirely plausible relative to each other, and there are many other plausible scenarios that could be considered
- Each scenario reveals the potential challenges and choices that Metropolitan could face given the conditions of the scenario
- The value of scenario planning to Metropolitan is to increase awareness and preparedness, with no attempt to control, select, or predict the likelihood of the uncertain and uncontrollable conditions found in the scenario

As a decision support method, scenario planning provides Metropolitan a means to confront uncertain futures with choices that increase preparedness, improve resiliency, and manage vulnerabilities across a broad range of plausible outcomes. It also allows Metropolitan to properly weigh the tradeoffs and opportunity costs for those choices under a broad range of contingencies. Choices that perform well in several scenarios are potentially more beneficial than those that only perform well under a single group of assumptions.

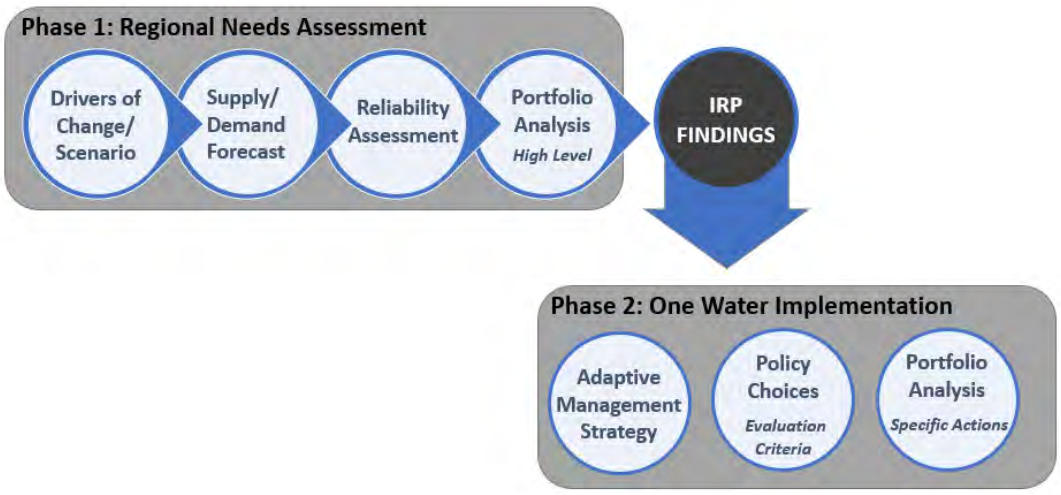
IRP Process Roadmap

With the 2020 IRP decision support method, Metropolitan explicitly examined underlying drivers of change for the water supply and demand outlook for Southern California. It used that knowledge to follow the causes and consequences of different outcomes logically. The 2020 IRP process followed the roadmap depicted in **Figure 2-1** and is divided into two phases:

- Phase 1: Regional Needs Assessment
- Phase 2: One Water Implementation

This report completes the IRP Regional Needs Assessment phase and offers findings to inform implementation. In the One Water Implementation phase, portfolios will be advanced by identifying policies, programs, and projects which provide regional solutions to the IRP Regional Needs Assessment findings. A comprehensive, adaptive management strategy will be developed in the One Water Implementation phase to guide these specific actions.

***Figure 2-1**: Roadmap for Phases 1 and 2 of 2020 IRP*



Identify Drivers of Change

The first step of the Regional Needs Assessment was to identify major sources of unavoidable and external uncertainty, or "drivers of change." This step included engaging stakeholders to help identify the drivers and select major ones to move forward into the scenario analysis. Key drivers such as climate change, regulatory requirements, population growth, and the economy have uncertain but potentially significant effects on both water supply and demands in Southern California. Outcomes of these factors greatly affect future water supply reliability.

Drivers of change were investigated through a collaborative and iterative process. Metropolitan staff engaged with the Board, member agencies, and other interested parties to solicit input on drivers of change. This involved defining and grouping a coherent set of drivers and assessing their relative impacts on Southern California's water supplies and demands. This process included an online survey collecting input from Board, member agencies, and other interested parties, asking respondents to indicate the relative importance of drivers of change. The most important drivers that emerged from the process ultimately became the basis for the IRP Scenarios discussed in this report. **Table 2-1** shows the rank order of the drivers of change based on the survey (MWDSC, 2020c).

Table 2-1: *Metropolitan's Drivers of Change Survey, Ranked by Cohort*

Board Members	%	Member Agencies	%	External Interested Parties	%
Colorado River Cooperation	95%	Colorado River Cooperation	91%	Hydrologic Variations	92%
Hydrologic Variations	90%	Stress on River Basins	87%	Outages & Disasters	87%
Stress on River Basins	90%	Direct Potable Reuse	83%	Stress on River Basins	84%
Emerging Regulations	86%	Hydrologic Variations	83%	Direct Potable Reuse	81%
Direct Potable Reuse	76%	Groundwater Contamination	78%	Groundwater Contamination	78%
Outages & Disasters	76%				

Note: Percentages are based on responses that indicated each driver of change to be either "extremely important" or "very important."

Develop Scenarios

The next step of Phase 1 was to establish alternative planning scenarios. This involved the development of separate sets of assumptions for the key drivers of change. These sets of assumptions became the basis for IRP scenarios.

Metropolitan then developed three increasingly refined iterations of IRP scenarios. The first iteration used hypothetical "Strawman Scenarios" as a proof of concept to demonstrate the feasibility of constructing scenarios from the drivers of change (MWDSC, 2020a). In September 2020, staff presented a draft set of "preliminary scenarios" that used initial drivers of change assumptions (MWDSC, 2020b). Staff incorporated extensive feedback by Board members, member agency staff, groundwater basin managers, and experts in demographics, water demand, and climate science. This process resulted in the "refined scenarios." The refined scenarios are the final scenarios that formed the basis for the reliability assessment analyses and resulting findings discussed in this report.

Supply and Demand Forecasts

The work to this point was largely qualitative. The next step was to quantify the impacts on supply and demand given the drivers-of-change assumptions for each scenario. Metropolitan conducted extensive modeling to forecast the region's retail demand, local supply projections, and resultant demand on Metropolitan over the 25-year time horizon. Additional modeling was performed to determine Metropolitan's imported supply capability for the conditions reflected in each scenario. For each of the three iterations of the four scenarios leading up to the "refined scenario," a corresponding set of retail demand forecasts, local supply projections, demands on Metropolitan, and supply capability were produced and presented to the Board IRP Committee, member agencies, and external workshops.

Reliability Assessment

After the scenarios were quantified in terms of supply and demand, the next step was to perform the reliability assessment. This began by establishing what was projected to occur if the trends identified in the scenarios continued without intervention. These was labeled the "Take No Action" case. Here, "Take No Action" means what would happen to water supplies and demands without intervention and as a result of the scenario's assumptions such as externalities outside of Metropolitan's control. The "Take No Action" case showed what would happen if Metropolitan relied solely on existing supply resources and trends. The resulting difference between supplies and demands became the "supply-demand gap," which quantifies levels of reliability.

This analytical technique isolated reliability problems posed by each scenario from the influence of presupposed solutions, allowing like-for-like comparisons between scenarios. The next analytical step enabled a clean slate for applying quantified solutions appropriate to each scenario's unique circumstances. The reliability assessment modeling was performed on each scenario to quantify the supply-demand gap projected to occur over a 25-year planning horizon ending in 2045. Reliability assessments for the preliminary and refined scenarios were presented to the Board IRP Committee in December 2020 and June 2021, respectively (MWDSC, 2020d; MWDSC, 2021a).

High-Level One Water Portfolio Analysis

The final step of the IRP Regional Needs Assessment was completing a portfolio analysis. This analysis examined each scenario to determine, in concept, what combinations of investments would be necessary to fill the gaps identified in the reliability assessment. This analysis used three mutually exclusive supply categories: core, flexible, and storage. These categories encompass different characteristics, and all resource management options are subsets of these categories. **Core supplies** are resource management actions that augment supply or reduce Metropolitan demand and remain available each year. **Flexible supplies** are implemented as needed and include savings from deliberate efforts to change water use behavior. **Storage supplies** are the capability to save water supply to meet demands later. Using a combination of three supply categories allows for a more diverse and balanced portfolio approach.

The results of these high-level portfolio analyses were presented to the Board IRP Committee in July and September 2021 (MWDSC, 2021a, 2021c). Draft findings were presented at the November 2021 Board IRP Committee (MWDSC, 2021b). The quantitative work of the Regional Needs Assessment is described in detail in Chapter 4, "Results: Phase 1 Regional Needs Assessment" of this report. Findings from the Phase 1 Regional Needs Assessment are discussed in Chapter 5, "Findings."

Phase 2: One Water Implementation

The next phase of the IRP will take the results and findings of the Phase 1 Regional Needs Assessment into a collaborative, deliberative process to come up with regional, integrated solutions. Using a One Water approach, the implementation phase will translate Phase 1's high-level portfolio analysis into potential policies, programs, and projects needed to address the findings and mitigate the potential shortages identified in this work. A comprehensive, adaptive management strategy and evaluation criteria will be developed in the implementation phase to guide these specific actions. The adaptive management strategy will also establish a process for monitoring key reliability indicators to support policymaking.

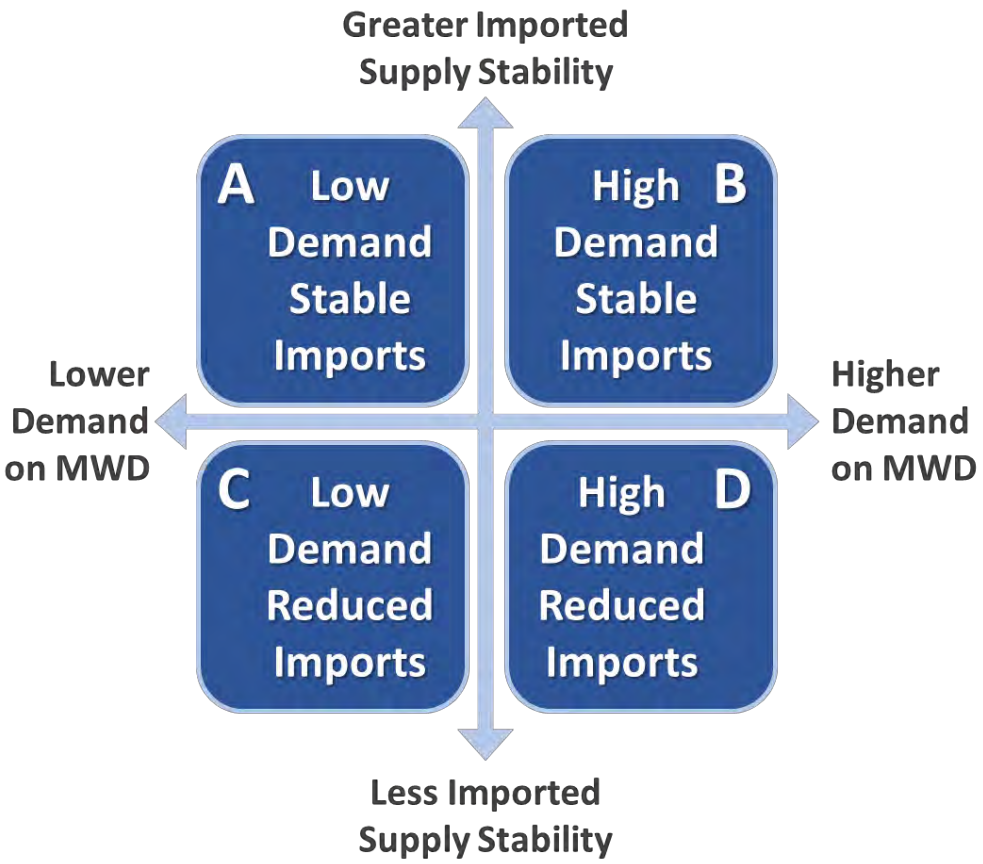
Chapter 3 – Quantifying Uncertainties

Scenario Framework and Descriptions

Quantifying uncertainties began with developing scenarios built on a comprehensive identification of drivers of change that affect supply stability and demands on Metropolitan. These drivers of change encompass basic phenomena such as climate change, economic trends, regulations, and demographic growth outside of Metropolitan's ability to control (i.e., exogenous) but fundamentally shape water reliability. Drivers of change were quantified where possible and defined to avoid double-counting their individual effects and establishing linkages between drivers.

Building on input received from the Board, member agencies, and the expert consultants, **water demands on Metropolitan** and **stability of imported supply** were identified as being the most impactful to water reliability for the region. Metropolitan then examined the drivers of change within this framework, ensuring internal consistency. This resulted in four plausible scenarios. Metropolitan then quantified the associated assumptions to reveal supply-demand gaps, against which actions could be tested. These four scenarios are shown in **Figure 3-1**.

***Figure 3-1**: 2020 IRP Scenario Framework*



As illustrated by **Figure 3-1**, the scenario framework contrasts four distinct plausible scenarios for water supply reliability planning in Metropolitan's service area. Each scenario examined a range of plausible high/low water demand coupled with a range of potential stable/reduced imported water supplies to meet the region's water demand. Inherent in determining demands on Metropolitan are consideration of local supply resources.

The major themes and narrative for the four scenarios are:

- **Scenario A – Low Demand/Stable Imports:** Gradual climate change impacts, low regulatory impacts, and slow economic growth.

  This scenario is characterized by lower retail water demands and stable regional and local supplies. Demands are impacted by lower economic and demographic growth and a continuing water use ethic across the region. Both regional and local supplies show more stable production due to less severe climate change, less restrictive regulatory constraints on existing water supply projects, and relatively robust implementation of new water supply projects at the local level.

- **Scenario B – High Demand/Stable Imports:** Gradual climate change impacts, low regulatory impacts, high economic growth.

  This scenario is characterized by higher retail demands and stable regional and local supplies. Demand is impacted by higher economic and demographic growth and a rebound of water use. Both regional and local supplies show more stable production due to less severe climate change impacts, less restrictive regulatory constraints on existing water supply projects, and relatively robust implementation of new water supply projects at the local level.

- **Scenario C – Low Demand/Reduced Imports:** Severe climate change impacts, high regulatory impacts, slow economic growth.

  This scenario is characterized by lower retail water demands and less stable imported supplies. Demand on Metropolitan is suppressed by lower economic and demographic growth and successful efforts among member agencies to manage water-use behavior and drought-proof local supplies. This scenario couples a struggling economy (i.e., slow growth) with the rapid onset of climate change impacts affecting imported supplies more than less-vulnerable local supplies.

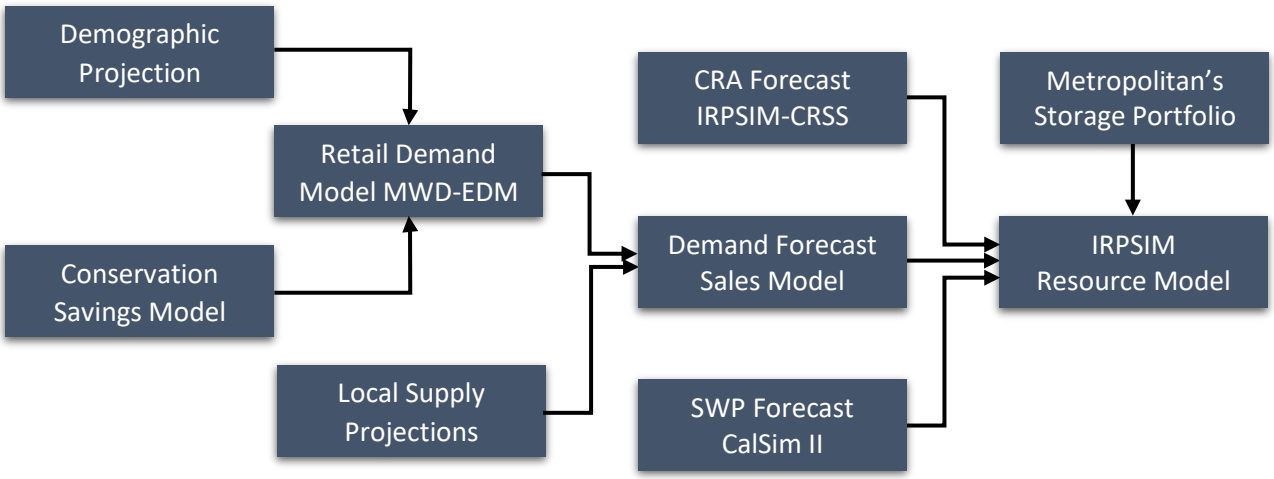
- **Scenario D – High Demand/Reduced Imports:** Severe climate change impacts, high regulatory impacts, and high economic growth.

  This scenario is characterized by higher retail demands, unstable imported, and diminishing local supplies. Demands are impacted by higher economic and demographic growth and a rebound of water use. In this scenario, severe climate change impacts both imported and local supplies. Demands on Metropolitan are increasing due to rapidly increasing demands and diminishing yield from local supplies. Local efforts to develop new local supplies are unable to mitigate these losses. Losses of regional imported supplies are equally dramatic.

Forecasting Supplies and Demands

Reliability means meeting all of the region's water demands through a combination of Metropolitan supplies, local supplies, and increased conservation. The Regional Needs Assessment quantified the range of plausible future water needs for the region through a detailed projection of demographic growth, conservation, local supply production, and the resultant need for imported water. **Figure 3-2** shows the modeling components which create the demand forecast. The demand forecast is then combined with the imported supply forecasts and the storage portfolio to assess reliability.

Figure 3-2: *Metropolitan's modeling framework for quantifying uncertainties.*



Total Retail Demand

Total demand includes M&I, agriculture, seawater barrier, and replenishment uses. Metropolitan's IRP modeling framework assesses each demand category by member agency based on characteristics unique to the member agencies.

Retail M&I Demand Forecast

Metropolitan uses a retail demand model, known as MWD Econometric Demand Model (MWD-EDM), to forecast future retail municipal and industrial (M&I) demands for each scenario using projected demographic growth and conservation savings for each of the four IRP scenarios. Metropolitan constructed demographic growth projections for Southern California with assistance from the Center for Continuing Study of the California Economy (CCSCE). CCSCE's projections were based on studies published by the U.S. Census Bureau. In addition to demographic growth, MWD-EDM also included drivers of change such as smaller lot size for future homes, future conservation, and water use ethic and rebound. MWD-EDM produces retail M&I forecasts for each scenario and member agency.

Conservation savings input for MWD-EDM were estimated using Metropolitan's Conservation Savings Model to produce post-conservation forecasts. The model calculates savings from plumbing code compliance, savings from conservation programs administered by Metropolitan and member agencies, and from price-effect conservation where water saving is realized by retail customers attributable to the effect of changes in the price of water. The Conservation Savings Model calculated conservation savings for each scenario and member agency.

At the retail consumer level, some types of water use vary more than others. Much more variability (i.e., discretion) in water using behavior is associated with outdoor use than indoor use. Because most outdoor use is for watering lawns and gardens, it makes sense that outdoor use and overall water use would increase during warmer and drier weather conditions, all else being equal. Metropolitan's modeling framework simulates the effects of weather conditions on retail demand over time.

Retail Demand/Demand Management Findings:

1) *Variability in retail demand largely comes from changes in outdoor water use. Outdoor water use behavior is complex, influenced by weather and climate and by awareness of water scarcity and other conservation measures.*
2) *It is important to pay attention to demand rebound, demand growth, and demand reductions, and take appropriate regional measures as necessary.*

However, not all things are held equal over time. Consumer behavior and ethics appear to have changed significantly since the 2015 IRP Update, as can be inferred from regional per capita water use that has remained relatively low since the 2015 drought. Consumers are influenced to reduce their water using behaviors through greater environmental awareness, rising water prices, and conservation messaging and restrictions. These consumer signals have been increasing in frequency and intensity, coinciding with the severity of recent droughts, which in turn may be a symptom of climate change. For instance, with incentives from Metropolitan and local water agencies and perhaps encouraged by the example of early-adopter neighbors, more and more Southern California residents have taken action to permanently reduce outdoor water use by removing their lawns since 2015. Conscientious outdoor water use reinforced by ongoing drought conservation measures, combined with the improving efficiency of new water using devices, have kept the region's retail water demands relatively low every year through 2019, the year that Metropolitan used to calibrate its demand projections for the 2020 IRP Regional Needs Assessment. This is despite fluctuations in weather conditions that would have otherwise driven demands higher. This is not to say that consumer ethic would not revert back to higher-use, especially in the absence of continued intervention. With regard to scenario planning, consumer water use ethic will continue to be a considerable force for greater or lesser water reliability, and future trends are uncertain in a long-term planning horizon. This uncertainty is reflected in the scenarios.

MWD-EDM calibrates the forecast to 2019 M&I water use by member agency, which serves as the anchor point of the forecast. Calibrating the model to 2019 assumes that the water-use ethic from 2019 would continue. However, the IRP scenarios also assume some rebound in water use. Conservation savings were categorized as (1) **structural** based on efficiency improvements such as replacing water fixtures with more efficient ones, and (2) **behavioral** reflecting changing consumer water use behavior in response to conservation messaging and education. Structural conservation is more permanent and unidirectional, while behavioral conservation can fluctuate over time. For example, outdoor behavioral conservation such as reducing the number of watering days for lawns during a drought reduces water use. Returning to previous watering schedules after the drought would increase water use which can be described as a demand rebound. If a complete rebound were to occur, overall retail demand would be more than 10 percent higher than a forecast without any rebound.

Other Retail Demand Forecast

In addition to retail M&I demand, the IRP reliability assessment considered retail agricultural, seawater barrier, and replenishment demands. Retail agricultural demand consists of water use for commercial irrigation of crops. Uncertainties about agricultural use include land-use changes, regulatory requirements, and economic conditions, which ultimately impact the operation cost for agricultural water users. Higher costs for agriculture could plausibly lead to a decline in water use. Additionally, a warmer climate could increase the water use requirements of existing crops. For the 2020 IRP, Metropolitan coordinated with member agencies to develop agricultural demand projections.

Seawater barrier demand prevents seawater intrusion into coastal groundwater basins. Metropolitan worked with groundwater basin managers to determine the barrier requirements based on groundwater levels, injection wells, and regulatory permits. Uncertainties include climate change impacts from rising sea levels. For example, overcoming hydraulic pressure from rising seas necessitates increasing seawater barrier demands from local recycled water projects and supplementing imported water. For the 2020 IRP, Metropolitan assumed seawater barrier demands could plausibly increase in scenarios with higher relative sea-level rise associated with severe climate change impacts.

Replenishment demand maintains sustainable groundwater basin health and production. Metropolitan quantified replenishment demand only from recycled water and imported water. Replenishment demand projections provided by member agencies are informed by groundwater basin management policies, groundwater production, and natural and artificial recharge assumptions. For the 2020 IRP, Metropolitan held workshops with groundwater basin managers and member agencies to discuss impacts to replenishment demands, including climate change and regulatory requirements. Outcomes of these discussions highlighted the importance of the timing and implementation of indirect potable reuse and stormwater capture projects and potential changes to natural and artificial recharge due to climate change. Feedback from these workshops was incorporated into replenishment demand projections for each scenario.

Local Supply Projections

Local supplies are produced to meet individual agency demands and are key to determining how much Metropolitan supply is needed. They include groundwater, surface water, the Los Angeles Aqueduct, recycled water, groundwater recovery, and seawater desalination. Local supply projections use information from several sources, including local Urban Water Management Plans, Metropolitan's annual local supply survey, and coordination with local agency staff.

For the 2020 IRP, Metropolitan held focused workshops with the member agencies to gain insights on the challenges facing local supplies and the potential impact on water reliability. These workshops discussed the same drivers identified earlier (economic conditions, climate change, and regulatory restrictions). Through these workshops, the effect of the drivers on existing local supplies and the timing and implementation of future local supply projects was considered.

From these discussions, Metropolitan developed local supply projections that examined the degradation of existing supplies in combination with different timing and implementation of the inventory of future

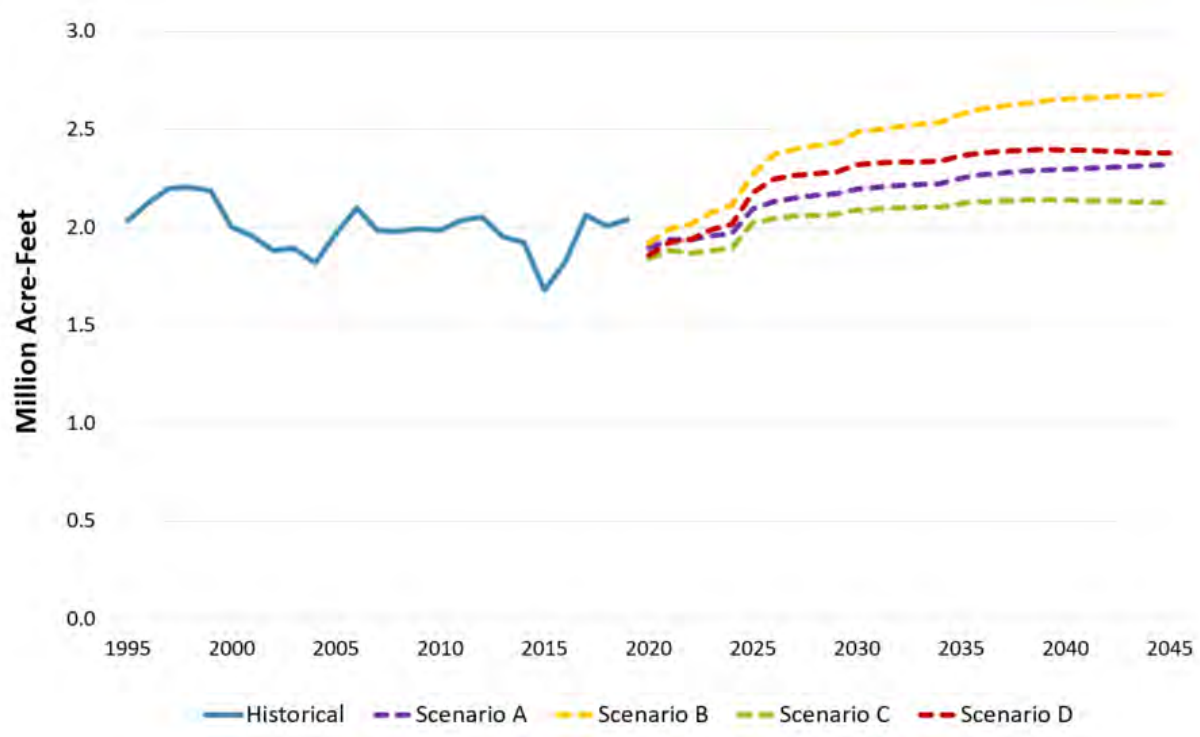
local supply projects provided by member agencies. One example of local supply degradation is decreased groundwater production due to a loss of replenishment from changing precipitation patterns or reduced return flows from outdoor irrigation. Additionally, while there was a large inventory of future local supply projects, many still require additional permitting and design. Thus, there remains uncertainty in when projects will come online and how much new water those projects will produce.

Figure 3-3 demonstrates the broad range of potential outcomes of local supply production. Depending on the region's success in implementing new projects and preventing the degradation of existing supplies, the region may continue to see modest growth in local production. The level of growth in future local supply is important to offset varying levels of growing demands, as any growth in demand that cannot be offset by new local supply adds additional demand on Metropolitan.

Local Supply Findings:

1) *Impacts to reliability occur if local supply assumptions are not achieved; therefore, it is important to track the progress of local supply development as one of the signposts in the One Water Implementation phase.*
2) *Additional actions may be needed should existing and future local supply levels deviate from IRP assumptions.*

Figure 3-3: *Total Local Supply under Average Conditions*



Determining Demands on Metropolitan

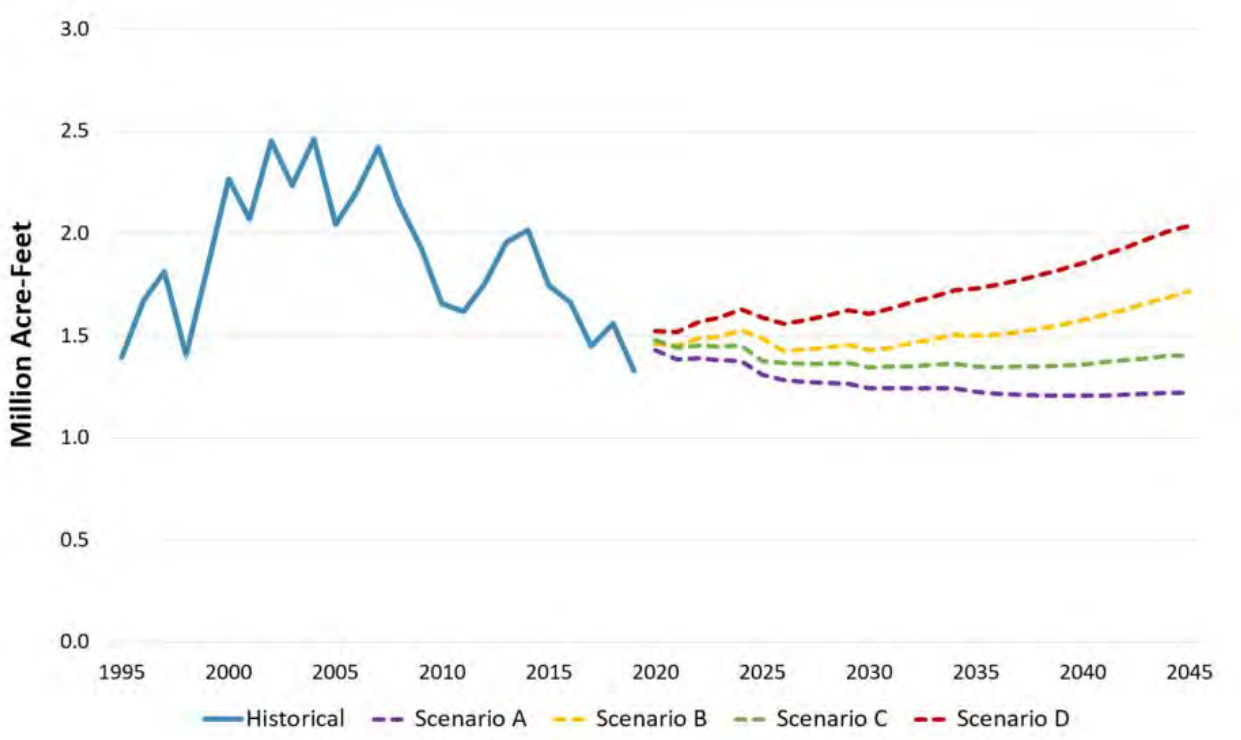
Once retail demand forecasts and local supply projections are developed, the next step is to calculate future demand on Metropolitan. Imported water from Metropolitan serves as a supplemental supply source for its 26 member agencies. For some member agencies, their primary sources of water are

produced locally. When local supplies are insufficient to meet retail demands, member agencies purchase supplemental water from Metropolitan. These purchases constitute the demands on Metropolitan.

Demands on Metropolitan are calculated using Metropolitan's Sales Model. This model accounts for weather-related variations to retail demands and local supplies and ultimately produces a range of forecasted demand on Metropolitan. For the 2020 IRP, Metropolitan engaged with climate expert consultants to develop techniques to incorporate climate change impacts to local precipitation within the Sales Model's existing 96 hydrologic sequence methodology. These modifications increased the frequency and intensity of dry years and decreased the frequency of wet years (but increased their intensity) while maintaining a similar long-term average precipitation. The Sales Model forecasts a range of demands on Metropolitan for each IRP scenario as shown in **Figure 3-4**.

Retail Demand/Demand Management Finding:
Metropolitan's future supply reliability may fluctuate based on demand increases and decreases.

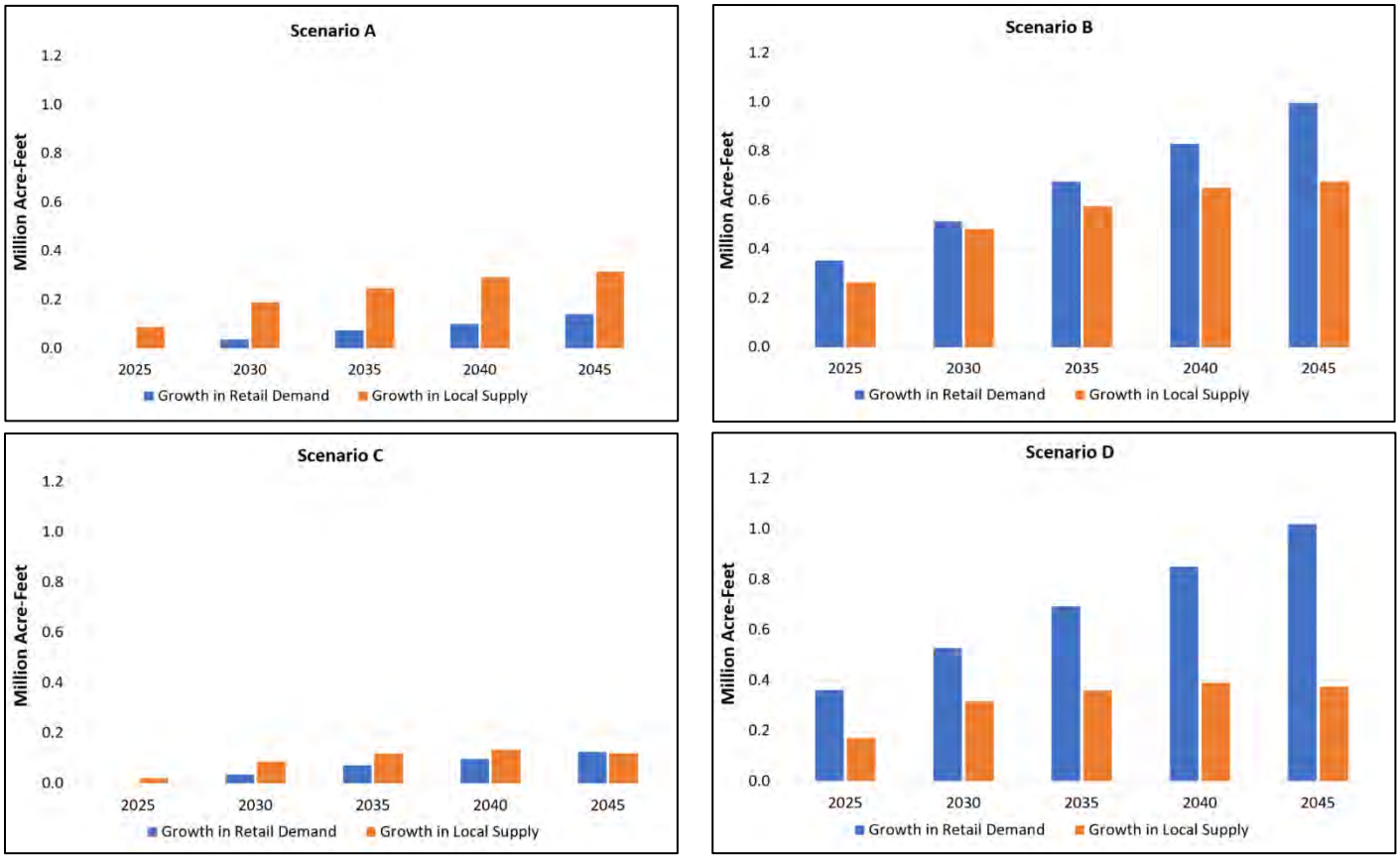
Figure 3-4: *Total Net Demand on Metropolitan*



Local Supply Finding:
Maintaining existing and developing new local supplies is critical in helping manage demands on Metropolitan.

Demand on Metropolitan is driven by the relative growth of the region's retail demand and local supply production. The difference between retail demand and local supply production is the assumed demand on Metropolitan. **Figure 3-5** shows the relative growth compared to 2020 of retail demand versus local supply production growth for each scenario. In Scenarios B and D, where retail demand growth is high, the proportion of unmet demand needed to be satisfied by Metropolitan is larger than the proportion for the lower demand Scenarios A and C. Despite having the highest assumed local supply growth in Scenario B, retail demand growth outpaces local supply production growth and additional actions would be needed to manage growing demands on Metropolitan in that scenario. In Scenarios A and C, the projected growth in local supply production is greater than the forecasted growth in demand, highlighting the importance in growing and maintaining local supply production in all scenarios.

Figure 3-5: *Growth in Demand vs. Growth in Local Supply Production Relative to 2020 in Average Conditions, Scenarios A, B, C, and D*

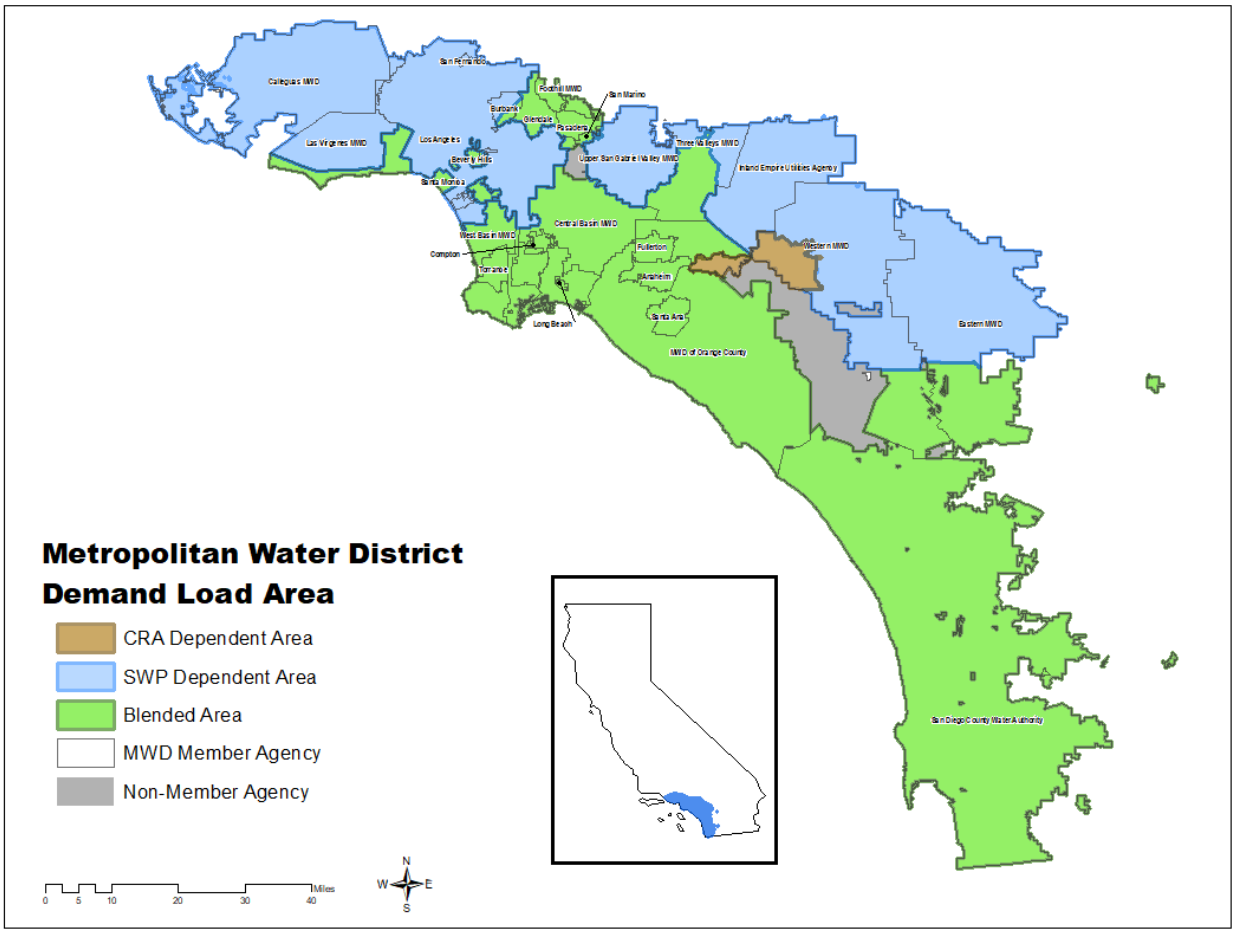


IRPSIM Resource Model

Water supply-demand gaps for the scenarios were analyzed with IRPSIM Resource Model (IRPSIM). IRPSIM is a water supply and demand mass balance simulation model. IRPSIM simulates water resources needed to meet demands, which allows Metropolitan to identify supply-demand gaps and measure whether a potential resource mix is likely to be reliable. IRPSIM considers the availability and accessibility of its imported water supply sources, including its storage portfolio to the demand load areas. The forecasted demands on Metropolitan are allocated to different portions of Metropolitan's regional distribution system, referred to as demand load areas.

IRPSIM models three primary demand load areas. The first is the "SWP Dependent Area," shown in **Figure 3-6**, where demands can only be satisfied with SWP supplies and associated storage programs. The second and smallest is the "Colorado River Dependent Area," where demands can only be satisfied with Colorado River supplies and associated storage programs. The third and largest is the "Blended Area," where demands can be satisfied by both SWP and Colorado River supplies and their respective storage programs.

Figure 3-6: *Demand Load Area Map*



Through entitlements and the development of long and short-term supply programs, Metropolitan has secured the ability to deliver the full capacity of the Colorado River Aqueduct of roughly 1.2 million acre-feet in any given year. In conjunction with local supply production and storage, this supply can satisfy demands in the blended areas. The SWP has system capacity and hydrologic variability that creates an annual supply that historically ranged from 100 TAF to 1.9 MAF. When the SWP supply exceeds the SWP Dependent area demand, water can be stored directly into SWP storage facilities and/or used in the blended areas, enabling Metropolitan to store imported supply within Colorado River storage facilities.

Metropolitan Imported Supplies Finding: *Variability and capacity in SWP supplies provide opportunities to store water during wet periods for use in dry years, including Colorado River storage. Metropolitan's ability to distribute or store SWP supplies when they materialize will enhance the region's reliability, particularly the SWP Dependent Areas. The Colorado River system and Colorado River Aqueduct capacity do not offer the same opportunities concerning SWP storage.*

IRPSIM uses a sample of 96 years of historical hydrology (1922-2017) as a reliability test. This methodology generates 96 different outcomes for each forecast year and thus allows Metropolitan to evaluate the probabilities of surpluses and shortages over the 25-year planning horizon. IRPSIM generates the magnitude and frequency of shortages, which is the metric of reliability used in the reliability assessment analyses. Shortages within an IRPSIM simulation occur when there is insufficient supply to satisfy a demand or when available supplies are not accessible, resulting in an unmet need within Metropolitan's service area.

As represented in **Figure 3-2,** IRPSIM has four key inputs: demands on Metropolitan, SWP supply, CRA supply, and Metropolitan's storage portfolio. The Sales Model provides the input for demands on Metropolitan as described in the previous section. IRPSIM is where scenario-specific impacts related to Metropolitan's Colorado River and SWP imported water supplies are considered in the analysis. In addition, IRPSIM simulates Metropolitan's entire storage portfolio by considering operational constraints, put and take capacities, contractual arrangements, and other operational considerations. IRPSIM balances the needs for imported supply and storage as detailed below.

SWP Forecast-CalSim II

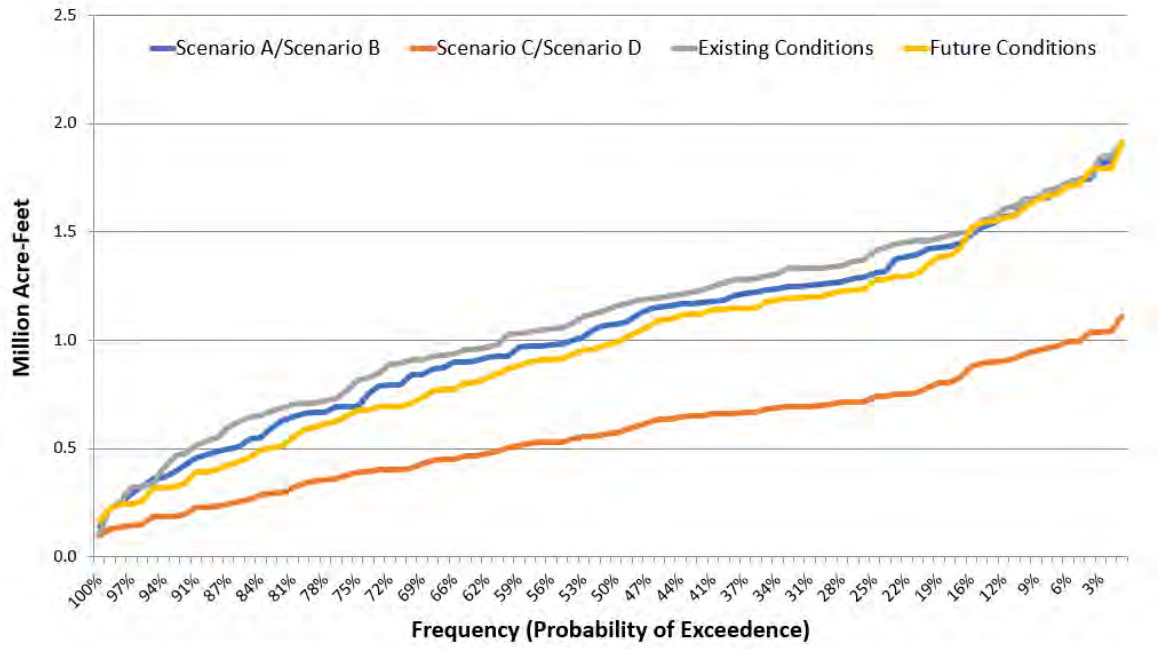
Forecasts of SWP supplies were based on modeling studies produced by DWR using their CalSim-II model. The results of the CalSim-II model are published in DWR's 2019 Delivery Capability Report (DCR) (DWR, 2020). The 2019 DCR provides SWP supply estimates for an existing condition that does not include climate change and a future condition that includes climate change. As shown in **Figure 3-7**, the SWP reliability curve for Scenarios A and B reflect a moderate climate change and regulatory future while Scenarios C and D reflect severe climate change and regulatory impacts.

Metropolitan Imported Supplies Finding: *Existing imported supplies are at risk from various drivers of uncertainty.*

Metropolitan used the 2019 DCR existing and future study projections as a starting point and guidance from climate experts to reflect the regulatory and climate change impacts assumed in the IRP scenarios.

The resulting SWP deliveries for Metropolitan in 2045 are shown in **Figure 3-7** and compared to the 2019 DCR existing and future condition projections.

Figure 3-7: *Metropolitan's 2045 SWP Imported Supply Reliability Based on the 2019 DCR*



CRA Forecast - IRPSIM and CRSS

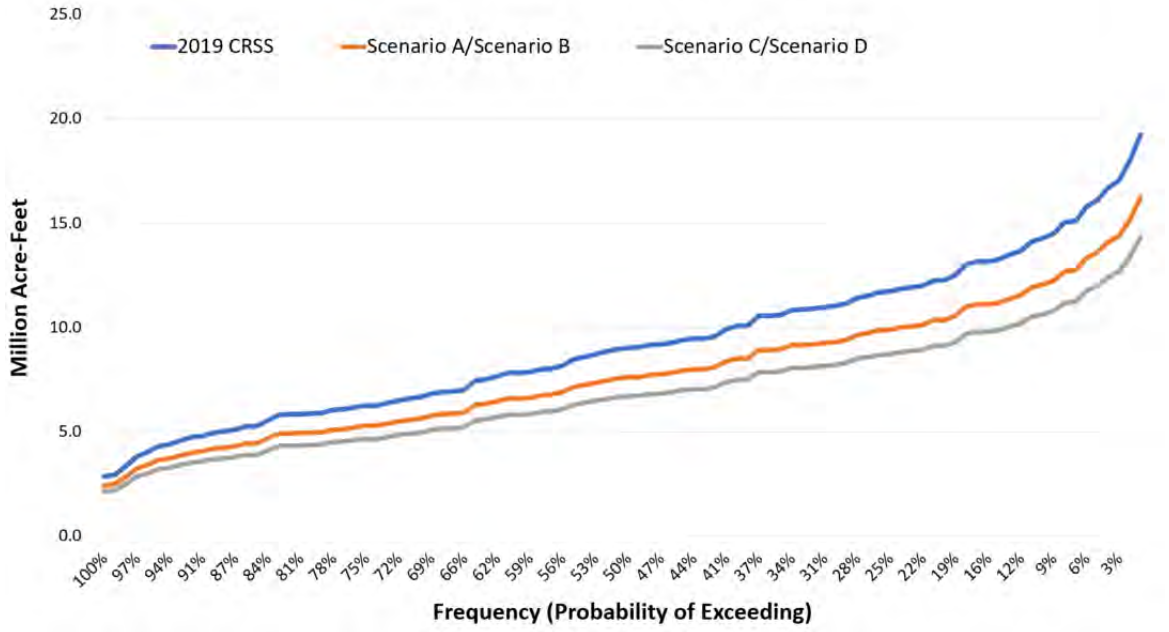
Forecasts of base supplies from the Colorado River were generated within IRPSIM with hydrological inputs provided by the United States Bureau of Reclamation (USBR).

In prior IRPs, projections for Colorado River supplies were generated directly by the Colorado River Simulation System Model (CRSS) and used in IRPSIM. This is a modeling package developed, maintained, and used by USBR to simulate future operations and deliveries of the Colorado River reservoir system. Given major changes in the operations of the Colorado River and to better reflect Metropolitan's use of its Intentionally Created Surplus storage account, Metropolitan now generates its own surplus and shortage characterization of the Colorado River system. IRPSIM still uses the same inputs as CRSS, including initial reservoir conditions and hydrologies for Lake Powell and Lake Mead. The model inputs used in the 2020 IRP are used in USBR's January 2020 official CRSS run (USBR, 2021).

As previous chapters have discussed, Scenarios A and B are characterized by stable imported supplies, and Scenarios C and D by unstable imported supplies. For future Colorado River supplies, this stability is influenced by differing assumptions for climate change and future cooperation between the lower basin states in Colorado River operations.

Climate change is incorporated into CRA supplies by adjusting the Lake Powell and Lake Mead inflow hydrologies and evaporation rates. Through consultation with climate change experts and previous research, a relationship between the decrease in runoff and increase in atmospheric temperature was incorporated in the hydrology (Woodhouse, et al 2021). **Figure 3-8** shows the reduction of Powell inflows due to modeled climate change for the IRP scenarios.

Figure 3-8: *2045 Lake Powell Inflows*



Future operations of the Colorado River and cooperation between the lower basin states and Mexico also influence the stability of Colorado River supplies. The Interim Guidelines, Binational Agreement 323 and the Drought Contingency Plan (DCP) all act to stabilize the elevation of Lake Mead and prevent shortages. The 2007 Interim Guidelines for Lower Basin Shortages and the Coordinated Operations for Lake Powell and Lake Mead (Interim Guidelines), DCP and Minute 323 will expire in 2026. Without a future agreement taking its place this could lead to a greater chance of shortage and less available Colorado River water in the future. For Scenarios A and B that reflect stable imported supply, these three agreements were assumed to extend through the life of the forecast. For Scenarios C and D that reflect less stable imported supplies, the Interim Guidelines were extended, but the DCP and Minute 323 were modeled to expire in 2026.

Chapter 4 – Results: Phase 1 Regional Needs Assessment

Technical results for the Regional Needs Assessment were based on two distinct analytical processes:

1. Reliability Assessment
2. High-Level Portfolio Analysis

The reliability assessment defined and quantified the problems presented by various scenarios. The high-level portfolio analysis explored how different categories of actions could address the reliability needs of each scenario. These results inform the forthcoming IRP One Water Implementation phase. This chapter provides details of the results and explains how to interpret those results (**Figures 4-1** through **4-3**).

Reliability Assessment

The reliability assessment used IRPSIM to quantify the frequency and magnitude of shortage or surplus for each scenario on an annual basis between 2020 through 2045. For ease of interpretation, results are either presented in five-year increments (beginning with 2025 and ending in 2045) or in a single year (2045). The assessment also considers Metropolitan's storage capacity. The terms "gross" and "net" are used to describe the types of surplus and shortage conditions that occur. **Gross shortage** refers to supply-demand gaps before any take from available storage; **net shortage** refers to the remaining supply-demand gap after using available storage. Similarly, **gross surplus** refers to supplies before filling storage, while **net surplus** refers to surplus supplies that occur after all available storage has been filled. The following section summarizes the results for each scenario.

Low Demand/Stable Imports Scenario A

Scenario A was characterized by **low** demands on Metropolitan and **stable** local and imported supplies. The reliability assessment for Scenario A highlights how gaps can be addressed with existing resources and storage programs/supplies. As a result, there are no net shortages throughout the forecast horizon through 2045, as seen in **Figure 4-4**.

Scenario A reliability assessment details are shown for the forecast year 2045 in **Figures 4-5** and **4-6** with highlights listed below:

- All of the gross shortages are met with available storage, leaving no net shortage.
- Metropolitan's existing conveyance and storage capacity would only manage a portion of the gross surplus supplies, leaving up to 770 TAF of net surplus supply occurring 50 percent of the time.
- End-of-year storage is expected to be full 87 percent of the time.
    - Supplies above capacity regularly remain after satisfying the supply-demand gaps identified in this scenario and present an opportunity for new exchanges or to fill new storage capacity and improve water reliability in the Southwest.

High Demands/Stable Imports Scenario B

Scenario B is characterized by **high** demands on Metropolitan and **stable** imported supplies. Net shortages occur between 1 to 5 percent of the time during the planning horizon, as shown in **Figure 4-7**. All net shortages occur in the SWP Dependent Areas (**Figure 3-6**). There are no net shortages in the blended areas (areas that receive both SWP and CRA water) or areas that receive just

CRA water, indicating that accessibility or lack thereof to CRA water is not driving shortages. When system constraints are removed in IRPSIM (e.g. when Colorado River water and blended area storage is allowed to reach SWP Dependent Areas) the shortages in Scenario B are eliminated as seen in **Table 4-8**. This further supports the finding that for Scenario B, the projected shortages may be reduced with system flexibility investments.

Scenario B reliability assessment details are shown for the forecast year 2045 in **Figures 4-8** and **4-9** with highlights listed below:

- A majority of the gross shortages can be reduced with available storage, decreasing the probability of net shortage to 5 percent.
- Maximum net shortage is expected to be up to 300 TAF.
- Metropolitan's existing conveyance and storage capacity would only manage a portion of the gross surplus, leaving up to 400 TAF of net surplus supplies occurring 25 percent of the time.
- The end-of-year storage is expected to be full approximately 45 percent of the time.
    - Metropolitan would face challenges storing available supplies, presenting an opportunity for new exchanges or to fill new storage capacity and improve water reliability in the Southwest.

Low Demands/Reduced Imports Scenario C

Scenario C is characterized by **low** demands on Metropolitan and **reduced** imported supplies. Net shortages occur between 1 to 5 percent of the time during the planning horizon, as shown in **Figure 4-10**. Note that no net shortages occur in the forecast year 2030, due to the Arvin-Edison Banking Program assumed to return online in 2025. With low demands in this scenario, the additional storage capacity provided by this banking program is sufficient to meet the supply-demand gap in 2030. Similar to Scenario B, all shortages occur in SWP Dependent Areas. When system constraints are removed in IRPSIM, the shortages are reduced as seen in **Table 4-8**. This further supports the finding that for Scenario C, the projected shortages may be reduced with system flexibility investments.

Scenario C reliability assessment details are shown for the forecast year 2045 in **Figures 4-11** and **4-12,** with highlights listed below:

- The majority of the gross shortages can be reduced with available storage, leaving a 5 percent probability of net shortage.
- The maximum net shortage is expected to be up to 200 TAF.

SWP Dependent Area Findings:

1) *Vulnerabilities in the SWP Dependent Areas are more severe given reduced reliability of SWP supplies and Metropolitan distribution system constraints. Actions identified in the implementation phase must prioritize addressing the SWP Dependent Area's reliability challenge.*
2) *New core supplies must be accessible to the SWP Dependent Areas. Greater access to existing core supplies can also increase SWP Dependent Area reliability.*
3) *Enhanced accessibility to core supplies and storage, both existing and new, will improve SWP Dependent Area and overall reliability. This includes improvements to Metropolitan's distribution system and capacity to deliver non-SWP supply and storage.*

- After filling gross surplus supplies in available storage, Metropolitan could still expect up to 350 TAF of net surplus supplies occurring 25 percent of the time.
- The end-of-year storage is full roughly 41 percent of the time.
    - Metropolitan would face challenges storing available supplies presenting an opportunity for new exchanges or to fill new storage capacity and improve water reliability in the Southwest.

High Demands/Reduced Supplies Scenario D

Scenario D is characterized by high demands on Metropolitan and **reduced** imported supplies. Shortages occur between 2 to 66 percent of the time during the planning horizon, as seen in **Figure 4-13**.

Before 2035, the net shortages occur exclusively in the SWP Dependent Areas. After 2035 the likelihood and magnitude of these net shortages increase, but net shortages also emerge in blended areas. The expanded net shortages point to impacts from not enough Colorado River supply. Shortages occurring in both the SWP Dependent and blended areas in later forecast years highlight that current imported supplies may be insufficient for Metropolitan to meet its reliability goal for the entire service area.

Metropolitan Imported Supplies Finding: *Shortages on the Colorado River will limit the reliability of Colorado River Aqueduct deliveries as a core supply in the future.*

When system constraints are removed in IRPSIM, the shortages are eliminated or decreased in years prior to 2040 as seen in **Table 4-8**. However, the same analysis does not show a decrease in shortages in the later years and also shows that there is a slight increase in shortages in 2040 and 2045. This further supports the finding that for Scenario D, the projected shortages may be reduced with system flexibility investments until such time where challenges to Colorado River and other blended area supplies become more severe. The later increase in shortage magnitude is a result of Colorado River water being utilized to meet demands in the SWP Dependent Areas in earlier years. Because of this, there is less Colorado River and blended area supplies being stored and available to meet the total demands of the service area in later years.

Scenario D reliability assessment details are shown for the forecast year 2045 in **Figures 4-14** and **4-15** with highlights listed below:

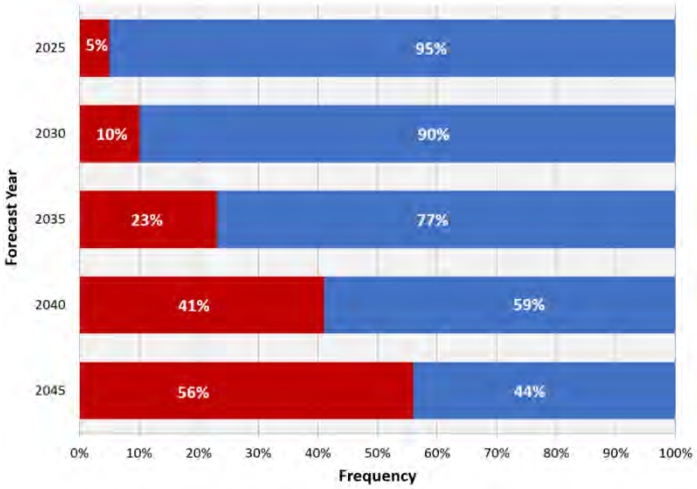
- The majority of the gross shortages cannot be reduced with available storage, leaving a 66 percent probability of net shortage conditions.
- The maximum net shortage is expected to be up to 1.22 MAF.
- Under Scenario D, frequent shortages and fewer surplus conditions indicate that storage and conveyance capacity alone will not solve the reliability problem without supply improvements.
- Scenario D shows there will not be enough surplus water for Metropolitan to fill storage.
    - This stems from the impacts of climate change and regulatory restrictions limiting imported water supply development, paired with the need to use stored supplies to satisfy demands.

The next section shows a series of example graphs and their related interpretations, followed by detailed graphs corresponding to each scenario.

Detailed Reliability Assessment Results

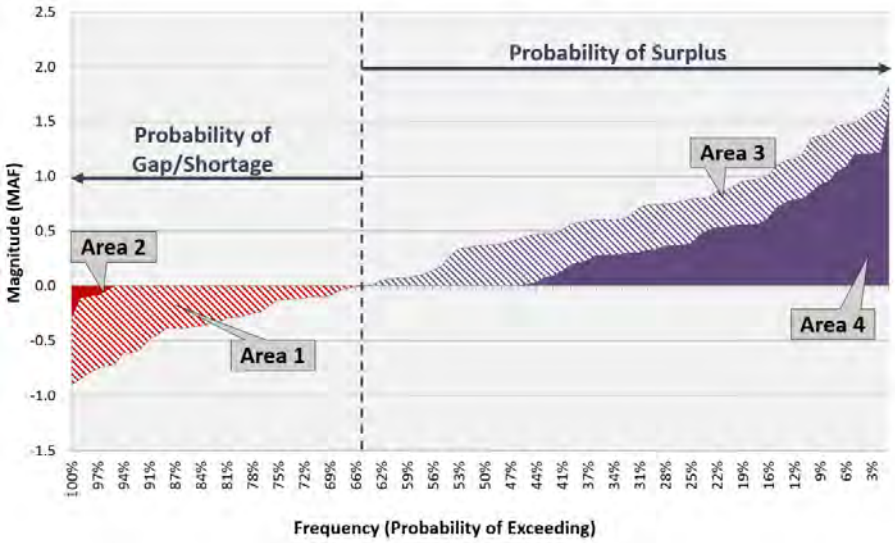
Figures 4-1 to **4-3** are examples of the three graphics that detail the reliability assessment results. These examples are illustrative to aid the reader in interpreting the later graphs.

***Figure 4-1**: Example **Net Shortage** Assessment through the Planning Horizon*



Net Shortage Assessment – This graph shows the frequency and timing of net shortage conditions (red) and all other conditions (blue). Net shortages are defined when all available supplies, including accessible storage, are depleted and there remains an unmet demand. All other conditions are defined when storage is withdrawn to satisfy a demand, and/or when water is available and stored to manage supplies not needed to meet a demand.

***Figure 4-2**: Example **Shortage/Surplus** Probability Assessment for 2045*

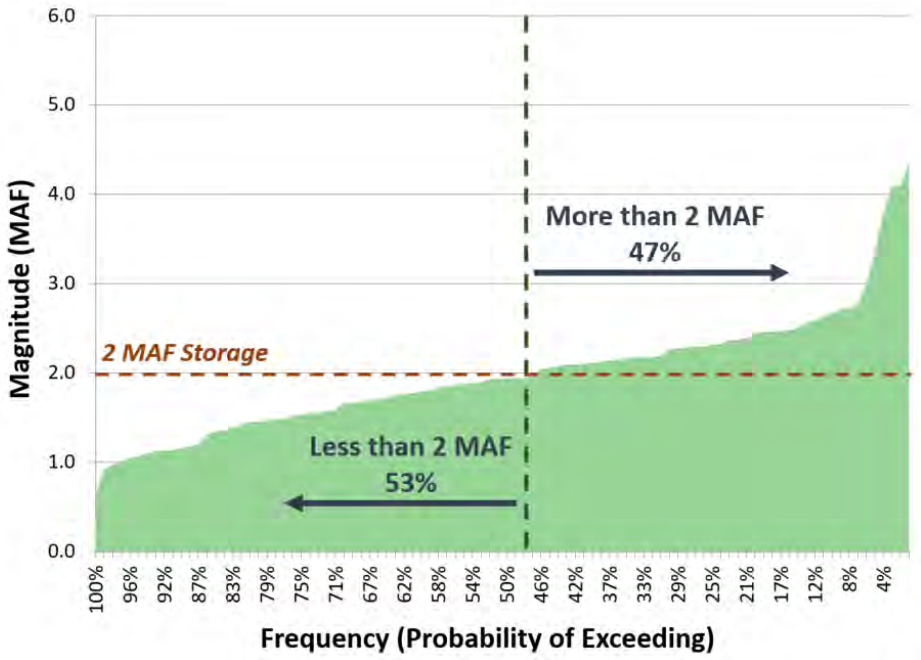


Shortage/Surplus Probability Assessment – This exceedance curve provides magnitude and probability of gross and net shortages/surpluses and the impact of storage actions.

Area 1 & 2 – Gross Shortage: Magnitude and frequency of supply-demand gap prior to taking from available storage
Area 2 – Net Shortage: Magnitude and frequency of supply-demand gap after taking from available storage
Area 3 & 4 – Gross Surplus: Magnitude and frequency of surplus prior to putting into available storage
Area 4 – Net Surplus: Magnitude and frequency of surplus after putting into available storage

Actions that decrease shortage probabilities and magnitudes generally appear as an increase in surplus probability and/or magnitude. Eliminating shortage requires an increased probability/magnitude of surplus.

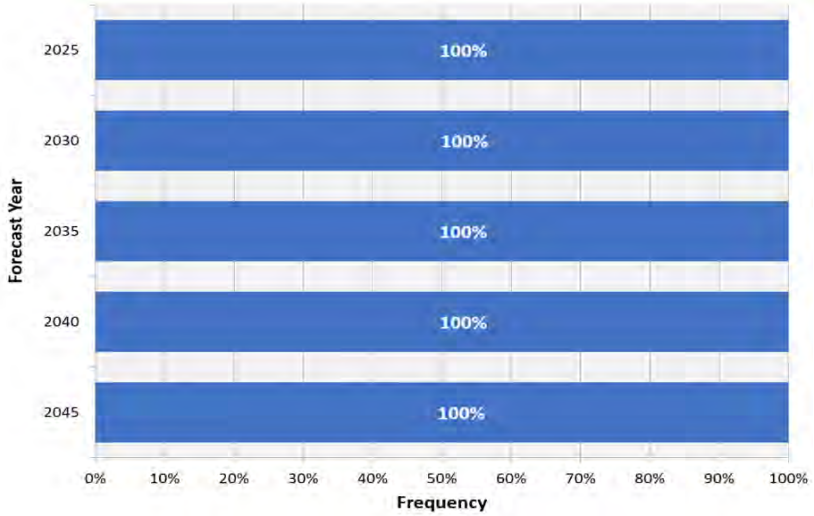
***Figure 4-3**: Example **Storage** Graph for 2045*



Storage Graph – This graph shows end of year storage level probabilities. The probability of a given end of year storage level can be determined by locating the intersection of a selected storage level (y-axis) with the storage curve (green shaded region). To the left of the intersection shows the probability of an end of year storage less than the desired amount, while the right of the intersection shows the probability of more than the desired amount. The volume of water necessary to achieve full storage varies by scenario based on hydrologic conditions, contractual arrangements, and program operations.

Low Demands/Stable Imports Scenario A Reliability Assessment Results

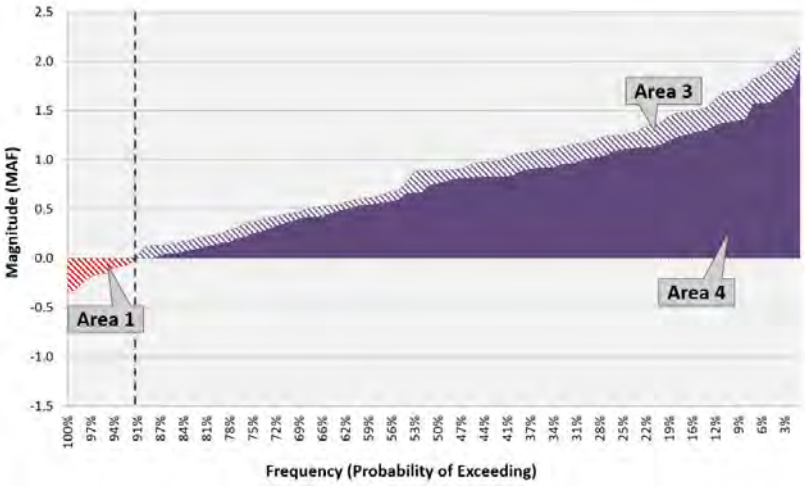
Figure 4-4: *Scenario A – **Net Shortage** Assessment through the Planning Horizon*



Scenario A: **Low** demands
Stable imports

All supply-demand gaps can be managed through available storage. This scenario shows 100% reliability across the planning horizon.

Figure 4-5: *Scenario A – **Shortage/Surplus** Probability in 2045*



Prior to taking available storage actions, surplus conditions have a 91% frequency and shortages conditions have a 9% frequency.

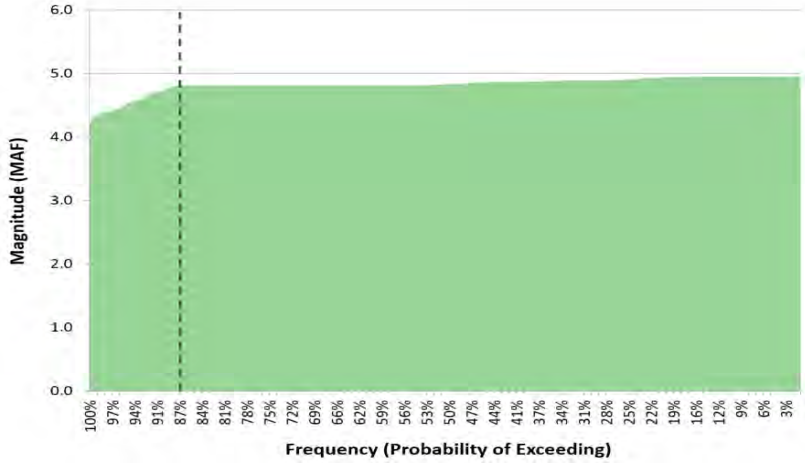
Area 1 & 2 – All supply-demand gaps are managed by taking from available storage

Area 2 (Not shown) – No net shortage

Area 3 & 4 – Gross surplus

Area 4 – Up to 770 TAF of net surplus supply occurs 50% of the time

Figure 4-6: *Scenario A – **Storage** Probability in 2045*

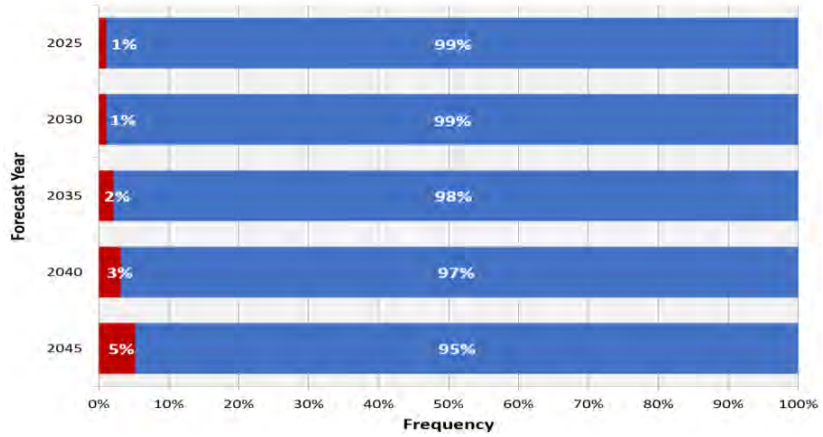


Storage expected full 87% of the time.

The probability of total storage less than 1.0 MAF is 0%.

High Demands/Stable Imports Scenario B Reliability Assessment Results

Figure 4-7: *Scenario B – **Net Shortage** Assessment through the Planning Horizon*



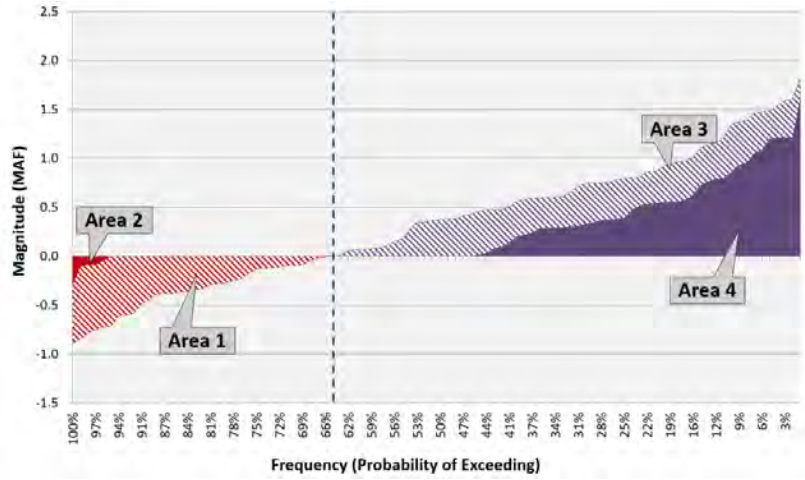
Scenario B: **High** demands
Stable imports

Net shortages possible across entire planning horizon.

Net shortage probability grows from 1% in 2025 to 5% in 2045.

Net shortages occur only in **SWP Dependent Areas**.

Figure 4-8: *Scenario B – **Shortage/Storage** Probability for 2045*



Prior to taking available storage actions, surplus conditions have a 65% frequency and shortage conditions have a 35% frequency.

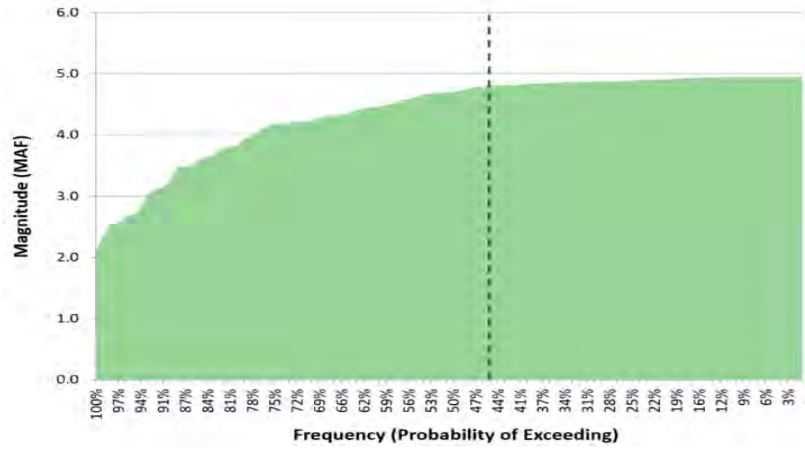
Area 1 & 2 – Gross shortage

Area 2 – Net shortages occur 5% of the time with a maximum magnitude of 300 TAF

Area 3 & 4 – Gross surplus

Area 4 – Up to 400 TAF of net surplus supply occurs 25% of the time

Figure 4-9: *Scenario B – **Storage** Probability for 2045*

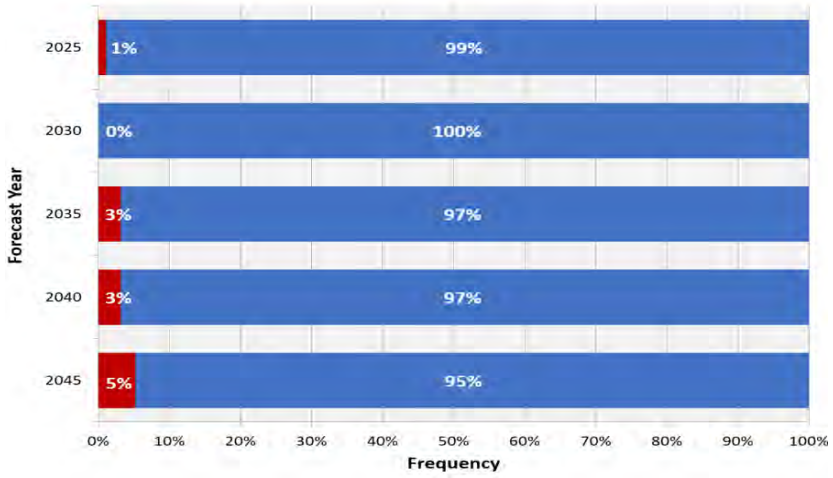


Full storage expected 45% of the time.

The probability of total storage less than 1.0 MAF is 0%.

Low Demands/Reduced Imports

Figure 4-10: *Scenario C – **Net Shortage** Assessment through the Planning Horizon*



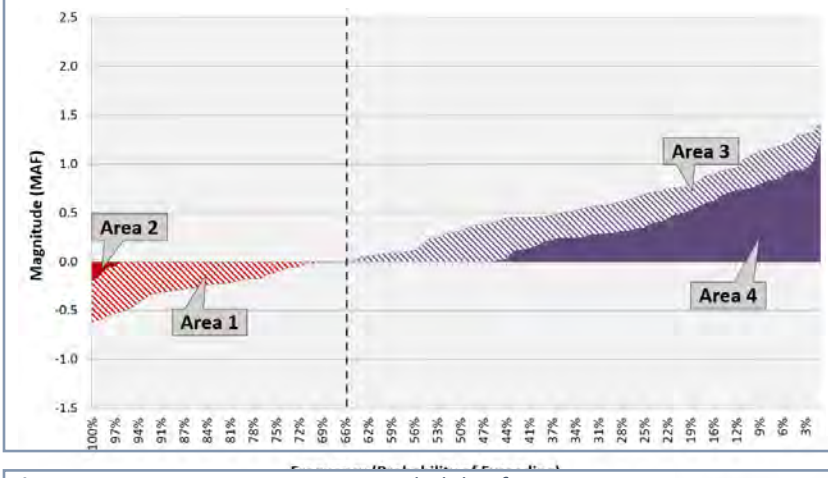
Scenario C: **Low** demands
Reduced imports

Net shortages possible across entire planning horizon.

Net shortage probability grows from 1% in 2025 to 5% in 2045.

Net shortages occur only in **SWP Dependent Areas**.

Figure 4-11: *Scenario C – **Shortage/Surplus** Probability for 2045*



Prior to taking available storage actions, surplus conditions have a 66% frequency and shortage conditions have a 34% frequency.

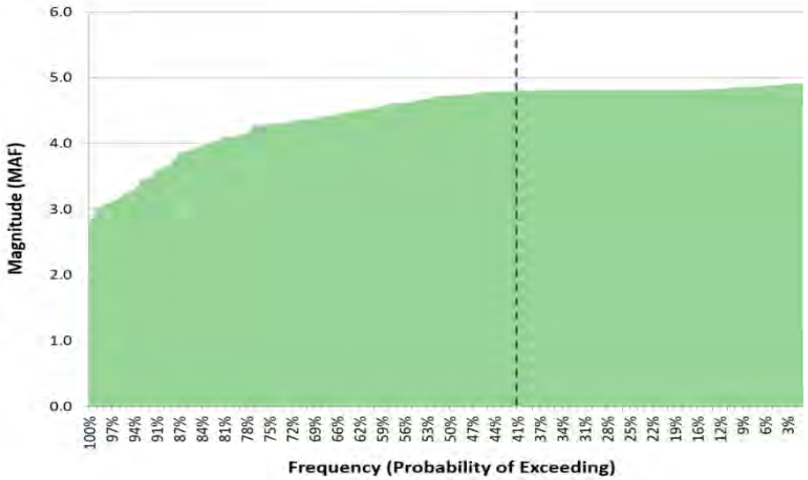
Area 1 & 2 – Gross shortage

Area 2 – Net shortages occur 5% of the time with a maximum magnitude of up to 200 TAF

Area 3 & 4 – Gross surplus

Area 4 – Up to 350 TAF of net surplus supply occurs 25% of the time

Figure 4-12: *Scenario C – **Storage** Probability for 2045*

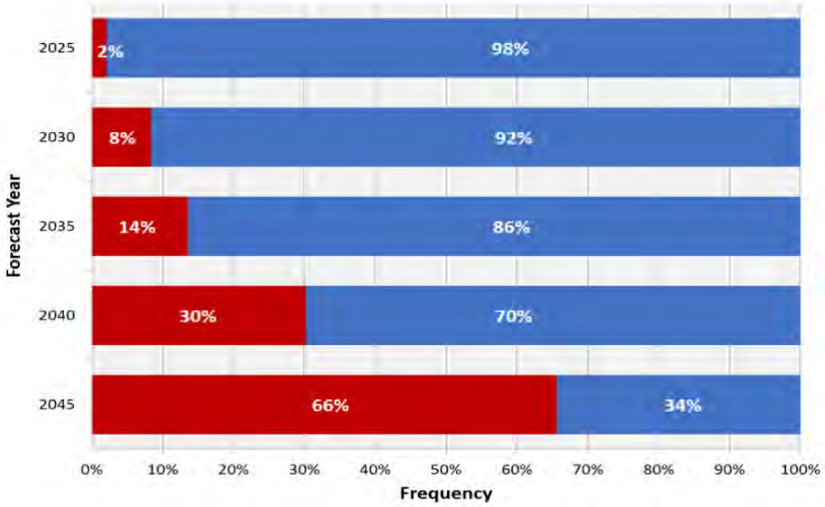


Full storage expected 41% of the time.

The probability of total storage less than 1.0 MAF is 0%.

High Demands/Reduced Imports Scenario D Reliability Assessment Results

Figure 4-13: *Scenario D –* ***Net Shortage*** *Assessment through the Planning Horizon*



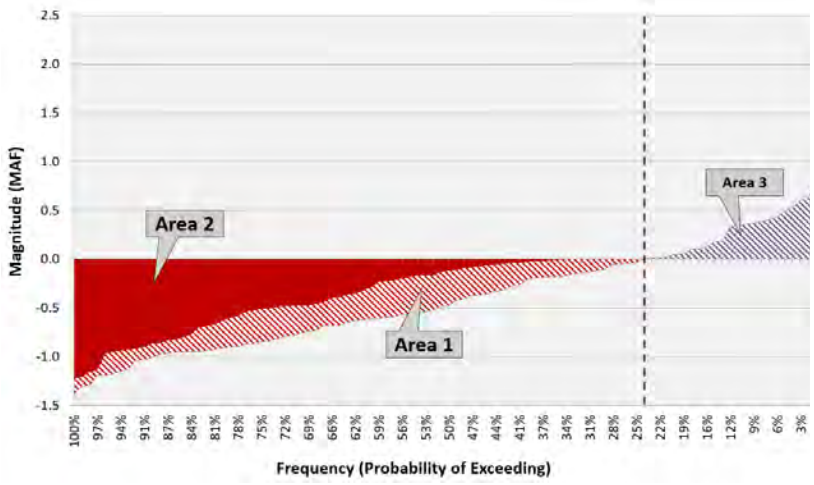
Scenario D: **High** demands
Reduced imports

Net shortages possible across entire planning horizon, and greater than 10% after 2030.

Net shortage probability grows sharply from 2% in 2025 to 66% in 2045.

Net shortages occur **system-wide** beyond 2035.

Figure 4-14: *Scenario D –* ***Shortage/Surplus*** *Probability for 2045*



Prior to taking available storage actions, surplus conditions have a 24% frequency and shortage conditions have a 76% frequency.

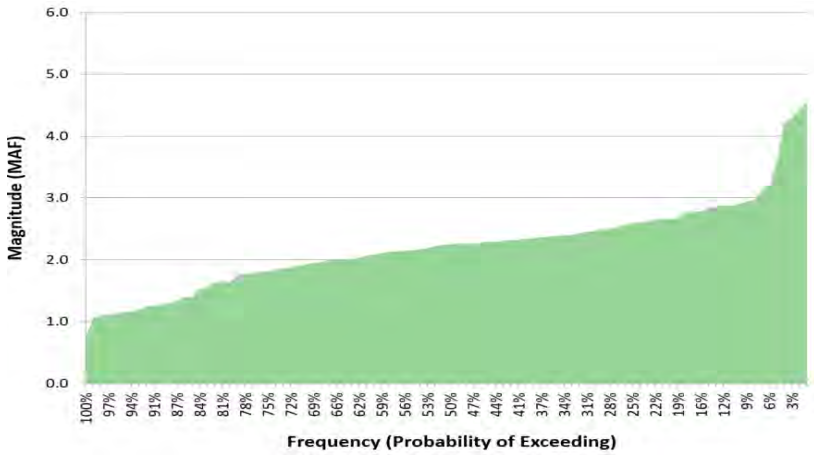
Area 1 & 2 – Gross shortage

Area 2 – Net shortages occur 66% of the time with a maximum magnitude of 1.22 MAF

Area 3 – Gross surplus

Area 4 (Not shown) – Does not exist in this scenario. Supplies, when available, can be stored

Figure 4-15: *Scenario D –* ***Storage*** *Probability for 2045*



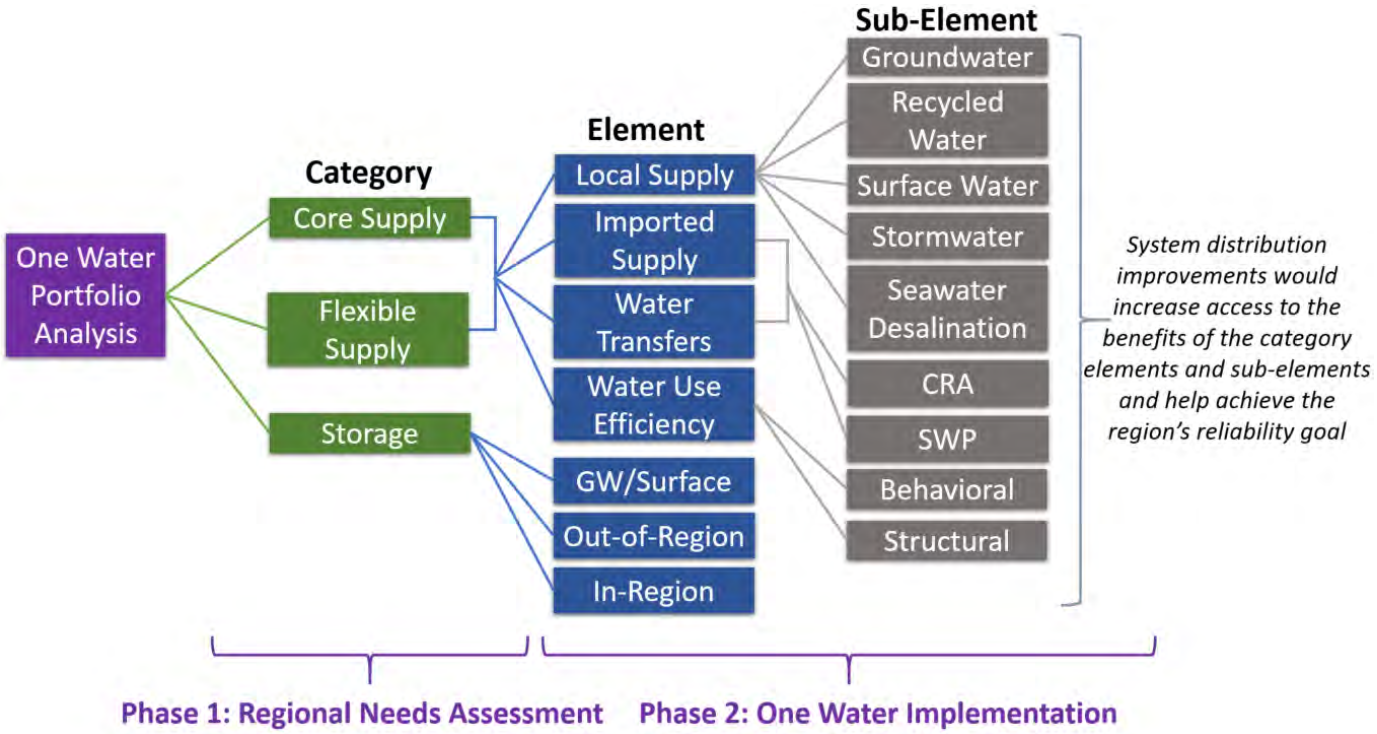
Full storage not expected in 2045. Limited imported supply along with the need to use stored supplies to satisfy demands prevents this scenario from filling storage capacity.

The probability of total storage less than 1.0 MAF is less than 2%.

High-Level One Water Portfolio Analysis Results

While the reliability assessment identified the potential shortages in each scenario, the portfolio analysis aimed to determine a high-level resource mix that tackles the supply-demand imbalances faced within each scenario. Eliminating the identified shortages would allow Metropolitan to meet its 100 percent reliability goal.

Figure 4-16: *Levels of One Water Portfolio Analysis*



Note: The elements and sub-elements identified are examples and not meant to be an exhaustive list.

The 2020 IRP's One Water portfolio analysis uses a hierarchical framework, shown in **Figure 4-16**, to characterize the different actions and investments. Metropolitan tested configurations at the highest "Category" level as part of the Regional Needs Assessment. Each category refers to one of three different types of supply (core, flexible, and storage), further defined in **Table 4-1**. With the preferred technical feasibility determined at the category level in the Regional Needs Assessment, further policy direction will be sought in the One Water Implementation phase to establish the basis for a more specific resource mix from the full spectrum of elements and sub-elements that comprise a holistic One Water approach. Below the "Category" level, element-level resource options such as water use efficiency can sometimes fulfill the role of either core supply or flexible supply but not both at the same time. Whether it serves the function of a core supply or flexible supply depends on the nature of the project or program. For example, structural water use efficiency programs that replace fixtures and repair leaks resemble a core supply because they provide a reliable, constant stream of water savings into the future. A conservation media campaign to encourage conscientious water consumption during a drought resembles a flexible supply because it is implemented on an as-needed basis.

Table 4-1: *Category Definitions*

Category	Definition	Notes	Examples
Core Supply	A supply that is generally available and used every year to meet demands under normal conditions and may include savings from efficiency gains through structural conservation.	High reliability and value if used often. Expensive otherwise.	• Colorado River basic apportionment • IID/Metropolitan conservation agreement • Code-based conservation
Flexible Supply	A supply that is implemented on an as-needed basis and may or may not be available for use each year and may include savings from focused, deliberate efforts to change water use behavior.	Expensive if used too much or too often. Better value if used occasionally.	• Palo Verde Land Management, Crop Rotation, and Water Supply Program • North-of-Delta annual transfers • Water Supply Alert • Conservation advertising campaigns
Storage	The capability to save water supply to meet demands at a later time.	Converts core supply into flexible supply. Evens out variability in supply and demand.	• Diamond Valley Lake • SWP Article 56 carryover • SWP flexible storage • Antelope Valley-East Kern High Desert Water Bank

Several assumptions were incorporated into the methodology to determine appropriate high-level resource mixes for Scenarios B, C, and D. Resource mixes for new portfolio actions are comprised of three categories: 1) core supply, 2) flexible supply, and 3) storage (see **Table 4-1** above).

The Regional Needs Assessment showed that net shortages were occurring in the SWP Dependent Areas (areas that cannot receive Colorado River supplies) for Scenarios B, C, and D. As such, additional core supply and storage were modeled as supplies that could reach the SWP Dependent Areas. These modeled supplies could also be used to meet water demand in the blended area (areas that receive SWP and Colorado River water). The additional flexible supply is not location-specific but is assumed to be available wherever the shortage is occurring (SWP Dependent or blended).

The portfolio analyses tested how the supply-demand gap in each scenario might be met using each category (core, flexible, and storage) separately. ***These category-specific tests enabled Metropolitan to conclude that rather than relying on any single category of portfolio actions, it is more practical in every scenario to pursue a more balanced and diversified mix.*** This provided a valuable starting point in determining the most suitable resource mix for each scenario.

After the portfolio categories were modeled in isolation, a mix of all three categories was modeled for each scenario. This analysis examined a range of additional storage to identify a more practical core and

flexible supply requirement. The following methodology was used in the portfolio analysis to determine the high-level resource mix for each scenario:

1. **Flexible Supply**
   Identify an achievable, flexible supply threshold not to be exceeded in any given year

   - The flexible supply threshold was set at 100 TAF and represents a realistic supply that can be secured in dry years when they are likely to be needed. Past experience has shown that SWP transfers supplies, an example of flexible supply, has limited availability, high cost, and losses associated with securing those supplies.
   - Absent core supply and storage development, the flexible supply identified is equivalent to the maximum shortage amount in any given forecast year.
   - Development of core supply and storage helps reduce the need for flexible supplies and achieve the established threshold.

2. **Storage**
   Establish a range of additional storage to complement core supply development for each scenario

   - The assessment looked at an additional storage capacity of 0, 100, 250, and 500 TAF.
   - Put/takes for the additional storage were defined as half of the capacity (e.g., 50 TAF put/take for a capacity of 100 TAF). This represents a realistic "middle-of-the-road capability"(between a surface water reservoir and a groundwater banking type program) appropriate for planning purposes.
   - The additional storage was modeled to come online in 2035 to provide a realistic timeline for acquisition, permitting, construction, and other implementation-related requirements. Existing storage programs were extended through 2045 with the assumption that current contracts will be renewed with the same terms.

3. **Core Supply**
   Determine core supply needed to achieve the reliability goal by testing the range of additional storage while not exceeding the flexible supply threshold

   - This core supply is not static and may increase throughout the forecast to ensure that the maximum flexible supply target (shortage amount) is not surpassed.

Low Demands/Stable Imports Scenario A Portfolio Analysis Results

Scenario A is characterized by **low demands** on Metropolitan and **stable local and imported supply**. In this future, there is no net shortage and no intervention is needed by Metropolitan; the reliability goal is achieved through consumer demand reduction efforts and sufficient local supply development. As such, no new investments in core, flexible or storage are necessary.

High Demands/Stable Imports Scenario B Portfolio Analysis Results

The challenges presented in Scenario B mainly result from **increasing demands** throughout the service area. The portfolio analysis first looked at the development needed for each portfolio category alone to achieve reliability, as shown in **Table 4-2** for the forecast year 2045.

Table 4-2: *Scenario B – Forecast Year 2045 Portfolio Category Need – Not Combined*

New Storage	New Flexible Supply	New Core Supply
TAF 500 TAF (250 TAFY put/take capacity)	300 TAF	150 TAF

The results revealed that upwards of 300 TAF of flexible supplies would be needed to achieve reliability, or a new 500 TAF storage capacity surface reservoir would be required. It was deemed unrealistic and risky to depend on such a large amount of flexible supply in a dry year when these supplies would typically be needed, and excessive to build a reservoir similar in size and scope as Diamond Valley Lake. Instead, to identify possible efficiencies gained through combining these portfolio categories, a mix of these categories was investigated. The results of that analysis are shown in **Table 4-3**.

Table 4-3*: Scenario B – Forecast Year 2045 Portfolio Category Need – Combined*

Modeled Storage	Core Supply Needed by 2045
0 TAF	100 TAF
100 TAF	70 TAF
250 TAF	30 TAF
500 TAF	30 TAF

Table 4-3 illustrates how various surface reservoir sizes impact core supply development need while staying within the flexible supply threshold. Without new storage, 100 TAF of additional core supply is needed by 2045 to eliminate net shortages. The core supply need reduces from 100 TAF to 30 TAF with 250 TAF of new storage capacity. The analysis also reveals no additional reduction in the core supply need if new storage capacity is increased to 500 TAF. This suggests that a new storage capacity above 250 TAF is unnecessary to reduce the core supply need and may be an overinvestment.

Low Demands/Reduced Imports Scenario C Portfolio Analysis Results

Scenario C is characterized by **low demands** on Metropolitan and **unstable local and imported** supplies due to a more severe climate change future. The shortages in Scenario C are mainly due to decreasing local and imported supplies. The magnitude of the net shortages in Scenario C are slightly less than those in Scenario B and indicate that higher demands have a more significant impact on reliability than the modeled unstable local and imported supplies. **Table 4-4** shows the development of each portfolio category alone for the forecast year 2045 to achieve 100% reliability.

Table 4-4: *Scenario C – Forecast Year 2045 Portfolio Category Need – Not Combined*

New Storage	New Flexible Supply	New Core Supply
TAF 500 TAF (250 TAFY put/take capacity)	200 TAF	100 TAF

Results show that developing 100 TAF of new core supply could alone eliminate net shortages in this scenario without the need for additional storage or flexible supply. Additionally, approximately 200 TAF of flexible supplies would be needed to achieve reliability, or a 500 TAF storage capacity surface reservoir would be required. Like Scenario B, the amount of additional storage or flexible supply alone was too great to be a realistic solution in a dry year and a combination of these portfolio categories was examined. The results of that analysis are shown in **Table 4-5**.

Table 4-5: *Scenario C – Forecast Year 2045 Portfolio Category Need – Combined*

Modeled Storage	Core Supply Needed by 2045
0 TAF	50 TAF
100 TAF	15 TAF
250 TAF	15 TAF
500 TAF	15 TAF

Scenario C required less additional core supply than Scenario B under all modeled storage conditions. If no additional storage is contemplated, 50 TAF of additional core supply is needed by 2045 to eliminate net shortages. The core supply need reduces from 50 TAF to 15 TAF with the addition of 100 TAF of new storage capacity. The analysis also reveals no additional reduction in the core supply need if new storage capacity is increased to 250 TAF. This suggests that a new storage capacity above 100 TAF is unnecessary to reduce the core supply need and would be a potential over-investment.

High Demands/Reduced Imports Scenario D Portfolio Analysis Results

Scenario D experiences larger impacts than the other three scenarios due to both **higher demands** on Metropolitan and **unstable imported supplies**. The compounded effects lead to shortages of substantially greater magnitude with a higher likelihood. The efficacy of the individual portfolio categories was determined by first modeling them separately, with results shown below in **Table 4-6**.

Metropolitan Imported Supplies Finding: *Maintaining existing imported supply reliability reduces the need for new core supply development and leverages years of investments.*

Table 4-6: Scenario D – Forecast Year 2045 Portfolio Category Need – Not Combined

New Storage	New Flexible Supply	New Core Supply
Storage up to 1.5 MAF with put/take capacity of 750 TAF/year still does not provide 100% reliability.	1.2 MAF	650 TAF

Adding new storage up to 1.5 MAF with a put/take capacity of 750 TAF were modeled. As the amount of modeled storage increased, results showed diminishing returns regarding decreasing probability and magnitude of net shortage. ***This led to the conclusion that there is no realistic amount of additional storage that could be modeled that would eliminate net shortage in Scenario D.*** Results also indicate that it would take 1.2 MAF of flexible supply or 650 TAF of new core supply to eliminate net shortage

alone, both of which are unrealistic management strategies. Even more than Scenarios B and C, a combination of portfolio categories is vital to eliminating net shortages. As with the other scenarios, a combined approach was modeled, and the results of this combination of portfolio categories is shown below in **Table 4-7**.

Table 4-7: Scenario D – Forecast Year 2045 Portfolio Category Need – Combined

Modeled Storage	Core Supply Needed by 2045
0 TAF	650 TAF
100 TAF	600 TAF
250 TAF	550 TAF
500 TAF	500 TAF

Storage Finding: *Expanding existing or developing new storage programs and investments in Metropolitan's distribution system can reduce the need for new core supply development to meet potential future shortages and adapt to climate change.*

Scenario D highlights the need for investments in a combination of core, flexible, and storage supplies. Additions of new core supply and storage work together in tandem; more water in storage reduces how much core supply is needed, while in turn, more core supplies mean water is readily available in non-dry years to accumulate in storage over time. More specifically, Scenario D requires significantly greater amounts of additional core supply than Scenarios B and C. With 500 TAF of additional storage capacity, there is still a need for an additional 500 TAF of core supply by 2045. When extra storage is reduced, the corresponding core supply increases.

Table 4-8: *Probability of Shortage With and Without Distribution System Constraints*

Year	Scenario B		Scenario C		Scenario D	
	Constraints	No Constraints	Constraints	No Constraints	Constraints	No Constraints
2025	1%	0%	1%	0%	2%	0%
2030	1%	0%	0%	0%	8%	0%
2035	2%	0%	3%	0%	14%	5%
2040	3%	0%	3%	0%	30%	31%
2045	5%	0%	5%	4%	66%	67%

Table 4-8 shows the probability of shortage with and without distribution system constraints that restrict deliveries of Colorado River water and other blended area supplies to portions of Metropolitan's service area. This was analyzed by comparing two IRPSIM model runs. The first run contained the existing system configuration that reflects current capacity to deliver water to the SWP Dependent areas. The second run reflects a theoretical removal of these system constraints.

General Observations

The portfolio category analysis revealed similar patterns across scenarios. As a general rule, less core and flexible supply were necessary to achieve the reliability goal when after adding storage. Additionally, there was a notable drop in the flexible supply need in the forecast year 2025 when the Arvin-Edison Banking Program is assumed to return to service after being shut down due to water quality concerns. ***This shutdown shows how important SWP banking programs are to Metropolitan's reliability in light of vulnerabilities in the SWP Dependent Areas.***

Currently IRPSIM models all SWP banking programs to operate throughout the planning horizon. The Arvin-Edison Banking Program result shows that ***extending the contract terms for the other SWP banking programs is vital to Metropolitan's long-term reliability.*** Maintaining existing imported supplies that utilize existing storage programs, including SWP banking, is necessary and may reduce the need for new core supply development and leverages years of investments.

SWP Dependent Areas and Storage Finding:

Storage capacity, put/take capabilities, and accessibility are critical considerations for the SWP Dependent Area. New storage capacity and put/take capabilities should be consistent with the portfolio analysis. New storage must be accessible to the SWP Dependent Areas.

Storage Findings:

1) Maintaining Metropolitan's existing storage portfolio is critical, including the consideration of re-negotiating contracts when they expire.
2) When evaluating storage options, put/take capabilities are essential; even storage programs with modest put/take capabilities help reduce the need for flexible supply.

Chapter 5 - Findings

The IRP's goal in guiding Metropolitan's investments is to avoid retail water shortages and mandatory end-user cutbacks. This reliability goal recognizes that although tolerance for voluntary conservation measures varies among member agencies, Southern Californians clearly distinguish voluntary and responsible conservation from mandatory cutbacks. A vision for regional success is for every Southern California consumer and business to have access to affordable, high-quality water at all times. To this end, the Regional Needs Assessment highlights important areas of vulnerability to Metropolitan's reliability goal. Findings from the Regional Needs Assessment fall within five key focus areas:

1. SWP Dependent Areas
2. Storage
3. Retail Demand/ Demand Management
4. Metropolitan Imported Supplies
5. Local Supply

These findings are summarized and discussed below. The scenario analyses found plausible reliability outcomes by the year 2045, with potential shortages ranging from no net shortage at all under Scenario A to as high as 1.2 MAF under Scenario D. As Metropolitan proceeds towards implementation in the next phase of the IRP, specific actions must address these gaps in a manner consistent with the portfolio category analysis identified in Chapter 4.

SWP Dependent Areas Findings

- *Vulnerabilities in the SWP Dependent Areas are more severe given reduced reliability of SWP supplies and Metropolitan distribution system constraints. Actions identified in the implementation phase must prioritize addressing the SWP Dependent Area's reliability challenge.*
- *New core supplies must be accessible to the SWP Dependent Areas. Greater access to existing core supplies can also increase SWP Dependent Area reliability.*
- *Enhanced accessibility to core supplies and storage, both existing and new, will improve SWP Dependent Area and overall reliability. This includes improvements to Metropolitan's distribution system and capacity to deliver non-SWP supply and storage.*
- *Storage capacity, put/take capabilities, and accessibility are critical considerations for the SWP Dependent Area. New storage capacity and put/take capabilities should be consistent with the portfolio analysis. New storage must be accessible to the SWP Dependent Areas.*

Water demand in Metropolitan's service area is met by combining its imported supplies via the SWP and Colorado River Aqueduct, storage reserves, and local supply production. These spatially diversified water supplies increase reliability by buffering supply impacts with any one source. In general, when one or more supply sources are challenged, the other sources are depended on more to satisfy the region's demand.

Portions of Metropolitan's service area, however, cannot receive water from both imported supply sources and do not have enough local supply to meet demand. Those portions of Metropolitan's service area where Colorado River supply cannot access, referred to as "SWP Dependent Areas" as shown in **Figure 3-6**, are of particular concern if low SWP Table A Allocations become more frequent.

A crucial finding of this IRP recognizes that SWP Dependent Areas present a severe vulnerability to regional water reliability. Across scenarios, this vulnerability emerges as a common thread among foreseeable risks. Whenever shortages occur in any scenario, they involve a mismatch between accessible supplies and demands in the SWP Dependent Areas. This puts additional pressure on the Colorado River, local, and storage supplies to satisfy a larger proportion of the regional demand. Consequently, resolving reliability issues for the SWP Dependent Areas will address the larger reliability issues for the entire region.

As SWP core supplies become less reliable over time, as analyzed in the four scenarios, the risks to reliability posed by the SWP Dependent Areas are exacerbated. Because of these vulnerabilities, actions identified in the One Water Implementation phase should prioritize addressing SWP Dependent Areas. New core supplies and new/or existing storage must first address and reach SWP Dependent Areas. However, investing in conveyance and distribution to improve core, local, and storage supply access to the SWP Dependent Areas should also be evaluated to determine if overall system reliability is compromised. Additionally, potential shortages in the Colorado River, as seen in Scenario D, can limit the effectiveness of system improvements.

Storage Findings

- *Storage capacity, put/take capabilities, and accessibility are critical considerations in maintaining reliability under the region's current and future conditions, especially for SWP Dependent Areas.*
- *Maintaining Metropolitan's existing storage portfolio is critical, including the consideration of re-negotiating contracts when they expire.*
- *Expanding existing or developing new storage programs and investments in Metropolitan's distribution system can reduce the need for new core supply development to meet potential future shortages and adapt to climate change.*
- *When evaluating storage options, put/take capabilities are essential; even storage programs with modest put/take capabilities help reduce the need for flexible supply.*

Storage is vital to reliability under current and plausible future conditions. Core supplies and storage capabilities work together in tandem; dependable core supplies are needed to fill and refill storage before and after dry years, and ample storage capacity is needed to make the most of opportunities for core supplies when they become available. Three major conclusions related to storage emerge from the IRP analysis:

1. Expanding existing or developing new storage programs will be needed to help balance new core supply development and mitigate future shortages. This may include policies and programs enabling Metropolitan's use of local storage during drought conditions.
2. A holistic approach is essential when evaluating storage options. Evaluation of put-and-take capabilities should take into account the amounts and timing of water that can be moved and

spatial considerations, such as the source of water and access to the various parts of Metropolitan's distribution system. New storage development and or expanding distribution flexibility to move existing storage to the SWP Dependent Areas should be investigated in the implementation phase.

3. Furthermore, several of Metropolitan's existing storage programs will expire over the next 15 years, within the planning horizon of the 2020 IRP. Without further action to extend these agreements, Metropolitan will lose more than 1.6 MAF of total storage volume by 2037. The IRP reliability analyses assume that these programs will remain in place. Still, their possible expiration remains a threat to regional reliability until such programs are extended or replaced. This is an example of the active management that is constantly required and highlights the ongoing need for collaboration with Metropolitan's banking partners. These known administrative risks are apart from other, more uncertain operational risks, such as contamination, new regulatory restrictions, and seismic disturbances.

Retail Demand/Demand Management Findings

- *Metropolitan's future supply reliability may fluctuate based on demand increases and decreases.*
- *Variability in retail demand largely comes from changes in outdoor water use. Outdoor water use behavior is complex, influenced by weather and climate and by awareness of water scarcity and other conservation measures.*
- *It is important to pay attention to demand rebound, demand growth, and demand reductions, and take appropriate regional measures as necessary.*
- *Managing long-term demands through the efficient use of water reduces dependency on supplies, helps preserve storage, and helps reduce the need for extraordinary conservation measures.*

Conservation has long underpinned Metropolitan's long-term water supply reliability strategy. Metropolitan administers regional conservation programs and co-funds member agency conservation programs designed to increase water use efficiency and bolster water conservation ethics. Conservation comes from two areas of change: structural conservation which involves increases in water use efficiency, and behavioral conservation, which involves modifying consumer water-using behavior through messaging, education, pricing, and mandates. Of these two forms of conservation, structural conservation is more permanent, akin to a core supply. Water-efficient device retrofits, landscape conversions, plumbing codes, and leak prevention contribute to ongoing structural water savings. Conservation device retrofits help recover storage in future years by lowering demands in all years, not only drought years. In contrast, behavioral conservation is less permanent and can wax and wane due to various influences outside of Metropolitan's direct control. The IRP recognizes water use behavior, represented by per capita water use, as a major uncertainty for regional demands over time. The IRP scenarios confirm that Metropolitan's future reliability is highly sensitive to changes in water demands. Under Scenario A, with low demands and

Retail Demand/Demand Management Finding:
Managing long-term demands through the efficient use of water reduces dependency on supplies, helps preserve storage, and helps reduce the need for extraordinary conservation measures.

stable imports, no net shortages are anticipated through the year 2045. Demands also remain low in Scenario C, with low frequencies of net shortages occurring throughout the planning horizon. Meanwhile, Scenarios B and D consider what might happen if per capita water demands rebound to levels approaching historical usage. While Scenario B shows similar frequencies of net shortages as Scenario C, the magnitudes of such shortages are greater. Under Scenario D, where there is both increase in demands on Metropolitan and significant loss of imported core supply, there is a high risk of shortage and an inability to ever refill storage to capacity by the year 2045.

Increased demands, whether from growth or from per capita use, represent a major risk to reliability. Demands can increase from rebounding per capita water use, but even with efficient use, total demands can still increase as the population and economy grow over time. Variability in retail-level demands mostly comes from outdoor water use, which is influenced by weather and climate and other factors that affect water-using behaviors. Baseline conservation programs help with every scenario. Monitoring demands and intervening as appropriate will be critical. Managing demands through efficient use of water reduces dependency on costly supplies, helps preserve storage, and defers the need for disruptive extraordinary conservation measures such as emergency declarations and water supply allocations.

Metropolitan Imported Supplies Findings

- *Existing imported supplies are at risk from various drivers of uncertainty.*
- *Maintaining existing imported supply reliability reduces the need for new core supply development and leverages years of investments.*
- *SWP supplies are highly susceptible to varying hydrologic conditions, climate change, and regulatory restrictions.*
- *Variability and capacity in SWP supplies provide opportunities to store water during wet periods for use in dry years, including Colorado River storage. Metropolitan's ability to distribute or store SWP supplies when they materialize will enhance the region's reliability, particularly the SWP Dependent Areas. The Colorado River system and Colorado River Aqueduct capacity do not offer the same opportunities concerning SWP storage.*
- *Shortages on the Colorado River will limit the reliability of Colorado River Aqueduct deliveries as a core supply in the future.*

Imported supplies remain essential as core supplies to the region. They are a valuable legacy of decades of planning and investment. As source waters, they provide good water quality and supply benefits that, once lost, are very difficult to replace. Metropolitan's core supplies from the Colorado River Aqueduct are generally less susceptible to volatility from year-to-year hydrologic conditions than Metropolitan's core supplies from the SWP. However, all of the region's imported supplies face significant threats from various drivers of uncertainty, including climate change. While there is little scope for obtaining new additional imported core supplies, taking action to preserve the region's legacy imported supplies is crucial for several reasons.

Imported supplies, primarily the SWP supplies, uniquely reinforce reliability by their ability to leverage Metropolitan's storage capacity in wet periods for use in dry years and by diversifying supply sources across multiple watersheds. Because water resources available to the Metropolitan service area come from three geographically distinct regions—Northern California, the Colorado River, and local

resources—a relatively dry year affecting one of these three regions can be offset by relatively abundant supplies from the other two regions. For example, a year of ample precipitation within Metropolitan's service area tends to depress demand and enhances local water resources, further reducing demands on imported supplies. A wet year in the Sacramento-San Joaquin watersheds increases the SWP Table A allocation, facilitating reduced diversions from the Colorado River in favor of storing supplies in Lake Mead or in the Desert Water Agency/Coachella Valley Water District Advanced Delivery Account.

Conversely, a shortfall on the SWP may require system operational modifications to maximize Colorado River diversions and the delivery of Colorado River supplies to the SWP Dependent Areas. Each increment of existing imported supply reliability prevented from loss offsets the need to develop new alternative core and flexible supplies that may be more costly, may take considerable lead time to bring online, and may not be easily integrated into the region's water distribution system. SWP Dependent Areas are so-called because they currently rely on SWP water to meet at least part of their demands; any practical alternative supplies to meet SWP Dependent Area demands would also have to be potable and accessible to those relatively isolated portions of Metropolitan's distribution system.

Local Supply Findings

- *Maintaining existing and developing new local supplies is critical in helping manage demands on Metropolitan.*
- *Impacts to reliability occur if local supply assumptions are not achieved; therefore, it is important to track the progress of local supply development as one of the signposts in the One Water Implementation phase.*
- *Additional actions may be needed should existing and future local supply levels deviate from IRP assumptions.*

Demand on Metropolitan's imported supplies are a function of total regional demands and the local supplies available within the region to meet them. Local supplies are the front line in securing regional reliability. Local supplies regularly meet roughly half of the region's total urban demands; in some years it can be more than 60 percent. Because imported core supplies cannot be expected to increase even in the face of population and economic growth, the region's reliance on existing and new local supplies relative to imported supplies will only grow in the future. The IRP scenarios reveal that safeguarding the region's vast inventory of existing local supplies is as crucial as preserving existing imported supplies.

Continued performance of local supplies cannot be taken for granted, for as with imported supplies, many factors can impede local supply development and production, including funding, contamination, changing regulatory requirements, and climate change. For example, there has been a decline in groundwater production in the past 20 years, affected by limited availability of imported supplies for replenishment, variability in natural replenishment from rainfall, and emerging contaminants. At the same time, the region has made substantial gains in recycled water development, but continued success will be more difficult moving forward. This is due to the reduction of available of wastewater effluent, which stems from conservation, constraints in distribution systems, and rising costs from increasing salinity.

The region's reliability is highly sensitive to local supplies, as it comprises such a large portion of the region's total supply. As a part of the Regional Needs Assessment, Metropolitan engaged with member

agencies and basin managers to identify the potential timing and implementation of planned projects and operation of groundwater basins appropriate for each IRP scenario. Impacts to reliability will occur if local supply assumptions are not achieved; therefore, it will be important to track progress of local supply development as part of the signposts in the One Water Implementation phase. Metropolitan currently fosters local supplies through various programs and funding support, including its Local Resources Program. Metropolitan will continue to support the development of local supplies by Member Agencies.

Conclusion: Reason for Optimism with a *One Water Approach*

Collectively, these findings instill a sense of optimism about Southern California's water future. Metropolitan has identified the tools necessary to adapt to a variety of plausible futures successfully. It is also well within Southern California's control to avoid a fate with increased per-capita water use and higher demands that would prove unsustainable.

One Water is the collaborative, community approach that matches the right tools for the emerging needs of the future. The precise combination of actions will emerge as more is known about the future that we actually face. Southern California is poised to be agile enough to adjust its portfolio of water actions to keep up with our changing times.

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CASE STUDY: INTEGRATED WATER SUPPLY PLAN UPDATE STRATEGY

Final Report

Integrated Water Supply Plan Update Strategy 2020

Prepared for
Tarrant Regional Water District





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List of Abbreviations

ASR	Aquifer Storage and Recovery
CEC	Contaminants of Emerging Concern
IWSP	Integrated Water Supply Plan
NTWMD	North Texas Municipal Water District
TRWD	Tarrant Regional Water District

Executive Summary

In 2013, Tarrant Regional Water District (TRWD) issued its first Integrated Water Supply Plan (IWSP). The plan explored roughly a dozen new supply alternatives against a range of demand projections, recommended a suite of near-term "No-Regrets" projects, and presented in conclusion a series of decision trees to support for future decision-making, based on success of near-term projects and potential for future regional partnerships.

Since the release of the 2013 IWSP, TRWD has completed the Richland Chambers Wetlands, (The Wetlands now operate at a higher capacity as recommended in the 2013 IWSP), implemented effective regional water conservation measures, refined its water demand projections (the upper bounds of which still approximate the "Accepted Projections" in the 2013 decision tree, if, perhaps for different reasons), and has acquired land for the Cedar Creek Wetlands. The District is in a position to reevaluate supply and demand, and choose or reformulate a path for new supply development. It is time to update the IWSP.

TRWD identified a list of activities which, taken as a whole, would constitute a comprehensive update of the IWSP. Table ES-1 lists and defines these key elements of the IWSP Update:

Table ES-1: IWSP Update Elements

Task Definitions	Notes
Transmission System Planning Guidance	Includes known rehabilitation, alternatives for existing sources, and plans for new source transmission
Explore Regional Collaboration	Determine if partnerships with Dallas, NTMWD, and/or TRA are beneficial and practical
Hydrologic Updates	Determine if available water in existing sources is likely to be significantly less than current permitted values
Refine Initial IWSP Supply Alternatives	Update alternatives in 2013 IWSP for cost, yield, institutional practicalities, etc.
TRWD Risk / Gap Assessment (supply/demand)	Understand the combined risks of supply and demand uncertainty
Different Supply Portfolios	Refine, modify, or replace portfolios in the 2013 IWSP decision tree
Customer Collaboration	Includes educating member utilities and soliciting input on IWSP recommendations
Identify New Sources (not in IWSP)	Includes any alternative supply source not evaluated in the 2013 IWSP
Resilience Assessment	Vulnerability assessment of individual sources and the system as a whole
Consequences of Inaction	Effectively, the equivalent of the "DO NOTHING" alternative in federal studies
Customer Risk Appetite	Explaining the differences between 98% and 100% reliability, and associated costs

The central question of this Scenario Planning Phase of the study was therefore: "What is the most effective orchestration of these tasks, in terms of sequence and grouping, that will be most resilient to critical near-term risks and uncertainties, and which will be adaptable?" In other words, the goal was to develop a thoughtful sequence of planning activities / investments that will help TRWD avoid inefficiencies or rework, incomplete steps, missed opportunities, or unnecessary steps. The other

important component of the goal statement was to orchestrate the update process in a way that could easily adapt to changing conditions, decision points, or other influential factors.

The process of Scenario Planning was employed, in which TRWD framed its path forward by defining a group of plausible future conditions (in the near-term) marked by broad uncertainty and potentially impactful consequences of that uncertainty on the planning process itself. Unlike a traditional definition of a scenario in modeling-based studies, where a scenario is defined as input conditions translated into output performance (for example), Scenario Planning is based on the principle of **building immunity to uncertain future conditions**, or "plausible scenarios."

Many driving forces were considered that could potentially impact the effectiveness or efficiency of the TRWD planning process. These included the following:

- Cost of Water
- OneWater/Sustainability
- Internal Factors/Operations
- Environmental Considerations
- Resource Issues
- Near-Term Actualization of Long-Term Trends
- Private Partnership Opportunities
- Regulatory Drivers
- Regional Dynamics
- Water Quality
- Hydrologic Uncertainty
- Customer Perception
- Political Impacts

Of these factors, those that were characterized by the highest uncertainty and potentially the most significant impacts ("high risk") included political factors, customer perceptions, hydrologic uncertainty, regional dynamics, and regulatory drivers. Of these, the four most potentially impactful risks were identified as:

- Hydrologic Uncertainty
- Regional Dynamics
- Customer Perceptions
- Regulatory Drivers

Various combinations of these uncertainties were explored to define plausible future conditions which served as the backdrop against which various strategies for the IWSP Update process were compared. Figure ES-1 illustrates the two "grids" that helped define the plausible future conditions that guided the strategy development for the IWSP Update:

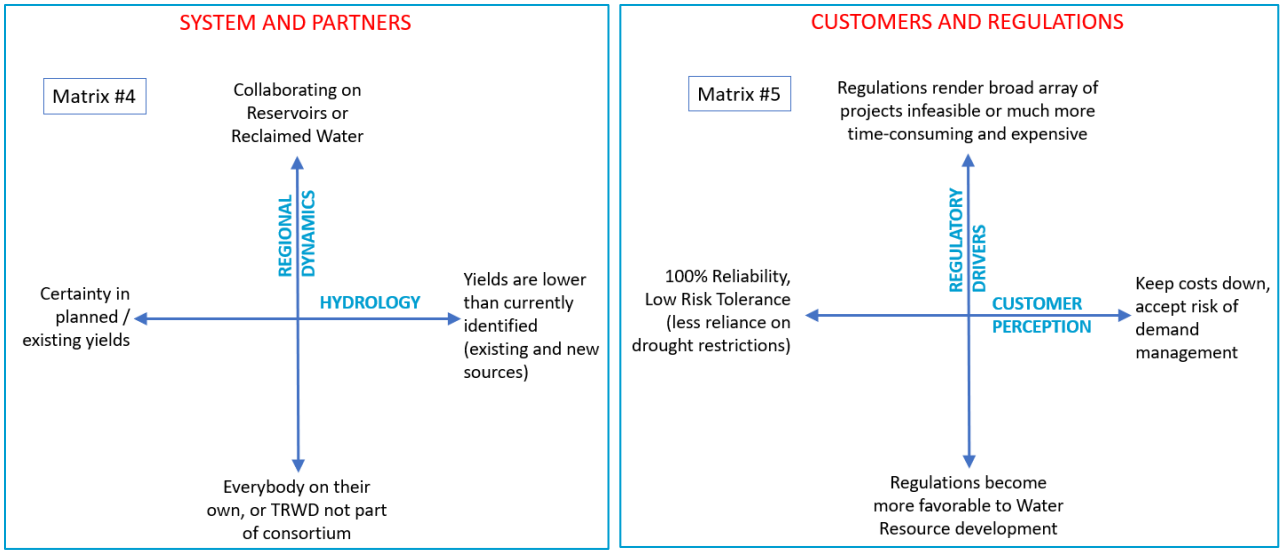


Figure ES-1: The Framework: Plausible Future Conditions Based on Key Risks

The IWSP Update strategy development process was supported by a series of facilitated workshops, breakout sessions, and follow-up conversations with departmental leads. By comparing the elements of the IWSP Update from Table ES-1 against the "risk space" of plausible near-term future conditions in **Figure ES-1**, an adaptive strategy is presented in this document which prioritized the elements of the IWSP Update, identified triggers that would change priorities, and which ultimately can serve as a roadmap for effective and efficient execution of the IWSP Update process.

The recommended strategy is illustrated in **Figure ES-2.** This report explains, step by step, how this strategy was developed collaboratively within TRWD (**Sections 2.0 – 6.0**), and also includes work plan outlines and additional planning guidance for each individual task (**Sections 7.0 – 9.0**). The plan was formulated by experimenting with various sequences of planning tasks to discern which sequences provided some clear **immunity to the greatest near-term risks of inefficient or ineffective planning**. Adaptation triggers were added to further provide buffering against uncertain future conditions by re-prioritizing certain tasks based on future conditions as they evolve.

Some of the key findings are summarized below:

- **Hydrologic Uncertainty**: Without understanding the yield of existing sources (which may be less than what is permitted when climate change, sedimentation, and future regulatory conditions are accounted for), it is impractical to embark on any of the other tasks with confidence. Understanding currently available water is the cornerstone of all subsequent tasks. This task, therefore, received the highest priority.
- **Regional Partnership Potential**: Similarly, without understanding the potential for TRWD to partner with the North Texas Municipal Water District and/or the City of Dallas on large regional supply alternatives, focus on either supply sources or portfolios could be ineffective or inefficient. For this reason, exploring regional partnerships was also given a high priority in the sequence of IWSP Update tasks. Regional supply efforts languish for years in discussion and preliminary study with no firm timetable for permitting and development. Effective scenario planning encourages efforts to acquire an updated understanding of regional project partnership potential. This understanding allows TRWD to integrate all water supply strategies into a prioritized and sequenced development plan or supply portfolio. Clarity with regard to regional supply project potential allows the District's

staff, governance and customers to clearly understand proposed water supply development and support effective decision making.

- **Blending Supply and Demand Uncertainty**: Combining the results of the hydrologic analysis (above) with the recently completed Service Area Demand Study will help provide solid quantifiable guidelines for how much new water is needed, and when. This is the "Supply/Demand Gap Analysis," and is also given a high priority in the sequence of tasks because it identifies the criticality of timing and sizing of new supplies and transmission infrastructure.
- **Transmission System Planning Guidance**: This is not so much an element of the Update Process as it is a continual thread throughout it (and outside of it). It can, and should, begin with the prioritization of tasks which do not necessarily depend on future supply plans, then evolve into conceptual planning for future supplies that appear to be favorable or preferable, and ultimately proceed into a full Transmission System Master Plan for Existing and New Sources. Information from other tasks will support the Transmission System Planning, and vice versa.
- **Other Parallel Pathways**: Other factors that should be considered throughout the IWSP Update, but which themselves do not necessarily constitute a specific identifiable task, include:
  - Consideration of TRWD's Reliability Criteria – All evaluations should consider supply needs and costs for providing water based on TRWD's 98% reliability criteria through the drought of record (which reflects modeling uncertainty, and not necessarily water shortage). However, consideration should be given throughout the IWSP Update process to explore the tradeoffs associated with reducing the need for customer demand restrictions during periods of hydrologic stress.
  - Resilience: All tasks should consider resilience of resources and infrastructure not only to climate trends but also to other forms of shock: Contamination, natural disasters, major demographic shifts, etc.
  - Customer Collaboration: As TRWD learns more about the factors and drivers that will shape its long-term supply plan, information will be shared with customer cities. However, meaningful feedback on decisions cannot be expected until a recommended supply portfolio, associated costs, and incremental costs between 98% and 100% reliability are fully developed for discussion.

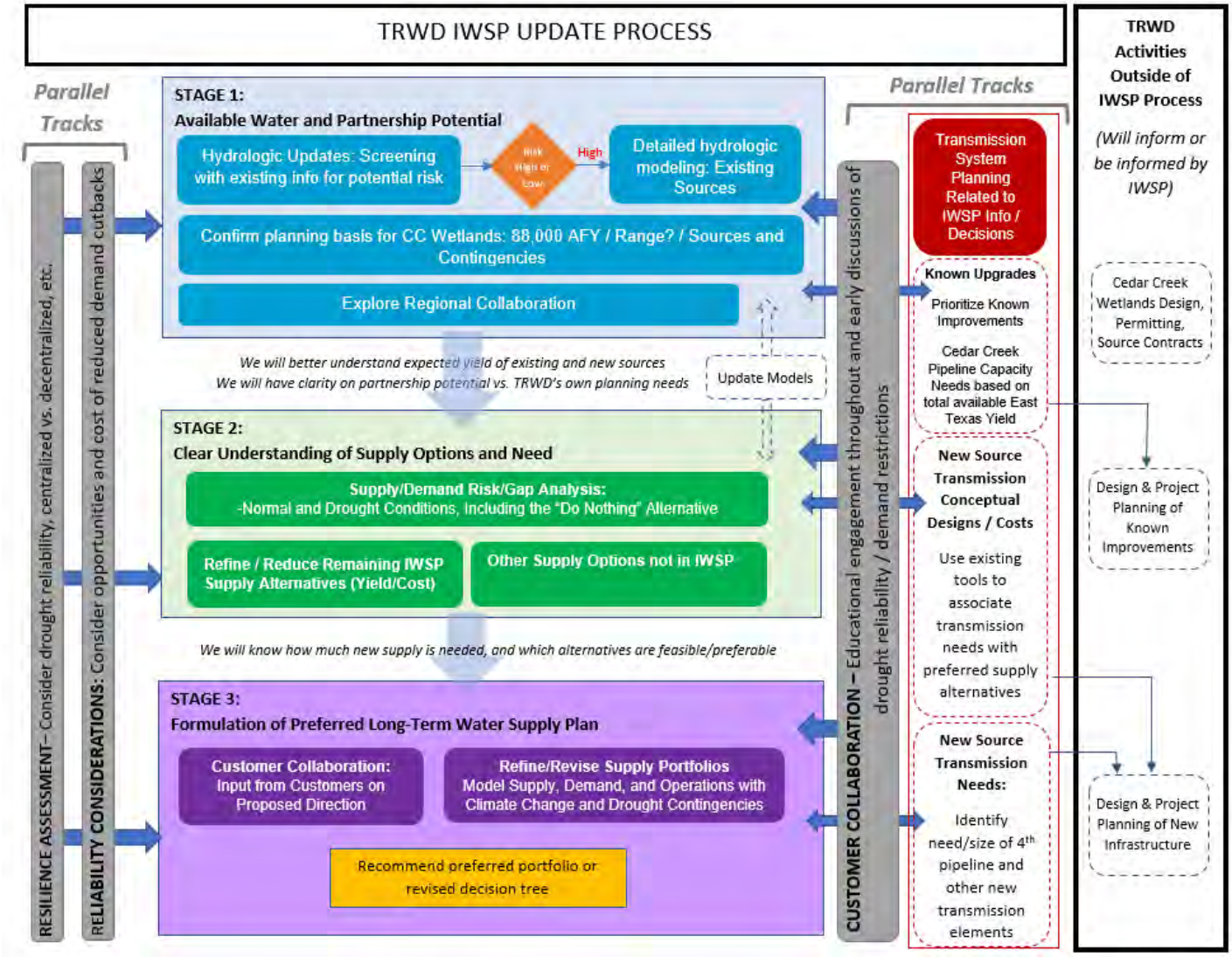


Figure ES-2: Adaptive IWSP Update Strategy

Section 1

Background and Purpose

In 2013, TRWD issued its first Integrated Water Supply Plan (IWSP). It explored roughly a dozen new supply alternatives against alternative demand projections, and presented in conclusion a decision tree with which TRWD could make near term "no regrets" investments in supply enhancement, evaluate the effectiveness of these steps in the near-term, and choose a branch of the decision tree to follow based on the success of the initial decisions and the evolution of conditions in that short timeframe.

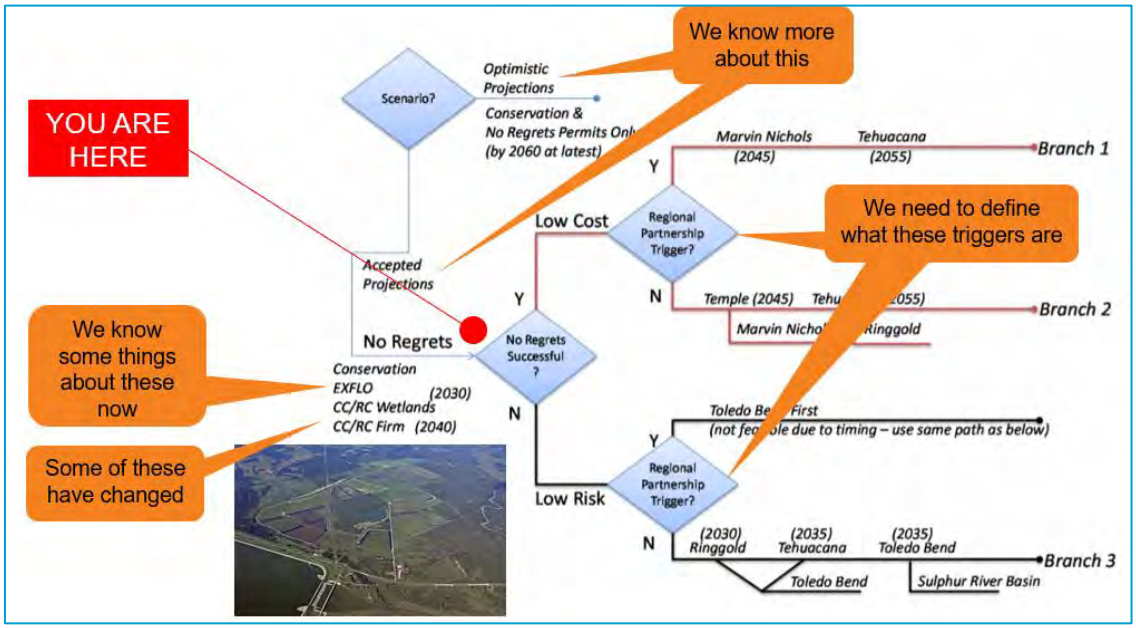


Figure 1-1: TRWD's IWSP Decision Tree and Recent Evolution of Information

**Decision Tree image (augmented here) extracted from TRWD's Integrated Water Supply Plan, 2013*

Since the release of the IWRP, TRWD has invested in the Richland Chambers wetlands (which are operational at a higher capacity than planned in the IWSP), implemented effective water conservation measures, refined its water demand projections (the upper bounds of which still approximate the "Accepted Projections" in the decision tree, if, perhaps for different reasons), and has acquired land for the Cedar Creek Wetlands. The District is in a position to reevaluate supply and demand, and choose or reformulate a path for new supply development. It is time to update the IWSP.

The decisions are complicated by the fact that some of the driving factors have changed, and will influence not only the ultimate trajectory of water supply but the planning process itself. The decision tree can still provide useful guidance, but there are numerous uncertainties that could affect the way in which TRWD proceeds with making its long-term decisions.

This Scenario Planning process was purposefully designed to highlight the factors whose uncertainty and potential impacts of that uncertainty could risk inefficiencies, incomplete steps, missed opportunities, or

unnecessary steps in the IWSP Update process. By understanding these risks, the process can be orchestrated in a thoughtful and adaptive way to reduce TRWD's exposure to critical risks.

Important to note is that this Scenario Planning is aimed at producing a strategy for the process of updating the IWSP, not at the updated plan itself. As such, we have focused on near-term uncertainties (within the next 3-5 years, over which the IWSP update activities will be executed), and not necessarily on long-term uncertainties that could affect implementation of water supply strategies.

The end goal of this document is to highlight the factors whose uncertainty and potential impacts of that uncertainty could risk inefficiencies, incomplete steps, missed opportunities, or unnecessary steps in the IWSP Update process. By understanding these risks, the process can be orchestrated in a thoughtful and adaptive way to reduce TRWD's exposure to critical risks, and ultimately allow the District to confidently move forward into the original decision tree, or modify it based on current conditions, needs, and risks.

Section 2

Planning Horizon

Unlike many scenario planning exercises, the planning horizon for this effort is considered to be "near-term," with a focus on the next 3-5 years. This is not a scenario planning exercise for determining new water sources, but rather an exercise in helping to ensure that the update of the IWSP is efficient, effective, and complete. While many of the risks identified in the process will have both near-term and long-term uncertainty, this process focuses attention on near term risks that could affect the efficiency of the plan update process, not necessarily the implementation of the plan itself. Figure 2-1 illustrates the focal period for this scenario planning exercise in yellow.

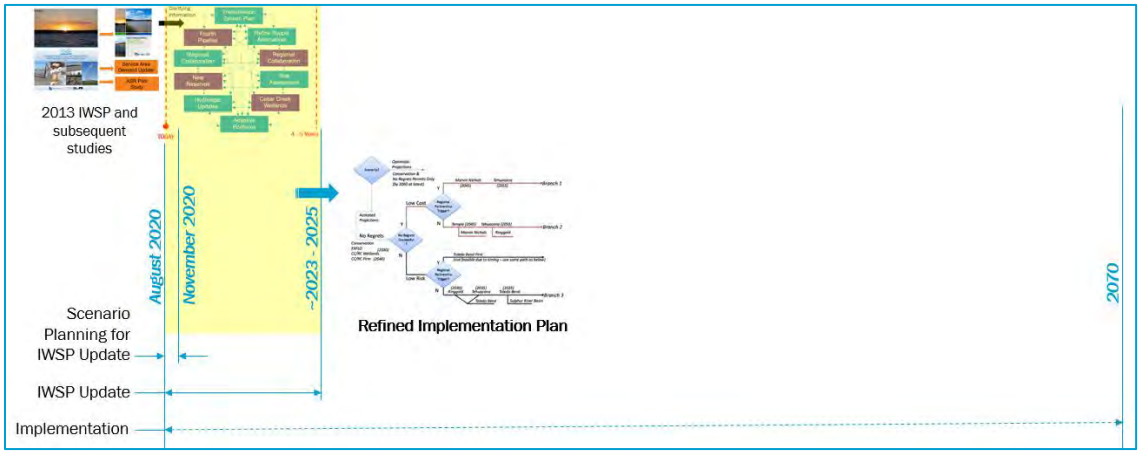


Figure 2-1: Planning Horizon for the IWSP Update

Section 3

List of Activities that Comprise the IWSP Update

Unlike the 2013 IWSP, which was developed as a single project, the update of the IWSP in response to this work and the compendium of work completed between 2013 and 2020 will take the form of a series of different activities. The purpose of this Scenario Planning Exercise, in fact, has been to develop a strategy that orchestrates these activities in an efficient, productive way.

The scope of work included six example activities, which were broadly assumed to be destined for incorporation into the IWSP Update process. This list was expanded by TRWD during the first of four workshops supporting this strategy development, and the entire list was later refined by clarifying definitions and dividing one of the activities into two. Table 3-1 lists the activities that will be described, prioritized, and sequenced in this IWSP Update Strategy. Work Plan outlines and considerations for Level of Effort for the 11 activities are included in Sections 8.0 and 9.0.

Table 3-1: Activities to be Included in the IWSP Update

Source	Initial Activity Definitions	Refined Definitions (in bold)	Notes
Originally in Scope of Work as Suggestions	Transmission System Master Plan	Transmission System Master Plan	Includes known rehabilitation, alternatives for existing sources, and plans for new source transmission
	Explore Regional Collaboration	Explore Regional Collaboration	Determine if partnerships with Dallas, NTMWD, and/or TRA are beneficial and practical
	Hydrologic Updates	Hydrologic Updates	Determine if safe yield and firm yield of existing sources has decreased based on new information
	Refine Supply Alternatives	**Refine Initial IWSP Supply Alternatives**	Update alternatives in 2013 IWSP for cost, yield, institutional practicalities, etc.
	Long Term Risk Assessment / Appetite	**TRWD Risk / Gap Assessment (supply/demand)**	Understand the combined risks of supply and demand uncertainty
	Alternative Supply Portfolios	**Different Supply Portfolios**	Refine, modify, or replace portfolios in the 2013 IWSP decision tree
Added by TRWD in Workshop #1	Customer Collaboration	Stakeholder Outreach	Includes educating member utilities and soliciting input on IWSP recommendations
	Nontraditional Supply Evaluation	**Identify New Sources (not in IWSP)**	Includes any alternative supply source not evaluated in the 2013 IWSP
	Resilience Assessment	Resilience Assessment	Vulnerability assessment of individual sources and the system as a whole
	Consequences of Inaction	Consequences of Inaction	Effectively, the equivalent of the "DO NOTHING" alternative in federal studies
		Customer Risk Appetite	Explaining the differences between 98% and 100% reliability, and associated costs

Section 4

Scenario Planning History and Theory

Scenario planning has been used by organizations for decades to help prepare for uncertain futures. It offers insight into plausible combinations of risk (uncertain factors and the significance of their potential impacts) which could emerge as future realities, and against which decisions made today can be tested. Scenario planning provides a structured framework for organizations to identify factors that could influence their future, characterize the uncertainties associated with each factor, and determine how impactful each range of uncertainty could be. Within this framework, today's decisions can be tested to see how resilient they may be to various combinations of the most impactful future uncertainties.

Figure 4-1 begins to illustrate the concept. Unlike the traditional concept of "scenarios" in modeling or planning studies (where a "scenario" might represent a series of inputs that lead to a deterministic output), scenarios in scenario planning describe impactful uncertainties that create a structured space for planning – a framework of plausible future scenarios against which to test decisions. While traditional planning may be more deterministic or probabilistic, scenario planning simply focuses on preparing for the most impactful plausible future.

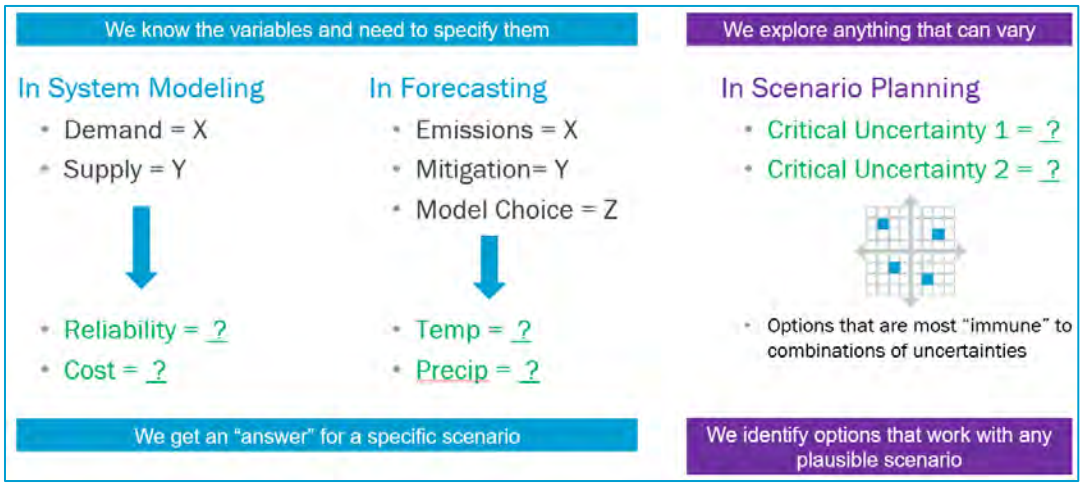


Figure 4-1: Traditional Planning and Scenario Planning

One useful way to visualize the philosophy of scenario planning is show in Figure 4-2. Many traditional planning methods attempt to forecast future conditions either deterministically or probabilistically, and base decisions on the "most likely" future. Scenario Planning acknowledges that beyond any probable future are a wide range of plausible future, none considered any more probable than any other. In this context, the resilience of decisions made today can be tested against a range of plausible future condition to determine durable they can be shown to be against any potential future.

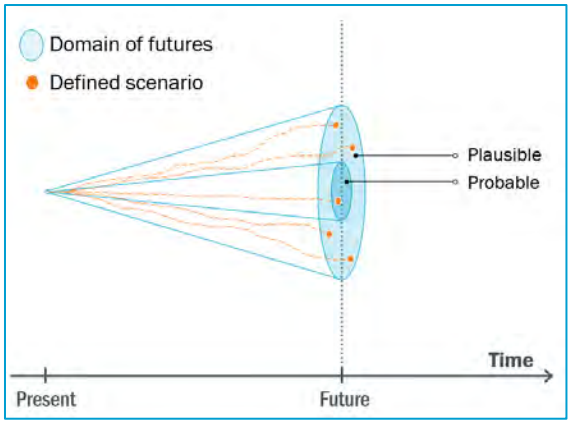


Figure 4-2: Plausible Future Scenarios Emphasized Over Probable

More specifically, scenario planning combines the most uncertain and most impactful future conditions (perhaps climate, perhaps economics, perhaps politics or institutional leadership, perhaps public health, perhaps demographics, etc.) and combines them across their full spectrum of possibilities in the form of 2 x 2 matrices to create four quadrants that describe plausible future conditions. Resource management or institutional strategy decisions are then formulated and tested in all four quadrants of uncertainty (all four "scenarios"), so that organizations are well-equipped to handle whatever future conditions evolve.

A useful analogy is Asset Management, where facilities are renewed based on the combined influence of likelihood and consequence of failure. In the scenario planning realm, we look at uncertainty and potential impacts of that uncertainty in much the same way to guide institutional decisions.

Figure 4-3 illustrates a typical process for scenario planning, in generic terms. The remaining figures in this section illustrate the process in more detail, but generically. TRWD's results for this same framework are included in Section 5.0.

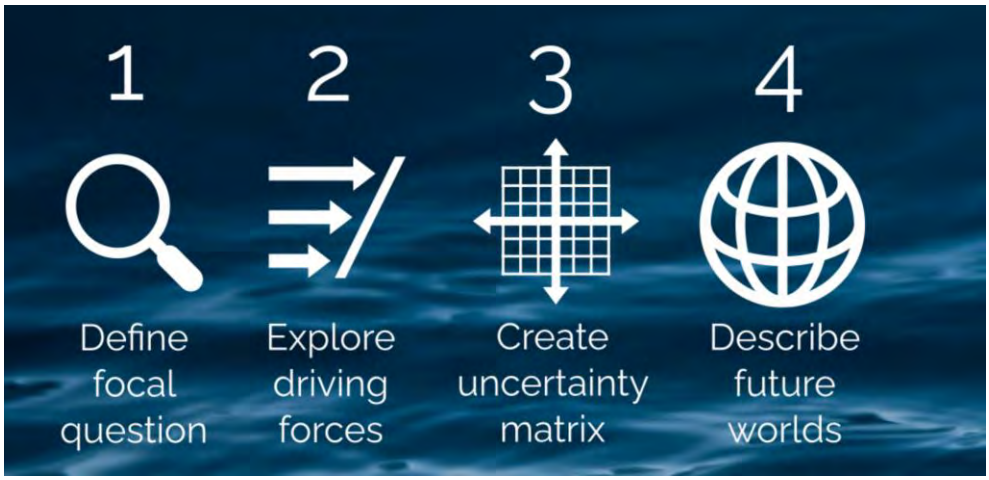


Figure 4-3: Standard Scenario Planning Process

The Specific Steps in Scenario Planning (Generic)

Step 1: Define the Focal Question

Articulate the driving question that must be addressed.

Step 2a: Brainstorm Factors That Could Influence Future Conditions (Drivers)



Figure 4-4: Brainstorming Factors

Step 2b: Group the Factors by Theme and Rank Based on Uncertainty

"Uncertainty" is defined here as the range of possible outcomes, without yet considering the consequences of each range.

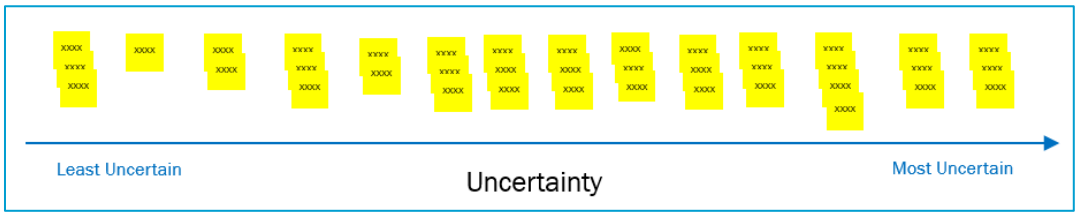


Figure 4-5: Organizing Factors

Step 2c: Rank Each Group of Factors by the Criticality/Impactfulness of its Uncertainty

"Impactfulness" is defined as the potential consequences of experiencing either end of the spectrum of uncertainty.

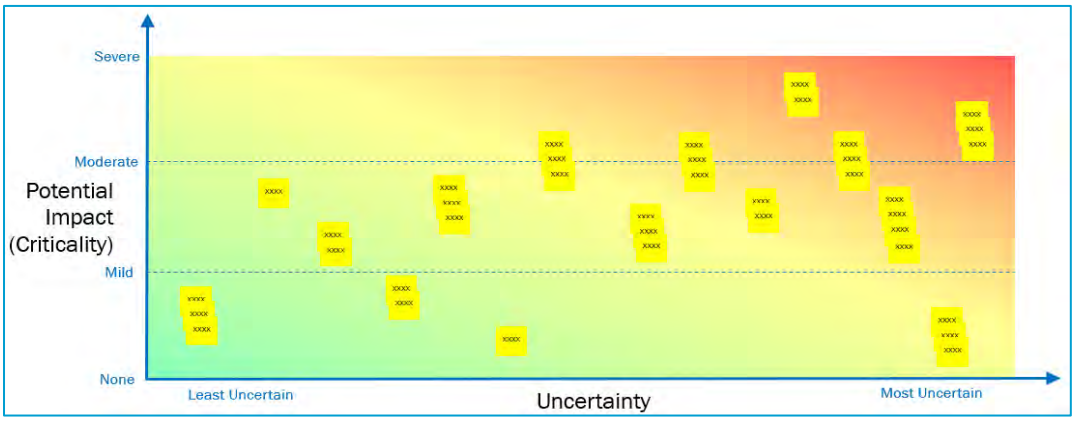


Figure 4-6: Characterizing Potential Impact of Not Knowing

Step 3a: Combine the Factors with Highest Critical Uncertainty (Greatest Risks) into 2 X 2 Grids

The axes of each grid are defined as the extreme ranges of uncertainty, and do not necessarily need to be positive/negative

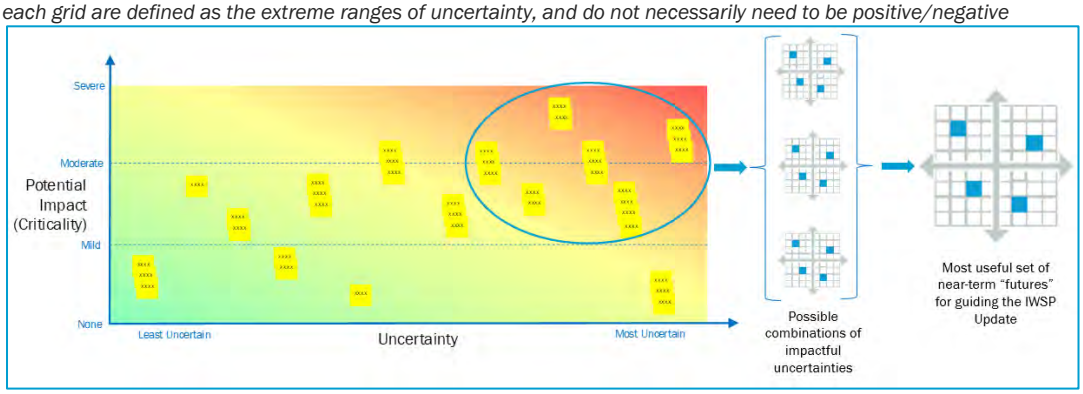


Figure 4-7: Combining Risks

Step 3b: Identify the Most Useful Grid (or Grids) for Future Planning

This is an example only, and does not reflect the drivers or axes defined by TRWD – See Section 5.0.

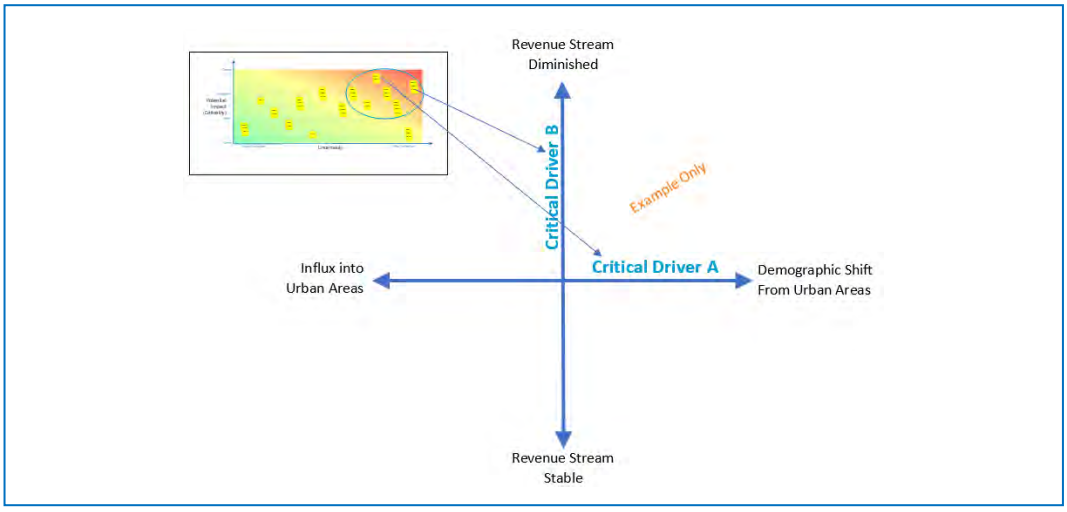


Figure 4-8: Defining Plausible High-Risk Futures

Step 4a: In Narrative Form, Describe the 4 Quadrants as Equally Plausible Future Scenarios

This is an example of on quadrant description from TRWD's Scenario Planning Exercise

Quadrant B: **TRWD Collaborates with Other Providers, but Yields of Existing and New Supplies are Reduced.** In this future, TRWD knows that new data, methods, or climate trends have reduced the permitted yield from existing sources, and yield from prospective new sources is lower than expected in the first draft of the IWSP. Knowing this, TRWD has entered into partnership with Dallas and NTMWD (or perhaps others) to develop a large new regional reservoir(s) and/or a coordinated plan for TRA Reuse.

Step 4b: Test Alternatives for Resilience to Future Conditions in Each Grid Quadrant



Figure 4-9: Testing Alternatives or Decisions Against Plausible Futures

Section 5

Summary and Conclusions from TRWD's Scenario Planning Process

5.1 Workshop Summaries

Four workshops were held with TRWD staff ("The Group") to facilitate the process outlined above. The group included Darrell Andrews, Laura Blaylock, Dan Buhman, Linda Christie, Dustan Compton, Brenton Dunn, Jason Gehrig, Woody Frossard, Zach Huff, Rachel Ickert, Dave Marshall, Jim Oliver, Wayne Owen, Nicole Rutigliano, and Alan Thomas.

Workshop 1: August 7, 2020

Scenario Planning Theory and Identification of Alternatives

Workshop 2: August 14, 2020

Drivers and Impactful Uncertainties

This workshop covered steps 1-2 in the process shown in Section 4, and was augmented by two small-group breakout discussions to complete the work.

Workshop 3: September 3, 2020

Develop Scenarios For Critical Near Term Risk

This workshop covered step 3 in the process shown in Section 4.

Workshop 4: September 17, 2020

Explore Alternative IWSP Update Strategies

Step 4a of the process shown in Section 4 was completed offline (describing the resulting scenarios in narrative form). Step 4b was completed in this workshop.

The results of the workshops are presented below in the context of the 8 steps outlined in Section 4.0:

Step 1: Define the Focal Question

Each workshop focused the group on the following question:

> *How can TRWD update the IWSP over the next 3-5 years with a strategy that minimizes the risk of inefficiencies, incomplete steps, missed opportunities, or unnecessary steps.*

Steps 2a and 2b: Brainstorm Factors That Could Influence Future Conditions (Drivers), Group the Factors by Theme, and Rank the Themes Based on Relative Uncertainty

The following pages summarize the deliberations with snapshots of the white-boards and a tabular summary of ideas. The Group was asked to identify factors that could influence the

strategy for the IWSP Update in the near-term (during the IWSP Update process), group them into related themes, and then rank them based on their relative uncertainty to each other. In this first exercise, we did ***not*** account for the criticality of potential consequences or the uncertainty (this comes next), but rather, the possible range of outcomes that could manifest themselves within the short planning horizon as "plausible." This became our working definition of "uncertainty." **Figures 5-1 and 5-2 and Table 5-1** report the results of these first two steps, first in the form of whiteboard brainstorming, and then in an organized table, in which relative uncertainty increases from left to right.

White-Board Exercise: Near Term Drivers of the IWSP Update, Grouped by Common Themes and Partially Ranked by Uncertainty (Same information in following table for readability)

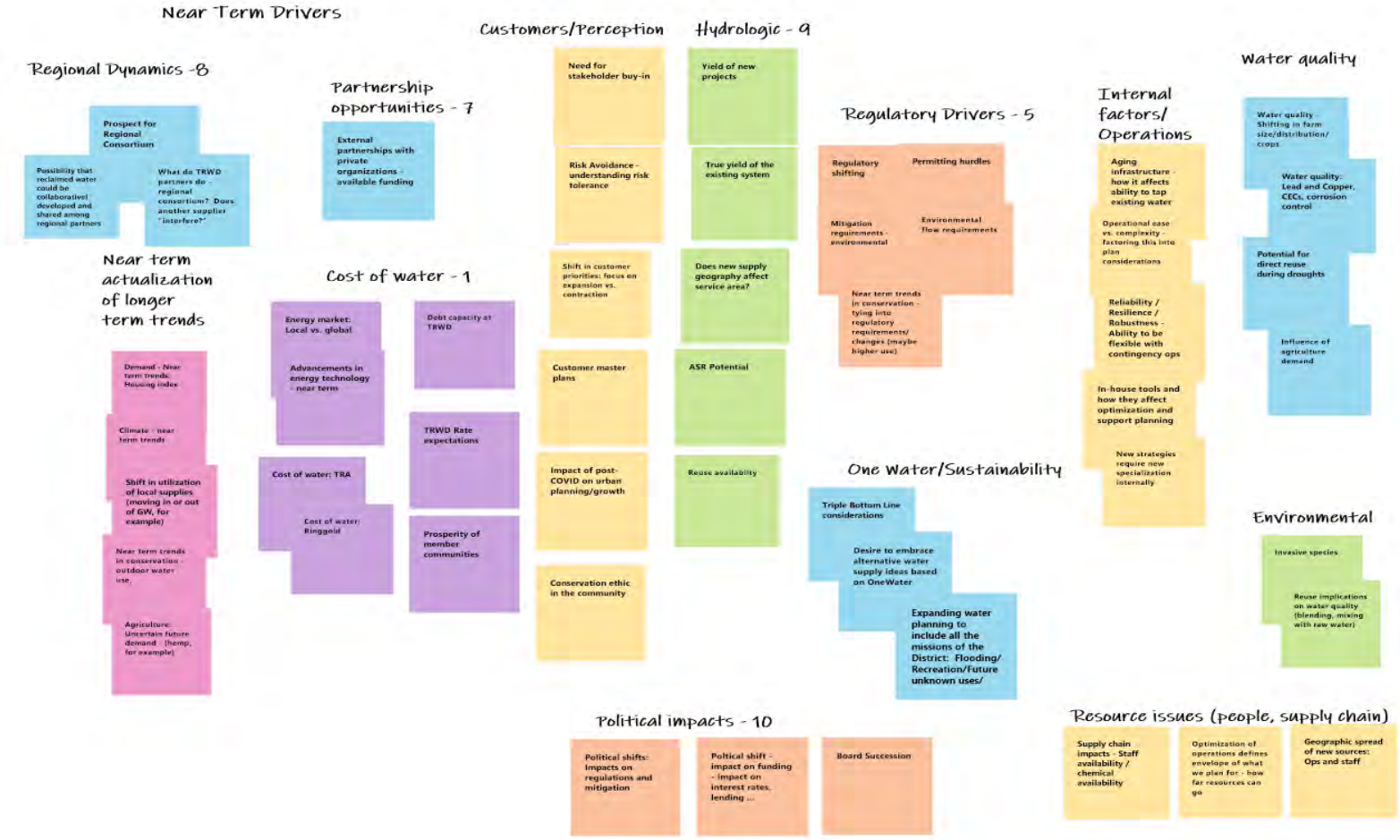


Figure 5-1: Themed Drivers for the IWSP Update
*(Text is included in **Table 5-1**)*

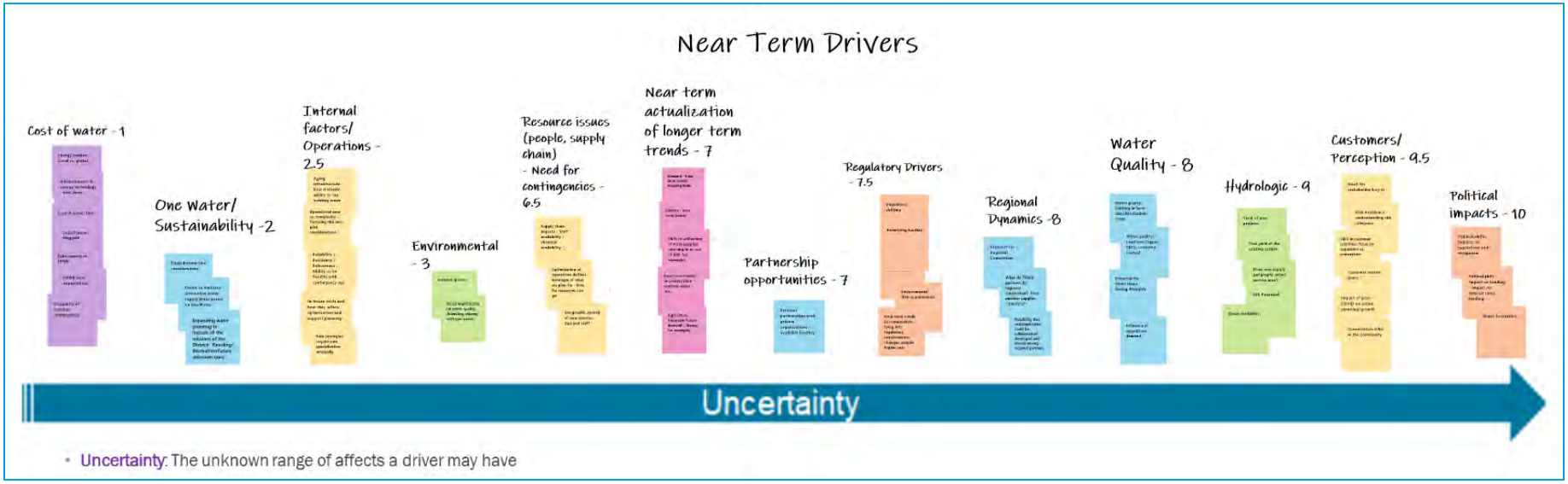


Figure 5-2: Themed Drivers Ranked by Relative Uncertainty

*(Text is included in **Table 5-1**)*

Table 5-1: Themed Drivers, Ranked by Relative Uncertainty

THEMED NEAR-TERM DRIVERS (Ranked by Relative Uncertainty, but Not Criticality Yet)

Relative Uncertainty (Range of possible futures): 1-10 *

1	2	2.5	3	6.5	7	7	7.5	8	8	9	9.5	10
Cost of Water	OneWater/ Sustainability	Internal Factors / Operations	Environ-mental	Resource Issues	Near-Term Actualization of Long-Term Trends	Private Partnership Opportunities	Regulatory Drivers	Regional Dynamics	Water Quality	Hydrologic	Customers / Perception	Political Impacts
Energy market: Local vs. Global	Triple Bottom Line factors	Aging infrastructure and ability to tap existing sources	Invasive species	Supply chain impacts – staff & chemical availability	Near term demand trends / housing index	External partnerships with private orgs – available funding	Regulatory shifts	TRWD prospect for regional consortium	Water quality impacts from shift in ag. size/crops/ distribution	Yield of new supplies	Need for stakeholder buy-in	Political shifts- impacts on regs and mitigation
Advancements in energy tech.	Desire to embrace alternative supplies based on OneWater	Operational ease vs. complexity	Reuse implications on water quality (blending/ mixing)	Optimization of ops defines envelope of what to plan for	Near term climate trends		Permitting hurdles	Actions of other regional providers: consortium, supply "interference"	Lead/Copper, CECs, Corrosion control	Revised yield of existing TRWD system	Risk avoidance – knowing risk tolerance	Political shifts- impacts on funding, interest rates, lending
Cost of TRA water	Expanded water planning to include all missions: Flooding/Rec /Future uses	Reliability/ Resilience / Robustness – Flexibility with contingency ops		Geographic spread of new sources affects ops and staff	Shift in utilization of local supplies (e.g: more/ less GW)		Mitigation requirements	Possibility for collaboration on reclaimed water -shared resource	Potential for direct reuse during droughts	Could new supply geography affect service area?	Shift in customer priorities: Expansion vs. contraction	TRWD Board Succession
Cost of Ringgold water		In-house tools and how they support planning			Near term conservation trends, indoor and outdoor		Environ-mental flow requirements		Influence of ag demand	ASR Potential	Evolution of customer master plans	

Table 5-1: Themed Drivers, Ranked by Relative Uncertainty

THEMED NEAR-TERM DRIVERS (Ranked by Relative Uncertainty, but Not Criticality Yet)

Relative Uncertainty (Range of possible futures): 1-10 *

1	2	2.5	3	6.5	7	7	7.5	8	8	9	9.5	10
Cost of Water	OneWater/ Sustainability	Internal Factors / Operations	Environ-mental	Resource Issues	Near-Term Actualization of Long-Term Trends	Private Partnership Opportunities	Regulatory Drivers	Regional Dynamics	Water Quality	Hydrologic	Customers / Perception	Political Impacts
Debt capacity at TRWD		New strategies require new specialized skills			Future ag. Use – (e.g: hemp farming)		Near term trends in conservation – maybe higher use			Reuse Availability	Impact of COVID on urban planning / growth	
TRWD rate expectations											Conservation ethic in community	
Prosperity of member communities												

** "Uncertainty" was defined as the range of plausible conditions that could develop, with a score of 1 representing a very narrow band of plausible future conditions, and 10 representing a very broad range of plausible futures. These rankings are completely independent of the criticality, or impact, of these uncertainty ranges with respect to the IWSP Update process – these will be examined in the next step to form the basis of the future scenarios.*

During the deliberations for steps 1 and 2, several ideas were offered that are likely to affect the implementation of the plan, sometimes in addition to its actual update, and sometimes instead of its update. These were categorized as Long-Term Drivers, and the list below is a log of these ideas to be used during the IWSP Update process itself. Some are also listed with the short-term drivers, as near-term actualization of these factors could influence the orchestration of the Plan Update. Because these were supplemental outputs of the workshop (not the primary purpose), this list may help inform subsequent planning efforts, but should not be construed as an exhaustive list of the long-term drivers for water supply.

Long Term Drivers for Consideration in IWSP Update (Beginning of a List):

- 50-year climate trends
- Climate shifts that impact water quality
- Long-term demand trends
- Aging infrastructure
- Economic prosperity within the community
- Technological advancements
- Reliability/Resilience/Robustness – Ability to be flexible with contingency operations
- Population / Urban growth

Step 2c: Rank Each Group of Factors by the Criticality/Impactfulness of its Uncertainty

"Impactfulness" is defined as the potential consequences of experiencing either end of the spectrum of uncertainty.

Results are shown on the next page, as **Figure 5-3**. A vertical axis was added to the uncertainty axis to represent the Potential Impact, or Criticality of the uncertainty associated with each driver. Another way to consider the impactfulness is by asking the question, "Does not knowing the outcome of a particular driver have significant influence on our IWSP Update strategy, possibly causing inefficiencies, missed opportunities, or incomplete steps?"

Step 3a: Combine the Factors with Highest Critical Uncertainty (Greatest Risks) into 2 X 2 Grids

The group identified the circled factors in **Figure 5-4** as being representing the greatest risk to an efficient and thorough process of updating the IWSP (here, "Risk" is defined as the combination of uncertainty and the potential impacts of that uncertainty".) They experimented with different combinations of drivers, 2 at a time, to great grids of plausible future decision space. In each grid, the 2 selected drivers are used as the axes, and the extreme ends of the axes represent the two ends of the uncertainty spectrum. In this context, the opposing ends of an axis need not necessarily be positive/negative, or worst to best, but rather, two plausible but opposing descriptions of uncertain conditions that span the spectrum. The 5 drivers that were used experimentally to explore different combinations of uncertainties are identified in **Figure 5-4**, and the five grids are identified in **Figure 5-5 through 5-9**.

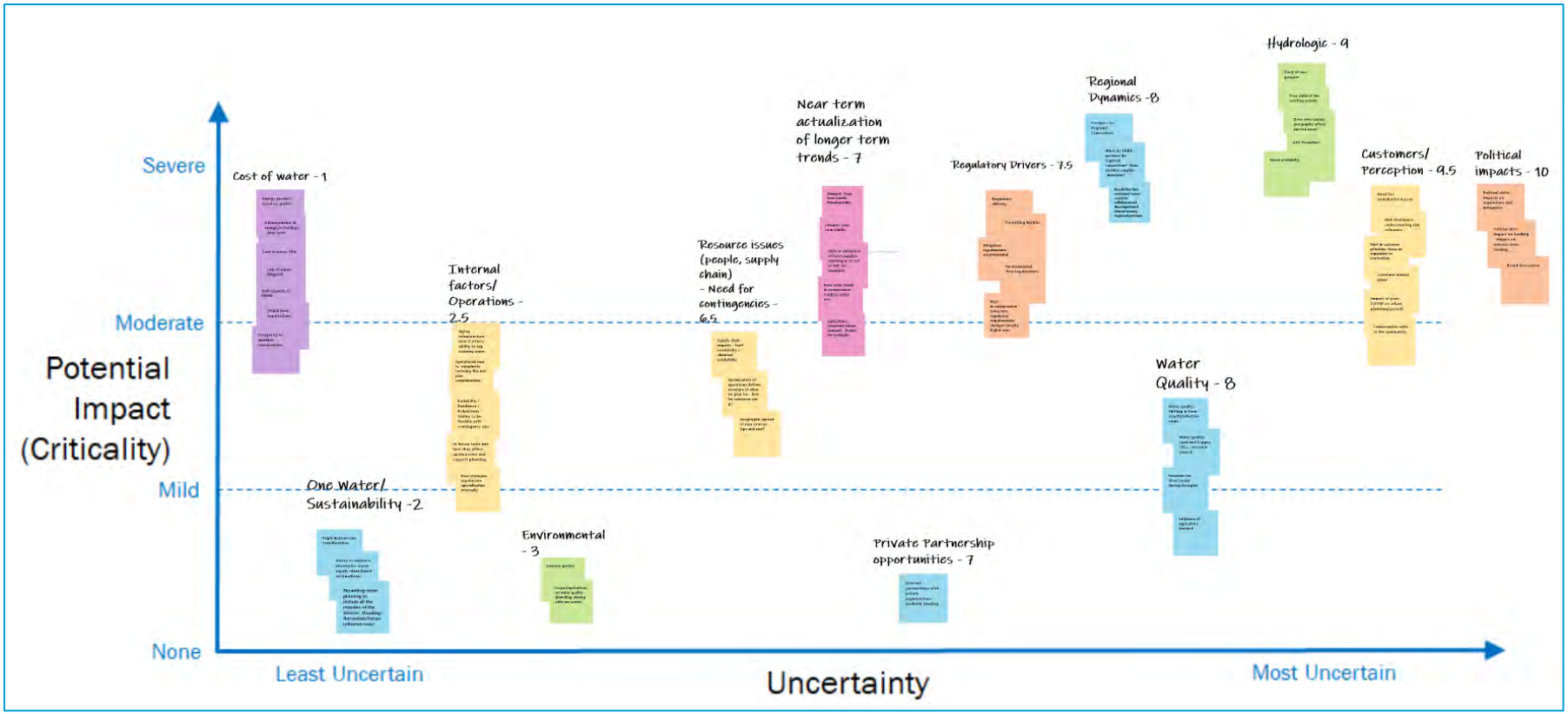


Figure 5-3: Drivers Ranked by Uncertainty(x) and the Criticality of that Uncertainty (y)

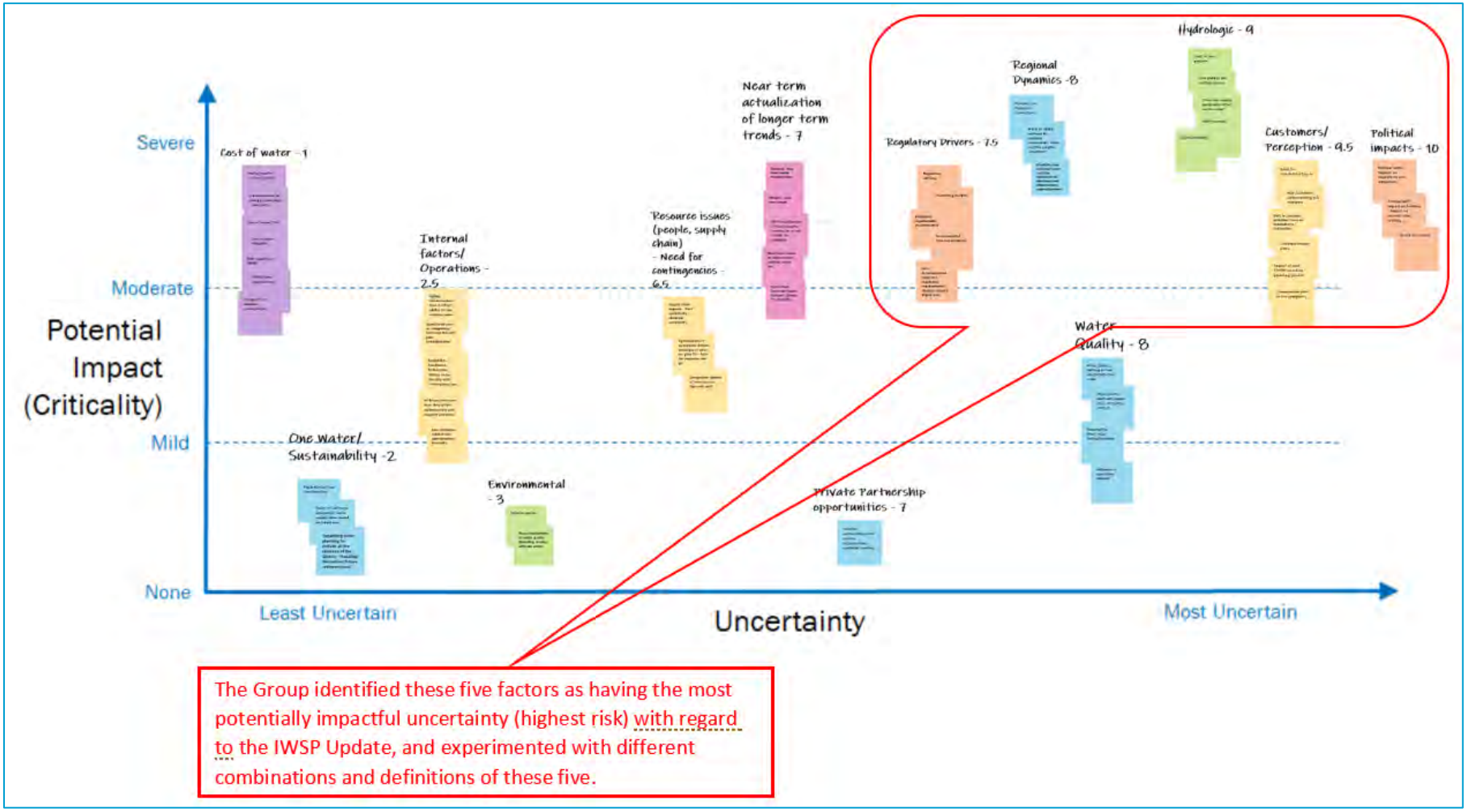


Figure 5-4: The Five Most Critically Uncertain Factors (Highest Risk)

Experimental Matrix #1:
Critical Uncertainties: Regional Dynamics and Customer Perception

Note that the "space" in the quadrants can be used to assess how well a particular strategy is prepared for the plausible future contained within that space.



Provided for visual reference

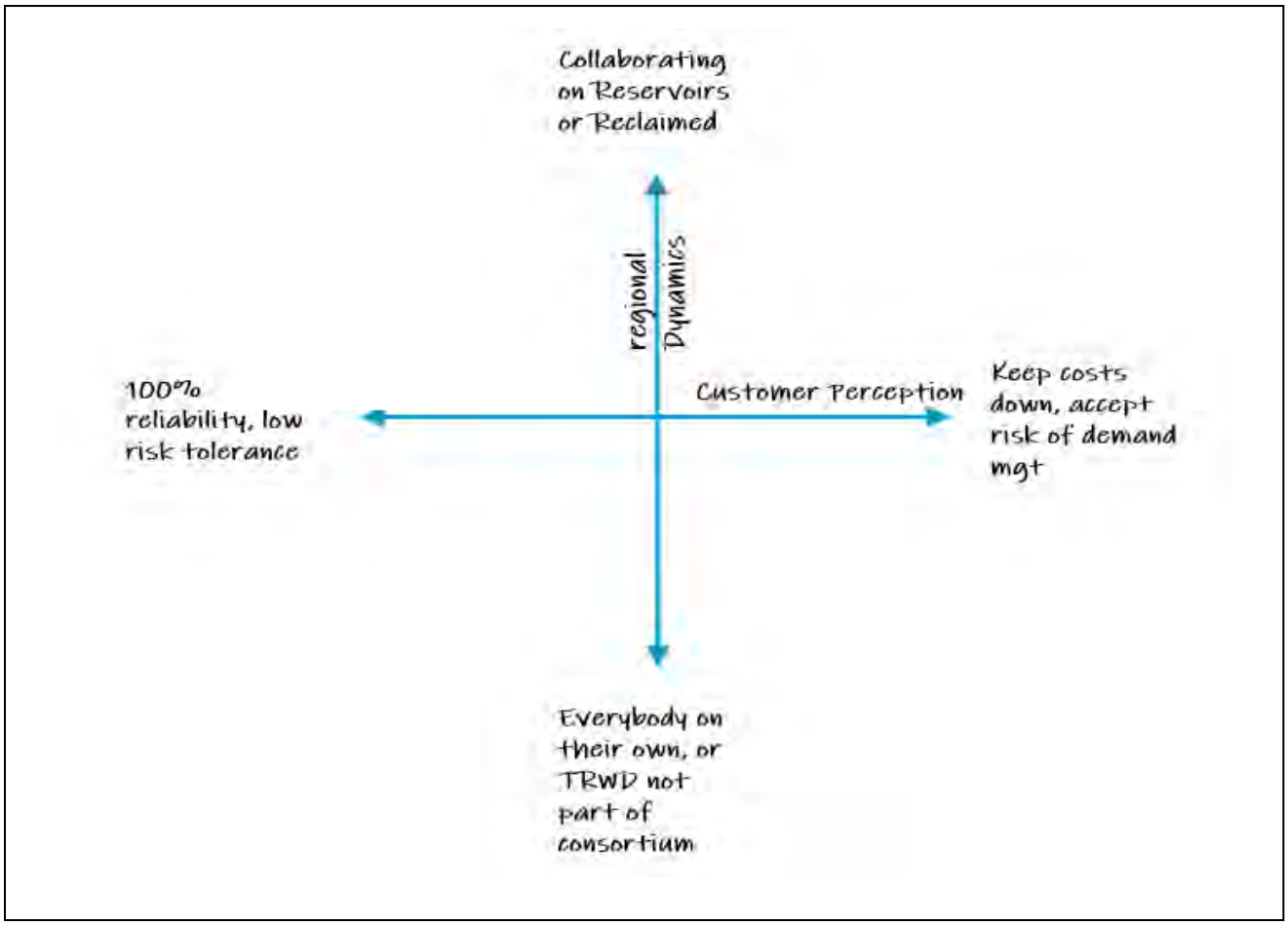
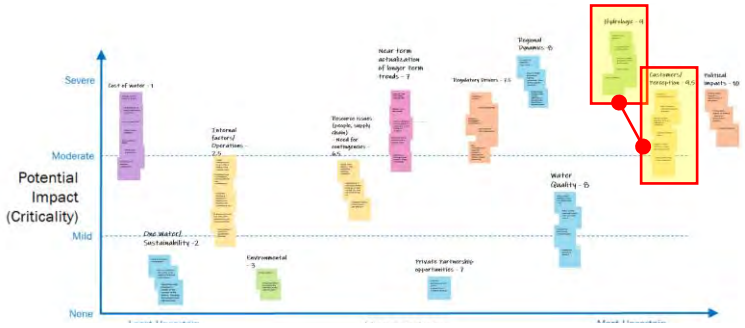


Figure 5-5: Experimental Risk Matrix #1

Experimental Matrix #2:
Critical Uncertainties: Hydrology and Customer Perception

Note that the "space" in the quadrants can be used to assess how well a particular strategy is prepared for the plausible future contained within that space.



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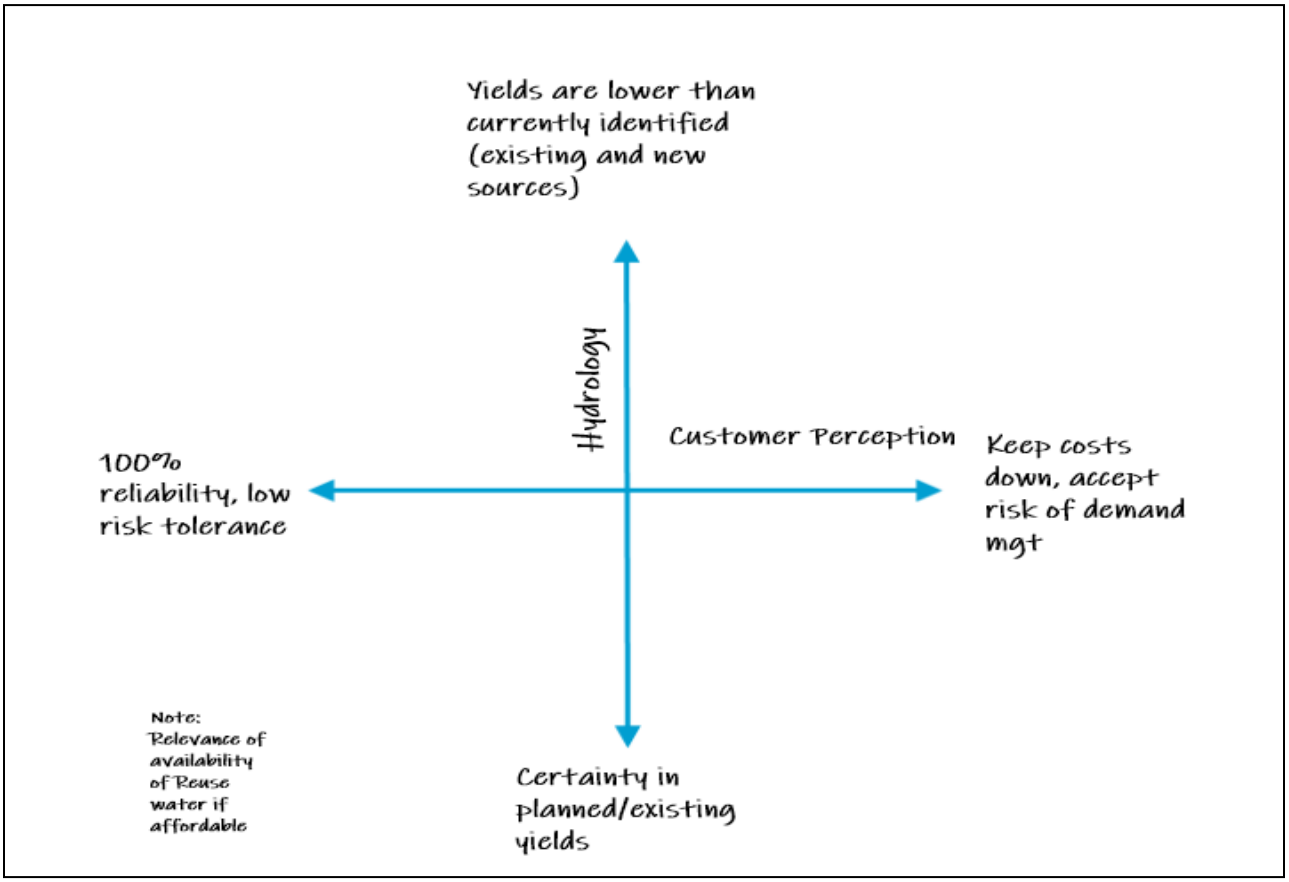
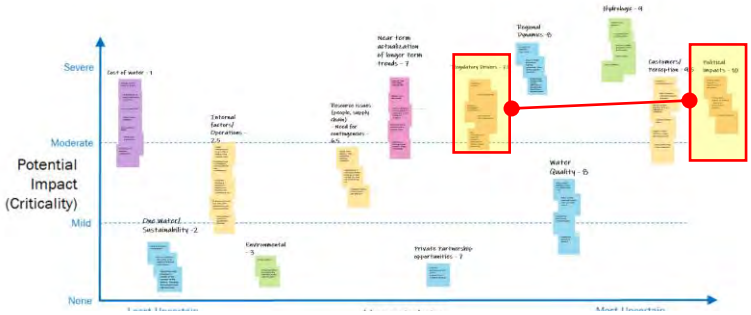


Figure 5-6: Experimental Risk Matrix #2

Experimental Matrix #3:
Critical Uncertainties: Regulatory Drivers and Political Impacts

Note that the "space" in the quadrants can be used to assess how well a particular strategy is prepared for the plausible future contained within that space.



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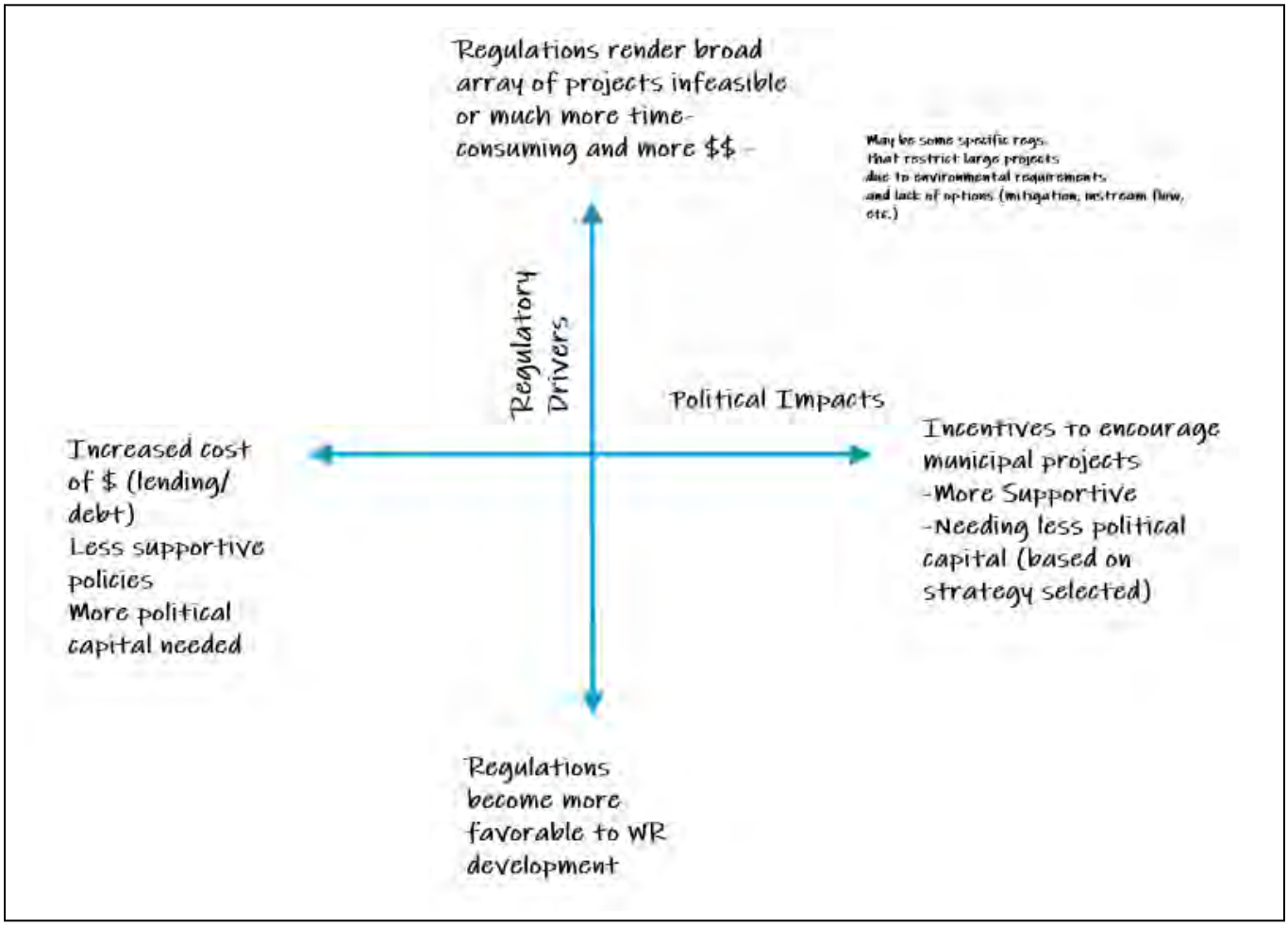
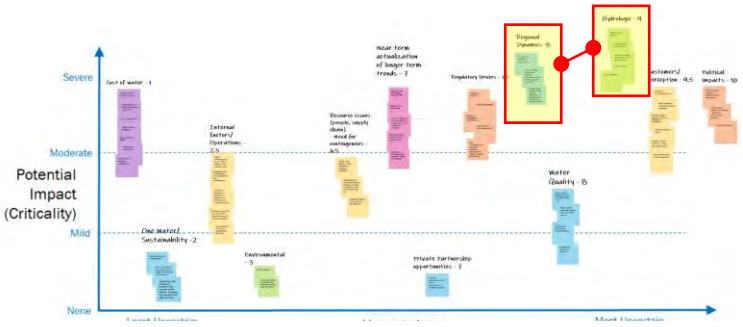


Figure 5-7: Experimental Risk Matrix #3

Experimental Matrix #4:
Critical Uncertainties: Regional Dynamics and Hydrology

Note that the "space" in the quadrants can be used to assess how well a particular strategy is prepared for the plausible future contained within that space.



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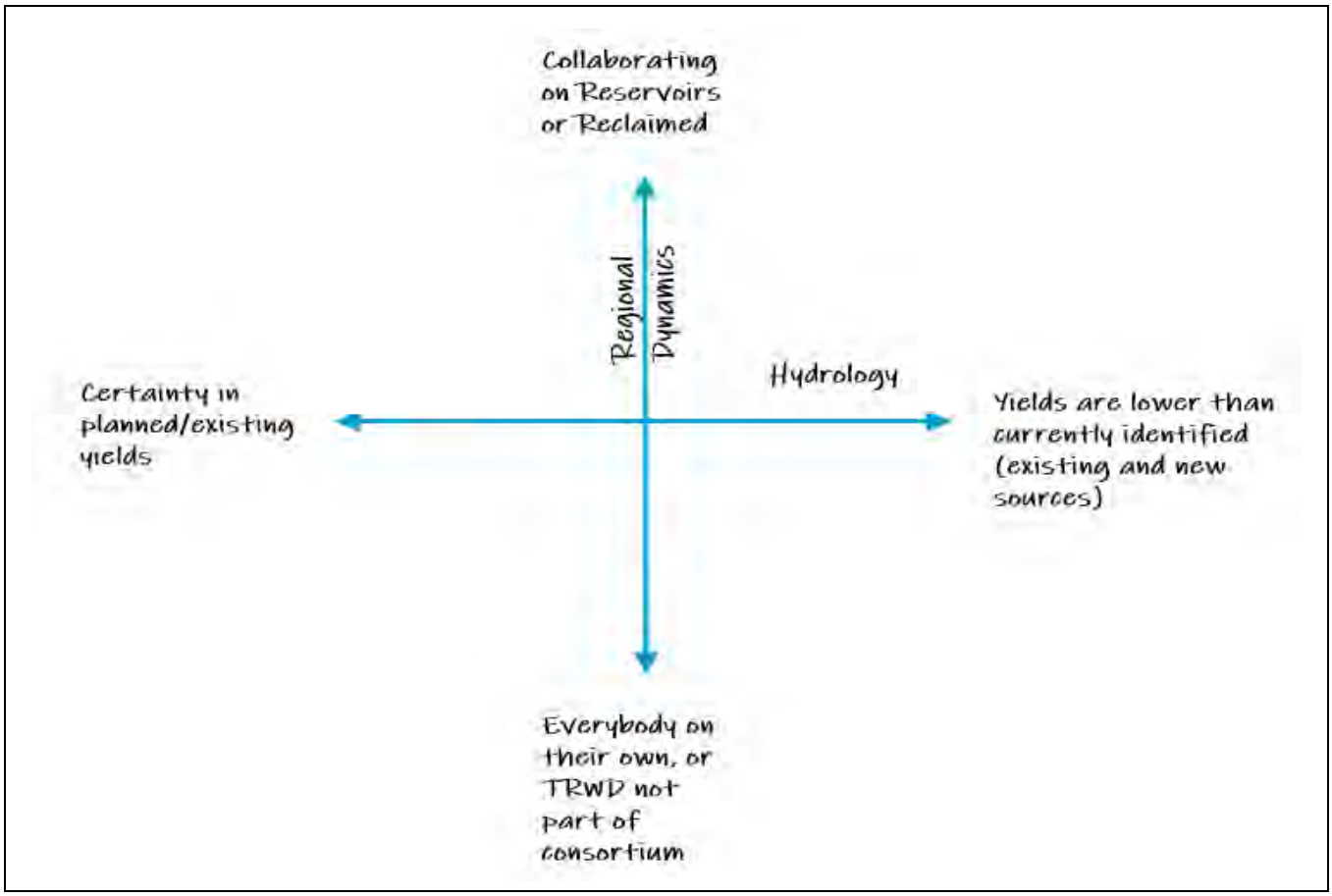
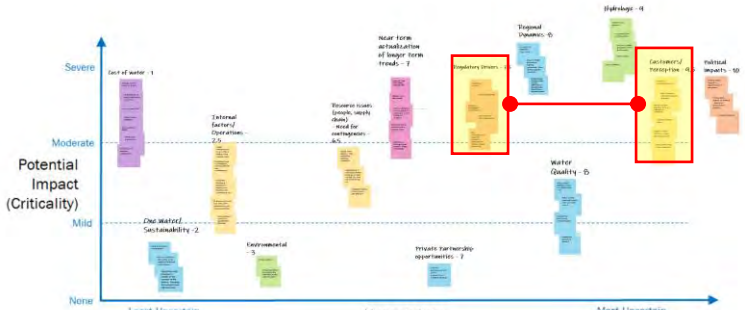


Figure 5-8: Experimental Risk Matrix #4

Experimental Matrix #5:
Critical Uncertainties: Regulatory Drivers and Customer Perception

Note that the "space" in the quadrants can be used to assess how well a particular strategy is prepared for the plausible future contained within that space.



Provided for visual reference

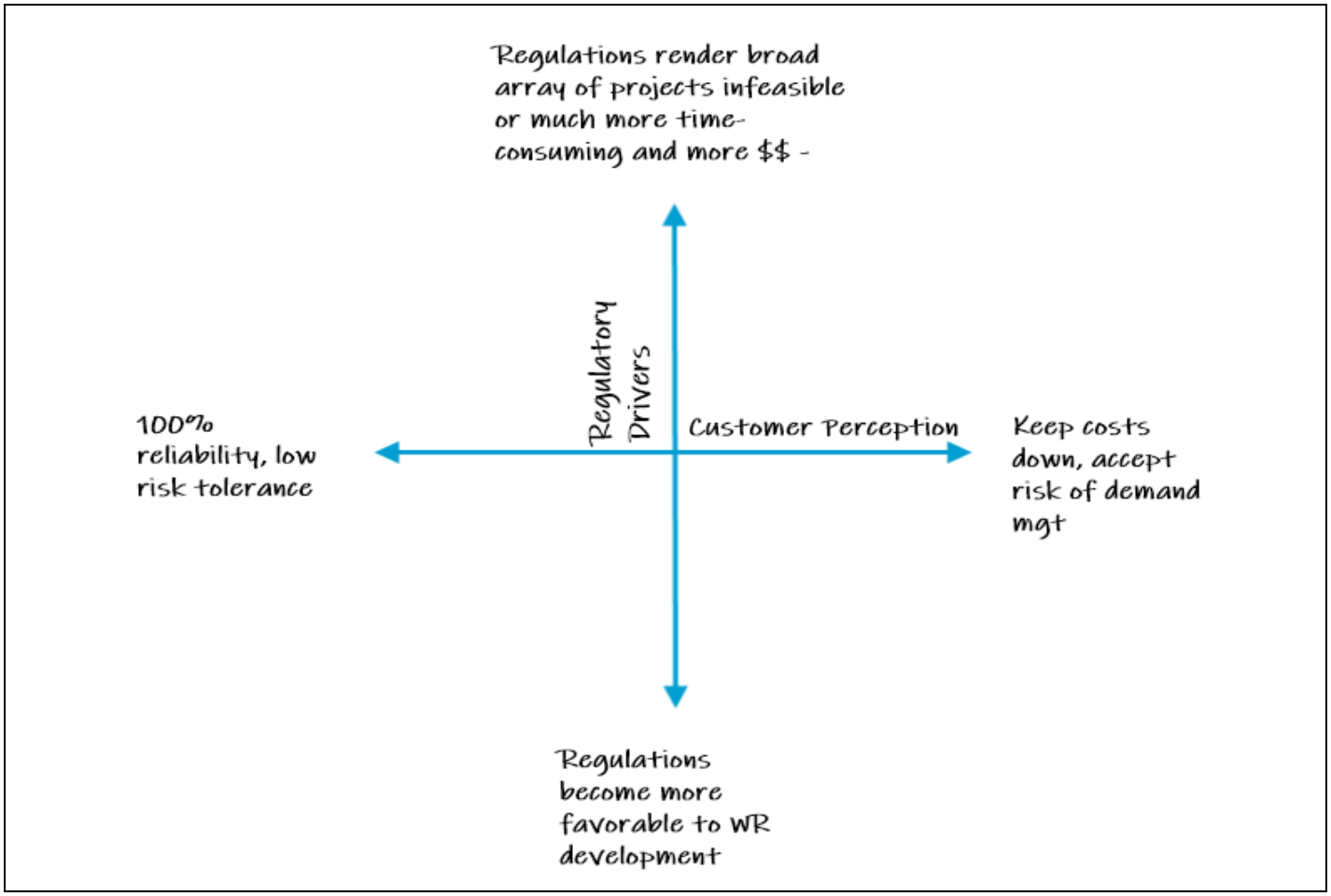


Figure 5-9: Experimental Risk Matrix #5

Step 3b: Identify the Most Useful Grid (or Grids) for Future Planning: While standard Scenario Planning practice focuses on the combination of the two most critical and most instructive risks, TRWD developed two important matrices (4 risks with 8 combinations) that focus on very different aspects of its water planning needs: The system itself ("System and Partners"), and the people who regulate or depend upon it ("Customers and Regulators"). The project team and TRWD agreed that formulating an IWSP Update Strategy using both matrices as a framework would be useful (in fact, that doing so with only one of the two matrices would leave critical gaps), and would not require significant additional effort (since the update strategy is not the prioritization of actual investments, but of 6-10 planning activities associated with the Plan Update). **The group deemed Matrices #4 and #5 (from above) the most useful to help formulate an IWSP Update Strategy that is prepared for the potentially impactful future conditions they describe** (see **Figure 5-10** below):

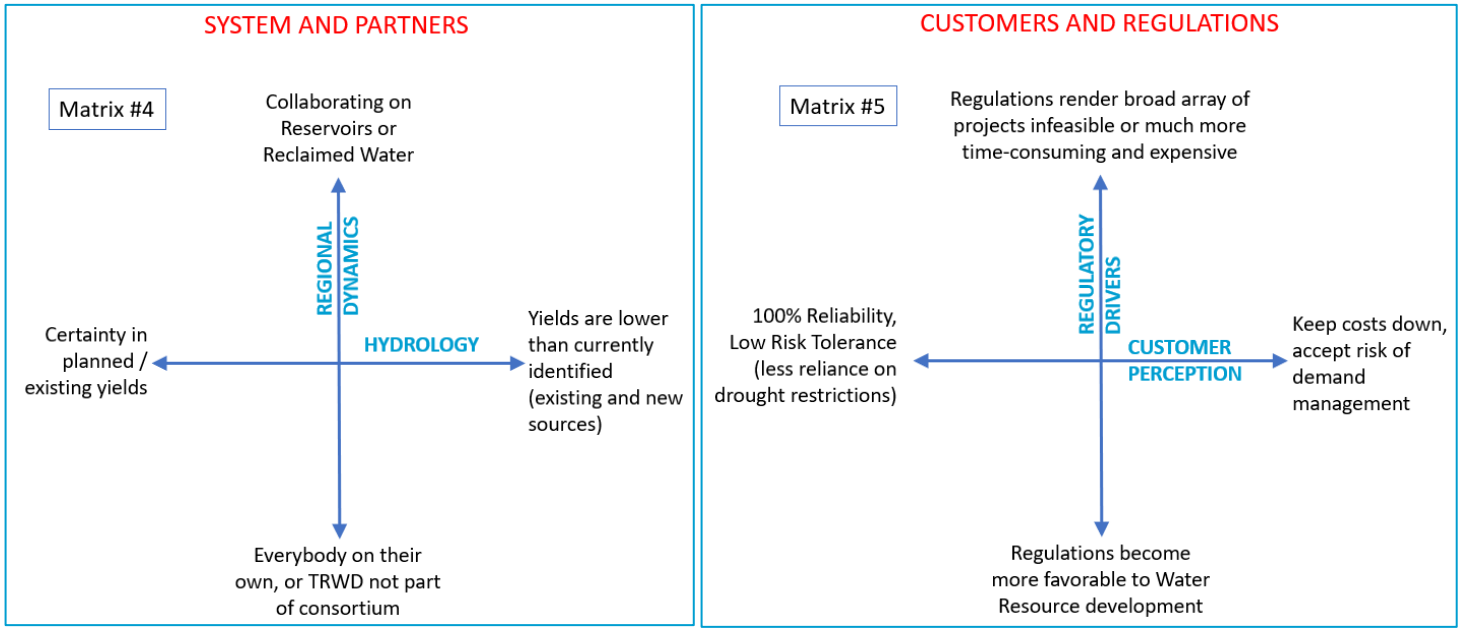


Figure 5-10: Selected Risk Matrices for Alternatives Evaluation

Step 4a: In Narrative Form, Describe the Quadrants as Equally Plausible Future Scenarios

Each quadrant below represents a plausible future (A "Scenario") in which two critical risks have evolved in the near term in a way that could affect the IWSP update. Each quadrant is unique, and represents the evolution of the two risks to one end of their potential spectrum of uncertainty. For this exercise, none of the 8 quadrants are considered any more likely than any other – instead, they are all deemed "plausible," and therefore worthy of consideration while formulating the IWSP Update Strategy. The rest of this memorandum offers a narrative description of each quadrant, kept brief to support future workshop discussions. Each narrative includes a list of several relevant uncertainties that might drive decisions – these lists are not intended to be exhaustive, but to help focus discussion.

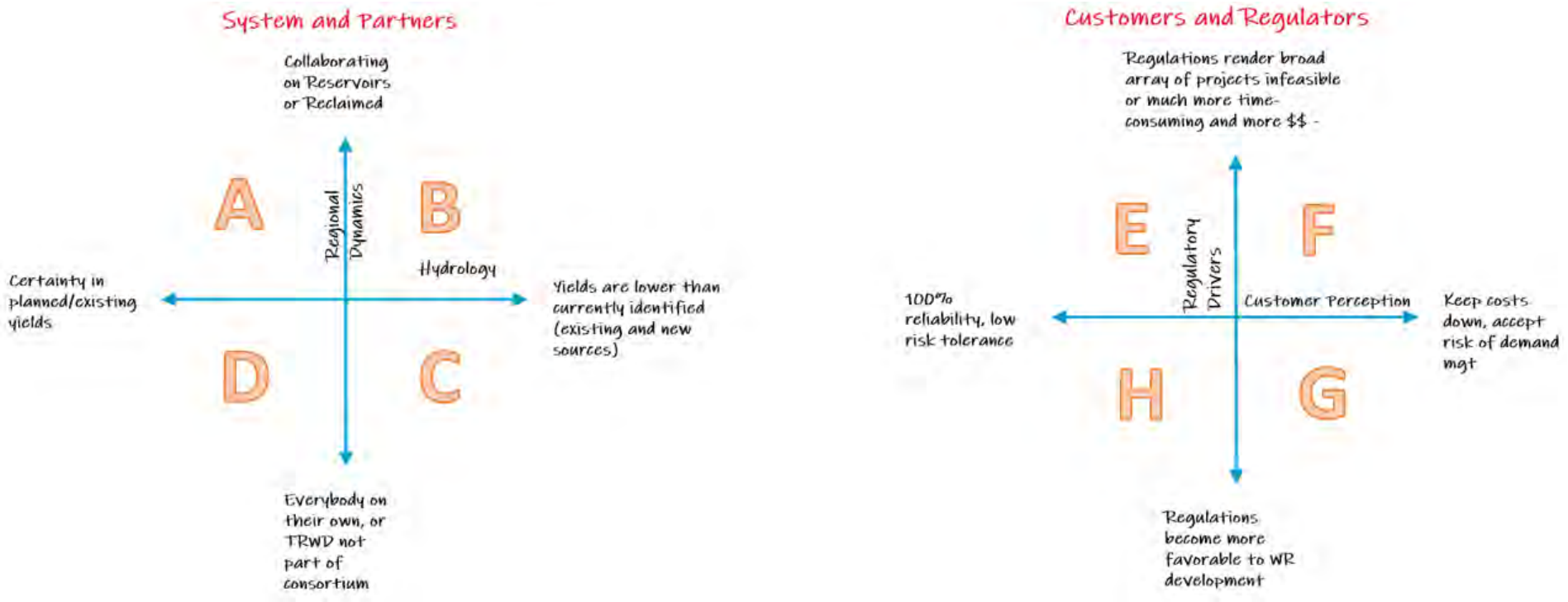


Figure 5-11: Selected Scenarios Identified by Quadrant for Narrative Descriptions

Narrative Descriptions of Plausible Near-Term Futures

SYSTEM AND PARTNERS MATRIX

Scenarios A through D represent uncertain future conditions in hydrology and regional dynamics.

A. **TRWD Collaborates with Other Providers, and Existing Yield Permits/Estimates are Valid.** In this future, there is confidence that existing sources can continue to produce what they are currently permitted to produce, and that potential yield of new sources is sufficiently characterized. After exploring partnerships with Dallas and NTMWD (or perhaps others) to focus on large new regional reservoirs and/or a coordinated plan for Regional Reuse, TRWD has previously entered into partnerships to develop new regional water sources and transmission. Key relevant uncertainties related to this future include:

- *When are new supplies needed?*
- *Which sources are most appropriate for regional development?*
- *What is the availability, and feasibility, and cost of Reclaimed Water?*
- *Is there regional interest in ASR?*
- Is there regional consensus on timing, financing and permitting of regional sources of supply?

Is there a regional concept for reserving and purchasing reclaimed water?

B. **TRWD Collaborates with Other Providers, but Yields of Existing and New Supplies are Reduced.** In this future, TRWD knows that changing conditions and have reduced the actual amount of available yield from existing sources, and yield from prospective new sources is lower than expected in the first draft of the IWSP. Knowing this, TRWD has previously entered into partnership with Dallas and NTMWD to develop a large new regional reservoir(s) and transmission. Additionally, there could be a focus on a coordinated plan for Regional Reuse. Key relevant uncertainties related to this future include:

- *When are new supplies needed with reduced yield of existing sources?*
- *Which sources are most appropriate for regional development?*
-
- *Which new sources can make up the current and future gap for TRWD, and when?*
- *How far can reclaimed water get us if it is shared, and if current yields are reduced?*
- *Is there regional consensus on timing, financing and permitting of regional sources of supply?*
- *Is there a regional concept for reserving and purchasing reclaimed water?*

C. **TRWD is on its Own (No Regional Partnerships), and Yields of Existing and New Supplies are Reduced.** In this future, TRWD knows that changing conditions and climate trends have reduced the actual amount of available yield from existing sources, and yield from prospective new sources is lower than expected in the first draft of the IWSP. Also, whether or not regional

partnerships were explored, TRWD is not pursuing regional development of sources, and all new sources are TRWD projects alone. Key relevant uncertainties related to this future include:

- *When are new supplies needed with reduced yield of existing sources?*
- *Which new sources can make up the current and future gap for TRWD, and when?*
- *How far can reclaimed water get us if we have to compete for it on price/reliability (without collaboration), and if current yields are reduced?*
- *Without large regional sources, can TRWD rely on a portfolio of smaller new supplies to make up the gap in yield and support future demand? (Is this a good or bad?)*
- *Does ASR make sense for the TRWD system?*

D. **TRWD is on its Own (No Regional Partnerships), and Existing Yield Permits/Estimates are Valid.** In this future, there is confidence that existing sources can continue to produce what they are currently permitted to produce, and that potential yield of new sources is sufficiently characterized. Also, whether or not regional partnerships were explored, TRWD is not pursuing regional development of sources, and all new sources are TRWD projects alone. Key relevant uncertainties related to this future include:

- *When are new supplies needed based on existing (unchanged) yield of existing sources?*
- *Which new sources can make up future gap for TRWD, and when?*
- *How far can reclaimed water get us if we have to compete for it on price/reliability (without collaboration)?*
- *Without large regional sources, can TRWD rely on a portfolio of smaller new supplies to support future demand? (Is this a good thing or a bad thing?)*
- *Does ASR make sense for the TRWD system?*

CUSTOMERS AND REGULATORS MATRIX

Scenarios A through D represent uncertain future conditions in hydrology and regional dynamics.

E. **Risk-Averse Customers Demand 100% Reliability, and Regulations Render Many Supply Options Infeasible.** In this future, customers are no longer willing to depend on demand management for curtailing water use when supply becomes short – they want 100% reliability through droughts, seasonal peaks, climate change, etc. TRWD's planning basis of 98% reliability (aimed at keeping costs down with low risk while acknowledging model uncertainty) loses its persuasive rationale. Maybe this is due to climate trends, economic unrest, or a continuing public health crisis. At the same time, regulations for environmental mitigation and streamflow requirements evolve to the point at which certain projects, especially very large ones, become either infeasible or impractical due to the cost or time constraints of the permitting processes. Key relevant uncertainties related to this future include:

- *When does TRWD need more supply?*
- Which *sources remain viable and practical?*

- *What does 100% reliability mean today, and what does it mean in the future – How costly is it to provide buffering supply to reduce the need for customer water use restrictions (and how much water is needed)?*
- *Is there a portfolio that is both permittable and reliable, and is it available in time?*
- *Where do we lean for the highest reliability of supply, and how can we secure as much water as needed/possible from highly reliable sources?*
- *Is partnership in large regional sources of supply the only* way to meet demand reliably? Affordably?

F. **Customers Willing to Accept Risk of Demand Management if it Keeps Costs Low, but Regulations Render Many Supply Options Infeasible.** In this future, customer philosophies on reliability remain largely intact, and they are willing to rely on water conservation during periods of water stress, knowing that supply shortfalls are calculated to be manageable, and that there is not such a thing as 100% reliability in water supply. They understand that preparing for drought management on the demand side saves costs on the supply side, and so TRWD's planning basis need not change. At the same time, regulations for environmental mitigation and streamflow requirements evolve to the point at which certain projects become either infeasible or impractical due to the cost or time constraints of the permitting processes. Key relevant uncertainties related to this future include:

- *When does TRWD need more supply (given that demand management remains a viable strategy?)*
- Which *sources remain viable and practical?*
- *Is there a portfolio that is both permittable and reliable, and is it available in time?*
- *Is partnership on large regional supply alternatives the only way to meet demand reliably? Affordably?*

G. **Customers Willing to Accept Risk of Demand Management if it Keeps Costs Low, and Regulations Become More Favorable to Water Resource Development.** This is the most favorable future from this matrix, and perhaps from both matrices, as it allows the most flexibility in considering new sources. In this future, customer philosophies on reliability remain largely intact, and they are willing to rely on water conservation during periods of water stress, knowing that supply shortfalls are calculated to be manageable, and that there is not such a thing as 100% reliability in water supply. They understand that preparing for drought management on the demand side saves a lot of cost on the supply side, and so TRWD's planning basis need not change. Meanwhile, regulations in Texas are relaxed, or perhaps partnerships incentivized, such that new development of water supply projects is streamlined and more predictable. Key relevant uncertainties related to this future are largely strategic questions:

- *When does TRWD need more water (since demand management remains a viable strategy)?*
- Is TRWD's *best strategy to partner or not?*
- *Can we / should we expand our service area (that is, will we have more than enough supply?)*
- *Centralized or decentralized* – One large source or distributed smaller sources?

H. **Risk-Averse Customers Demand 100% Reliability, but Regulations Become More Favorable to Water Resource Development.** In this future, customers are no longer willing to depend on demand management for curtailing water use when supply becomes short – they want 100% reliability through droughts, seasonal peaks, climate change, etc. TRWD's planning basis of 98% reliability (aimed at keeping costs down with low risk while acknowledging model uncertainty) loses its persuasive rationale. Maybe this is due to climate trends, economic unrest, or a continuing public health crisis. Meanwhile, regulations in Texas are relaxed, or perhaps partnerships incentivized, such that new development of water supply projects is streamlined and more predictable. Key relevant uncertainties related to this future include:

- *When does TRWD need more supply?*
- What *does 100% reliability mean today, and what does it mean in the future – How costly is it to provide buffering supply to reduce the need for customer water use restrictions (and how much water is needed)?*
- *Is there a portfolio that is reliable enough, and is it available in time?*
- *Is partnership on large regional sources of supply the only way to meet demand reliably? Affordably?*
- *Should TRWD be more aggressive and develop new water earlier than originally planned?*

Step 4b: Test Alternative IWSP Update Strategies for Resilience to Future Conditions in Each Grid Quadrant

1. The Group was advised that the goal of the deliberations for this workshop was not to finalize a prioritized sequence of tasks for the IWSP Update, but to experiment with ways of formulating the update strategy using the information developed to date. However, the results were focused and collaborative and produced some "early wins" (activities with broad consensus as high priorities for early action), as well as an overall framework for the strategy itself.
2. The Group discussed different possibilities for combining the four axes identified as crucial in Workshop 3, including an example 3 x 3 matrix (8 scenarios), or a "four-dimensional" matrix of each possible combination of 4 quadrants in one matrix with each and every quadrant in the other (16 scenarios). Alternatively, **the Group agreed that evaluating both matrices separately (4 scenarios considered prior to evaluating the other 4 scenarios) would yield the most value for the purposes of the IWSP Plan Update.**
3. The Group opted for testing individual activities rather than themed groupings against the backdrop of the risk matrices, believing that too much time might be expended to develop themes, and opted to work on testing the decision space directly in the time available.
4. The Group recognized that some activities, through early action, can inform TRWD about which quadrant from Matrix 4 (Hydrology and Regional Dynamics) they may be in, which will make it easier to develop immunity to the scenarios in Matrix 5 (Customers and Regulators). In other words, certain early actions reduce uncertainty in Matrix 4, and allow the uncertainties in Matrix 5 to be addressed with a better understanding of available water and partnership potential. The Group discussed that while they do not necessarily have control over the scenarios in either matrix, they can better understand which quadrant they will be in in Matrix 4, but not Matrix 5, and that this could influence early actions.

5. Following these decisions, the Group mapped the various activities to Matrix #4 (Hydrology and Regional Dynamics), noting that certain early steps could help them reduce uncertainty by identifying early in the IWSP Process which quadrant (scenario) they are in. Once identifying early actions to reduce uncertainty in Matrix #4, they completed the experimental sequencing using the scenarios in Matrix #5. **The following notes were captured as they relate to specific update activities, and visual summaries follow in several forms.**

   a. **EARLY STEPS TOWARD INCREASED CONFIDENCE:** The Group agreed that the Hydrologic Updates and a better understanding of regional partnership potential were necessary precursors to all of the other tasks (in order to be fully informed and avoid inefficiencies). These can be considered positive early steps that will improve clarity and confidence in subsequent decisions, as TRWD can pursue these activities as soon as possible, regardless of how the rest of the strategy takes its shape. Pursuing these early also eliminates the uncertainty in Matrix 4 by indicating which quadrant they will be working in, and making it that much easier to address Matrix 5.

   b. **Reliability as a Continuous Thread:** In addressing the axis in Matrix 5 regarding uncertain customer expectations on supply reliability, the Group recommended considering a potential desire by customers to reduce the need for demand restrictions during drought. TRWD's simulation protocol has long been to target98% reliability from its simulated sources and transmissions facilities, and to consider this as fully reliable, attributing the additional 2% to modeling uncertainty, and a small volume that could theoretically be managed with demand management even if it were truly accurate. The group recommended that this continue throughout the IWSP Update process, but that as an overarching approach to each task, we consider the prospect that customers may desire fewer demand restrictions during drought, and that perhaps we simulate various demand reduction measures to examine the range of costs and water volumes associated with cutting back vs. not cutting back. This could help make the work resilient to this uncertainty, over which TRWD has very little control, and also inform decision making for the customers that can influence this uncertainty.

   c. **Refining Supply Alternatives:** The refinement of supply alternatives in the IWSP will largely be driven by the hydrologic updates and the ways in which partnership potential changes the cost, availability, schedule, etc. of large regional alternatives. This will also include a subjective evaluation, in that knowledge to date (and based on hydrologic updates and partnership potential), could render certain supply alternatives no longer valid. The scope for this work could vary project-to-project, but should include as a minimum:

      i. Knowledge to date

      ii. Impacts of potential partnership on availability and cost

      iii. Impacts of hydrologic assessment

   d. **Stakeholder Involvement:** The Group agreed that primary stakeholders are the customer cities, who may need detailed cost and reliability information to provide meaningful feedback – therefore, while education and information sharing can be an ongoing enterprise, TRWD does not expect buy-in or agreement on future strategies until most or all of the IWSP Update information is developed and recommendations are available.

e. It made sense to disaggregate TRWD's Risk Assessment (supply and demand risks) from the Risk Appetite of Customers, since they are affected by different factors and knowledge of the former may be needed to truly gage the latter.

f. Transmission System Planning – The Group recognized that many of the decisions about capacity, location, and timing of new transmission infrastructure and facilities will depend on water availability, partnerships, and preferred supply alternatives, and that while the IWSP may help inform transmission needs, many aspects of transmission system planning and design will be conducted outside the context of the IWSP update. However, there are known improvements within the existing system that need to proceed sooner. For that reason, it may be wise support decision making for known improvements early in the IWSP Update process, and the planning for unknown sources/capacities/timing after the hydrology, partnerships, and new sources have been identified. For this reason, Transmission System Planning should be an ongoing discussion during the IWSP Update, and serve as one of the continual parallel paths for giving and receiving information to/from all other IWSP tasks.

g. **Resilience:** The Group did not have time to discuss where/how Resilience should be included in the analysis, but further discussions with TRWD will reveal whether this should be a near-term set of goals/guidelines, and end-point assessment, or a continuous thread of factors throughout the IWSP Update.

h. **Summary of Three Continuous Threads:** Three continuous threads, which are tasks themselves, should run concurrently throughout the IWSP Update:

   i. Reliability represented using TRWD's standard practice of representing 100% supply reliability with 98% reliability in simulation models, attributing differences to modeling uncertainty and demand management flexibility. However, consideration should be given throughout to the potential volumes of additional water (and its cost) that might be needed to significantly reduce the need for customer water restrictions during droughts (accomplished by simulating scenarios with and without demand restriction assumptions).

   ii. Transmission System Planning – inform and be informed by each step, and also inform processes within TRWD but outside the IWSP Update program.

   iii. Stakeholder Education – as opposed to participatory involvement, it will be important to collaborate with customer cities on findings, trends, and emerging preferences as the process evolves, then solicit their direct feedback toward the end when cost/reliability impacts are clear.

   iv. Resilience goals/guidelines, and end-point assessment as a continuous thread of factors throughout the IWSP Update.

Other continuous threads may include keeping an eye on near-term decisions or developments with the Cedar Creek Wetlands, Ringgold, etc.

Figure 5-12 illustrates the whiteboard diagram of the way the Group sequenced the IWSP activities in **Table 3-1** in response to the two risk matrices (tasks higher in the diagram occur earlier). There was strong agreement that reducing uncertainty in water availability and regional partnership potential would help shape the rest of the plan update with more clarity. **Figure 5-13** refines the white-board schematic to illustrate the IWSP Update Strategy (as framed by the workshops) more cleanly, as reported back to the group in the meeting notes and included here for reference (Full description of the recommended strategy is included in **Section 6.0**). The strategy is further refined in **Section 6.0** with the addition of triggers, specific delineations within certain tasks, etc.

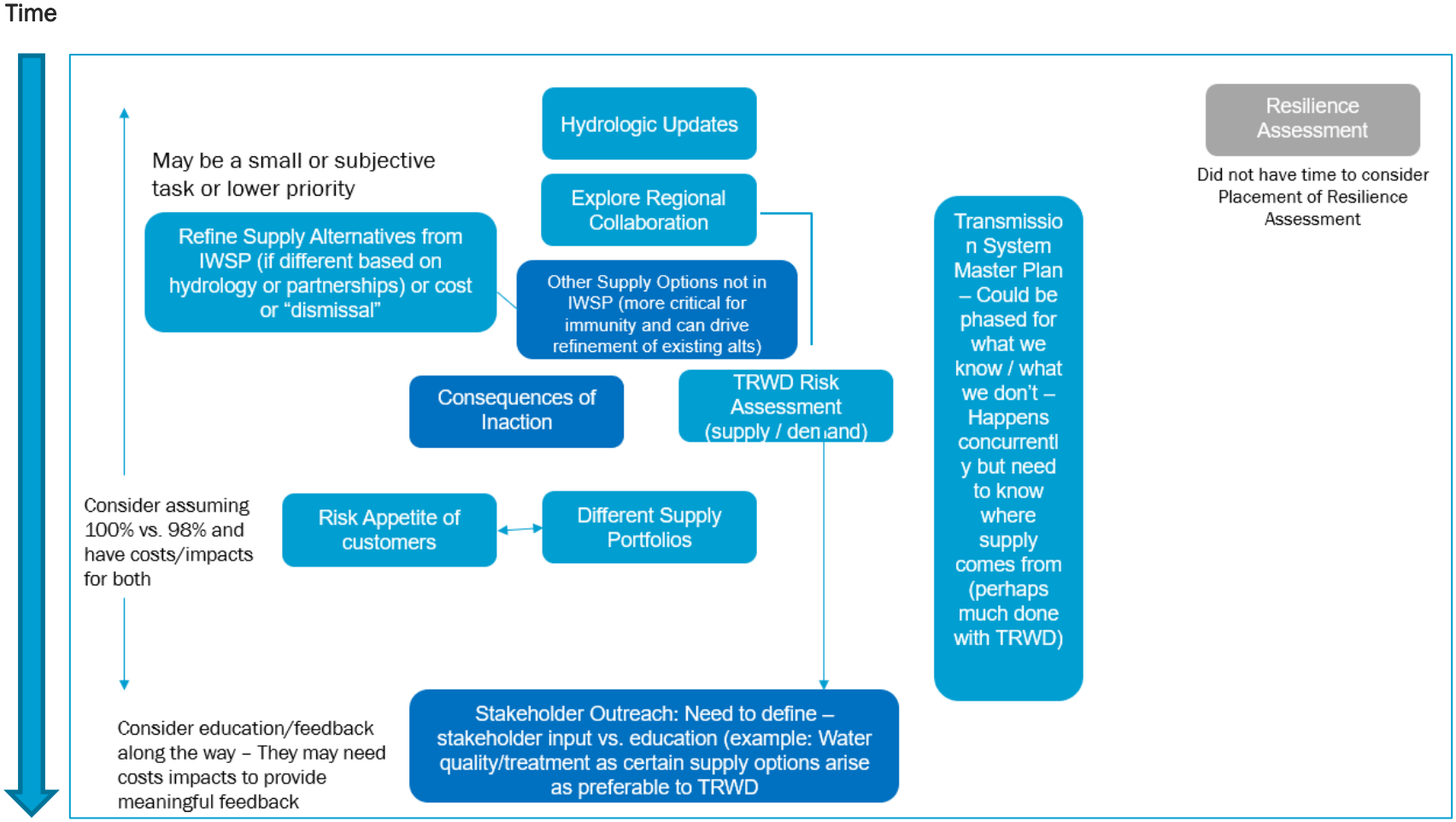


Figure 5-12: Whiteboard Arrangement of IWSP Update Tasks Orchestrated to Address Both Risk Matrices

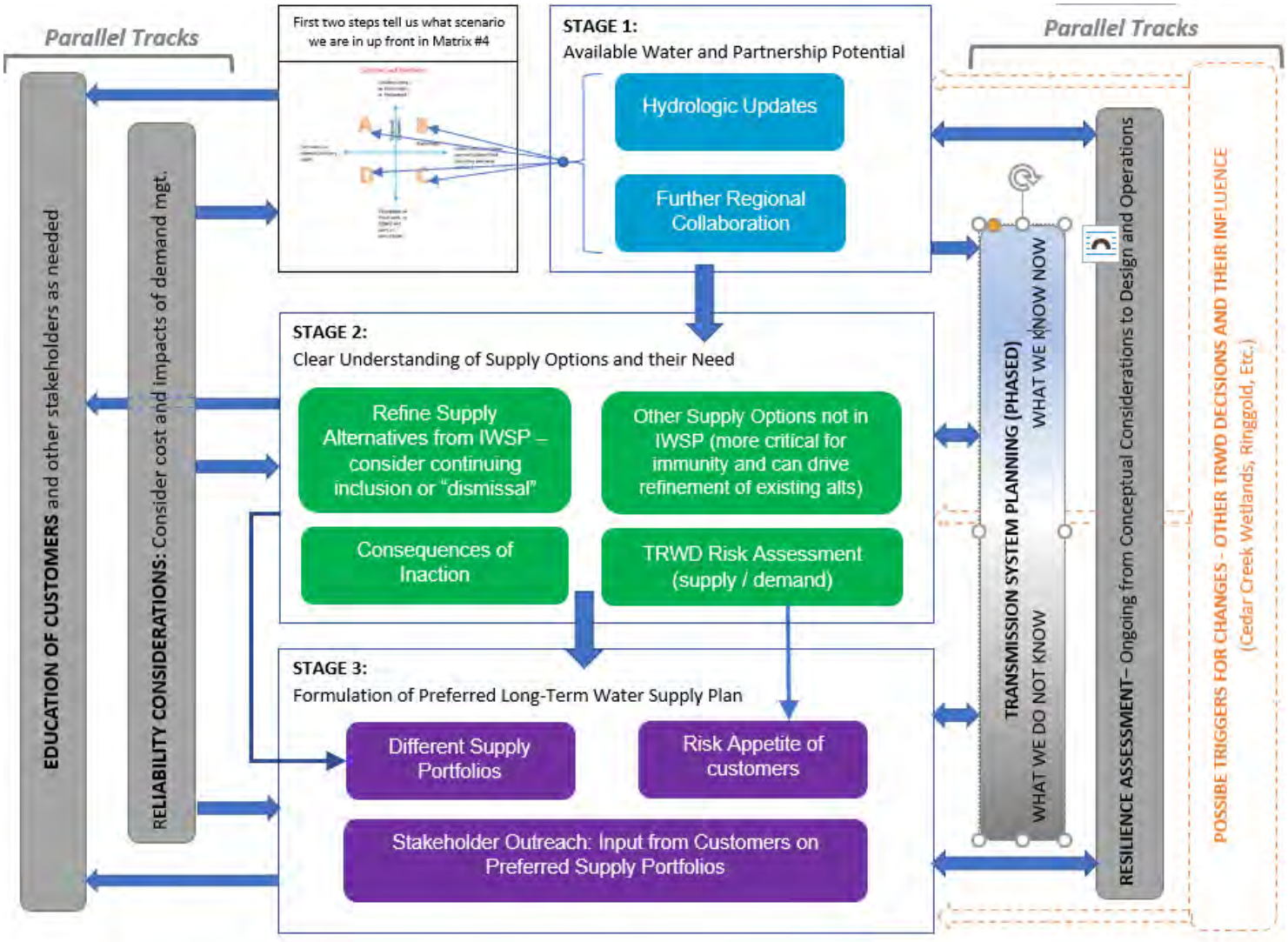


Figure 5-13: Summary of the Workshop Output and Suggested Sequencing of IWSP Update Activities
Refer to Section 6.0 for additional refinements and explanation

Section 6

Recommended Adaptive Sequence for the IWSP Update

Through the workshop process, the elements of the IWSP Update process were arranged in a strategic sequence to address the most impactful near-term risks. The strategy requires flexibility to re-prioritize as conditions might change, and the general framework in **Figure 5-13** was refined into an adaptive and more detailed framework in **Figure 6-1** (with a legend preceding it).

Three Stages: The recommended IWSP Update process is divided into three stages. Several parallel tracks are also proposed following the definition of each stage, which will be integrated into each of the stages as appropriate:

- **Stage 1** focuses on early answers to important uncertainties about availability of water in existing sources, and opportunities to partner with other water providers on large new sources or water agreements. Addressing these issues and reducing or eliminating uncertainty will enable TRWD to more effectively define and orchestrate a future supply portfolio. Specifically, this stage includes the following tasks:
  - Hydrologic Updates for existing and possibly for new sources
  - Explore Regional Partnerships, and potentially screen alternatives as a result
  - Potentially conduct the Supply/Demand Gap Analysis (this could occur either in Stage 1 or Stage 2, or perhaps more effectively as a bridge between the two stages once clarity is developed for current yield and partnership potential.)
  - Parallel Tracks: Customer Collaboration / Reliability discussion / Transmission System Integration with updated Customer masterplans for treatment / nodal demands

- **Stage 2** adds definition to new supply alternatives, both by expanding information from the 2013 IWSP and examining the viability of other alternative sources that have not yet been examined in detail. Specifically, this stage includes the following tasks:
  - Supply/Demand Gap Analysis (if not conducted in Stage 1, or as a bridge between Stages 1 and 2).
  - Refine/Reduce Remaining IWSP Alternatives
  - Explore additional supply alternatives not included in the 2013 IWSP
  - A useful bridge between Stages 2 and 3 would be preliminary discussions of potential project portfolios using the information generated to date.
  - Parallel Tracks: Customer Collaboration / Reliability discussion / Transmission System Integration with updated Customer masterplans for treatment / nodal demands

- **Stage 3** aims to consolidate information from the first two stages into a recommended supply portfolio, with adaptation triggers for conditions that may change over the long term. This stage also focuses on feedback and support from TRWD customer cities. Specifically, this stage includes the following tasks:
  - Stakeholder Outreach / Customer Collaboration (more formal meetings to exchange information to guide final decisions)
  - Refine/Revise Supply Portfolios such that either a single preferred pathway (with adaptation options) is identified, or the decision tree updated to reflect current information and decision points with multiple branches (as in 2013) that depend on manifestation of future conditions or decisions. In other words, it is too early to tell whether a single preferred pathway will be recommended in this IWSP Update, or if the different branches of the decision tree will be refined, altered, or culled to provide branches that respond to different conditions, or which provide onramps and offramps to/from a single preferred branch (pathway). But this IWSP Update will provide a roadmap for decisions and timing of future water supply sources and transmission.
  - Parallel Tracks: Customer Collaboration / Reliability discussion / Transmission System Integration with updated Customer masterplans for treatment / nodal demands

Parallel Tracks: Four activities associated with the IWSP Update will run concurrently with all stages:

- **Transmission System Master Planning:** This will begin early with known rehab and expansion projects for existing pipelines, and will continue with conceptual design of transmission infrastructure for alternative new sources, then follow with detailed engineering and design of transmission infrastructure for recommended new sources. Much of the transmission system work will occur outside the framework of the IWSP Update, but certain prioritization, sizing, and configarational elements will be informed by IWSP information and decisions.
- **Reliability Considerations:** All evaluations should consider supply needs and costs for providing water based on TRWD's 98% reliability criteria through the drought of record (which reflects modeling uncertainty, and not necessarily water shortage). However, consideration should be given throughout the IWSP Update process to explore the tradeoffs associated with reducing the need for customer demand restrictions during periods of hydrologic stress..
- **Resilience**: Throughout all stages of work, considerations must be made for resilience not only to climate and drought, but to other forms of shock, including economic conditions, public health crises, Contaminants of Emerging Concern (CECs), sociopolitical considerations, perceived social inequities, etc.
- **Customer Collaboration**: Throughout the IWSP Update process, TRWD will endeavor to collaborate with customer cities of findings and decisions, enabling customers to provide informed opinions on the recommendations in the updated plan.

Key Adaptation Points: This process has identified three points of inflection, at which the recommended priorities could change:

- **Hydrologic Assessment:** If the existing sources are found to have significantly less reliable yield than what is currently permitted, it is recommended that the supply/demand gap assessment (blending the newly developed hydrologic information with the recent demand projection refinements) be accelerated to inform TRWD of potential near term supply gaps.
- **Regional Partnership:** If TRWD opts to collaborate with other regional water providers on either a large new water source or on a collective agreement for TRA Reuse water, it would be wise to screen out (or at least temporarily de-emphasize) IWSP alternatives that would either be redundant to the

large collective project(s), or which might counter a collective regional shift toward centralized supply.

- **Cedar Creek Pipeline:** Based on the hydrologic analysis and the value of 88,059 AFY projected yield from the Cedar Creek Wetlands (higher than the 52,000 AFY assumed in the original IWSP), the rehab and sizing of the Cedar Creek Pipeline should be accelerated to among the highest priorities in transmission system planning for the existing infrastructure.

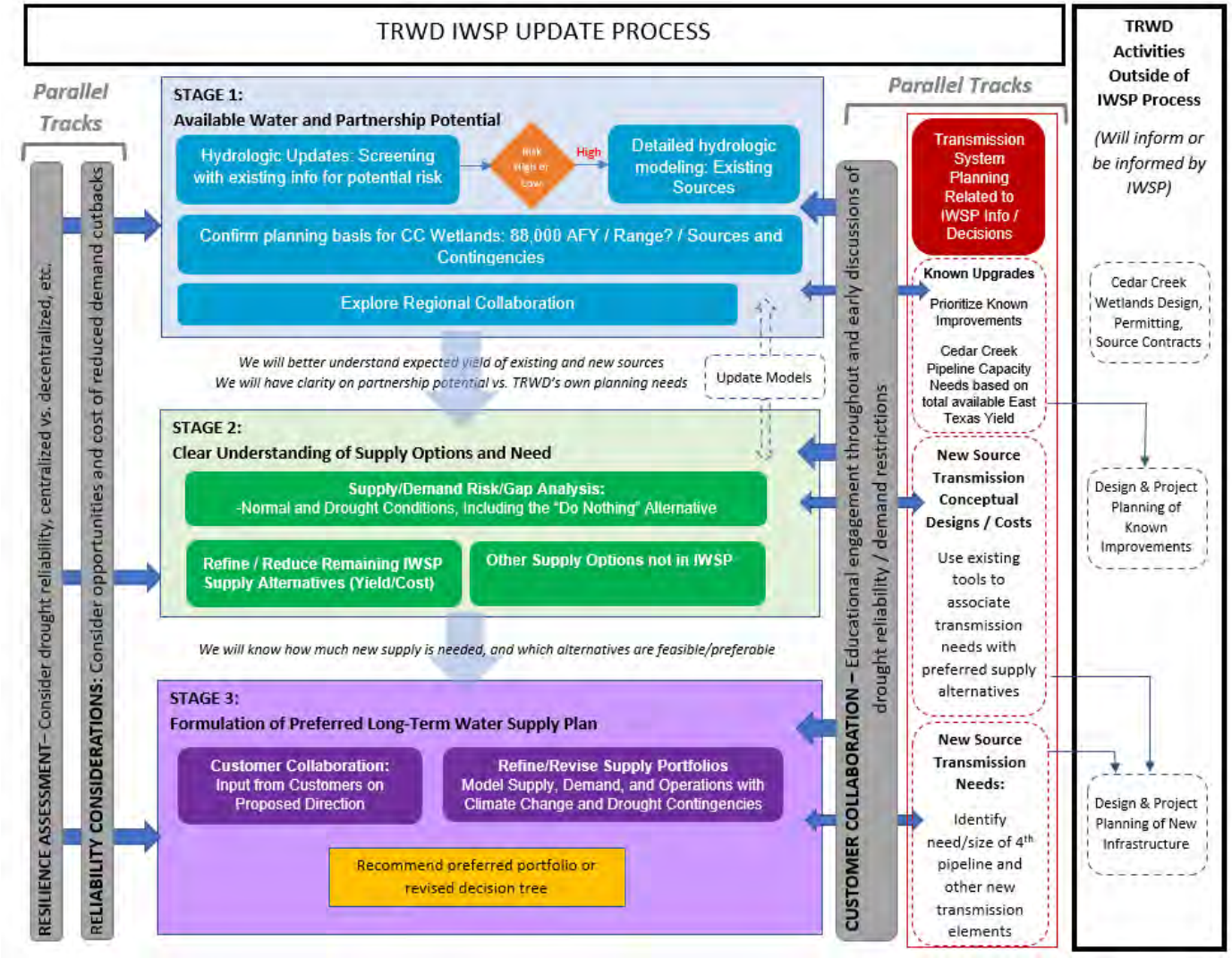


Figure 6-1: Adaptive IWSP Update Strategy

Section 7

Work Plan Outlines for IWSP Update Activities

This section offers outlines of work plans for each of the major tasks identified in this study as elements of the IWSP Update. The intent is that these outlines can provide useful guidance for developing full scopes of work for TRWD staff supported projects and professional services projects for procurement. The outlines are not intended to be exhaustive lists of subtasks or full scopes of work, nor are they all intended for consulting firms, but are offered to help frame the questions to be addressed, the steps to address them, and to provide insight into the level of effort for each. Table 7.1 provides a quick reference to relevant sections:

Table 7-1: List of Work Plans by Subsection

Subsection	Work Plan Outline
7.1	Hydrologic Updates
7.2	Explore Regional Collaboration
7.3	Document Cedar Creek Wetland Yield
7.4	Supply/Demand Gap Analysis
7.5	Refine/Reduce Remaining IWSP Alternatives
7.6	Explore Supply Alternatives Not in 2013 IWSP
7.7	Refine Supply Portfolios
7.8	Customer Collaboration
7.9	Transmission System Planning Guidance

7.1 Hydrologic Updates

Principal Questions:

- Are currently permitted yield values from existing supply sources likely to decrease (either in the form of reduced permit limits or in the form of actual water available), due to climate changes, environmental regulations, sedimentation, or other factors?
- Secondarily, are these changes likely to affect bulk yield projections from any or all of the supply sources in the 2013 IWSP or new alternatives identified during the 2021 IWSP Update?

Suggested Tasks:

A. Data Review:
   a. Consult with North Texas Municipal Water District on their projections for the potential for regional reductions in supply yield.

b. Review TRWD's Dendrochronological / Palmer Drought Severity Index study (Texas Water, 2020) on potential impacts on actual water availability.
c. Collect ranges of climate projections for North Texas through 2100.
d. Determine if streamflow or other environmental regulations are likely to impact yield in future years.
e. Determine if established climate prediction ranges are accounted for in A and B, or what impact they could have.

B. From the data review, determine conceptual values for plausible and probable reductions in yield for TRWD's primary sources (evidential or prospective – not based on new hydrologic modeling yet).

C. If there is high likelihood that plausible yield reduction could exceed 5% (approximately, or a similar value that can be associated with more than accumulated data uncertainty with climate and hydrologic data), it is recommended that more extensive climate/hydrologic modeling occur. More detailed rainfall-runoff modeling and reservoir dynamics are likely to be required to simulate ranges of year-over-year climate patterns and resultant yield impacts that could be plausible in the future. Any necessary WAM modeling should be based on the TCEQ WAM model. Determine the appropriate collaboration with TCEQ and Regional Water Providers to understand water availability modeling issues that must be understood to properly evaluate hydrologic issues with existing permitted supplies, known supply alternatives and future alternatives to be evaluated in this 2021 IWSP Update. Downscaled climate projections for North Texas should be collected to represent a range of plausible conditions to determine if a new baseline drought should replace the historic drought of record as the baseline for yield assessment. *For consistency, this hypothetical drought, should it be identified, should also be used in subsequent tasks related to source yield.*

D. Consider consulting with TCEQ on any results of WAM modeling with the TCEQ WAM model, if appropriate.

E. If the potential changes to TRWD's existing source yield are significant, determine if the regional trends between TRWD and NTMWD are strong enough to suggest that estimated yields from future supply alternatives per the 2013 IWSP could also be affected.

F. Consider the potential benefits, risks, and processes associated with a system yield permit to determine if this could be a viable, practical, and beneficial alternative to individual yield permits.

7.2 Explore Regional Collaboration

Principal Questions:

- Is there interest among TRWD and other regional providers, specifically Dallas, North Texas Municipal Water District (NTWMD), and possibly the Trinity River Authority to pursue regional water supply alternatives collaboratively?
- Is it more beneficial to TRWD to participate in a regional collaboration on large new supplies and/or TRA water sharing agreements, or to pursue supply portfolios independently?

Suggested Tasks

Note: It is recommended that scoping this work be done conjunctively with other regional water providers who agree to take part in discussions. Some discussions about format and process have already taken place, and what is offered below is an outline that could help offer structure to the pending conversations. The objective here is to allow TRWD's 2021 IWSP Update to provide an opportunity for regional partners to reengage in structured discussion of regional collaboration on large regional supply and transmission projects.

A. Draft a Memorandum of Understanding with Dallas and/or NTMWD to engage in a series of (a) facilitated workshops or (b) exploratory conversations. Neither (a) nor (b) would result in binding commitments, but would establish principles for moving forward collaboratively and provide each organization with enough information to decide on its own whether or not to participate in any potential regional collaboration.

B. Agree on whether the discussions will be facilitated by an independent third party, or if the parties can explore among ourselves. It would be recommended that in either case, each party involve staff or consultants.

C. Meeting #1: The parties would share information on the status of long-term water supply plans, forecasted supply gaps, system improvements and optimization, and estimated costs of supply portfolios currently under consideration. The parties would agree in principal to a finite list of regional supply options to consider, so that discussions can be grounded in facts and avoid too much speculation. Alternatives may include Marvin Nichols Reservoir, Reallocation of Wright Patman Reservoir, Toledo Bend Reservoir, Red River off channel storage, Oklahoma water, regional ASR, pooling of reclaimed water sources and wetland operations, and supply and transmission system integration. *It is recommended that the parties discuss the potential for a shared contract for reclaimed water, in which allocations over time could be arranged by the parties.*

D. Meeting #2: The parties would provide available cost and yield estimates (updated, if available) for the list of potential regional supplies that emerge from Meeting #1, and either reconcile differences or agree on appropriate ranges (potentially with follow-up analysis and correspondence).

E. Meeting #3: The parties would discuss a conceptual framework for collaboration, and discuss considerations for timing, cost sharing, yield allocations, etc. for alternatives deemed worthy of continued evaluation.

F. Between Meeting #3 and Meeting #4, each party would prepare an analysis of how the cost and value of proposed regional alternatives fit (or do not fit) into their own available supply portfolios. If the analysis suggests that a fit is reasonable, each party would refine cost and yield estimates as the basis for a conceptual strategy.

G. Meeting #4: The parties will share their individual findings on how well one or more regionally developed sources fit into their long-term strategies, whether they deem the benefits to outweigh the costs and risks, etc. Basically, each party will preliminarily indicate whether or not they believe a regional collaboration is in its best interest. If no party wishes to advance the prospect

further, the talks end. If two or more parties want to pursue further investigation/negotiation on one or more alternatives, the talks continue.

H. Meeting #5: Develop a detailed proposal for regional collaboration on one or more specific alternatives with two or more of the parties. The proposal will include cost sharing, timing, responsibilities for design, ownership, management, yield allocations, etc. The proposals are to be non-binding, and offered for approval of the respective Boards for further advancement.

I. Develop a common understanding between the parties of permitting requirements, general feasibility, and any potential obstructions to the prospective collaboration(s). [At this time, the discussions would not involve regulatory agencies.]

7.3 Document Cedar Creek Wetlands Yield, Land Requirements, Source Options, and Operational Flexibility

Principal Questions:

- The wetlands are currently permitted for 88,059 AFY, which exceeds the original permitted value at the time of the 2013 IWSP of 52,000 AFY. This task is aimed at documenting sources of water, timing, and any remaining steps (land acquisition, design, etc.) to produce this yield.

Suggested Tasks:

A. From existing documentation (Cedar Creek Wetlands Report, Permits, Design Documents, Etc.), prepare a brief technical memorandum documenting the permitted yield from the Cedar Creek Wetlands, the projected or alternative sources of water over time, design schedules, and any potential flexibility in future operations (joint operation in early years with other water providers, expanding yield beyond 88,059 AFY in the future, etc.) This is not a task that generates new information, but consolidates broadly distributed information into a helpful summary document that can confidently inform the IWSP Update process.

7.4 Supply/Demand Gap Analysis

Principal Questions:

- Under future conditions for supply coupled with future demand levels, what gap in water supplies will TRWD experience?
- Is there spatial variation in the demand gap that cannot be alleviated with other supplies by moving water through TRWD's system?
- What is the quantity of future water supplies that TRWD will need to develop in order to meet future demands and where is that supply needed?

Suggested Tasks:

A. **Model Updates:** Update Supply / Operations Models as Recommended in Section 9.0.

B. **Demand Ranges:** Develop tools to assist in quantifying the potential supply gap.

a. Consider using the demand scenarios in TRWD's 2020 Service Area Demand Study to bound the potential gaps, or:
b. [Recommended – See also **Section 9.0**]: Consider advancing the dynamic water demand forecasting tool that builds upon the data and methods developed under TRWD's Service Area Demand Study (TRWD is currently working on this in-house). The tool could be used to generate additional scenarios, should more be needed. If the COG releases updated demographic projections which are significantly different than those used in the Demand Study, the tool could be used to input the updated projections.
c. Develop a simple way to input new demand scenarios into TRWD's supply model (See **Section 9.0** for recommendations on future supply modeling).

C. **Consequences of Inaction**: This task will begin with a workshop in which TRWD staff can provide input, direction, and come to an agreement on what constitutes the "Do Nothing" supply scenario.

a. **Total Annual Supply:** Key demand scenarios (high, low, expected, for example) should be compared to the "do nothing" supply scenario, which presents the true gap if TRWD takes no action. The "do nothing" should take into account yield reductions in supply from climate change and/or sedimentation, aligned with the analyzed scenario. Ensure that all sources have updated hydrology per **Section 7.1.**
b. **Drought Resistance:** Key demand scenarios (high, low, expected, for example) should also be compared against future supply portfolios aimed at total annual water availability year-over-year, but which do not explicitly include intermittent drought-resistant supplies, such as reclaimed water, recharged groundwater, and other sources aimed at only intermittent emergency use. The purpose here is to determine if intermittent supplies can provide a meaningful buffer against drought-driven supply gaps in a more effective way than expanding the portfolio of continuous supplies (aimed at yearly yield) that may not be as efficient (overshooting supply needs or less than optimum operations during most years). Ensure that all sources have updated hydrology per **Section 7.1**.

D. **Risk/Gap Simulation:** Using the Supply and Demand tools available, simulate the various branches of the 2013 Decision Tree to help determine if risks or timing of supply needs have changed. Ensure that scenarios include 98% and 100% reliability through the drought of record, and that all sources have updated hydrology per **Section 7.1**.

7.5 Refine/Reduce Remaining IWSP Alternatives

Principal Questions:

- Which of the 2013 IWSP supply alternatives remain viable and practical, and should be carried forward for further analysis or refinement?
- Has regional collaboration changed TRWD's prior focus on large regional supply alternatives to different large regional projects?
- Is the predicted yield from the supply sources affected by the same hydrologic uncertainties as addressed in 7.1?
- Do the construction and operating costs for the original alternatives need to be updated or refined to be current with Region C guidelines and/or other studies?

Suggested Tasks:

A. **Screening**: TRWD to conduct two facilitated internal workshops to screen the 2013 IWSP Supply Alternatives based on 2013 findings and recommendations, current knowledge, continued relevance, regional potential, and factors such as viability, practicality, risk, and perceived comparative value to other alternatives. The first workshop would serve to collate all relevant information on the alternatives and sort them into categories such as "preferred", "neutral," or "not likely preferred." The second workshop would make final collaborative decisions on which alternatives to carry forward into the rest of the IWSP Update process for the more detailed analysis in 'B' through 'F' below, and also in Section 7.8 below (Refinement of Portfolios).

The following steps apply to sources selected for further study and consideration:

B. **Hydrologic updates**: Based on findings from 7.1 (Hydrologic Updates for existing sources), and specifically conclusions from 7.1E, evaluate potential changes in original yield estimates for alternative new sources. This could be a simplified conceptual correlation to results for TRWD Existing Sources and/or NTMWD results, or a more detailed hydrologic modeling evaluation of specific sources and their contributory basins (level of effort will be based on the progression of findings in earlier tasks). It may be advisable to determine both Safe Yield and Firm Yield from sources that were identified in 2013 as being preferred (included on one of the decision tree branches, or possibly as alternative portfolios), as the difference between the two may be a measure of temporary emergency water if ever needed. *Ensure that climate forecasts are used consistently through all tasks (see* ***Section 7.1****).*

C. **Capital cost review**: Review the 2013 IWSP capital cost estimates for each alternative, and update with any new information. Escalate costs to current value as appropriate.

D. **Phasing/Operational Study**: This task is aimed at the prospect of developing new supply sources in which transmission is more expensive than moving water through the existing system (that is, existing sources would remain the priority supplies). This could mean that water from new sources could be delivered in very small quantities for years or decades, and balancing this gradually accumulating benefit may be difficult with capital cost expenditures. To understand this, it is recommended that TRWD examine how new sources might be phased in over time, either to manage energy costs, transmission system construction schedules, water quality blending requirements, or perhaps to "re-optimize" the energy needs for all sources of water together, etc. Operational modeling (see recommendations in **Section 9.0** for updates on the supply-side modeling) may be warranted, and results will likely affect the operational cost review in 'E' below. If water is to be phased in from any new source gradually, it might be wise to compute the levelized cost of water (dollars per gallon of water delivered) for comparative purposes over time between alternative sources and their actual productive value (see explanation above). (The computation of levelized cost is only recommended if the delivery volumes from new sources could be highly variable from one decade to another.) Note that this task should utilize existing/expanded models, and not develop new models from scratch.

E. **Operational cost review**: Based on factors such as adjusted or escalated energy costs, adjusted volumetric yield estimates, phasing or blending needs (from 'D' above), re-examine expected annual operating costs for each new source that is carried forward from the screening in 'A'

above. Operational costs should include energy costs for transmission as well as standard facility O&M costs.

F. **Final List of Alternatives**: Produce final list of alternatives to carry forward from the 2013 IWSP to the portfolio evaluation in the Updated IWSP (per **Section 7.8**). Report on expected yield (firm and safe, potentially), updated capital cost, and estimated annual operating cost per decade.

7.6 Explore Supply Alternatives Not in the 2013 IWSP

Principal Questions:

- Are there viable additional supply alternatives that could provide reliable annual yield but which were not included in the 2013 IWRP, such as TRWD ASR, Regional ASR, TRWD Groundwater, Additional Reuse, Oklahoma supplies, etc.?
- Are there additional supply alternatives that could provide intermittent drought relief in addition to (or in lieu of) continued or expanded demand management measures, and which were not included in the 2013 IWSP? (Refer to discussion in the Gap Analysis, Section 7.4.C.b above.)
- Should these sources be considered as portfolios are developed or refined?
- What are their comparative costs and yield?

Suggested Tasks:

A. **Literature Review**: Collect and summarize reports on source water availability in the North Texas Region that could potentially support TRWD's long-term supply plan, but were not included in the 2013 IWSP. Such sources may include surface water reservoirs, water reclamation/reuse, deep groundwater, alluvial groundwater influenced by surface water, bank infiltration, Aquifer Storage and Recovery (ASR) at various scales, additional reclaimed water beyond TRA, interstate water in accordance with current rights and agreements, etc.

B. **Source Identification**: TRWD will conduct two internal facilitated workshops to compare the conceptual value of new alternatives (as presented in literature) to alternatives in the 2013 IWSP, both in terms of reliable annual supply, and in terms of intermittent yield during droughts. The first workshop will review the summaries of available reports and literature, and categorize potential new sources as "worth studying," "neutral," or "not worth studying." The second workshop will formulate a collaborative recommendation for which new sources to advance by further study (as outlined in the following steps) and potential inclusion in refined supply portfolios.

The following steps apply to sources selected for further study and consideration:

C. **Categorization of Potential New Sources**: Determine if each new source is likely to provide reliable annual yield year over year, or if intermittent yield for drought resilience would represent more appropriate utilization of available water. Determine state and federal permitting viability for either type of water use.

D. **Hydrologic Potential**: To the extent practical, estimate hydrologic availability from published sources of information. If new analysis or modeling is required, consider the potential effectiveness of high-level conceptual modeling first (water balance approach) to estimate the

order of magnitude of potential yield, and characterize the uncertainty in these estimates. If further analysis is warranted, consider conferring with the USGS or TCEQ on any hydrologic tools or estimates that may be available to assist. *Ensure that climate forecasts are used consistently through all tasks (see* ***Section 7.1****).*

E. **Capital cost review**: Estimate capital costs for new sources being studied. Ensure consistent time value of money with other cost estimates in separate tasks.

F. **Phasing/Operational Study**: (Refer to Task 7.5.D above, which discusses the same analysis for alternatives that were in the 2013 IWSP). Examine how new sources might be phased in over time, either to manage energy costs, transmission system construction schedules, water quality blending requirements, drought resilience operations, etc. Operational modeling (see recommendations in **Section 9.0** for updates on the supply-side modeling) may be warranted, and results will likely affect the operational cost review in 'G' below. If water is to be phased in from any new source gradually, it may be wise to compute the levelized cost of water (dollars per gallon of water delivered) for comparative purposes between alternative sources and their actual productive value. (Again, refer to 7.5D above for discussion). The computation of levelized cost is only recommended if the delivery volumes could be highly variable from one decade to another.) As per above, existing tools should be utilized (expanded as necessary) in lieu of creating new tools from scratch.

G. **Operational cost review**: Based on factors such as continuous or intermittent operations, phasing or blending needs (from 'F' above), examine expected annual operating costs for each new source that is carried forward from the screening in 'B' above. Operational costs should include energy costs for extraction and transmission (as relevant) as well as standard facility O&M costs.

H. **Final List of Alternatives**: Produce final list of alternatives to add to the IWSP Update process and portfolio evaluation (per **Section 7.8**). Report on expected yield (firm and safe, or intermittent drought yield and required replenishment cycle time), estimated capital cost, and estimated annual operating cost per decade.

7.7 Refine Supply Portfolios

Principal Questions:

- What are near-term and long-term supply deficits that the gap analysis presents?
- Are the decision tree branches presented in the 2013 IWSP still relevant, given what we have learned about existing supply yield, new supply alternatives, status of regional collaboration, and completion of the No-Regrets alternatives?
- Do we have enough information to determine which branch of the decision tree on which to focus with specific refinements?
- Does the decision tree need to carry multiple "branches" into the future (with the assumption that one branch would be identified as the primary pathway, with adaptation "on-ramps" and "off-ramps")?
- Determine the current relevance of the 2013 Decision tree and its multiple branches. Recall that two key factors for review of the 2013 IWSP decision tree relevance are to recognize the success of the No-Regrets alternatives, and the status of regional partnerships for a large water source.

- What is the primary pathway for long-term water supply projects?
- What are the most important long-term uncertainties, and how can the primary pathway be durable enough to adapt to these, or be immune to them?

Suggested Tasks:

A. **Analytical Framework for Portfolios**: Clearly define the timing of the need for new water sources through 2070. Compile a list of currently viable supply alternatives and compare to the original decision tree and its branches formulated in the 2013 IWSP.

B. **Final Screening of Portfolios**: Based on information gathered to this point, screen out any supply alternatives that are considered either impractical for any reason ("fatally flawed"), or clearly less preferred than a project of similar scope and scale (where both would be unnecessarily redundant). This should be accomplished with one or two workshops with TRWD staff.

C. **Scenario Planning for Long-Term Uncertainties**: Much of the analysis described above involves the simulation or evaluation of various *scenarios*, both for supply and demand. In the analytical context, a "scenario" is defined as a series of assumptions, configurations, conditions, and inputs that are processed through predictive tools to evaluate the effectiveness or cost-effectiveness of the TRWD supply system. The term "SCENARIO PLANNING," however, is different. It refers to defining plausible future conditions that are largely external to TRWD (climate, political conditions, natural disasters, demographic shifts or changes in societal behavior, etc.), and against which immunity can or should be designed or accounted for in decisions on future water supply. It is a proven technique used widely in long-term water planning in the US, and was used by TRWD to help determine the sequence of tasks within this document to provide short-term immunity against external unknown factors so that the IWSP Update can be focused, efficient, and informed. (Refer to sections 4 through 6 of this report for an overview of the Scenario Planning process, and how it was used by TRWD to generate these findings and recommendations). In the same way that Scenario Planning was employed to develop this IWSP Update process to help reduce near-term risks to the efficiency of the planning process (**Sections 4.0-6.0**), TRWD should employ Scenario Planning to address the most critical long-term risks to supply reliability and financial balance, and provide a framework for crafting a long-term supply strategy (the identification of new supply alternatives which, collectively, comprise TRWD's future water supply portfolio, which is defined below) that is adaptive or immune to these uncertainties. The resulting plausible future scenarios (long-term) will provide a backdrop against which to evaluate the robustness and immunity to risk of prospective supply portfolios.

D. **Conceptual Formulation of Portfolios**: It has been generally assumed that no single new supply source will suffice for TRWD's long-term water needs, and hence, it is the *combination* of future supply sources that must ultimately be compared and contrasted. We refer to these combinations of supply sources as "portfolios," each of which has advantages and disadvantages (costs, risks, and benefits), and perhaps some flexibility in scale and timing of its various elements. Based on timing of need, long-term uncertainties, partnership potential or decisions, and coordination with conceptual transmission system planning, formulate portfolios that could satisfy short-term and long-term supply needs with confidence. If TRWD is working

outside a regional partnership, it is recommended that alternative portfolios be developed for large, centralized supply and small distributed sources for comparative purposes. **It is recommended that any portfolio include consideration of drought contingencies,** either through operational changes of continuous supplies, or by inclusion of intermittent supplies specifically maintained for drought preparedness. Customer collaboration will be key in understanding risk tolerance for drought mitigation measures. Other guiding themes might include redundancy, permitting ease, cost, etc., though decisions on the themes for portfolios should be informed at the time based on work to date, and the scenario planning themes in 'C' above.

Note: It is too early to suggest an ideal strategy for portfolio development. Based on partnership potential, gap analysis, long-term risks (scenario planning) and other factors, portfolios might be developed conceptually in one or more of the following modes:

- *Refinement of a branch (or branches) of the 2013 decision tree*
- *New decision tree with branches addressing current conditions, issues, and new information with alternative, themed portfolios*
- *A single preferred portfolio, with appropriate adaptation triggers for onramps or offramps to/from alternative strategies or projects*

E. **Performance Analysis of Portfolios**: Refer to **Section 9.0** for recommendations on supply system modeling. It is recommended that alternatives still under consideration at this point be added to TRWD's RiverWare Model for operational evaluation, considering finer detail than the conceptual modeling in the 2013 IWRP, which focused on annual yield without operational specificity for new sources. Each supply source should be evaluated for phasing of available water over time, blending with other sources, balancing energy needs and drawdown, etc. In other words, new rules will be required to operate an expanded system of supplies, and these rules have not yet been explored or developed. In order to refine the District's yield and cost projections, it will be important to formulate effective operating rules for incorporating new and existing sources into a unified future system. This analysis should also include operations for long-term continuous yield, as well as drought contingency operations in which certain sources may be tapped only intermittently for drought resilience. As stated earlier, **it is recommended that any portfolio include consideration of drought contingencies,** either through operational changes of continuous supplies, or by inclusion of intermittent supplies specifically maintained for drought preparedness. The recommendations in Section 9.0, that we convert IWSP modeling into the TRWD RiverWare platform is offered for an important reason. The STELLA model used for the 2013 IWSP was designed for the Integrated Pipeline Study (to simulate both the TRWD and Dallas water supply systems), and its primary value was its ability to easily explore alternative operating rules for balancing energy needs between three pipelines instead of two, examining potential supply or transmission-related shortfalls associated with alternative operating protocols, and exploring water sharing possibilities with Dallas. When employed for the 2013 IWSP, the operations of existing sources (which included historic monthly rules and proposed new rules for the IPS) was mismatched with that of new sources (which distributed annual yield somewhat uniformly over months without operational specificity or energy optimization). This was sufficient then because it allowed for preferred alternative to be identified by comparing their generalized costs and reliability potential. As the Updated IWSP takes shape, it must rely on thoughtful development of operating rules for new sources that are synchronized with everything TRWD knows about existing operating rules, phasing in of the IPL, etc. This information exists

with more certainty and resolution in the RiverWare model than in the STELLA model. As such, part of this task (in concert with the recommendations in Section 9, which could begin at any time through the 3-phased IWSP Update process) should include a collaborative or facilitated process of defining the following features for inclusion in the TRWD RiverWare model based on past experience and foreseen needs:

a. New water sources and transmission infrastructure (alternatives) to include

b. Monthly operating rules and parameters to experiment with flexibility for each new source

c. Approach for simulating new pump stations (if needed) before the transmission systems are designed (for new sources)

d. Methodology for using the model to provide guidance for phasing of new sources and energy optimization (requires specific monthly operating rules, and potentially a new or expanded module to examine energy needs within the model to avoid exporting of results to energy and cost workbooks)

e. Potential variations to existing operating rules based on the integration of new sources.

f. Yield updates per Task 7.1 and others.

g. Avoid or simplify the exportation of model results for energy/cost post-processing.

h. Other updates as needed

F. **Cost Analysis of Portfolios**: In conjunction with the operational modeling in 'E' above, and the Transmission System Master Planning conceptual evaluations in Section 7.9, prepare capital and decadal operating cost estimates based on energy needs and O&M for each developed portfolio. For consistency, established TRWD tools should be used for this analysis, with coordination and/or training workshops as needed.

G. **(OPTIONAL TASK FOR CONSIDERATION, LIKELY OUTSIDE THE IWSP UPDATE PROCESS BUT INCLUDED AS A FACTOR IN TRANSMISSION SYSTEM DESIGN): Future Energy Source Evaluation**: Based on projected energy needs and potentially broad geographic distribution of energy requirements for new sources, it is recommended that TRWD conduct a study on the potential for renewable energy sources to play a significant role in future water pumping and transmission. This could include site-specific energy supplements, tie-ins to new or existing renewable generation facilities, contractual arrangements with energy providers, in-line energy recovery, etc. It is recommended that the study should evaluate the potential costs and benefits of greater reliance on renewable energy with respect Greenhouse Gas (GHG) emissions, energy costs, and other regional economic impacts (job creation or loss, for example).

H. **Primary Pathway and Adaptation Plan**: Based on all of the above work, this task should culminate in a clear roadmap for new supplies through 2070, with adaptive triggers based on climate, demand, economic, regulatory and other trends, as well as the actual performance of operational water sources. The output will be an updated decision tree, or a primary pathway toward new supplies with conditional and sequential triggers for decisions and adaptation. It should be accompanied with cost projections over time, a full schedule of planning, design, permitting, construction, phasing, and operational stages of each project, risk assessment

(based on the long-term scenario planning and other factors), and specifications to support detailed design of transmissions and storage facilities.

7.8 Customer Collaboration

Principal Questions:

- Do customer cities understand TRWD's analytical interpretation that 98% simulated reliability equates to 100% functional reliability, with the difference attributed to model uncertainty and ability to manage demand through droughts. More importantly, how do customers feel about current demand management programs and their long-term impacts and viability?
- Are customer cities willing to continue to accept the current and forecast levels of intermittent demand management measures as a principal component of drought management, and can we quantify the cost and benefits of alternatives?
- Do customer cities support the long-term strategy for TRWD's supply portfolio, its triggers for adaptation or substantial changes, and any partnerships on which future supply may depend?

Suggested Tasks:

A. **Educational Outreach**: Throughout the IWSP Update process, TRWD will provide updates on decisions, priorities, and steps in the process to customer cities, with the goal of helping them understand the end goal, and their ultimate ability to provide feedback once sufficient information has been developed to which they can credibly react.

B. **Individual Meetings**: After the alternatives have been evaluated (**Sections 7.5 and 7.6**), and while the portfolios of supply alternatives are developed enough to describe, but not yet finalized (**Section 7.7**), TRWD will meet individually with customer cities to review work to date in updating planning for long-term water supply, discuss financial impacts and options, explain the tradeoffs between associated with different levels of demand management), and solicit feedback on all of the above. Note that while customer collaboration has been identified by TRWD staff as an important task in Phase 3 of the IWSP Update process, it is also a parallel track that spans all three phases. TRWD may wish to conduct some individual meetings with customers earlier in the program to better understand risk appetite, share the approach for evaluating long-term supply options, and later in the program to share findings and recommendations. Key to this task will be to develop a roadmap for how and when information is exchanged throughout the IWSP Update process with customer cities.

Note that TRWD has determined that it is very important to have data (cost, water volumes, supply sources, etc.) identified prior to engaging customer cities in the discussion of future reliability, because the discussion would be purely conceptual (and likely idealistic) without understanding the magnitude of the tradeoffs involved. Early discussions with customers will likely focus on the approach and exchanging information on the alternative supply options. Later discussions, supported with data, will include findings and recommendations.

C. **Incorporation of Feedback**: TRWD will make final recommendations to its Board based on the technical work to date, and input from individual customer cities on near-term and long-term project priorities for a reliable long-term supply plan. It is expected that much of the tuning of the

plan may revolve around the customer cities' appetite for risk, and corresponding willingness to institute drought restrictions during times of water stress (98% vs. 100% reliability).

D. **Public Meeting to Present Path Forward:** Consultant will discuss with the District the path forward for meetings with customer cities to present and discuss the long-term water supply strategy.

7.9 Transmission System Planning Guidance

Many aspects of transmission system planning at TRWD fall outside the purview of the IWSP Update, but many of the decisions made during the Update will affect transmission needs. Likewise, certain transmission constraints may affect IWSP decisions. The tasks below are those that will link most directly to the IWSP Update by resulting from, or feeding into, IWSP decisions. It is expected that TRWD will orchestrate and manage the majority of transmission planning and engineering outside of the IWSP process.

7.9.1 Prioritize Known Improvements – Concurrent with Stage 1

Work with TRWD to establish criteria and a structured decision framework for prioritizing known improvements to existing infrastructure. Facilitate discussions between departments to help align decisions with institutional goals and schedules, as well as the evolving IWSP. Employ a Multi-Criteria Prioritization Tool with qualitative and quantitative factors as needed to help organize, process, and visualize information.

Key existing infrastructure needs that must be prioritized include:

- Sections 1D and 1E Pipeline from Arlington Outlet (Line J) to Rolling Hills Booster PS
- Section 9 of the IPL to Lake Benbrook
- New Richland Chambers Lake Pump Station (JRC1) (including whether to construct at a new, currently unknown location on the RC Reservoir, or adjacent to existing RC lake PS (RC1)
- Section 16 of the IPL from the new Richland Chambers Lake PS
- Cedar Creek Pipeline Replacement – potentially considered with these or separately, in 7.9.2 below, based on determination of hydrologic water availability and Cedar Creek Wetland target yield of 88,059 AFY minimum. Current order of priority based off of pipeline risk is: 10 miles in Section 2 (Waxahachie to Mansfield), 5 miles immediately downstream of Cedar Creek Lake Pump Station in Section 4, and CC Pipeline Crossing of Trinity River
- Construction of the third cell of the Kennedale Balancing Reservoir
- Cedar Creek Wetlands and 12-mile pipeline to CC Reservoir
- Construction of JB2 Booster Pump Station
- Construction of JB4 Booster Pump Station
- Addition of Pumps at JB3 Booster Pump Station

7.9.2 Cedar Creek Pipeline Rehabilitation and Sizing – Concurrent with Stage 1 or 2

The Cedar Creek Pipeline requires renewal/replacement, and possibly upsizing. Ten miles of Section 2 CC pipeline replacement in the Waxahachie to Mansfield area is currently at 60% design as of the end of 2020. Following in-house analysis, the existing distressed 72" PCCP in

this project west of the Waxahachie Pump Station will eventually be replaced with 90" welded steel pipe. Construction of the Phase 2 project is planned to begin in early 2024 following completion of the KBR Modifications to Cells 1 & 2. As for the CC pipeline from the Lake PS to Waxahachie, the future upsized pipe capacity will need to be determined. The potential capacity is dependent on findings in Stage 1 of the IWSP Update strategy (permitted capacity of the Cedar Creek Wetlands of 88,059 AFY and the hydrologic availability of water from Cedar Creek Reservoir). The Cedar Creek Pipeline Rehabilitation / Sizing work should be accelerated and at a minimum, considered in the prioritization of other known transmission infrastructure projects in 7.9.1.

7.9.3 New Source Transmission Conceptual Designs and Costs – Concurrent with Stage 2

This task will include conceptual transmission routes, capacities, and costs for new sources that are still deemed viable alternatives in Stage 2. Some sources may have been screened out as part of a partnership strategy or for other reasons. Level of detail for routes, capacities, capital costs, and energy needs/costs should be compatible with the 2013 IWSP estimates, that is, sufficient to compare and contrast alternatives. The needs and parameters for the prospective 4th Pipeline (from East Texas) cannot be fully understood until the preferred supply portfolio is recommended in Stage 3 of the IWSP Update process, though alternative configurations for the 4th Pipeline can certainly be explored during this conceptual phase.

7.9.4 New Source Transmission Final Designs and Costs – Following Stage 3 (for preferred or primary portfolio)

Note that this will likely take place outside the purview of the IWSP Update, but it is a natural and consequential follow-on to the Update and worth mentioning here as a parenthetical. This work will recommend the preferred pathway for new sources, highlight opportunities and strategies for regional partnership(s) including project prioritization and sequencing (supported by relevant tasks in the IWSP update process, such as 7.9.1 above), permitting, design, and construction.

Section 8

Considerations for Level of Effort for IWSP Update Activities

The original plan for this report was to provide planning-level cost estimates for the key tasks outlined in the preceding sections. However, since some of the tasks will be led or executed by TRWD staff, others may be collaborations between TRWD and consultants, and others may be consultant-led, it was suggested that estimating costs for such tasks would not have a common basis, and would be of little practical use at this stage in TRWD planning. Instead, as TRWD embarks on the recommended tasks and strategy in this document, one aspect of work will be transitioning appropriate work outlines from Section 7 into full scopes of work where necessary. As scopes are developed for each individual task or subtask, cost estimates can be developed by blending TRWD staff time with expected level of effort from external professionals, based on TRWD preferences and anticipated allocation of responsibilities for each task.

Section 9

Recommendation on Modeling for the IWSP Update

9.1 Supply and Operations Modeling

The refinement of alternative supply sources, and the formulation of future supply portfolios will necessitate the inclusion of source sequencing, blending, peaking, and other operational factors that were beyond the scope of the 2013 IWSP, which aimed simply to prioritize alternative sources for future consideration. This Update of the IWSP will recommend a path forward for supply development. However, additional details will be needed to examine operational factors and identify efficiencies. For example, some distributed new sources may be phased in over time with respect to their ultimate capacity and need, if it is cost-effective to do so. Timing of infrastructure, seasonal capacities, and more dimensions to energy balancing must be accounted for with more precision than the bulk annual yield used to prioritize source alternatives earlier.

Because of the foreseeable need to include detailed operating strategies that prioritize and sequence new and existing sources over time and in response to dynamic seasonal demand patterns, we recommend that the supply and transmission system modeling migrate to TRWD's existing RiverWare platform. This work can be supported by TRWD Water Resources Engineering Staff (see Section 7.7.E above for a detailed discussion and justification of factors on which TRWD and a consultant familiar with modeling needs and lessons-learned can collaborate). New source alternatives, which were simulated in TRWD's STELLA model for the 2013 IWSP, were simulated only in terms of bulk yield, and the complexity of the operating rules for existing sources was not extended to operations of potential new sources. Instead, the model was used to help determine how various combinations of new source alternatives could potentially fill gaps between future demand and supply, at what cost, and with what likely impacts to supply reliability.

Given that higher operational resolution is needed for *any* future modeling tools it is logical to dedicate that time in the RiverWare platform in order to consolidate TRWD supply system modeling and apply uniform operational resolution within RiverWare to potential new sources. There is efficiency to be gained here: If the STELLA model were to be used going forward, it would need to be stripped of simplified operating rules (based on source priorities but not on effective energy balancing), and re-programmed with more explicit operating rules. It would also need to be checked against any operational updates in RiverWare for the existing system. It is likely simpler and easier in the short term to expand the RiverWare model, and the long-term benefit will be a single tool that evaluates existing and new sources with both planning and operational resolution. It is therefore recommended that this IWSP Update is a good time to consolidate supply and operations modeling into the single platform of the RiverWare model, upon which TRWD already relies for both planning and operations.

9.2 Demand Modeling

It is recommended that TRWD continue to develop a dynamic water demand forecasting tool that builds upon the data and methods developed under TRWD's recently completed Service Area Demand Study.

The tool could be used to generate additional scenarios, should more be needed (especially if water use trends as a result of COVID-19 are considered to be partially persistent into the future). If the COG releases updated demographic projections which are significantly different than those used in the Demand Study, the tool could be used to input the updated projections. The demand tool could be generated in Excel and used to support the IWSP update by providing input to supply/operations modeling, and helping to bound timeframes for short-term and long-term needs. See **Section 7.4** for recommendation of how this could be included in upcoming work plans.

Section 10

Summary and Conclusions

This work has produced guidelines and an organized framework for updating TRWD's Integrated Water Supply Plan. The IWSP Update is composed of approximately a dozen different tasks aimed at refining and building on available information and the recent success of the 2013 IWSP Plan "No-Regrets" supply alternatives which TRWD has accomplished. The IWSP Update process is expected to take 3-5 years, on the assumption that TRWD proceeds with the Cedar Creek Wetlands design, 404 Permitting, Construction, and the Cedar Creek Pipeline renewal concurrently with the IWSP Update process, and not as a result of it.

A Scenario Planning process was employed to formulate an adaptive sequence of tasks that can offer protection from near-term risks, such as

- uncertain volumes of existing yield
- regional partnership dynamics,
- regulatory uncertainties
- customer perceptions of reliability.

These four issues proved to be the most potentially impactful near-term uncertainties that could affect the shape of the IWSP itself, even before implementation begins.

The recommended road map for the IWSP Update process is illustrated in **Figure ES-2 and Figure 6-1**, and key conclusions from **Section 6.0** are reiterated below:

Three Stages: The recommended IWSP Update process is divided into three stages:

- **Stage 1** focuses on early answers to important uncertainties about availability of water in existing sources, and opportunities to partner with other regional water supply providers on large new sources or water agreements. Addressing these issues and reducing or eliminating uncertainty will enable TRWD to more effectively define and orchestrate a future supply portfolio.
- **Stage 2** adds definition to new supply alternatives, both by expanding information from the 2013 IWSP and examining the viability of other alternative sources that have not yet been examined in detail.
- **Stage 3** aims to consolidate information from the first two stages into a recommended supply portfolio, with adaptation triggers for conditions that may change over the long term. This stage also focuses on feedback and support from TRWD Board of Directors and customer cities.

Parallel Tracks: Four activities associated with the IWSP Update will run concurrently with all stages:

- **Transmission System Planning Guidance**: This will begin early with known Cedar Creek Pipeline rehab and transmission expansion projects, and will support decision making and conceptual design of transmission infrastructure for known as well as future alternative sources. The IWSP Update will

help prioritize near-term needs, and also point to detailed engineering and design of transmission infrastructure for recommended new sources.

- **Reliability Considerations**: Throughout all stages of work, TRWD has decided to evaluate the supply system using its consistent principal that simulated values of 98% reliability translate to full reliability due to data uncertainty and ability to manage drought-related shortfalls. However, key to this work will be examinations and discussions with customer cities on continued willingness to impose demand reduction measures at various levels. Climate change may also affect these considerations.
- **Resilience**: Throughout all stages of work, considerations must be made for resilience not only to climate and drought, but to other forms of shock, including economic conditions, public health crises, Contaminants of Emerging Concern (CECs), sociopolitical considerations, perceived social inequities, loss of reservoir supply for 6 months due to a chemical or other contaminant spill, etc.
- **Customer Collaboration**: Throughout the IWSP Update process, TRWD will endeavor to inform customer cities of findings and decisions, enabling customers to provide informed opinions on the recommendations in the updated plan.

Key Adaptation Points: This process has identified two points of inflection, at which the recommended priorities could change:

- **Hydrologic Assessment**: If the existing sources are found to have significantly less reliable yield than what is currently permitted, it is recommended that the supply/demand gap assessment (blending the newly developed hydrologic information with the recent demand projection refinements) be accelerated to inform TRWD of potential near term supply gaps.
- **Regional Partnership**: If TRWD opts to collaborate with other regional water providers on either a large new water source or on a collective agreement for TRA Reuse water, it would be wise to screen out (or at least temporarily de-emphasize) IWSP alternatives that would either be redundant to the large collective project(s), or which might counter a collective regional shift toward centralized supply.

It is likely that additional factors would justify adjustments or adaptations of the planning activities outlined in this report. By providing consistency in themes throughout the process (reliability, resilience, and customer collaboration as continuous threads), and by providing examples of key adaptation triggers that are foreseeable, this report and its descriptions of the needs and work plans for each individual task should guide TRWD in making additional adaptations as needed. The ultimate goal is a process and product (Updated IWSP) that leads efficiently and comprehensively to a durable IWSP and its implementation.

CASE STUDY: SOUTH CAROLINA BASIN AND STATE WATER PLANNING

PEE DEE RIVER BASIN PLAN 2025







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Tim Brown, Grand Strand Sewer and Water
Cliff Chamblee, Sonoco Products Company - Hartsville
John Crutchfield, Duke Energy
Jason Gamble, Gamble Family Farms
Michael Hemingway, City of Florence
Megan Hyman, International Paper
Eric Krueger, The Nature Conservancy
Frances McClary, Williamsburg Soil and Water Conservation
Douglas Newton, Newton Farms
Hughes Page, Pee Dee Land Trust
Bob Perry, Water & Land Solutions
Lindsay Privette (Vice Chair), Pee Dee Regional Council of Governments
Buddy Richardson II (Chair), USDA-Farm Service Agency
John Rivers, Riverdale Farms, Inc.
Debra Buffkin, Winyah Rivers Alliance
Jeff Steinmetz, Francis Marion University
Cynthia Walters, Santee Cooper

South Carolina Department of Environmental Services

Brooke Czwartacki
Courtney Kemmer
Priyanka More
Scott Harder
Joe Koon
Alex Pellett
Hannah Hartley
Leigh Anne Monroe
Andy Wachob

South Carolina Department of Natural Resources

Dr. Joseph Ballenger
Hope Mizzell
Bill Marshall
Dr. Elliot Wickham
Jason Marsik

South Carolina Office of Resilience

Alex Butler

The Nature Conservancy

Eric Krueger

United States Geological Survey

Toby Feaster

Andrea Hughes

Clemson University

Dr. Luke Bower
Dr. Kendall Kirk
Dr. Joe Mruzek

Dr. Brandon Peoples
Dr. Nathan Smith
Dr. Thomas Walker III

Chikezie Isiguzo, PhD candidate

Duke Energy

John Crutchfield

Jeff Lineberger

Waccamaw Regional Council of Governments

Leigh Kane

City of Florence

Michael Hemingway

Grand Strand Water and Sewer Authority

Tim Brown

Georgetown Water and Sewer District

Michael Yip

North Carolina Dept. of Environmental Quality

Linwood Peale

Yadkin-Pee Dee Water Management Group

Aubrey Lofton

CDM Smith

John Boyer

Brown and Caldwell

Jane McDonough
Matt Lindburg

Stephanie Alimena
Beth Albrecht

JD Solomon (JD Solomon Solutions)

Acronyms

ACP	Atlantic Coastal Plain
AEP	Annual Exceedance Probability
AIW	Atlantic Intracoastal Waterway
AMI	advanced metering infrastructure
AMR	automated meter reading
ARI	Annual Recurrence Interval
ASR	aquifer storage and recovery
AWWA	American Water Works Association
BRIG	Building Resilient Infrastructure and Communities
cfs	cubic feet per second
CMOR	Condition Monitoring Observer Reports
CUA	Capacity Use Area
CWWMG	Catawba-Wateree Water Management Group
DMA	Drought Management Area
DRC	Drought Response Committee
EIA	Energy Information Agency
EPA	U.S. Environmental Protection Agency
EQIP	Environmental Quality Incentives Program
F	Fahrenheit
FEMA	Federal Emergency Management Agency
FERC	Federal Energy Regulatory Commission
FSA	Farm Service Agency
GIS	geographic information system
GDP	gross domestic product
gpm	gallons per minute
GSWSA	Grand Strand Water and Sewer Authority
GWMP	Groundwater Management Plan
HMGP	Hazard Mitigation Grant Program
IRA	Inflation Reduction Act
LEED	Leadership in Energy and Environmental Design
LIP	Low Inflow Protocol
MGD	million gallons per day
MGM	million gallons per month
MIF	Minimum Instream Flow
MRLC	Multi-Resolution Land Characteristics Consortium
NCDEQ	North Carolina Department of Environmental Quality
NDMC	National Drought Mitigation Center
NLCD	National Land Cover Database

NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
PFAS	per- and polyfluoroalkyl substances
PPAC	Planning Process Advisory Committee
P&R	Permitted and Registered
RBC	River Basin Council
REAP	Regional Economic Analysis Project
SCDA	South Carolina Department of Agriculture
SCDES	South Carolina Department of Environmental Services
SCDHEC	South Carolina Department of Health and Environmental Control
SCDNR	South Carolina Department of Natural Resources
SCO	State Climatology Office
SC ORFA	South Carolina Office of Revenue and Fiscal Affairs
SPI	Standard Precipitation Index
SWAM	Simplified Water Allocation Model
UIF	unimpaired flows
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USFWS	U.S. Fish and Wildlife Service
USGS	United States Geological Survey
WMA	Wildlife Management Area
WIFIA	Water Infrastructure Finance Information Act
YPD-DMAG	Yadkin-Pee Dee Drought Management Advisory Group

Chapter 1
Introduction

1.1 Background

The South Carolina Water Resources Planning and Coordination Act mandates that the South Carolina Department of Natural Resources (SCDNR) develop a comprehensive water resources policy for the state of South Carolina. SCDNR developed the first state water plan—the *South Carolina Water Plan*—in 1998. The plan was updated in 2004 following what is recognized as one of the worst multi-year droughts on record, which ended in 2002. One of the recommendations from the *South Carolina Water Plan, Second Edition* was forming advisory committees to develop comprehensive water resource plans for each of the state's four major river basins—the Ashepoo-Combahee-Edisto, Pee Dee, Santee, and Savannah. In 2014, when the development of surface water quantity models to support the planning process began, SCDNR and the South Carolina Department of Health and Environmental Control (SCDHEC), now the South Carolina Department of Environmental Services (SCDES)[1], further subdivided the basins based on SCDES's delineations used for the Water Quality Assessments. The eight planning basins are the Broad, Catawba, Edisto, Pee Dee, Lower Savannah-Salkehatchie, Saluda, Santee, and Upper Savannah, as shown in Figure 1-1. In 2016, SCDNR began working with the United States Geological Survey (USGS) to update the Coastal Plain Groundwater Model—another important tool to support development of water resource plans.

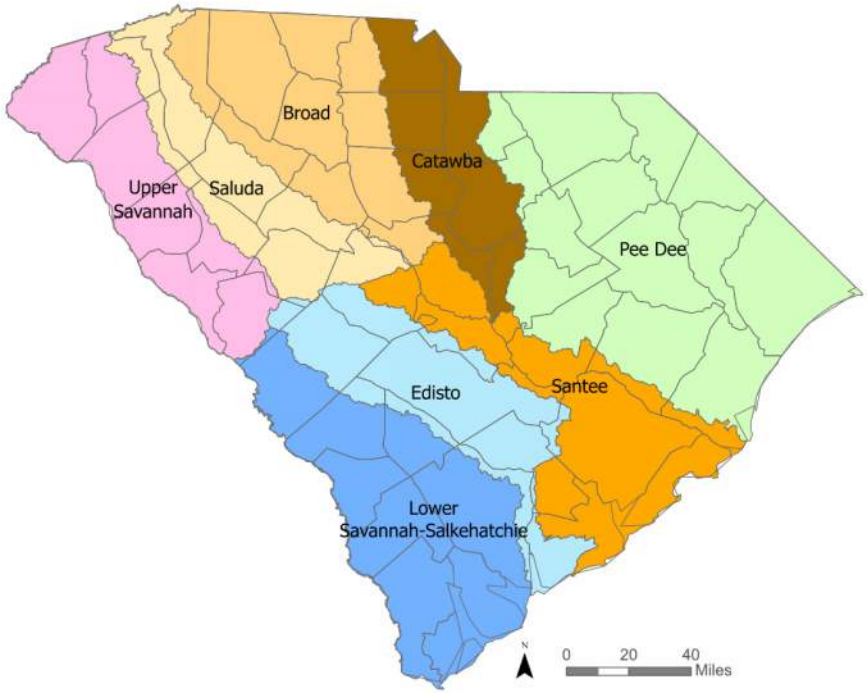


Figure 1-1. Planning basins of South Carolina.

Each of these water resource plans is called a River Basin Plan, which is defined in the *South Carolina State Water Planning Framework* (SCDNR

[1] [1] "Under state law, the South Carolina Department of Health and Environmental Control (SCDHEC) became two separate agencies on July 1, 2024. The two new agencies are the South Carolina Department of Environmental Services (SCDES) and South Carolina Department of Public Health (DPH)" (DHEC Restructuring. | SCDHEC). Activities carried out by the aforementioned DHEC, now SCDES, will be described under the new organizational structure of SCDES throughout this Plan.

2019; referred to hereafter as the Planning Framework) as "a collection of water management strategies supported by a summary of data and analyses designed to ensure the surface water and groundwater resources of a river basin will be available for all uses for years to come, even under drought conditions." The next update to the State Water Plan will build on the analyses and recommendations developed in the eight River Basin Plans.

River basins are seen as a natural planning unit for water resources since surface water in each basin is relatively isolated from water in other basins by natural boundaries. Each River Basin Plan will include data, analysis, and water management strategies to guide water resource development in the basin for a planning horizon of 50 years.

In each river basin, a River Basin Council (RBC) is established and tasked with developing a plan that fairly and adequately addresses the needs and concerns of all water users following a cooperative, consensus-driven approach. River basin planning is expected to be an ongoing, long-term process, and this plan will be updated every 5 years.

The Edisto River basin was the first of the eight river basins to begin and complete the process. The Pee Dee River basin is the third to develop a River Basin Plan, and the plan is presented in this document.

The Planning Framework focuses the first edition of River Basin Plans on water quantity. It also notes that water quality concerns may be highlighted and that water quality considerations will be more fully developed in later iterations of River Basin Plans. The Pee Dee River Basin Plan has recommendations for including water quality in the next plan update.

A River Basin Plan answers four questions:

1. What is the basin's current available water supply and demand?
2. What are the current permitted and registered water uses within the basin?
3. What will be the water demand in the basin throughout the planning horizon, and will the available water supply be adequate to meet that demand?
4. What water management strategies will be employed in the basin to ensure the available supply meets or exceeds the projected demand throughout the planning horizon?

1.2 Planning Process

The river basin planning process in South Carolina formally began with the development of the eight surface water quantity models starting in 2014 and the update of the Coastal Plain Groundwater Model in 2016. In March 2018, SCDNR convened the Planning Process Advisory Committee (PPAC). Over the next year and a half, SCDNR and the PPAC collaboratively developed the Planning Framework, which defines river basin planning as the collective effort of the numerous organizations and agencies performing various essential responsibilities, as described below. A more complete description of the duties of each entity are provided in Chapter 3 of the Planning Framework.

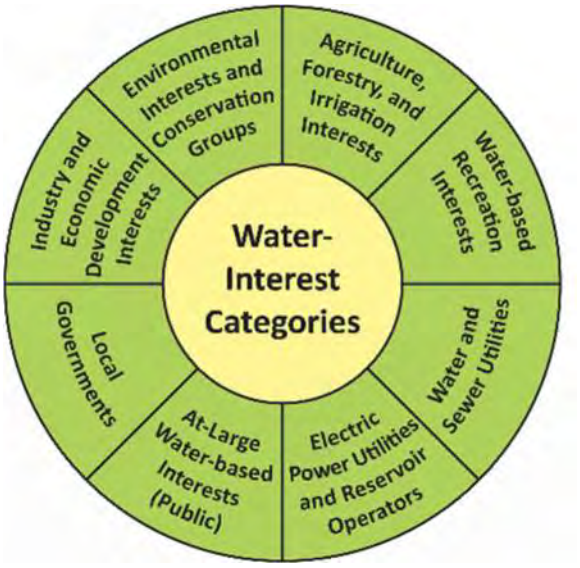


Figure 1-2. RBC water-interest categories.

- **River Basin Council**: A group of a maximum of 25 members representing diverse stakeholder interests in the basin. Each RBC includes at least one representative from each of the eight broadly defined stakeholder interest categories shown in Figure 1-2. The RBC is responsible for developing and implementing the River Basin Plan, communicating with stakeholders, and identifying recommendations for policy, legislative, regulatory, or process changes.

- **Planning Process Advisory Committee**: The PPAC is a diverse group of water resource experts established to develop and help implement the Planning Framework for state and river basin water planning. The PPAC will amend the Planning Framework as needed, review draft and final River Basin Plans, ensure consistency between the eight River Basin Plans, and advise SCDES on developing the new State Water Plan.

- **State and Federal Agencies**:
  - SCDES is the primary oversight agency for the river basin planning processes. Key duties of SCDES include appointing members to the PPAC and RBCs; educating RBC members on critical background information; providing RBCs and contractors with data, surface water models, and groundwater models; hiring contractors; and reviewing and approving the final River Basin Plans. SCDES is the regulatory agency that administers laws regarding water quality and use within the state. Key duties of SCDES include ensuring recommendations are consistent with existing laws and regulations and serving as an advisor for recommended changes to existing laws and regulations.
  - Other State Agencies: Representatives from other state agencies such as the Department of Natural Resources, Department of Agriculture, Department of Commerce, Forestry Commission, Rural Infrastructure Authority, and the Energy Office may be asked to attend RBC meetings in an advisory role.
  - Federal Agencies: Representatives from federal agencies such as the USGS, United States Army Corps of Engineers (USACE), and the Southeastern Power Administration (SEPA) may be asked to attend RBC meetings as formal advisors. Representatives from other federal agencies may be asked to attend RBC meetings in an advisory role.
- **Contractors**: SCDES will hire contractors to perform administrative, facilitative, technical, authorship, and public outreach functions. Specific roles include:
  - Coordinator: Performs administrative functions. Coordination of Pee Dee RBC meetings and other activities has collectively been shared by representatives from Brown and Caldwell and Clemson University. Brown and Caldwell, Clemson University, SCDES, the USGS, and CDM Smith collectively formed the Planning Team, which met at least monthly between RBC meetings.
  - Technical Contractor: Provides specific technical guidance. The USGS and CDM Smith served as technical contractors for the groundwater and surface water modeling, respectively.
  - Facilitator and Author: Guides RBC meetings in a neutral manner to encourage participation and provides River Basin Plan authorship services. Brown and Caldwell, along with JD Solomon, served in these roles for the Pee Dee RBC.
  - Public Outreach Coordinator: Engages stakeholders and the public in the planning process. JD Solomon served in this role for the Pee Dee RBC.

- **Groundwater and Surface Water Technical Advisory Committees**: SCDES-appointed groups with specific technical expertise intended to enhance the scientific and engineering aspects of the planning process.
- **Subcommittees and Ad Hoc Groups**: The Pee Dee RBC formed a subcommittee for each chapter of the River Basin Plan to contribute to and oversee the development of plan content. Chairs were elected for each subcommittee.
- **The Public and Stakeholders**: The public was invited to attend and provide comments at RBC meetings and designated public meetings. Additional detail on public participation is described in Section 1.4.

The creation of the Pee Dee RBC began with two public meetings organized by SCDNR on March 21 and 22, 2022, in the City of Conway and City of Darlington, respectively. The goals of these meetings were to describe the need and process for river basin planning to stakeholders and solicit applications to join the Pee Dee RBC. SCDNR accepted applications through April 2022 and selected RBC appointees in May 2022 based on their credentials, knowledge of their interest category, and their connection to the basin (i.e., RBC members must live, work, or represent a significant interest in the water resources of the Pee Dee River basin). The diverse membership of the RBC is intended to foster a variety of perspectives during development of the River Basin Plan. Pee Dee RBC members are listed with their affiliations and term lengths in Table 1-1. Term lengths are staggered to ensure continuity in the planning process.

Table 1-1. Pee Dee RBC members and affiliations.

Name	Organization	Position	Interest Category	Term Length (Years)
Everett Allen	Keep It Green/Inlet Bay & Stewards	Advisory Council & Member	At-Large	4
Michael Bankert	Legends Golf Course	Dir. Of Agronomy	Agriculture, Forestry, and Irrigation	2
Tim Brown	Grand Strand Sewer and Water	Chief of Plant Operations	Water and Sewer Utilities	3
Cliff Chamblee	Sonoco Products Company - Hartsville	Senior Environmental Engineer	Industry and Economic Development	3
John Crutchfield	Duke Energy	Hydro Compliance Manager	Electric-Power Utilities	2
Jason Gamble	Gamble Family Farms	Owner	Agriculture, Forestry, and Irrigation	3
Michael Hemingway	City of Florence	Utility Planning and Economic Development Director	Local Government	4
Megan Hyman	International Paper	Environmental Engineer	Industry and Economic Development	2
Eric Krueger	The Nature Conservancy	Director of Science	Environmental Interests	3
Frances McClary	Williamsburg Soil and Water Conservation	Chair	Water-Based Recreation	3

Name	Organization	Position	Interest Category	Term Length (Years)
Douglas Newton	Newton Farms	Owner	Agriculture, Forestry, and Irrigation	3
Hughes Page	Pee Dee Land Trust	Land Conservation Associate	Environmental Interests	3
Bob Perry	Water & Land Solutions	Senior Strategist	Environmental Interests	3
Lindsay Privette (Vice Chair)	Pee Dee Regional Council of Governments	Economic Development Director	Industry and Economic Development	2
Buddy Richardson II (Chair)	USDA-Farm Service Agency	RE Appraiser	At-Large	4
John Rivers	Riverdale Farms, Inc.	Vice President	Agriculture, Forestry, and Irrigation	2
Debra Buffkin	Winyah Rivers Alliance	Executive Director	Environmental Interests	2
Dr. Jeff Steinmetz	Francis Marion University	Director of the Freshwater Ecology Center	At-Large	4
Cynthia Walters	Santee Cooper	Senior Engineer	Electric-Power Utilities	2

For an up-to-date list of Pee Dee RBC members, see: https://www.des.sc.gov/programs/bureau-water/hydrology/water-planning/river-basin-planning/pee-dee-basin-planning/pee-dee-river-basin-council

The Pee Dee RBC began meeting in June 2022. The meetings were held as hybrid meetings with attendees participating both in person and via Zoom. Meetings were held monthly.

The planning process was completed in four phases, as specified in the Planning Framework:

- **Phase 1**: During the mostly informational Phase 1, RBC members heard presentations on topics such as water legislation and permitting; hydrology, monitoring, and low-flow characteristics; climatology; the South Carolina Drought Response Act; saltwater and freshwater aquatic resources; groundwater resources; surface and groundwater modeling; and the relationships between streamflow and ecologic conditions and diversity. Subject matter experts that presented information were from SCDNR, SCDES, USGS, the University of South Carolina, Clemson University, North Carolina Department of Environmental Quality (NCDEQ), the Yadkin-Pee Dee Watershed Management Group, Duke Energy, The Nature Conservancy, CDM Smith, and Brown and Caldwell.

- **Phase 2**: Phase 2 of the planning process focused on assessing past, current, and future surface water and groundwater availability. The RBC reviewed historical, current, and projections of future water use; 50-year planning scenario results from the surface water quantity model (referred to as the Simplified Water Allocation Model or SWAM); and groundwater trends identified using South Carolina's network of groundwater monitoring wells (the groundwater model was not fully updated at the time the River Basin Plan was completed). Potential water shortages and issues were identified and discussed.

- **Phase 3**: During Phase 3, water management strategies to address water availability issues were identified, evaluated, selected, and prioritized by the RBC based on their effectiveness, as determined by modeling and feasibility criteria such as cost, environmental impact, and socioeconomic impact.

- **Phase 4**: Legislative, policy, technical, and planning process recommendations were considered during Phase 4 of the planning process, which culminated in developing this River Basin Plan.

In the Pee Dee River basin, Phases 2 and 3 overlapped and were conducted in parallel to foster more strategic thinking around potential solutions and observed needs as well as interactively coupling the modeling and strategy formation. Figure 1-3 illustrates the process:

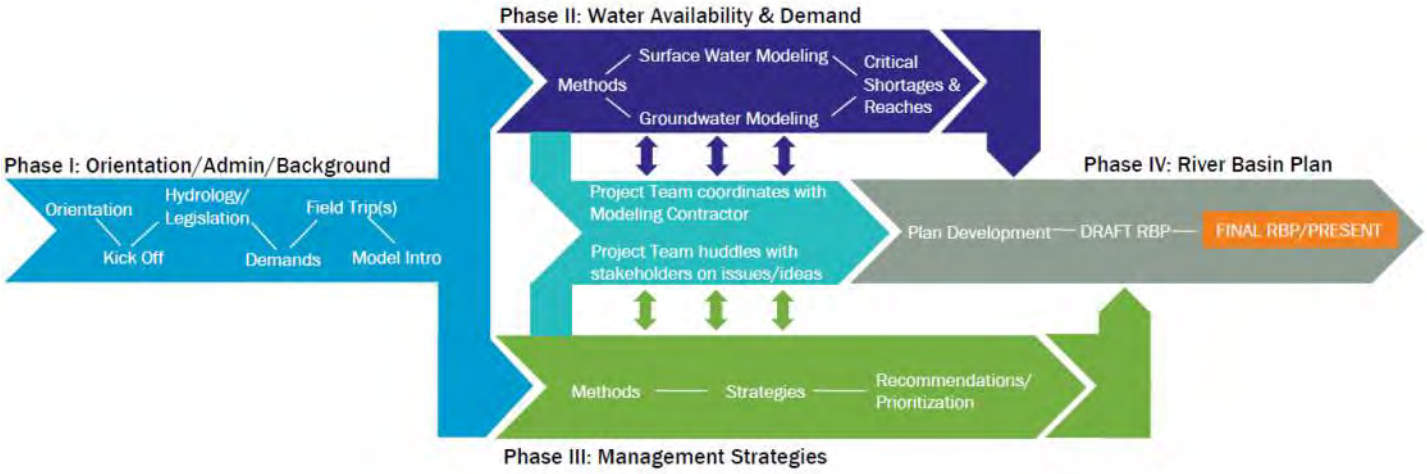


Figure 1-3. Structure of phased planning process used by the Pee Dee RBC.



RBC meeting at Clemson Pee Dee Research and Education Center in Darlington, SC, February 2023.
(Photo credit: JD Solomon)

Pee Dee RBC members participated in three field trips in the fall 2022, spring 2023, and summer 2024 to better understand the Pee Dee River and how water is withdrawn and used to support agriculture and public water supply needs.

- In October 2022, the RBC toured the Sumter Water Plant and learned about water use, water legislation, and permitting.
- In May 2023, the RBC visited Woodard Farms agricultural facility near Darlington, SC to better understand the importance and diversity of agricultural water uses.
- In July 2024, the RBC visited Sonoco's facility in Hartsville, SC to better understand industrial water uses.



RBC tour of Woodard Farms agricultural facility in May 2023.
(Photo credit: JD Solomon)

1.3 Mission Statement, Vision, and Goals

During Phase 1 of the planning process, the Pee Dee RBC developed a mission statement identifying the RBC's purpose, a vision statement establishing the desired outcome of the planning process, and actionable goals supporting their vision for the Pee Dee River basin. During the development process, the Pee Dee RBC discussed alternative language for the mission, vision, and goals, and selected the versions that best fit the RBC's preferences. The final mission statement, vision statement, and goals are listed in Table 1-2.

Table 1-2. Pee Dee RBC mission statement, vision statement, and goals.

Mission Statement
To develop, implement, monitor, and periodically revise a river basin plan for the surface and groundwater resources in the Pee Dee River basin.
Vision Statement
To make sure water is available for all in the Pee Dee River basin.
Goals
1. Develop and approve the River Basin Plan by June 1, 2024. 2. Review and update the River Basin Plan at least once every five years or amend it as needed. 3. Regularly communicate with stakeholders throughout the river basin. 4. Recommend policy, legislative, regulatory, or process changes.

1.4 Public Participation

Public participation is a vital component of the river basin planning process. All RBC meetings are open to the public. To promote visibility and encourage participation, meeting notices are posted on the SCDES Water Planning web page (https://www.des.sc.gov/programs/bureau-water/hydrology/water-planning) and are distributed to an email list. Meeting agendas, minutes, summaries, presentations, and recordings are posted on the SCDES website and are available to the public.

In addition to the RBC meetings, dedicated public meetings were held to distribute information and solicit feedback.

- The first two public meetings were held on March 21 and 22, 2022, in Conway and Darlington, respectively. At these meetings, the public was informed of the basin planning process and the plan for public participation. RBC membership applications were solicited at this meeting. There were 28 attendees at the March 21 meeting in Conway, and 53 attendees at the March 22 meeting in Darlington.

- The third public meeting was held after the release of the draft River Basin Plan. The draft plan was released on December 13, 2024, and the third public meeting was held on January 14, 2025 in Darlington. A summary of the plan was provided to attendees and a public comment period was opened, which included a verbal comment period at the meeting followed by a 30-day written comment period. There were 19 attendees at the third public meeting including members of the public, members of the RBC, SCDES staff, and consultants.

- A fourth public meeting on the River Basin Plan was not conducted to discuss final changes to the plan. The final River Basin Plan includes responses to all public comments received. While several productive public comments on the draft plan were received and some edits were made, the changes were not substantial, and a fourth public meeting was not necessary.

1.5 Previous Water Planning Efforts

1.5.1 Groundwater Management Plans

The Groundwater Use and Reporting Act (S.C. Code Ann. §49-5-10 et seq.) establishes conditions for the designation of Capacity Use Areas (CUAs) where excessive groundwater withdrawal may have adverse effects on natural resources; may pose a threat to public health, safety, or economic welfare; or may pose a threat to the long-term integrity of the groundwater source. Once a CUA is designated, a Groundwater Management Plan must be developed to study the area's groundwater availability and demand and offer strategies to promote the sustainability of the resource. The plan must balance both the current and potential future competing needs and interests of the area. In addition, all users within the CUA withdrawing more than 3 million gallons of groundwater in any month must obtain a groundwater permit. The Pee Dee River basin covers parts of three CUAs: the Santee-Lynches, the Pee Dee, and the Waccamaw, as shown in Figure 1-4.

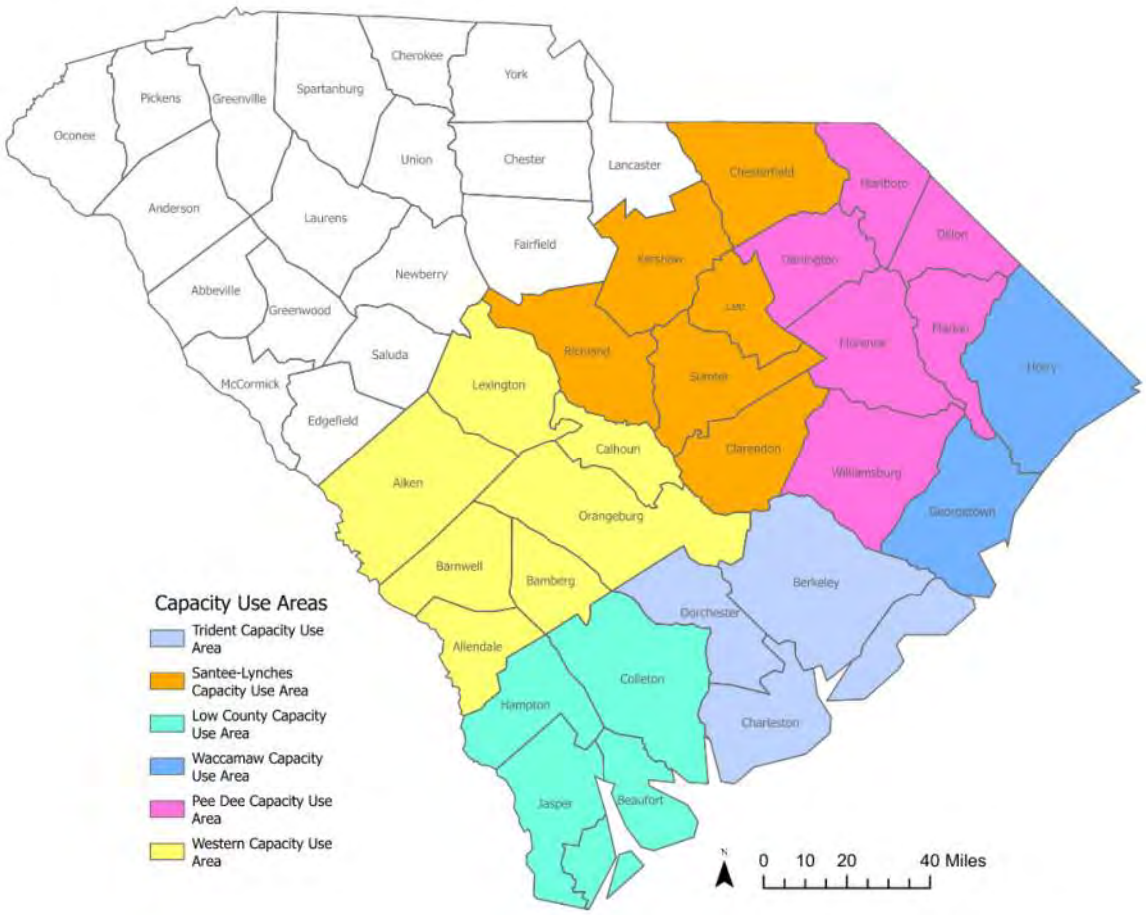


Figure 1-4. Capacity Use Areas.

- The Santee-Lynches CUA was defined in July 2021, and the Groundwater Management Plan was approved in August 2022.
- The Pee Dee CUA was designated in 2004, and the Initial Groundwater Management Plan was approved in 2018, with the latest Groundwater Evaluation Report in 2020.
- The Waccamaw CUA was defined in June 1979, and the Initial Groundwater Management Plan is dated August 2017.

In preparing the initial plans, SCDES convened stakeholder workgroups and solicited public comments. The plans describe current best practices for groundwater management. They are intended to be updated as more data are collected and following the application of the USGS Coastal Plain Groundwater Model of South Carolina.

For more information on Groundwater Management Plans, see:
https://des.sc.gov/programs/bureau-water/groundwater-management-planning

1.5.2 Drought Planning

The South Carolina State Climatology Office is responsible for drought planning in the state. The South Carolina Drought Response Act and supporting regulations establish the South Carolina Drought Response Committee (DRC) as the drought decision-making entity in the state. The DRC is composed of state agencies and local members representing various stakeholder interests. Local members are organized into one of four drought management areas (DMAs). The Pee Dee River basin spans the Northeast and Central DMAs. The DRC monitors drought indicators, issues drought status updates, determines nonessential water use, and issues declarations for water curtailment as needed. In addition to establishing the DRC, the South Carolina Drought Response Act also requires all public water suppliers to develop and implement their own drought plans and ordinances. Drought management plans developed by the public water suppliers in the Pee Dee River basin are further discussed in Chapter 8.

For more information on Drought Planning and the DRC, see: http://scdrought.com/committee.html

1.5.3 Watershed-Based Plans

Watershed-based plans have been developed for various watersheds throughout South Carolina to document sources of pollution and present a plan to protect and improve water quality within a watershed. While this first iteration of the Pee Dee River Basin Plan focuses on water quantity issues, previous planning efforts with the Pee Dee River basin that addressed water quality are worth noting. Water quality considerations may be more fully developed in future updates to the Pee Dee River Basin Plan.

In 1992, SCDES initiated its Watershed Water Quality Management program to better coordinate river basin planning and water quality management. Watershed-based management allows SCDES to address Congressional and Legislative mandates and improve communication with stakeholders on existing and future water quality issues. In the Pee Dee River basin, Watershed Water Quality Assessments (WWQA) were completed in

For more information on Watershed-Based Plans, see:
https://des.sc.gov/programs/bureau-water/watersheds-program/grant-funded-watershed-plans

1997, 2000, 2007, and 2015. The WWQAs of the Pee Dee River basin describe, at the watershed level, water quality related activities that may potentially have an adverse impact on water quality. The Pee Dee River basin was subdivided into 47 watersheds or hydrologic units. As of 2016, the WWQAs have been replaced by the South Carolina Watershed Atlas (https://des.sc.gov/programs/bureau-water/watersheds-program/sc-watershed-atlas), which allows users to view watershed information, add data, create layers from selected features, and export data for use outside of the application.

1.5.4 State Scenic River Management Plans

Segments of the Lynches, Little Pee Dee, and Black River have all been designated as State Scenic Rivers. As a part of this designation, a local advisory council was appointed for each segment, and this group developed River Management Plans for each waterbody. The plans were each developed with an engagement process, are non-regulatory in nature, and seek to identify local public values for the waterbodies, objectives and goals for stewardship of the waterbodies, and consensus-driven management solutions. Table 1-3 highlights the key components of the three major plans in this watershed.

Table 1-3. Scenic River Management Plan components.

Component	Lynches Scenic River	Little Pee Dee Scenic River	Black Scenic River
Year of Scenic River Designation	1994	2005	2001
Year of Management Plan Publication	2003	2008	2020
Length of Designated Segment	54 miles	48 miles	75 miles
Key Plan Categories	Water quality Recreational opportunities Maintaining the scenic quality of the river corridor Fisheries Wildlife and habitat management Community involvement	Land use and development Water quality and streamflow Recreational use and access Fish, wildlife, and habitat protection	History and cultural resources Land use Wildlife resources Water quality and streamflow Recreational and public access

The key plan categories are unique to each plan; however, there is consistency in what each region deems important. Water quality, recreational opportunities, stewardship of land development, and preservation of habitat are all examples of key objectives that are consistent across each of the plans. Through ongoing partnerships with the landowners, community groups, and other leaders, these plans aim to preserve and protect the scenic rivers.

"The mission of the Little Pee Dee Scenic River Advisory Council is to promote stewardship of the river for the benefit and enjoyment of present and future generations. Our focus will be conservation, utilization, awareness, protection and enhancement of the river's resources." *Little Pee Dee Scenic River Management Plan*

1.5.5 Water Use and Quality Studies for Yadkin-Pee Dee River Hydroelectric Project Relicensing

A water quality and quantity assessment of the Pee Dee River was undertaken during the Federal Energy Regulatory Commission (FERC) relicensing process for the Yadkin-Pee Dee Hydroelectric Project (FERC No. 2206) in the Pee Dee River basin. The hydroelectric project, owned and operated Duke Energy Progress, LLC (Duke Energy, formerly Progress Energy), consists of two developments: Tillery and Blewett Falls. The hydroelectric operations of the two developments are connected – the Tillery Development operates to meet on-peak, load-following, and transmission system support needs, and the Blewett Falls Development is operated using block loading as a peaking facility. As shown in the excerpted map in Figure 1-5, both these developments and associated dams are located along the Yadkin-Pee Dee River in North Carolina, which forms the Pee Dee River at the confluence of the Yadkin and Uwharrie rivers in Lake Tillery headwaters.

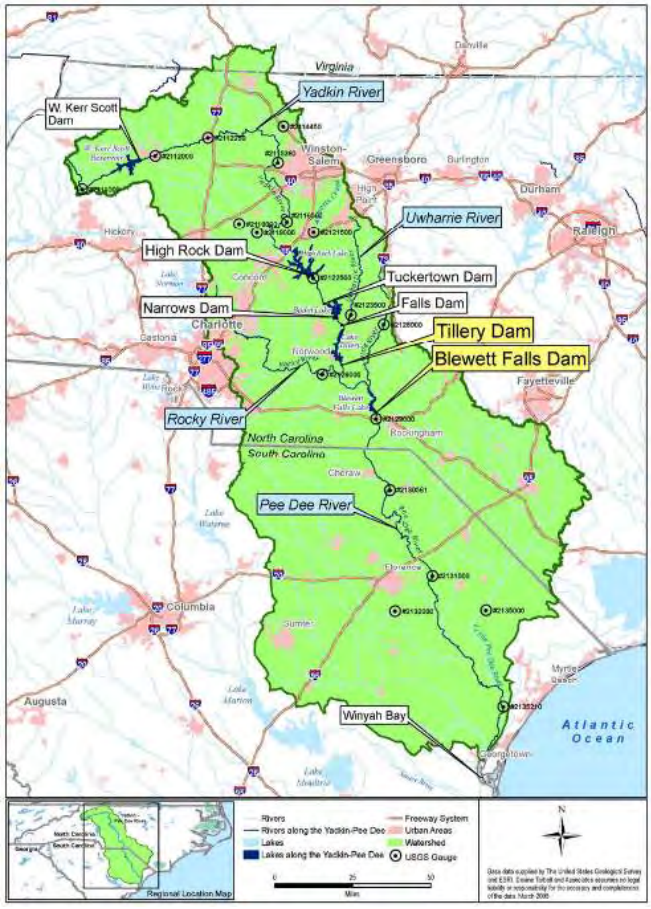


Figure 1-5. Map of the Yadkin-Pee Dee River basin showing location of Yadkin-Pee Dee and Yadkin Hydroelectric Developments.

Comprehensive relicensing water quality and habitat quality (instream flow) studies, published in 2006 as part of the federal relicensing application, were conducted to identify specific water and aquatic habitat quality impacts from the hydroelectric project. Studies were conducted during the relicensing process for the two developments to ensure they would comply with flow requirements, not disrupt migratory fish passage, and would mitigate water quality concerns in the river. Specifically, some reaches of the river below the developments had seasonal low dissolved oxygen (DO) impairments. The studies identified seasonal low DO concerns and impacts on habitat quality and wildlife due to regulated flow releases, they and developed solution pathways to incorporate in the new federal operating license for the Project. The relicensing reports summarized water quality sampling and instream flow modeling performed, as well as the design conditions of the two developments. Duke Energy developed a water quality assessment program during relicensing to mitigate the seasonal low DO impairments to meet state water quality standards. The program conducted from 2006 to 2011 included monitoring, assessment, and implementation of permanent DO enhancement equipment at both developments.

Duke Energy was issued a new 40-year FERC license on April 1, 2015 to operate the Yadkin-Pee Dee Hydroelectric Project, which specifically included license requirements for a seasonal flow release schedule to provide for riverine aquatic habitat, scheduled recreation flow releases and other instream flow needs, a Low Inflow Protocol (LIP) to address drought conditions in the river basin, and DO enhancement measures to ensure compliance with the applicable North Carolina water quality standards.

Cube Yadkin, which operates four hydroelectric developments (High Rock, Tuckertown, Narrows, and Falls) immediately upstream of the Yadkin-Pee Dee Hydroelectric Project also received a new FERC license for its Yadkin Project (FERC No. 2197) on September 22, 2016. The Cube Yadkin License also includes requirements for instream flow releases downstream of the Project, a LIP for drought management, and DO enhancement measures to meet state water quality standards.

1.6 Organization of this Plan

The Planning Framework outlines a standard format that all River Basin Plans are intended to follow, providing consistency in the organization and content. Consistency between River Basin Plans will facilitate the eventual update of the State Water Plan. Following the format outlined in the Planning Framework, the Pee Dee River Basin Plan is divided into 10 chapters as described below.

- **Chapter 1: Introduction** – Chapter 1 provides an overview of the river basin planning purpose and process. Background on the basin-specific history and vision for the future is presented. The planning process is described, including the appointment of RBC members and the roles of the RBC, technical advisory committees, subcommittees, ad hoc groups, state and federal agencies, and contractors.

- **Chapter 2: Description of the Basin** – Chapter 2 presents a physical and socioeconomic description of the basin. The physical description includes a discussion of the basin's land cover, geography, geology, climate, natural resources, and agricultural resources. The socioeconomic section describes the basin's population, demographics, land use, and economic activity, as these factors influence the use and development of water resources in the basin.

- **Chapter 3: Water Resources of the Basin** – Chapter 3 describes the surface and groundwater resources of the basin, and the modeling tools used to evaluate their availability. Monitoring programs, current projects, issues of concern, and trends are noted.

- **Chapter 4: Current and Projected Water Demand** – Chapter 4 summarizes the current and projected water demands within the basin. Demands for public water supply, thermoelectric power, industry, agriculture, and other uses are presented along with their permitted and registered withdrawals. The chapter outlines the methodology used to develop demand projections and the results of those projections.

- **Chapter 5: Comparison of Water Resource Availability** – Chapter 5 describes the methodology and results of the basin's surface water and groundwater availability analysis. This chapter presents planning scenarios that were developed and the performance measures used to evaluate them. Any water shortages, reaches of interest, or Groundwater Areas of Concern identified through this analysis are described. The shortages and areas of concern identified in this chapter serve as the basis for the water management strategies presented in Chapter 6.

- **Chapter 6: Water Management Strategies** – Chapter 6 presents the water management strategies developed as potential solutions to the shortages and areas of concern presented in Chapter 5. For each surface water or groundwater strategy considered, Chapter 6 includes a description of the

measure, results from a technical evaluation (as simulated in the appropriate model, if applicable), feasibility for implementation, and a cost-benefit analysis.

- **Chapter 7: Water Management Strategy Recommendations** – Chapter 7 presents the final recommendations for water management strategies based on the analysis and results presented in Chapter 6. The chapter discusses the selection, prioritization, and justification for each of the recommended strategies. Any remaining shortages or concerns are also discussed in this chapter.

- **Chapter 8: Drought Response** – Chapter 8 presents existing and proposed drought management plans. The first part of the chapter discusses existing drought management plans, ordinances, and drought management advisory groups. The second part presents drought response initiatives developed by the RBC.

- **Chapter 9: Policy, Legislative, Regulatory, Technical, and Planning Process Recommendations** Chapter 9 presents overall recommendations intended to improve the planning process and/or the results of the planning process. Recommendations to address data gaps encountered during the planning process are presented along with recommendations for revisions to the state's water resources policies, legislation, and agency structure.

- **Chapter 10: River Basin Plan Implementation** – Chapter 10 presents a 5-year implementation plan and long-term planning objectives. The 5-year plan includes specific objectives, action items to reach those objectives, detailed budgets, and funding sources. The long-term planning objectives include other recommendations from the RBC that are less urgent than those in the implementation plan. Future iterations of this plan will include a chapter that details progress made on planning objectives outlined in previous plans.



Forested waterway in the Pee Dee River basin.
(Photo credit: JD Solomon)

Chapter 2
Description of the Basin

2.1 Physical Environment

2.1.1 Geography

The Pee Dee River basin covers approximately 7,855 square miles making up 25 percent of the state's total land area. The basin covers the northeastern portion of the state between the border with North Carolina and the Atlantic Ocean. The basin is approximately pentagonal in shape.

The Pee Dee River basin overlays fourteen counties, fully encompassing seven. The counties present in the basin are shown in Figure 2-1.



County	Area in Pee Dee River Basin (sq. mi.)
Chesterfield	803
Clarendon	380
Darlington	562
Dillon	409
Florence	807
Georgetown	728
Horry	1,142
Kershaw	216
Lancaster	195
Lee	389
Marion	490
Marlboro	494
Sumter	447
Williamsburg	793
Total	7,855

Figure 2-1. Counties in the Pee Dee River basin and their area within the basin.

Figure 2-2 shows the major rivers, cities, and public lands in the Pee Dee River basin.

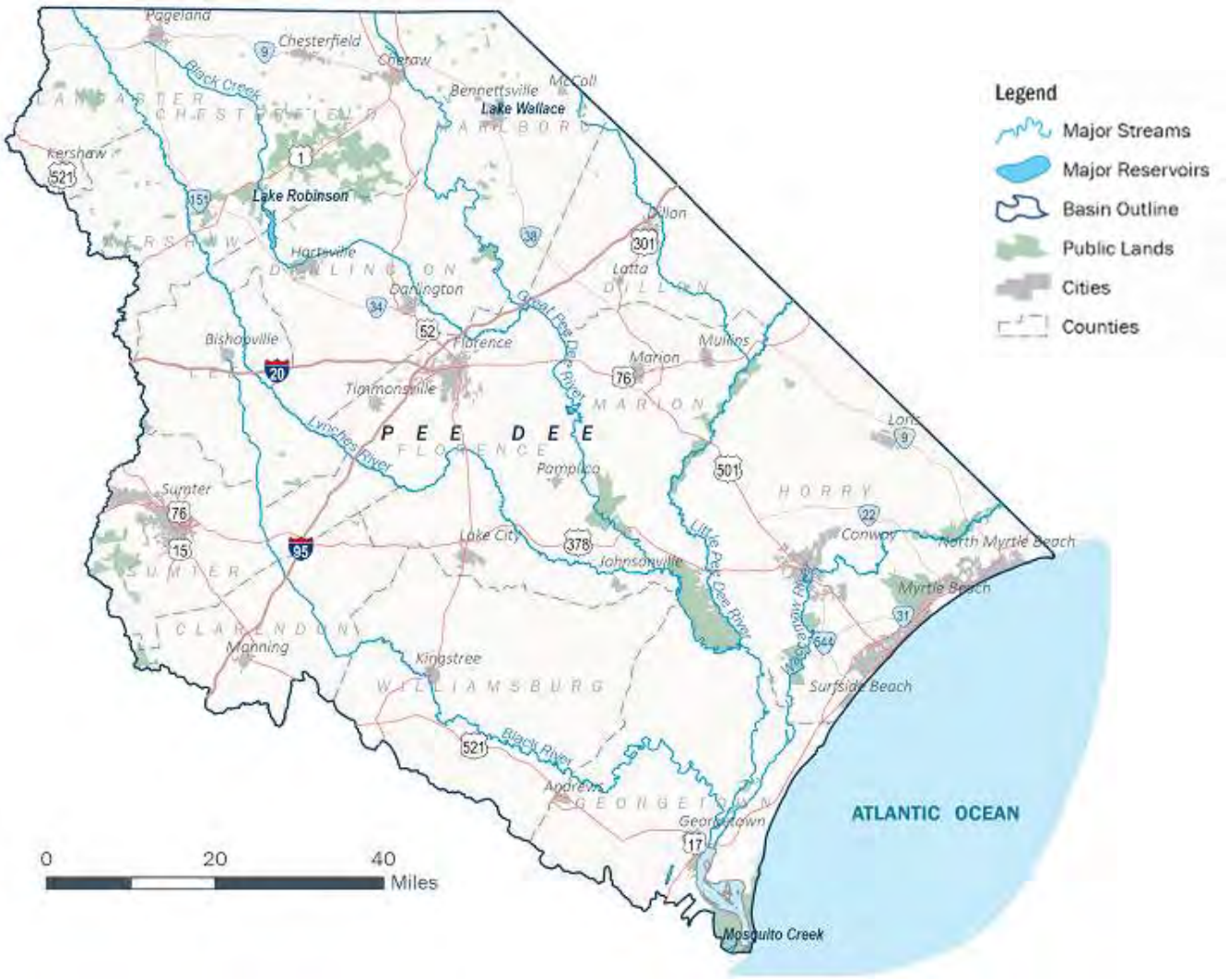


Figure 2-2. Pee Dee River and geographical features in South Carolina.

Five major rivers drain the Pee Dee River basin

- The **Great Pee Dee River** (or Pee Dee River) makes up the main stem, which originates in North Carolina as the Yadkin-Pee Dee River. Crossing into South Carolina, the Great Pee Dee River converges with four smaller rivers before discharging into Winyah Bay and the Atlantic Ocean in the southern part of the basin. A 70-mile reach of the Pee Dee River from the U.S. 378 bridge to Winyah Bay was designated as a State Scenic River in 2002. Black Creek is one of the tributaries to the Great Pee Dee River, and it has two major reservoirs along its length.
- The **Lynches River** drains the northwestern portion of the basin and flows into the Pee Dee River in Florence County. The Lynches River has the longest segment in the state that has been designated as a State Scenic River at 111 miles.

- To the east, the **Little Pee Dee River** originates in North Carolina and then traverses Dillon, Marion, and Horry counties before converging with the Pee Dee River. As is typical of Coastal Plain rivers, much of the Little Pee Dee River mainstem and tributaries flows through swamplands. Several segments of the Little Pee Dee River have been designated as State Scenic Rivers.
- Near the mouth of the river in Winyah Bay, the **Black River** and **Waccamaw River** (originating in North Carolina) both join, draining the southwest and southeast portions of the watershed, respectively. The Black River is associated with swamplands and includes a 75-mile segment designated as a State Scenic River. The Waccamaw River runs along the Coastal Plain, and its headwaters and half of its drainage area is in North Carolina.

The Pee Dee River in South Carolina is free flowing. However, reservoirs in North Carolina that produce hydropower influence flows in the Pee Dee River, particularly during low flows. A map showing the origins of the Pee Dee River in North Carolina, and the five major subbasins described above, is shown in Figure 2-3. About 42 percent of the Pee Dee River basin is located within South Carolina, and the majority of the rest of the basin is located in North Carolina with a small sliver located in Virginia. The mainstem of the river runs over 400 miles and traverses many different geographies.

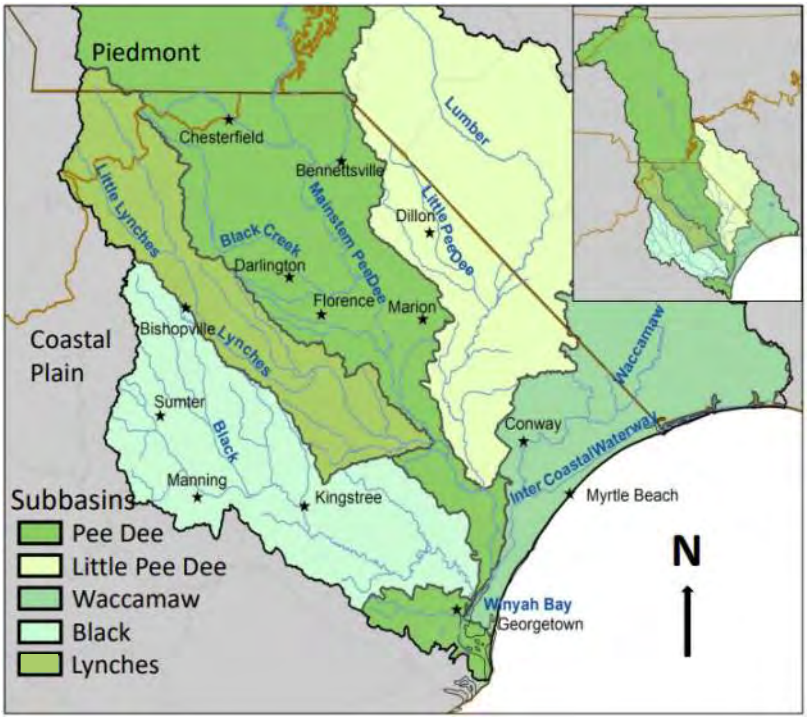


Figure 2-3. Pee Dee River and subbasins.

2.1.2 Land Cover

The Pee Dee River basin is largely made up of wetland, agricultural and wooded areas. A summary of land use types, taken from the Multi-Resolution Land Characteristics Consortium (MRLC), is presented in Figure 2-4. The MRLCs National Land Cover Database (NLCD) was used to develop a summary of land use types in the basin and a description of changes in land cover area from 2001 to 2019 (see Table 2-1). Since 2001, woodlands have decreased by around 146 square miles and is the land use category with the largest decline over that time period. Agricultural land has also decreased. Developed land has increased by approximately 73 square miles. Shrublands – which are areas dominated by shrubs less than five meters tall – have increased the most, gaining 128 square miles.

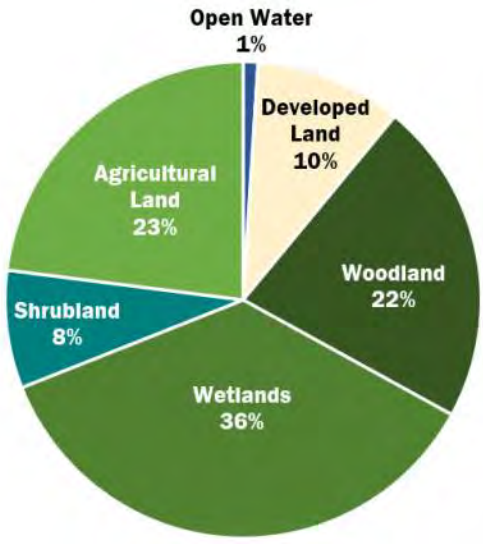


Figure 2-4. Pee Dee River basin land cover.

Table 2-1. Pee Dee River basin land cover and trends.

NLCD Land Cover Class	2001 Area (sq. miles)	2019 Area (sq. miles)	Change from 2001 to 2019 (sq. miles)
Open Water	105	107	2
Developed Land	707	780	73
Woodland	1,886	1,740	-146
Wetlands	2,826	2,823	-4
Shrubland	501	630	128
Agricultural Land	1,830	1,776	-53
Total Land Area	7,856	7,856	0



Forested area in the Pee Dee watershed.
(Photo credit: Matt Lindburg)

2.1.3 Geology

South Carolina's geology is described by the rock and sediment types present in a given location. The Pee Dee River basin spans multiple geologic units, which are illustrated in Figure 2-5. While many different geologic units are present across the state and basin, five major categories make up the majority of the basin: (1) Carolina Terrane, (2) Upper Cretaceous, (3) Pliocene, (4) Pleistocene, and (5) Holocene. Summaries of these units as described by SCDNR are provided in Table 2-2.

Table 2-2. Basin geology descriptions.

Geologic Map Unit	Description
Carolina Terrane	The lower part contains intermediate to felsic pyroclastic rocks that are collectively greater than 3 km thick, and it has been interpreted as a sequence of ash flow tuffs, possibly deposited in a sub-aerial environment. The upper part is predominantly clastic rocks. Separate from North America during Late Proterozoic and Cambrian time according to the fossil evidence.
Upper Cretaceous	Mostly micaceous, kaolinitic sands, with lenses of clay of variable thickness. Sands are mostly coarse sand to granule size, angular to subangular and poorly sorted, but some fine-grained, fairly well-sorted sand does occur. These sediments represent fluvial or upper delta-plain environments.
Pliocene	Marine sediments which are widely distributed from the coast to the Fall Line but are preserved at the surface below the Orangeburg Scarp. Documents the last major transgression of the sea over the Coastal Plain.
Pleistocene	Contains recent fluvial sands, backbarrier muds (i.e., marsh), and barrier beach sands that are less than 3 million years.
Holocene	Active deposition along the shore, behind the shore, and in stream valleys with an approximate maximum elevation of 10 feet at the ocean margin, where Holocene sediments overlap, overlie, or abut sediments of the Silver Bluff terrace. Most of the Carolina low country is covered by a 5- to 10-m thick blanket of unconsolidated Quaternary marine and fluvial deposits, which lie on semi-lithified Tertiary sediments. The oldest beach deposits are farthest inland and at the highest elevations; younger beach deposits are progressively closer to the ocean and at lower elevations.

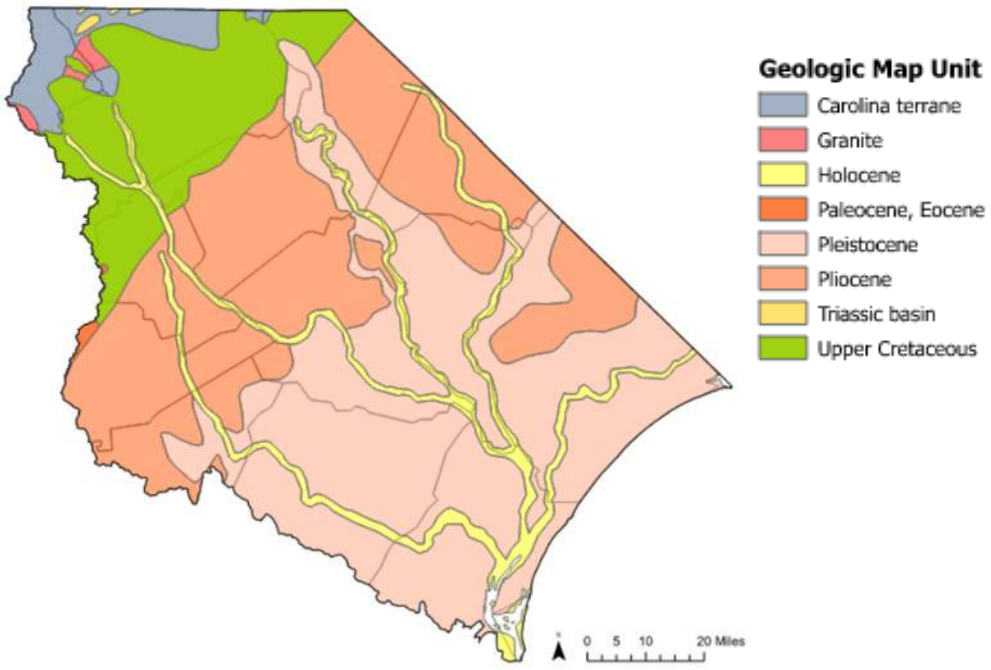


Figure 2-5. Generalized geologic map of the Pee Dee River basin (SCDNR).

2.2 Climate

2.2.1 General Climate

Much like the rest of the Carolinas, the South Carolina portion of the Pee Dee River basin's climate is humid subtropical with hot summers and mild winters. **Figure 2-6** shows the average annual temperature and the annual average precipitation for both the entire Yadkin-Pee Dee River basin and the South Carolina portion of the Pee Dee River basin, based on the current climate normals (1991-2020).

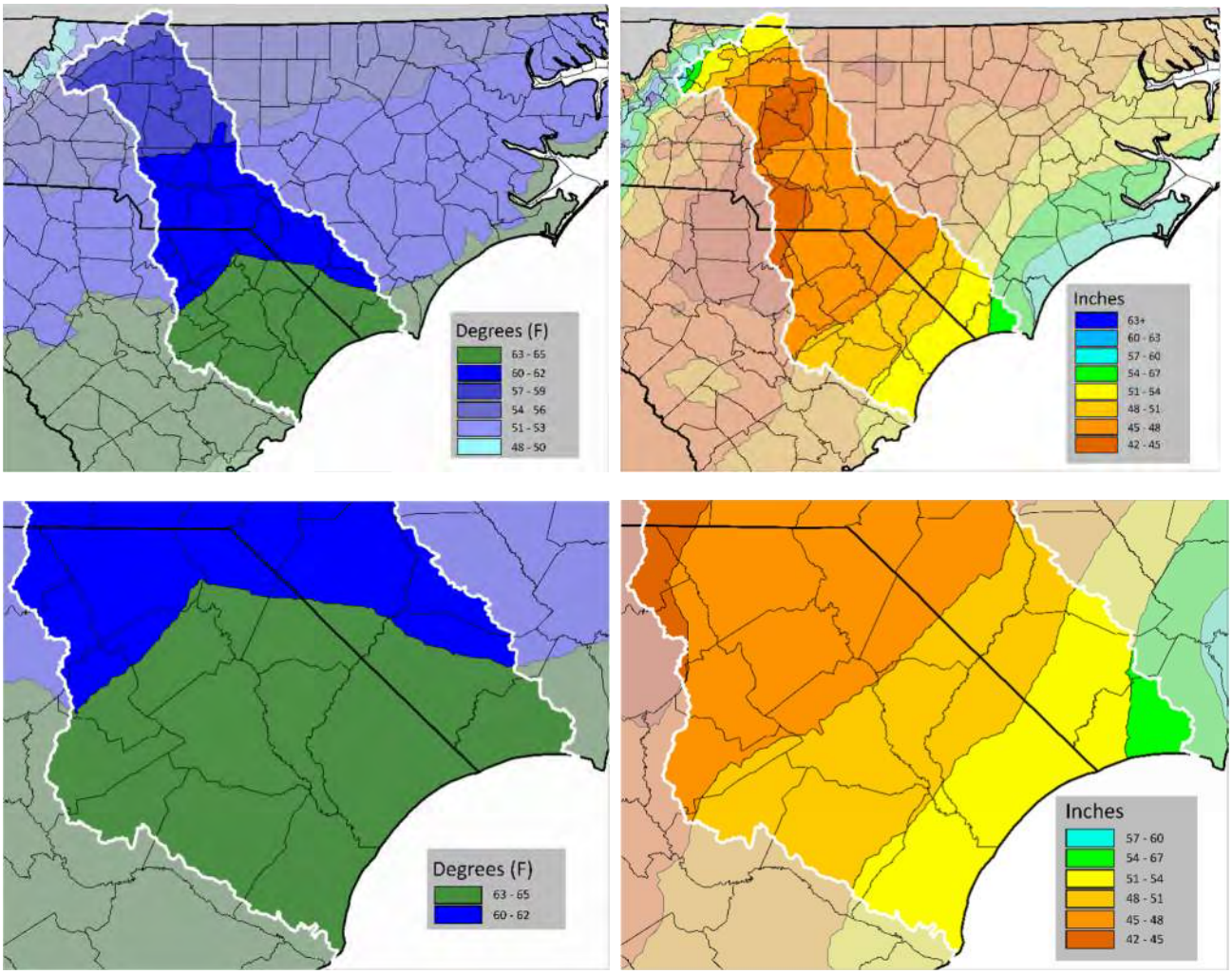


Figure 2-6. Normal annual average temperature and precipitation (1991-2020) for the entire Yadkin-Pee Dee River basin and the Pee Dee River basin within South Carolina.

In Figure 2-6, the temperature and precipitation data outside the basin are semi-transparent, and the coloration is slightly different than the legend. While the legend is applicable for the entire area in the figure, please reference it specifically for the basin.

The current climate normals maps for all of South Carolina for the parameters of temperature (average, maximum, and minimum) and precipitation at annual, seasonal, and monthly time steps are available on the South Carolina State Climatology Office's "Climate" webpage:

https://www.dnr.sc.gov/climate/sco/ClimateData/cli_sc_climate.php

The average annual temperature in the Yadkin-Pee Dee River basin ranges from 54 to 65 degrees Fahrenheit (F), with temperature increasing from the upper basin to the lower basin. Annual average precipitation for the entire basin ranges from 42 to 63 inches (in), with higher precipitation totals in the upper portions of the basin and along the coast, while the middle of the basin receives less precipitation. The annual average temperature for the South Carolina portion of the Pee Dee River basin ranges from 60 to 65 degrees F. The annual average precipitation for the South Carolina portion of the basin ranges from 42 in to over 54 in, with rainfall increasing towards the bottom of the basin.

Temperature and precipitation values vary both geographically and throughout the year. Figure 2-7 and Figure 2-8 show the monthly variation in temperature and precipitation at the meteorological stations "Statesville 2NNE," in Iredell County (NC) and "Florence Regional Airport," in Florence County (SC). For both Statesville 2NNE and Florence Regional Airport, temperature oscillates throughout the year, with July generally being the warmest month for both stations (average monthly temperature of 77.1 and 81.2 degrees F, respectively) and January being the coldest month (average monthly temperature of 38.5 and 45.4 degrees F, respectively). The average monthly temperatures at the Statesville 2NNE station are 4 to 8 degrees F cooler than Florence Regional Airport.

Precipitation also varies throughout the year for Statesville 2NNE and Florence Regional Airport. The wettest month for Statesville 2NNE is August (average monthly precipitation of 4.47 in) and July for Florence Regional Airport (average monthly precipitation of 5.61 in). For both Statesville 2NNE and Florence Regional Airport, the driest month is November (average monthly precipitation of 3.23 and 2.49 in, respectively). Statesville 2NNE has more consistent rainfall totals from month to month than Florence Regional Airport, which has higher monthly precipitation totals from June to September.

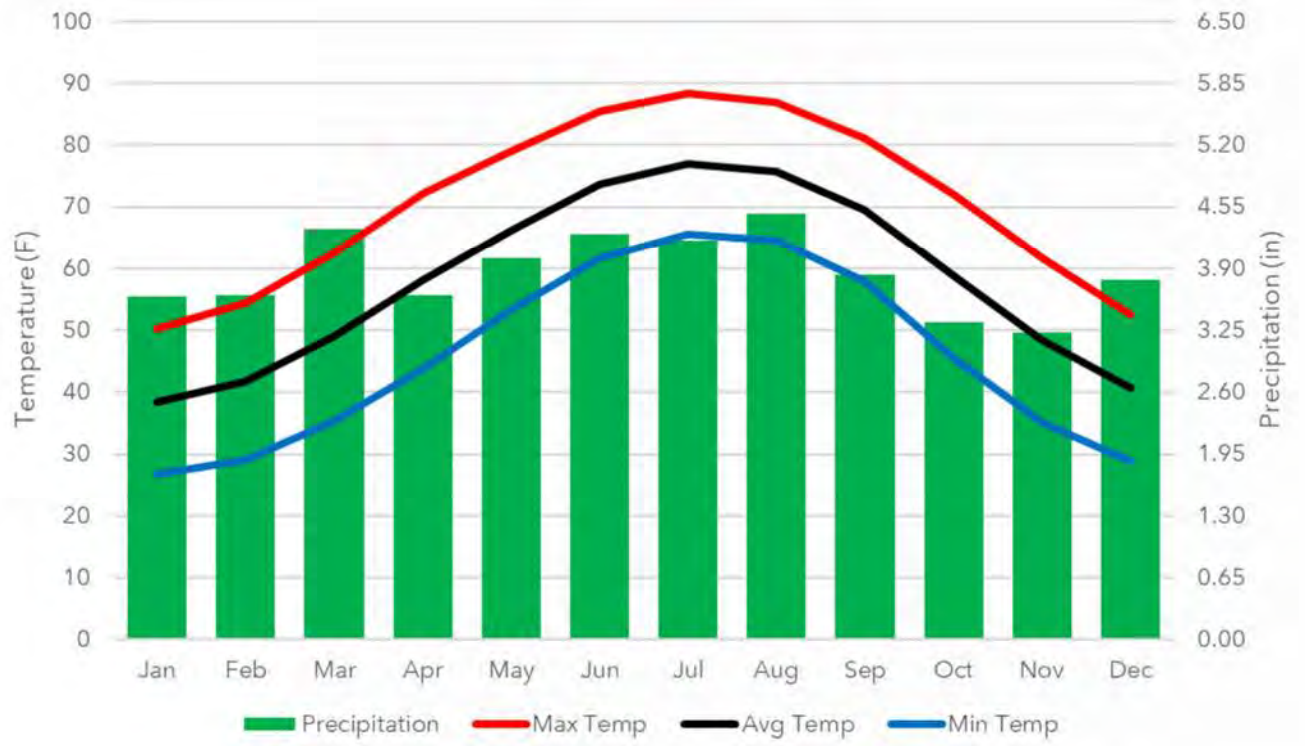


Figure 2-7. Statesville 2NNE (NC) monthly climate averages from 1948 to 2022 (SCDNR State Climatology Office 2023).

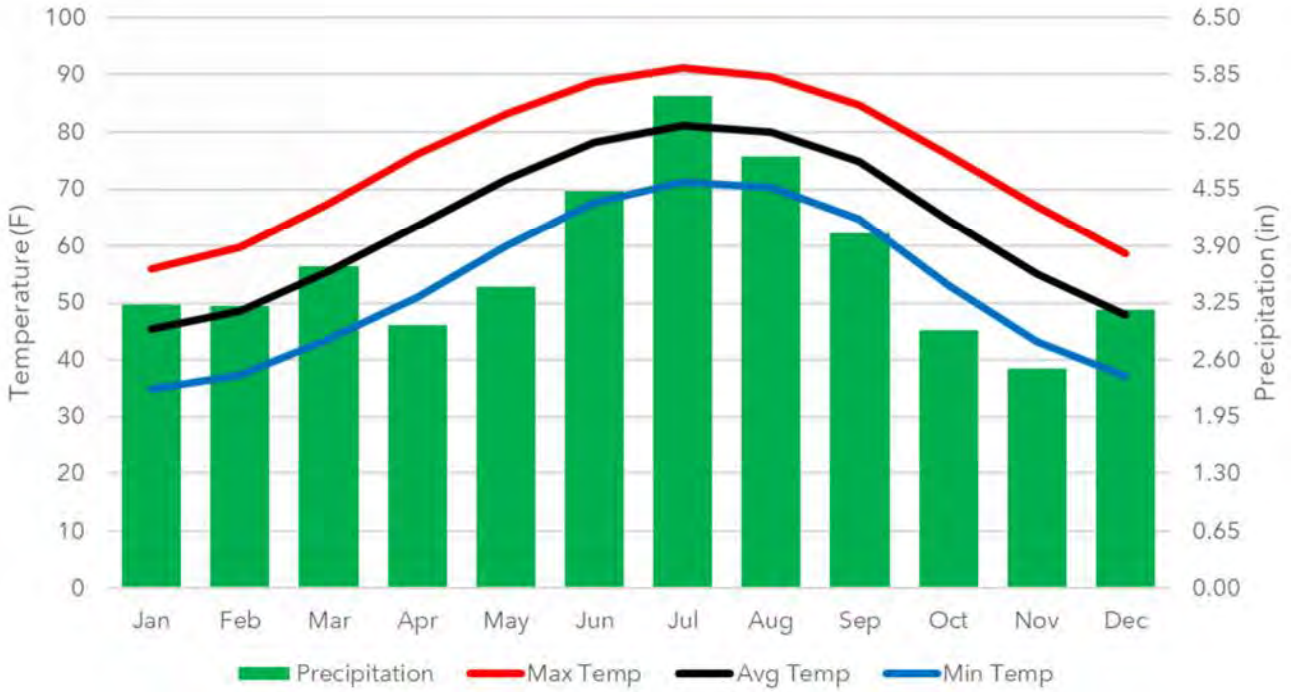


Figure 2-8. Florence Regional Airport (SC) monthly climate averages from 1948 to 2022 (SCDNR State Climatology Office 2023).

Through time, the annual average temperature and precipitation for the Carolinas and the Yadkin-Pee Dee River basin have varied (National Oceanic and Atmospheric Administration [NOAA], 2023; SCNDR State Climatology Office 2023). Figure 2-9 shows the annual average temperature for the 1948 to 2002 time period as well as the overall average annual temperature for that period. Through this period, Statesville 2NNE has an annual average temperature of 58.1 degrees F (Figure 2-9), and Florence Regional Airport has an annual average temperature of 63.9 degrees F (Figure 2-10). Table 2-3 shows the warmest and coldest five years for both stations. None of the top 5 warmest or coldest years are shared between the stations.

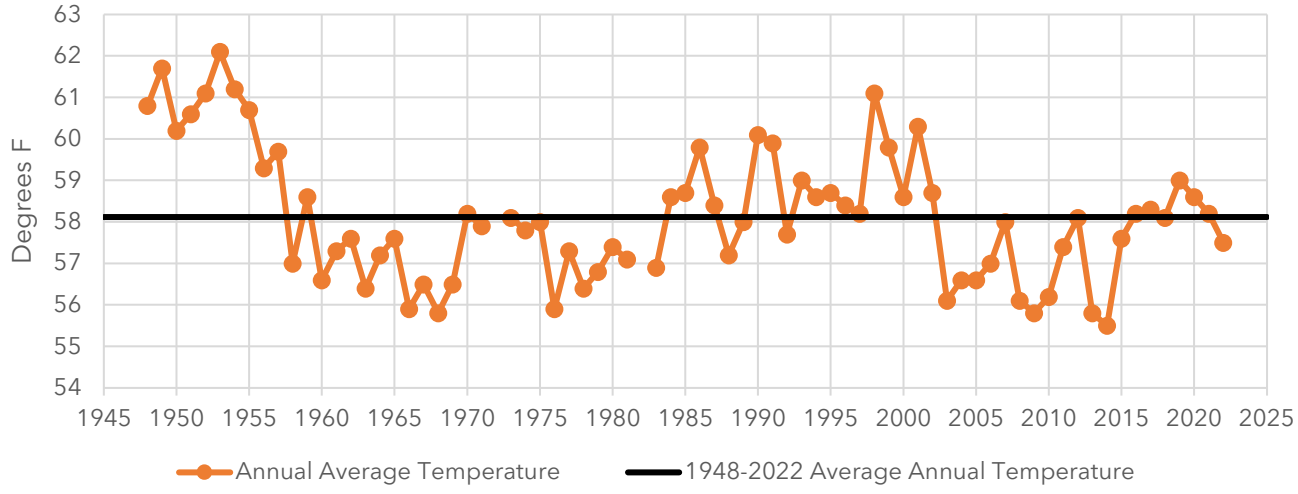


Figure 2-9. Annual average temperature for Statesville 2NNE, 1948 to 2022 (SCNDR State Climatology Office 2022).

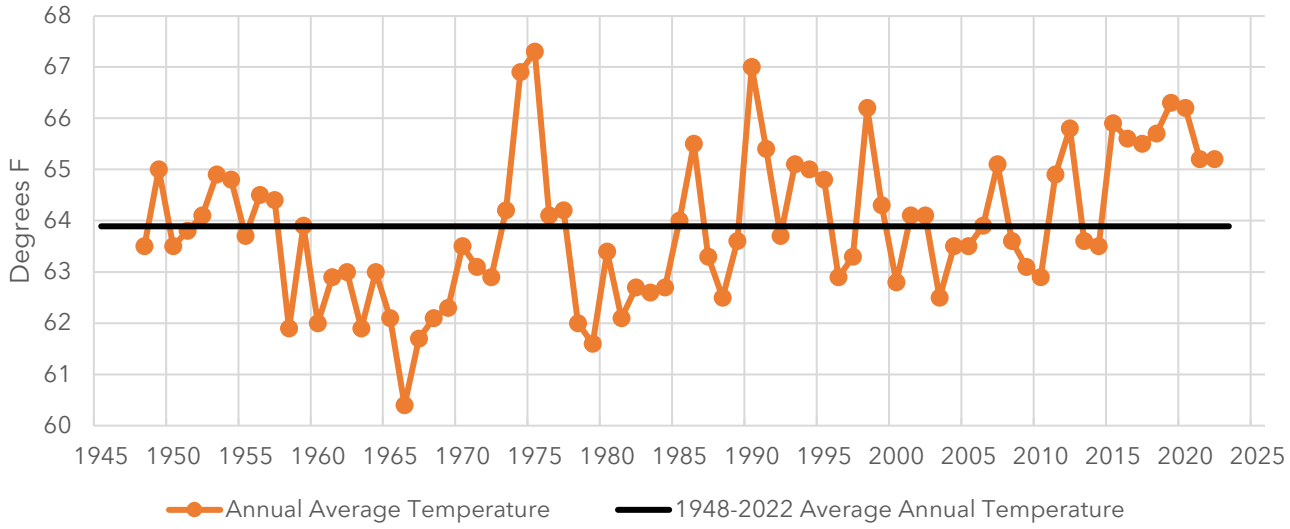


Figure 2-10. Annual average temperature for Florence Regional Airport, 1948 to 2022 (SCNDR State Climatology Office 2022).

Table 2-3. Five warmest and coldest years for Statesville 2NNE and Florence Regional Airport from 1948 to 2022 (SCNDR State Climatology Office 2023).

	Warmest		Coldest	
	Statesville 2NNE	**Florence R.A.**	**Statesville 2NNE**	**Florence R.A.**
1	1953 (62.1 F)	1975 (67.3 F)	2014 (55.5 F)	1966 (60.4 F)
2	1949 (61.7 F)	1990 (67.0 F)	1968 (55.8 F)	1979 (61.6 F)
3	1954 (61.2 F)	1974 (66.9 F)	2009 (55.8 F)	1967 (61.7 F)
4	1952 (61.1 F)	2019 (66.3 F)	2013 (55.8 F)	1963 (61.9 F)
5	1998 (65.1 F)	2020 (66.2 F)	1976 (55.6 F)	1958 (61.9 F)

Figure 2-11 shows the annual precipitation from 1948 to 2022 for Statesville 2NNE and Figure 2-12 shows the same for the Florence Regional Airport station as well as the annual average precipitation over that time period. Through this period Statesville 2NNE has an average annual precipitation of 46.21 inches and Florence Regional Airport has an average annual precipitation of 44.22 inches.

Table 2-4 shows the driest and wettest five years for both stations. While the wettest and driest years for the two stations are generally inconsistent, they both share 2001 as one of their driest years and share 2018 and 2020 as two of their wettest years. Specifically for Florence Regional Airport, the driest year on record (1954) matches South Carolina's driest year on record, which was part of the 1950s drought. The 2nd and 3rd driest years on record at Florence Regional Airport were also parts of notable droughts in South Carolina history, the 2010 to 2012 drought and 1998 to 2002 drought, respectively. Contrastingly, the 4th wettest year on record at Florence Regional Airport is 1964, which is the wettest year on record for the state of South Carolina. The 3rd and 5th wettest years (2016 and 2018, respectively) are due to heavy rains from tropical systems (Hurricane Matthew in 2016 and Hurricane Florence in 2018), both of which caused extensive flooding in the Pee Dee River basin.

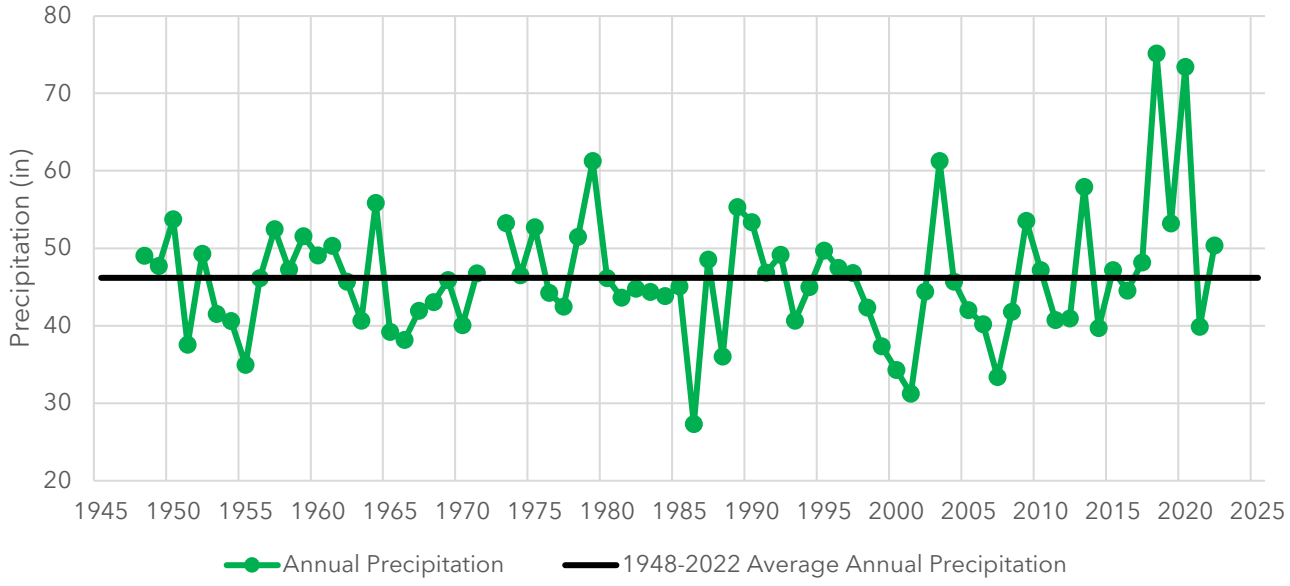


Figure 2-11. Annual precipitation for Statesville 2NNE, 1948 to 2022 (SCNDR State Climatology Office 2023).

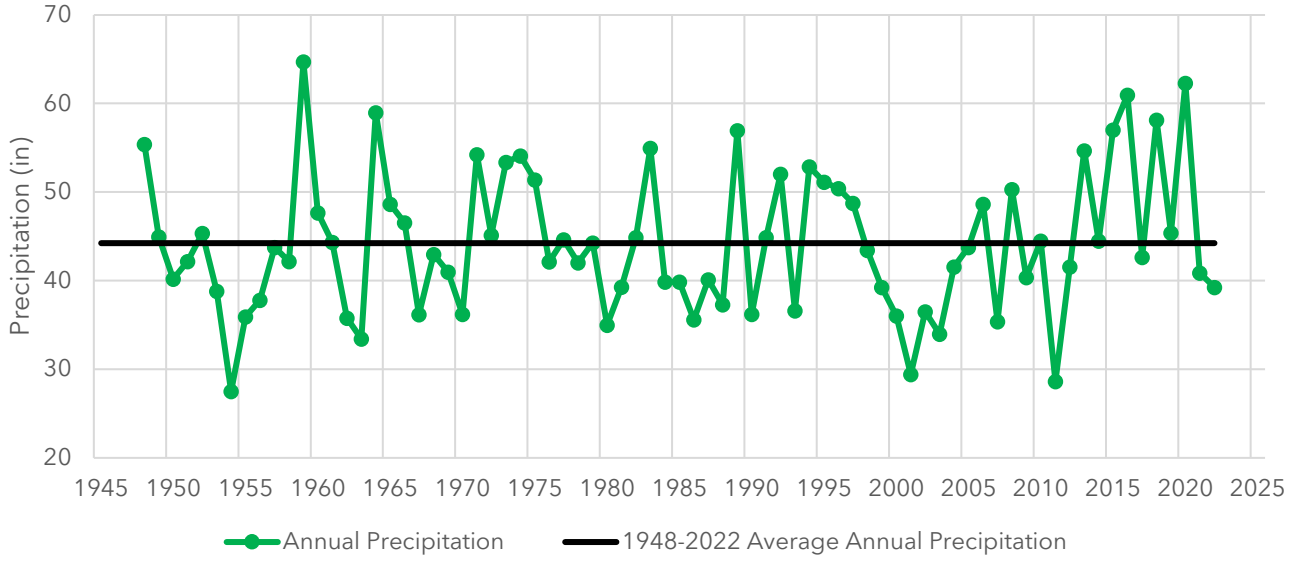


Figure 2-12. Annual precipitation for Florence Regional Airport, 1948 to 2022 (SCNDR State Climatology Office 2023).

Table 2-4. Five wettest and driest years Statesville 2NNE and Florence Regional Airport from 1948- 2022 (SCNDR State Climatology Office 2023).

	Driest		Wettest	
	Statesville 2NNE	**Florence R. A.**	**Statesville 2NNE**	**Florence R. A.**
1	1986 (27.31 in)	1954 (27.50 in)	2018 (75.12 in)	1959 (64.71 in)
2	2001 (31.22 in)	2011 (28.63 in)	2020 (73.40 in)	2020 (62.31 in)
3	2007 (33.37 in)	2001 (29.42 in)	1979 (61.24 in)	2016 (60.96 in)
4	1955 (34.29 in)	1963 (33.42 in)	2003 (61.24 in)	1964 (58.97 in)
5	1988 (34.95 in)	2003 (33.95 in)	2013 (57.91 in)	2018 (58.13 in)

Notes about climate data: The two stations were selected due to their long-term records (Statesville 2NNE: 1901 to present; Florence Regional Airport: 1948 to present), and they show the climatological differences in the upper and lower portions of the basin. Statesville 2NNE is in the middle of the entire basin, whereas Florence Regional Airport is in the lower portion of the entire basin and in the middle of the South Carolina portion of the Pee Dee River basin. While there are some stations in the basin that have longer periods of record, they were not presented here due to quality of data collection through time (SCDNR State Climatology Office 2023). The Statesville 2NNE station has two years of missing temperature data (1972 and 1982) and one year of missing precipitation data (1972). The missing annual values are due to one month of missing data during each of those years, which affects the annual average for that specific year. Florence Regional Airport does not have any missing data. It is also worth noting that the annual average values of temperature and precipitation for each station may not match their locations on the basin climatology images of Figure 2-6 due to differences in the period of records of the data. The long-term station data ranges from 1948 to 2022, while the data used for Figure 2-6 is based on the current climate normals (1991 to 2020).

2.2.2 Severe Weather

Severe weather, including thunderstorms, tornadoes, and tropical cyclones, can impact some or all portions of the Pee Dee River basin.

2.2.2.1 Severe Thunderstorms and Tornadoes

Between 45 and 63 thunderstorm days occur across the Pee Dee River basin annually, with typically more thunderstorm days occurring in the lower part of the basin than the upper part (NOAA 2023 https://www.noaa.gov/jetstream/thunderstorms). Although the number of thunderstorm days varies across the basin, the potential impact from each storm is equal across the basin. While thunderstorms occur throughout the year, severe thunderstorms are more common during spring (March, April, May) and summer (June, July, and August). For a thunderstorm to be considered severe, it must produce wind gusts of at least 58 miles per hour (mph), hailstones of 1 inch diameter or larger, or a tornado.

While the Pee Dee River Basin Plan focuses on low flows, long term water supplies, water demands, and the factors that drive them, severe weather events help characterize the climate of the Pee Dee River basin and is provided for reference only.

Tornadoes are violently rotating columns of air that descend from thunderstorms and contact the ground. Most of South Carolina's tornadoes are short-lived EF0 and EF1 tornadoes, the lowest strengths on the Enhanced Fujita (EF) Scale, with winds between 65 and 110 mph. However, even a tornado with the lowest intensity rating is dangerous and poses a significant risk to lives and property. Table 2-5 shows the number of tornadoes by intensity ranking, confirmed within the basin between 1950 and 2022. The counts are based on tornadoes that formed within one of the counties in the basin or the first county in the basin that the tornado crossed into if it formed outside the basin (so as to not "double count" any tornadoes that may have passed through multiple counties). Most of the basin's tornadoes rated EF0 and EF1. For reference, the EF-Scale became operational in 2007 and replaced the original Fujita scale (F-scale) used since 1971. The basin experienced 269 tornadoes between 1950 and 2022, with 51 of them being of significant strength (EF2 or higher). By county, Horry County has had the most tornadoes in in the basin (57) followed by Florence County (36) and Darlington County (28). Horry County has also had the most significant tornadoes (EF2 or higher) in the basin (11). Marlboro County has had the most EF4 tornadoes in the basin (3). No part of the Pee Dee River basin, nor South Carolina has experienced an EF5 tornado.

The South Carolina State Climatology Office collected the tornado figures from NOAA National Centers for Environmental Information (NCEI) Storm Events Database (https://www.ncdc.noaa.gov/stormevents/) as well as National Weather Service (NWS) Greenville-Spartanburg's (GSP) Historic Tornadoes in the Carolina and Northeast Georgia Database (https://www.weather.gov/gsp/tornado).

Table 2-5. Count of Tornadoes in the Pee Dee River basin by intensity ranking 1950 to 2022 (SCDNR State Climatology Office 2023).

Enhanced Fujita Scale	Wind Speed	Count
EF0	65-85 mph	101
EF1	86-110 mph	117
EF2	111-135 mph	40
EF3	136-165 mph	5
EF4	166-200 mph	6
EF5	200+ mph	0
Total number of Tornadoes in the Basin:		269

2.2.2.2 Tropical Cyclones

South Carolina has an 80 percent chance of being affected by a tropical cyclone (meaning tropical depression, tropical storm, or hurricane) each year and about a 3 percent chance for a major hurricane (a Category 3 storm with winds of 115 mph or higher) each year.

With an average size of approximately 300 miles in diameter, tropical cyclones can have far-reaching hazards, including storm surge, damaging wind, precipitation-induced flooding (flash flooding and riverine flooding), and tornadoes. For example, tornadoes produced by tropical cyclones form in the outer rainbands, which can be hundreds of miles from the storm's center. The remnants of Hurricane Jeanne (2004) passed through the South Carolina Upstate and upper portions of the Yadkin-Pee Dee River basin (NC) as a tropical depression. Jeanne spawned 17 tornadoes in South Carolina with 5 forming in the Pee Dee River basin.

Since 1851, 122 tropical cyclones have tracked through the Yadkin-Pee Dee River basin. For the entire basin, 61 were unnamed storms (pre-1951) and 61 were named storms (the naming of tropical storms and hurricanes started in 1951). The first named storm was Hurricane Able (1952), which reached Category 4 status but affected the basin with the strength of tropical storm. The most recent named storm to hit the basin was Hurricane Ian (2022), which affected the basin as a Category 1 hurricane. In just the South Carolina portion of the Yadkin-Pee Dee River basin, 88 tropical cyclones have tracked through the basin since 1851. Of these 88 tropical cyclones, 42 were unnamed storms (pre-1951) and 46 were named (since 1951). The first named storm to track into the Pee Dee River basin was hurricane Hazel (1954), which reached Category 4 status and hit the basin at that strength, making landfall at the South Carolina – North Carolina state line. The last storm to hit the Pee Dee River basin was Hurricane Ian (2022), affecting the basin as a Category 1 hurricane. Table 2-6 shows the number of hurricane strength storms to affect the basin by category. The Carolinas have not had a Category 5 strength hurricane track through it. The number of tropical cyclones used here only accounts for when the center of the storm tracked through a portion of the Yadkin-Pee Dee River basin. Due to the spatial extent of tropical cyclones, many systems have affected the Yadkin-Pee Dee River basin, but the storms' centers did not track through the basin.

Table 2-6. Number of tropical cyclones at hurricane-strength that tracked through the Yadkin-Pee Dee River basin (1851 to 2022).

Category	Windspeed	Entire Yadkin-Pee Dee	SC portion of Pee Dee
1	74-95 mph	17	15
2	96-110 mph	8	5
3	111-129 mph	2	1
4	130-156 mph	3	4
5	157+ mph	0	0
Total number of Hurricane Strength Storms		30	25

The last major hurricane (Category 3 or higher) to make landfall in South Carolina was Hurricane Hugo in September 1989 at Category 4 strength. While Hugo made landfall at Sullivan's Island (Santee River Basin), it tracked through the western edge of Sumter County, inside the Pee Dee River basin. Hugo caused significant impacts to much of the state, including the Pee Dee River basin, where storm surge along the coast and strong winds caused damage to personal property and infrastructure, as well as agricultural loss throughout the basin. Hugo significantly impacted the timber industry in the Pee Dee River basin.

Hurricane Matthew (2016) and Hurricane Florence (2018) were the most recent tropical systems to cause major impacts to the Pee Dee River basin. These impacts were primarily riverine flooding due to widespread, excessive rainfall. Multiple stations in the Pee Dee River basin received rainfall totals that were less than the 1 percent Annual Exceedance Probability (AEP) (Figure 2-13 and Table 2-7). The AEP is the percent chance that an event will happen each year. This is referred to as the Annual Recurrence Interval (ARI), which is a probability given in years, such as a 100-year event (which is the same as a 1 percent AEP). Below is a brief description of both Hurricane Matthew and Hurricane Florence. Each has a figure showing the ARI gridded map, as well as a station list with ARI value and total precipitation accumulation for the event.

Hurricane Matthew made landfall near McClellanville as a Category 1 hurricane. The remnants of Matthew dumped 10 to 17 inches of rain from Savannah, Georgia, through Florence, South Carolina, and

into a wide area of eastern North Carolina. The most widespread heavy rain fell in the Pee Dee River basin and into North Carolina, where significant flooding occurred. Rainfall totals across portions of the Pee Dee surpassed the record rains of the Charleston Hurricane in 1916 and Hazel in 1954.

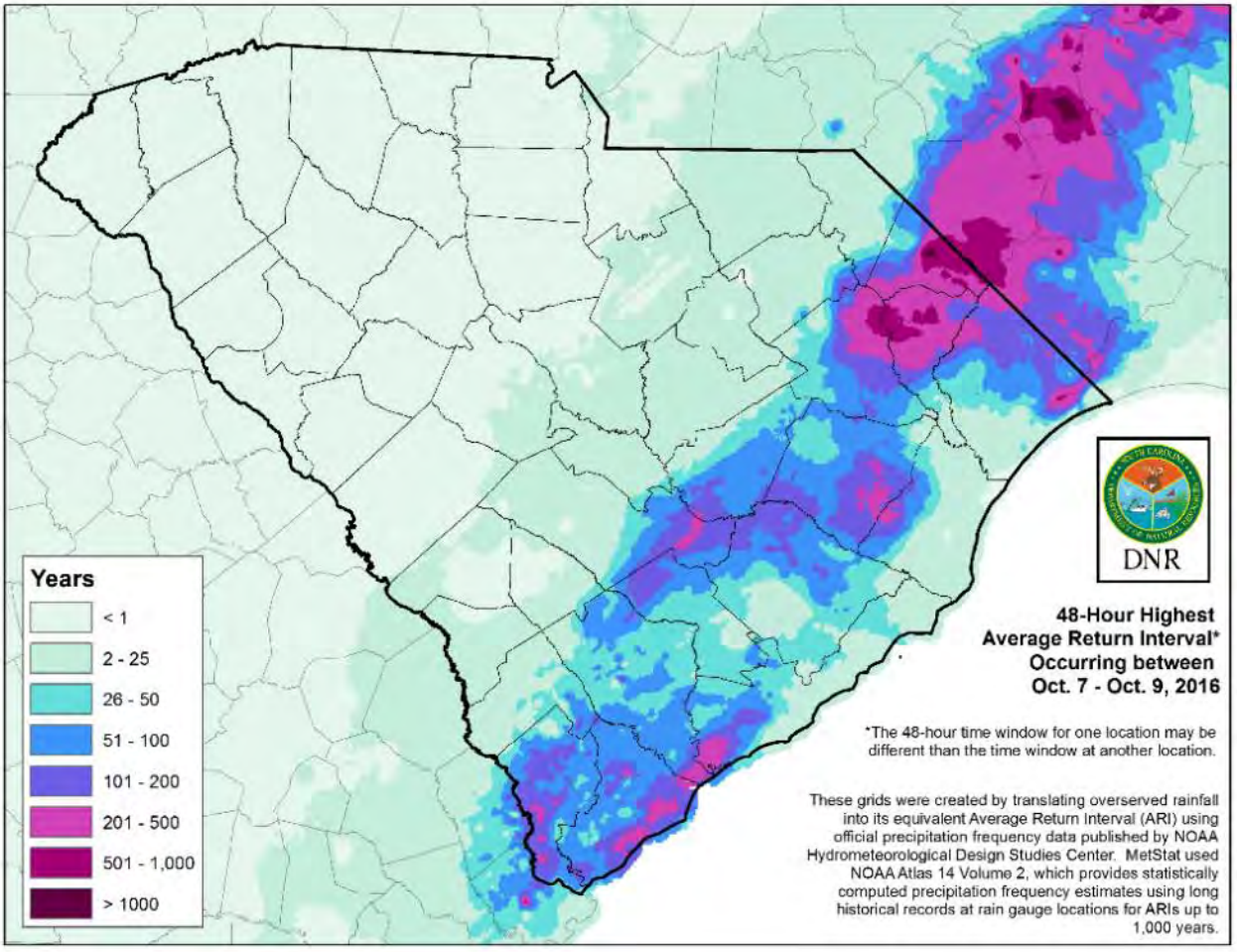


Figure 2-13. 48-hour ARI values in South Carolina from Hurricane Matthew (SCDNR State Climatology Office 2023).

Table 2-7. Pee Dee station 48-hour rainfall totals and annual exceedance probability from Hurricane Matthew (SCDNR State Climatology Office 2023).

October 7th – 9th, 2016		
Station	**Total precipitation**	**48- hour AEP (ARI)**
Marion	15.10 in	0.2% chance (500-year)
Manning	13.07 in	0.5% chance (200-year)
Florence	12.76 in	0.5% chance (200-year)

Tropical Storm Florence was a Category 1 Hurricane when it made landfall near Wrightsville Beach, North Carolina on September 14, 2018. It then weakened to a tropical storm, stalled, and remained nearly stationary for an entire day before it began a slow turn to the southwest, which is not a typical movement for tropical cyclones. It traveled across South Carolina at a speed of 2 to 3 mph. The slow-moving system

dropped over 30 inches of rain across portions of eastern North Carolina and over 20 inches in Chesterfield and Horry counties over four days. These totals equate to a 1,000-year event, which, in terms of AEP, equals a 0.1 percent probability of occurring in any given year. Additional stations in the Pee Dee River basin measured rainfall totals that ranged between 0.1percent and 1 percent AEP, or the 1,000- to 100-year event (Figure 2-14 and Table 2-8).

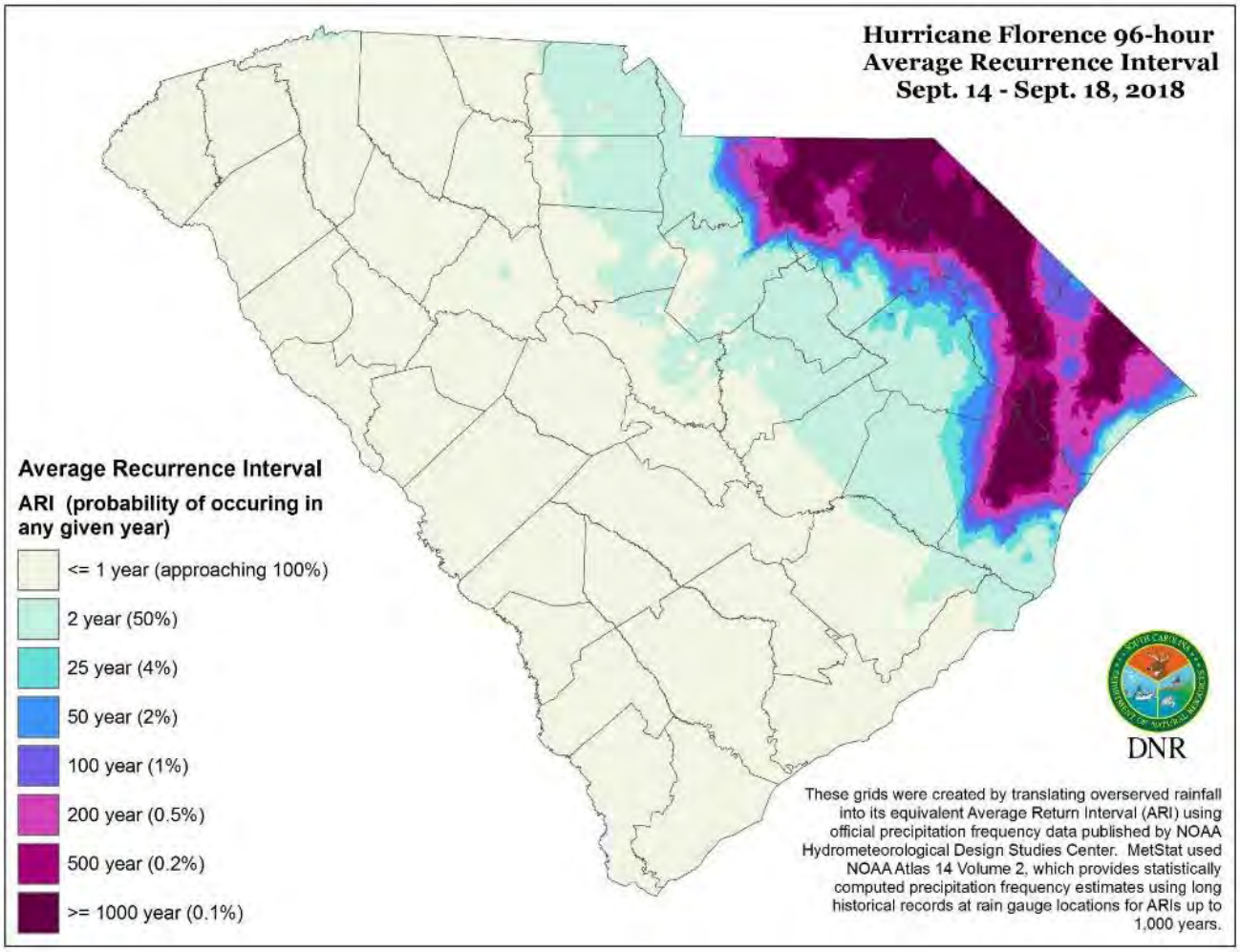


Figure 2-14. 96-hour (4-day) ARI values in South Carolina from Hurricane Florence (SCDNR State Climatology Office 2023).

Table 2-8. Pee Dee station 96-hour (4-day) rainfall totals and AEP from Hurricane Florence (SCDNR State Climatology Office 2023).

	September 14th – 18th, 2018	
Station	**Total precipitation**	**96-hour AEP (ARI)**
Cheraw	22.81 in	0.1% chance (1000-year)
Chester	17.11 in	0.1% chance (1000-year)
Marion	13.45 in	0.5% chance (200-year)
Hartsville	11.23 in	1% chance (100-year)
Darlington	11.14 in	1% chance (100-year)

For more information about tropical cyclones that have affected South Carolina, please visit the South Carolina State Climate Office's "Hurricane and Tropical Storms Database"

https://www.dnr.sc.gov/climate/sco/hurricanes/

2.2.2.3 Winter Storms

The Pee Dee River basin has been impacted by winter weather events, such as winter precipitation (snow, sleet, ice accumulation, and freezing rain accretion) and extreme cold. The South Carolina portion of the basin has a 20 to 50 percent chance of a snow event each year, with average annual snow accumulations ranging from trace amounts to 2 inches. Annual snow probability and average annual snowfall both decrease from the upper portions of the basin towards the coast. The largest snow accumulation in the basin occurred in 1973 between February 9th and 11th, with Manning (Clarendon County) and Florence (Florence County) receiving 21.0 inches and 17.0 inches, respectively. Other events, such as December 1989, February 2014, and January 2018 have also produced significant snow totals in the basin. Extreme cold affects a portion of the basin about every two to three years. Multiple noteworthy cold events have occurred in the Pee Dee River basin, including December 1985, January 1986, December 1989, January 2003, and most recently December 2022. During these events, minimum temperatures fell to single digits in the upper portion of the basin and into the teens in the lower portion of the basin.

Winter weather events are usually high-impact situations in South Carolina because of their infrequent sub-seasonal, seasonal, and annual occurrence. Winter precipitation mainly impacts travel and transportation; however, heavy snow accumulations and ice accretions have caused impacts to trees, power lines, and built structures. It only takes 0.5 in of ice accretion to cause these types of impacts. January 11 to 12, 2014 is a more recent event of ice accumulation and impacts in South Carolina, specifically in the Pee Dee River basin. While snow did fall in portions of the basin, ice accumulation was the major source of impact in the basin. Ice accumulation ranged from 0.1 to 1.0 inches. Marion, SC reported 1.0 inches of ice accumulation. Tree damage from this storm was comparable to the damage from Hurricane Hugo in September 1989. The impacts of this storm were significant enough that Dillon, Florence, Georgetown, Horry, Marion, and Williamsburg counties were declared in a federal "major disaster area."

Extreme cold events cause impacts as well. Water lines that are above ground or shallowly buried are most susceptible to freezing, due to cold temperatures. Water lines that freeze typically burst, which can cause water loss and flooding inside structures. While these types of events have occurred on a more localized scale through time, these types of impacts occurred on a large scale in the Pee Dee River basin during cold events in December 1985, January 1986, December 1989, January 2003, and most recently in December of 2022. During the December 1989 event, the extreme cold caused multiple water lines to burst, particularly along the coastal portion of the Pee Dee River basin, causing many residents to be without water. The impacts of this winter storm came just three months after Hurricane Hugo, where residents who were in the process of recovering and rebuilding then had to manage days without running water. The timing of these two events demonstrates how two unrelated hazards can have compounding impacts to affected communities. The most recent extreme cold event, December 23 to 26, 2022, caused many water lines to freeze and burst, which was a significant issue in homes and businesses that were vacant due to holiday travel. Beyond the internal water damage to homes and buildings, the number of line breaks caused some water systems to experience a significant drop in water

supplies. This extreme cold event highlights how other natural hazards besides drought can cause issues to water supplies, infrastructure, and delivery.

For more information about winter weather events that have affected South Carolina, please visit the South Carolina State Climate Office's "Winter Weather Database"

https://experience.arcgis.com/experience/7ae9e53751d547cabe5c1dbaa74b2336

2.2.2.4 Flooding

The general definition of a flood is the temporary condition of a partial or complete inundation of typically dry land. Fluvial flooding, also known as riverine flooding, is the flooding of typically dry areas caused by an increased water level of an established lake, river, or stream when the water overflows its banks. The damage from fluvial flooding can be widespread, extending miles away from the original body of water. This type of flooding is caused by excessive runoff from a severe or prolonged rain event.

While the Pee Dee River basin has experienced significant flooding in the past, such as the flood of 1928, more recent, notable floods in the basin are the 2015 flood, Hurricane Matthew (2016), and Hurricane Florence (2018). These three flood events were caused by excessive rainfall. Figure 2-15 below shows the areas in the Pee Dee River basin that experienced 1 percent, 0.5 percent, 0.2 percent and 0.1 percent AEP for rainfall multiple times between 2015 and 2018.

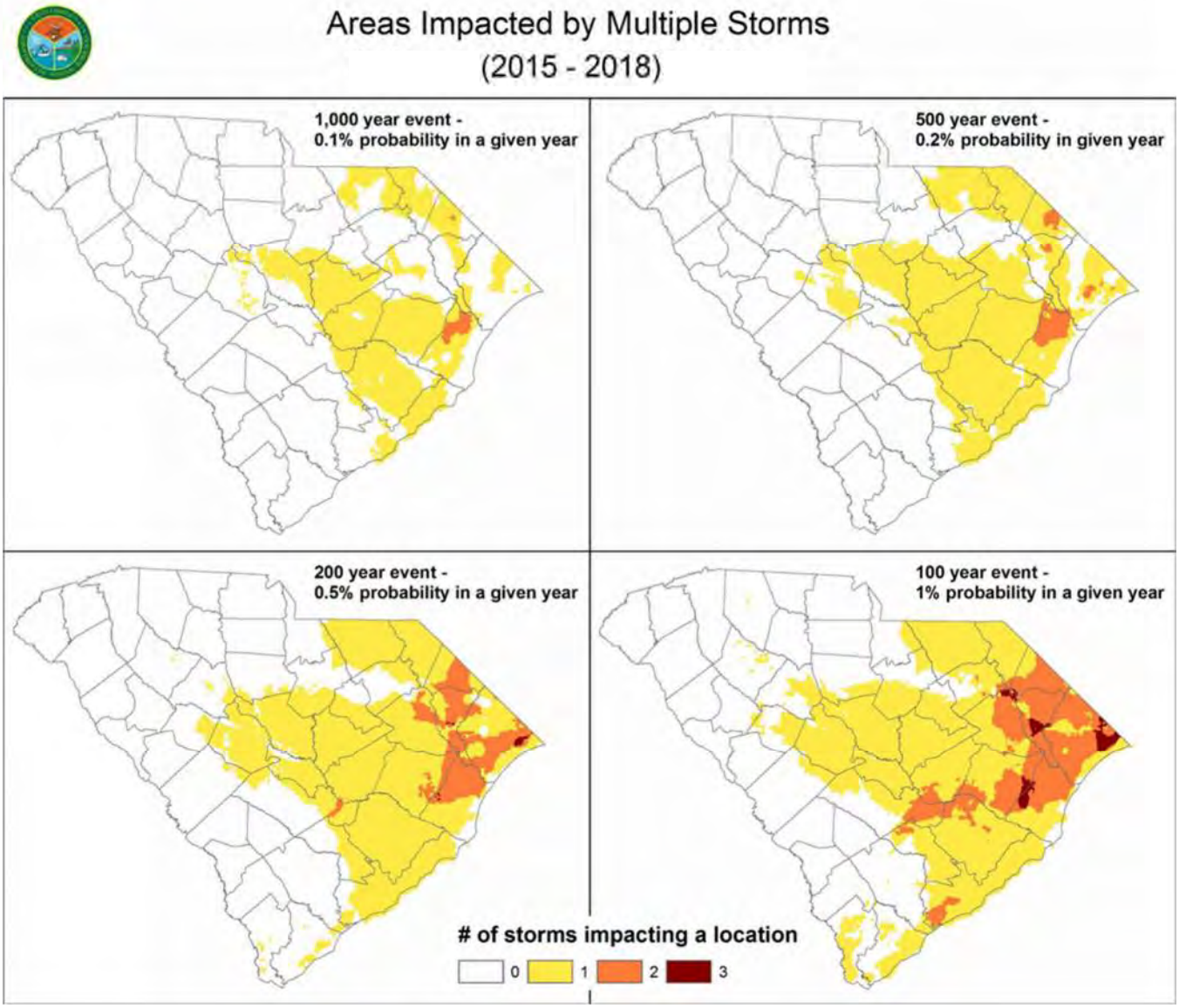


Figure 2-15. Areas impacted by multiple storms.

A record-setting and historic rainfall event occurred from October 1 to 5, 2015, producing widespread and significant flooding across much of South Carolina. The event's heavy rains and precipitation toward the end of September resulted in catastrophic flooding in some portions of the state. On October 1, a cold front swept across the state and stalled offshore for the next five days. This boundary tapped into deep tropical moisture over the Gulf of Mexico as it sat offshore of the Lowcountry. At the same time, Hurricane Joaquin rapidly strengthened over the Bahamas and interacted with the stalled coastal front, providing additional moisture into the region. All-time precipitation records were shattered, with rainfall totals ranging from 10 to over 26 inches from the Midlands to the coast (Figure 2-16 and Table 2-9). Streams and creeks swelled out of their banks. Seventeen USGS gages reached record peaks, including the Black River at Kingstree, which reported a crest of 22.65 ft., and a streamflow value of 83,700 cubic feet per second (cfs), surpassing the previous records set in 1973.

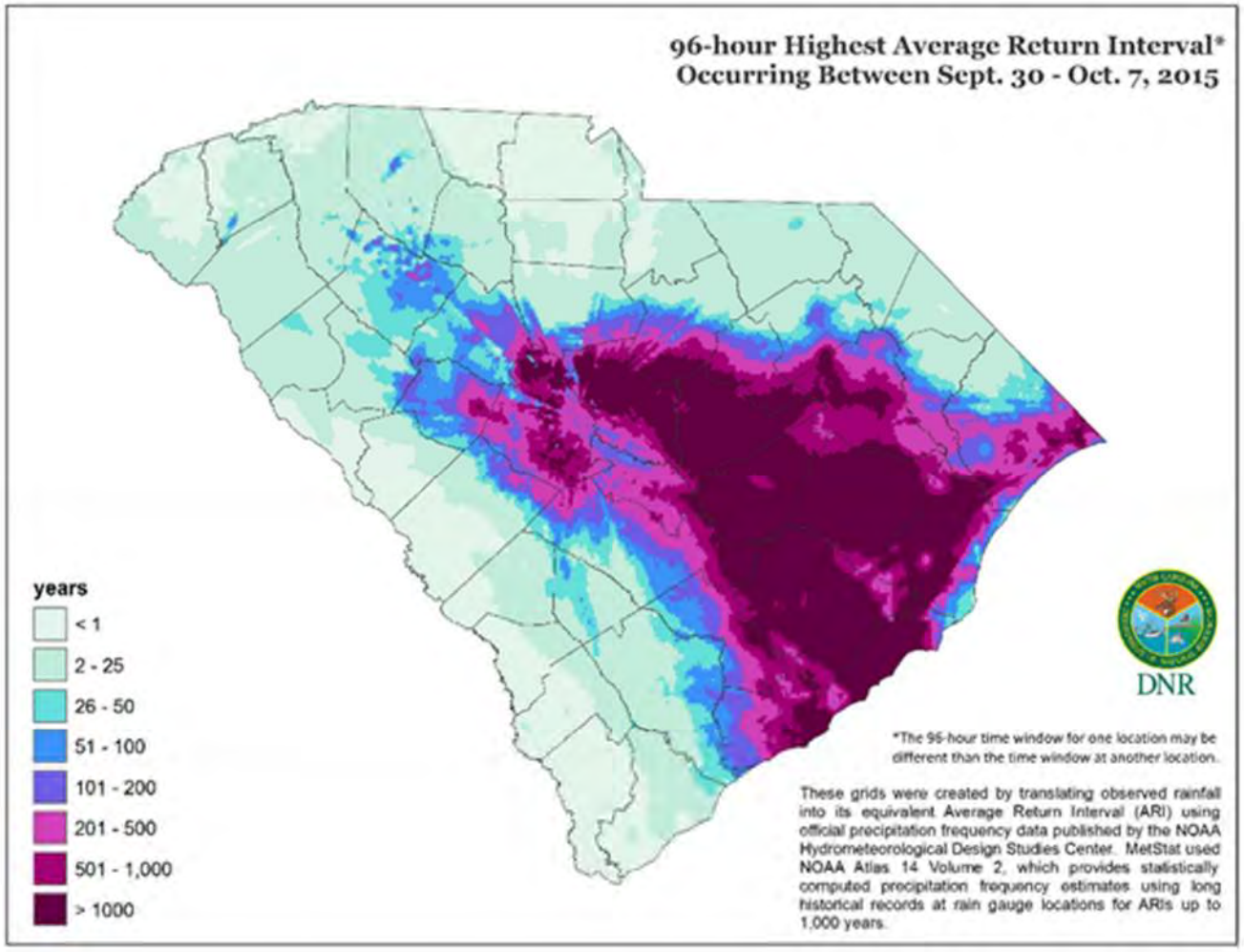


Figure 2-16. 96-hour (4-day) ARI values in South Carolina during the 2015 Flood event (SCDNR State Climatology Office 2023).

Table 2-9. Pee Dee station 96-hour (4-day) rainfall totals and AEP during the 2015 Flood event (SCDNR State Climatology Office 2023).

September 30th – October 7th, 2015		
Station	**Total precipitation**	**96-hour AEP (ARI)**
Georgetown	20.75 in	0.1% chance (1000-year)
Andrews	18.15 in	0.1% chance (1000-year)
Manning	12.71 in	0.5% chance (200-year)
Florence	10.59 in	1% chance (100-year)

Excessive rainfall for Hurricane Matthew and Hurricane Florence (described in Section 2.2.2.2) also created significant flooding conditions. Due to the excessive rain in Hurricane Matthew, the Lumber, Little Pee Dee, and Waccamaw rivers had swelled to a "Major Flood Stage" and were still rising on October 9, 2016. On October 12, the Little Pee Dee River at Galivants Ferry rose to 17.10 feet. Floodwaters from the

Lumber and Little Pee Dee rivers inundated the town of Nichols. The Waccamaw River near Conway reached a record stage of 17.89 feet on October 18, surpassing the flood of September 1928. Many non-elevated homes were flooded, and docks and decks, private or state-owned, were swept away. On November 2, after 25 days at or above minor flood stage (11 feet), the Waccamaw River near Conway dropped to below flood stage.

Hurricane Florence caused unprecedented flooding, as a portion of the excessive rainfall measured in North Carolina fell in the Yadkin-Pee Dee River watershed. Flooding plagued most of the Pee Dee River basin weeks after the initial landfall, significantly impacting the Black, Pee Dee, Little Pee Dee, Lumber, Lynches, and Waccamaw rivers and their tributaries. Many river gages reached crest values that fell within their locations' top five highest measured crests, while several of the rivers set new record crest values. The Pee Dee River at Peedee reached a height of 31.83 ft., 1.5 ft. lower than the historic crest of 33.3 ft. in 1945. During this event, gages along the Waccamaw exceeded previous record crests by three or more feet. While the impacts from Florence on their own were severe, it came two years after the extreme flooding from Hurricane Matthew, impacting many areas that were still recovering.

2.2.3 Drought

Drought is a normal part of climate variability that occurs in every climate. Drought results from a lack of precipitation over an extended period, often resulting in a water shortage for some activity, sector, or the environment. In contrast to other environmental hazards, droughts develop slowly over weeks, months, or years. While drought is driven by a lack of precipitation, multiple factors such as temperature, evapotranspiration, reservoir releases (where applicable), and water demands also need to be considered when evaluating how drought periods will impact stream and river flows in the basin. Severe drought conditions can contribute to diminished water and air quality, increased public health and safety risks, and reduced quality of life and social well-being. Because drought causes a lack of expected water across multiple sectors at different time frames, it is essential to plan for drought so water demands can be adequately met and managed before and during the next severe drought period.

Figure 2-17 and Figure 2-18 show the annual Standard Precipitation Index (SPI) value for Statesville 2NNE and Florence Regional Airport from 1948 to 2021 (the latest SPI data available for these stations). The SPI is a drought index that compares accumulated rainfall over a given period (here, 12 months) to the historical average, where the index values are standard deviations from the mean. Anything equal to or less than -1.0 is considered a drought. The lower the index value, the more severe the drought. The lowest SPI value was -2.69 for Statesville 2NNE in 1986 and -2.31 for Florence Regional Airport in 1954, matching each station’s driest year on record. In the last decade (2012 to 2021), Statesville 2NNE has had a mix of both dry and wet years, while Florence Regional Airport has had more wet conditions, with 5 of past 10 years having a SPI value of over 1.0, indicating excessively wet conditions. It should be noted that annual SPI values do not show short-term conditions, such as monthly or seasonal conditions. During a year with a negative annual SPI value, there can be months or seasons with positive SPI values, and vice versa. While the annual SPI time series is provided here for reference, it is not the only method for looking at wet and dry periods over time. Furthermore, the SPI only accounts for precipitation accumulation and does not consider wetness or dryness in terms of evapotranspiration, soil moisture, streamflow, or groundwater.

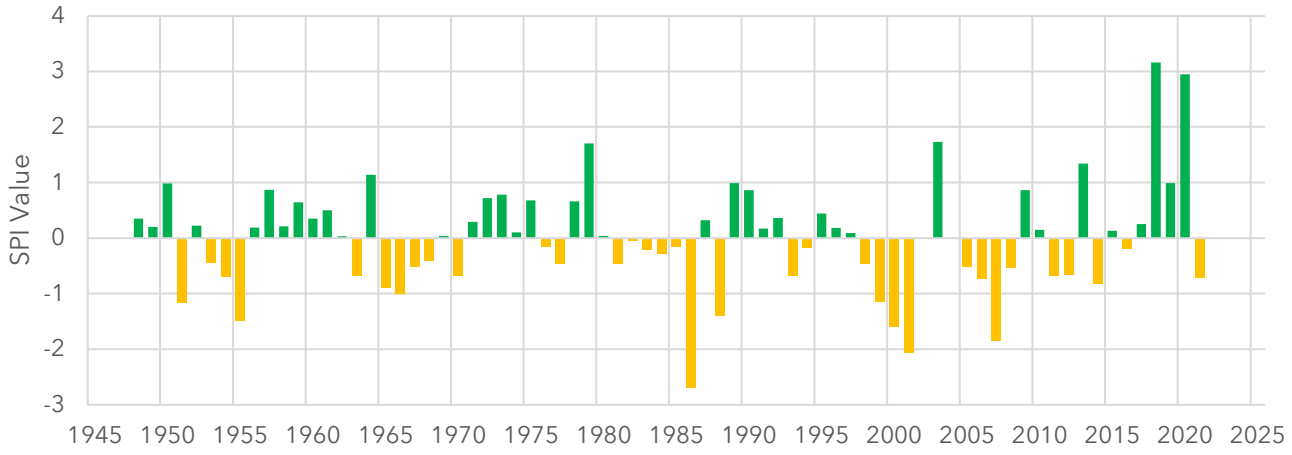


Figure 2-17. Annual Standard Precipitation Index (SPI) values for Statesville 2NNE 1948 to 2021 (SCDNR State Climatology Office 2023).

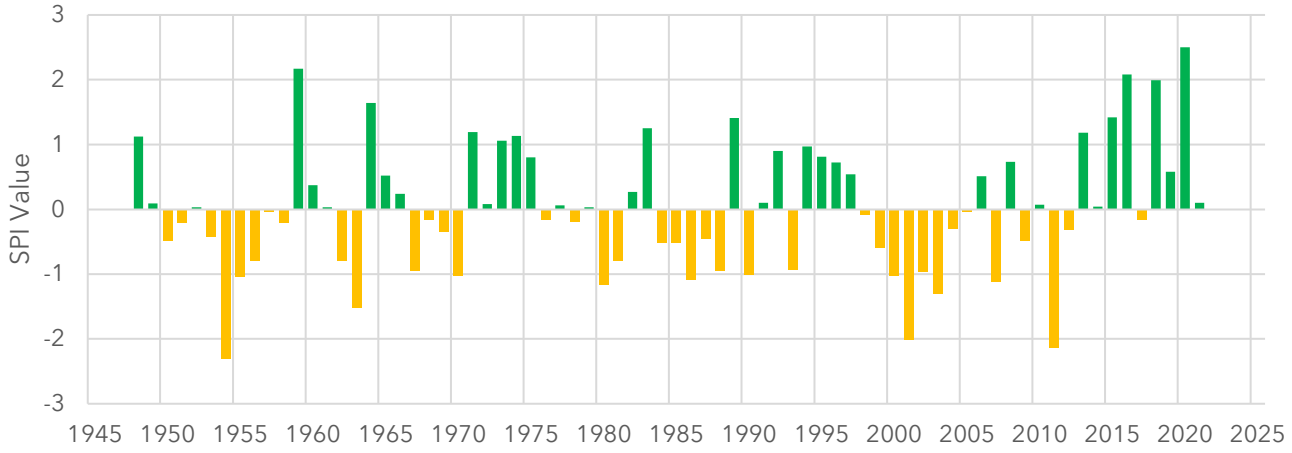


Figure 2-18. Annual Standard Precipitation Index (SPI) values for Florence Regional Airport 1948 to 2021 (SCDNR State Climatology Office 2023).

The impact of drought on streamflow in the basin was analyzed using four USGS streamflow gages, one for each of the major rivers in the South Carolina portion of the Pee Dee River basin. The four stations are Pee Dee River at Peedee, Lynches River at Effingham, Little Pee Dee River at Galivants Ferry, and Waccamaw River near Longs. Beyond the spatial component, these four stations were used due to their consistent long-term record. The period used was 1951 to 2022, as 1951 was the first year that the Waccamaw River near Longs station had a full year of data. While the other three stations have recorded data reaching back to the 1930s, the period of 1951 to 2022 was used to provide consistency for analyzing low flows among the four stations.

Table 2-10 shows lowest monthly average flow, which year it occurred, and the long-term average monthly flow for each month for the four stream gages. Table 2-10 also shows the year with the lowest average annual flow and the long-term average annual flow. Among these four stations, there are similarities and differences for which years the lowest average monthly flow was recorded. However, these lowest average monthly flows all took place during significant drought periods. The Lynches River at Effingham and the Little Pee Dee River at Galivants Ferry experienced their lowest average monthly

flow in July of 2022. Contrastingly, the Pee Dee River at Peedee experienced its record lowest monthly average flow in November 2001, and the Waccamaw River near Longs experienced its lowest monthly average flow in September of 1954. Although these four stations didn't experience record low monthly or annual average flows during the same time, they all experienced record low average flows during the 1998-2002 drought.

Table 2-10. Year of lowest monthly and annual average flow compared to the long-term average for the each of the four stream gages between 1951 – 2022.

	Pee Dee River at Peedee (USGS 02131000)												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
Year of Minimum Flow	1956	2001	2017	2006	2002	2002	2002	2002	2007	2001	2001	2001	2001
Lowest Avg Flow (cfs)	3,268	4,042	4,669	3,898	2,355	2,079	1,682	1,107	1,366	984	773	1,916	3,368
Long-term Avg Flow (cfs)	12,835	14,913	16,252	13,482	9,060	7,530	5,975	6,160	5,798	6,670	7,008	9,295	9,950
	Lynches River at Effingham (USGS 02132000)												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
Year of Minimum Flow	1956	2012	2002	2006	2002	2002	2002	2002	2007	2007	2007	2001	2002
Lowest Avg Flow (cfs)	387	427	464	328	206	107	88	103	109	114	156	213	397
Long-term Avg Flow (cfs)	1,508	1,735	1,870	1,403	774	623	597	642	624	706	680	1,021	1,015
	Little Pee Dee River at Galivants Ferry (USGS 02135000)												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
Year of Minimum Flow	2012	2012	2002	1981	2002	2002	2002	2002	1954	2007	2001	2007	2002
Lowest Avg Flow (cfs)	881	1,169	1,396	962	392	180	104	104	212	184	300	461	950
Long-term Avg Flow (cfs)	4,176	5,132	5,247	3,959	2,094	1,862	1,680	1,960	2,350	2,293	1,834	2,754	2,959
	Waccamaw River near Longs (USGS 2160700)												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
Year of Minimum Flow	2008	2012	2022	2002	2002	2002	1952	1954	1954	1983	1983	2007	2002
Lowest Avg Flow (cfs)	62	190	268	186	29	15	13	15	4	5	6	9	308
Long-term Avg Flow (cfs)	1,706	2,222	2,240	1,545	670	623	754	1,062	1,525	1,213	671	878	1,259

The driest hydrological year on record is 2002 and is the most significant drought the Pee Dee River basin has experienced in recent history. Severe impacts occurred across multiple sectors, including agriculture, recreation, forestry, and public water supply. Agricultural impacts included reduction of crop yields or yield loss, costs for digging new wells for irrigation, ponds going dry, as well as decreases in pasture productivity and the ability to adequately feed livestock. Low flows exposed hazards to boats and negatively affected business that rely on river recreation for income. Forestry delt with cascading impacts.

The potential for fire grew, leading to outdoor burn bans, while the reduced water availability stressed the trees. This stress allowed for increased susceptibility to the southern pine beetle, which caused billions in losses to the timber industry.

The summer and fall of 2002 were hydrologically the most intense portion of the 1998 to 2002 drought for the Pee Dee River basin. From June 2002 to November 2002, the South Carolina Drought Response Committee (DRC) declared the entire basin was in severe to extreme drought, with the entire basin being in extreme drought from July 2002 to September 2002. This is compared to the two prior years, when the basin was in incipient drought from May 2000 to May 2001 and in moderate drought from May 2001 to June 2002. During the summer and fall of 2002, the record low hydrologic conditions caused issues for public water supply in the basin. Multiple water systems called for voluntary water use reductions, with some implementing mandatory water restrictions. The Georgetown County Water System reported increasing salinity in their water supply. While normal river flows generally keep saline water far enough from the supply intakes in the river, the saline water was able to migrate upstream towards the intake due to the record low river flows. Luckily, the intense hydrologic drought conditions across the basin eased in November when much-needed rainfall helped to improve drought-stricken conditions in the basin.



Deep Hole Swamp in Florence County during August 2008 drought.
(Photo credit: http://scdrought.com/)

2.3 Natural Resources

2.3.1 Soils and Vegetation

Six land resource areas were defined by the Natural Resources Conservation Service (NRCS) based on soil conditions, climate, and land use. These areas are defined based on soil characteristics and their supported land use types, and they generally follow the boundaries of the physiographic provinces. The land use areas are shown in Figure 2-19.

The Pee Dee River basin includes portions of five land resource areas. The extents, names, and descriptions as presented in the South Carolina State Water Assessment (SCDNR, 2009) are shown in the figure below:

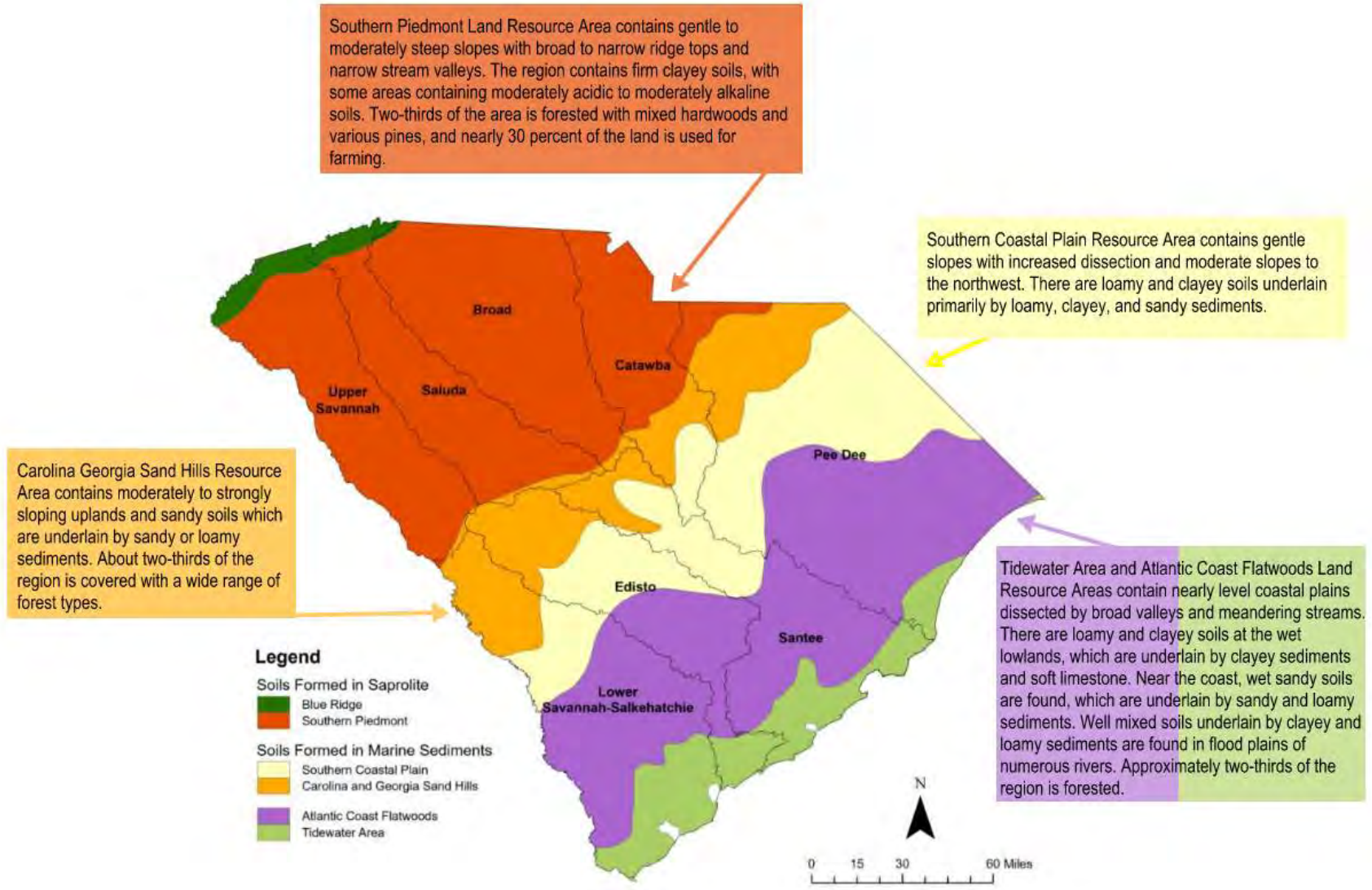


Figure 2-19. Generalized land resource soils map of South Carolina with descriptions.

2.3.2 Minerals

As of June 2023, the Pee Dee River basin has 145 active mines, which is about 30 percent of mines in the entire state (491 total). The majority within the Pee Dee River basin are sand and clay mines, with additional limestone, kaolin, shale, and gold mines present in the basin as well. According to the 2018 USGS Minerals Yearbook, South Carolina produced at least $975 million in nonfuel minerals in 2018.

2.3.3 Fish and Wildlife

According to a presentation by SCDNR on "Aquatic Resources of the Pee Dee Basin," 102 native fish species are in the Pee Dee River basin as well as 10 introduced non-native species representing a diverse assemblage.



Figure 2-20. Subset of freshwater fish sought by anglers (Freshwater Fish Identification (sc.gov)).

Recreation and Access in the Great Pee Dee River according to SCDNR:

> *"Those who fish the Great Pee Dee are known to seek a variety of species throughout the length of the river in a mix of fresh and saltwater environments. Freshwater fishes sought by anglers include various catfish, bass, bream, and shad species, also bowfin, carp, and gar. Saltwater fishes include red drum, black drum, seatrout, mullet, and flounder, as well as shrimp and blue crab."*

Twenty-nine species of freshwater mussels are in South Carolina, and 20 of these are present in the Pee Dee River basin. The health and presence of mussels can act as an indicator of ecosystem health, as they behave as filters for algae, bacteria, and fine particulate organic matter. Threats to mussel health include increased sediments, pollution from stormwater runoff, heavy metals and ammonia, and flow alterations.

The Pee Dee River basin provides habitat to numerous rare, threatened, and endangered species. In the counties with at least a portion of their areas in the Pee Dee River basin, there are 9 federally endangered species, 8 federally threatened species, and 18 at-risk species. Additionally, 46 species are protected by the Migratory Bird Treaty Act. The bald eagle, protected by the Bald and Golden Eagle Protection Act, has been noted in one county in the Pee Dee River basin. The basin is home to 9 state-listed endangered species, 9 state-listed threatened species, and 8 state-listed regulated species. State and federal endangered and threatened species in the counties covering the basin are listed in Table 2-11.

Table 2-11. Federal- and State-listed endangered and threatened species in Pee Dee River basin counties.

Federal Endangered	Federal Threatened	State Endangered	State Threatened
Shortnose Sturgeon	Seabeach Amaranth, Dwarf Amaranth	Shortnose Sturgeon	Loggerhead Sea Turtle
Atlantic Sturgeon	Loggerhead Sea Turtle	Piping Plover	Wilson's Plover
Red-Cockaded Woodpecker	Piping Plover	Rafinesque's Big-Eared Bat	Spotted Turtle
Schweinitz's Sunflower	Smooth Purple Coneflower	Red-Cockaded Woodpecker	Pine Barrens Treefrog
Carolina Heelsplitter	Pool-Sprite, Snorkelwort	Swallow-Tailed Kite	Carolina Pygmy Sunfish
Southern Spicebush, Pondberry	Black Rail	Pinewoods Darter	Bald Eagle
Pocosin Loosestrife, 'Roughleaf Loosestrife'	Wood Stork	Carolina Gopher Frog	Southern Hog-Nosed Snake
Northern Long-Eared Bat	Florida Manatee	Wood Stork	Broadtail Madtom
Canby's Cowbane		Florida Manatee	Least Tern

2.3.4 Natural and Cultural Preserves

Natural and cultural resources in South Carolina are protected by the SCDNR through two distinct programs: the Heritage Trust Program and the Wildlife Management Area (WMA) Program. According to SCDNR, the Heritage Trust Program was created in 1976 to "stem the tide of habitat loss by protecting critical natural habitats and significant cultural sites."

Ten natural preserves are in the Pee Dee River basin, and there are no cultural preserves. Additionally, six state parks are present within the basin. The locations of the sites are shown in Figure 2-21.

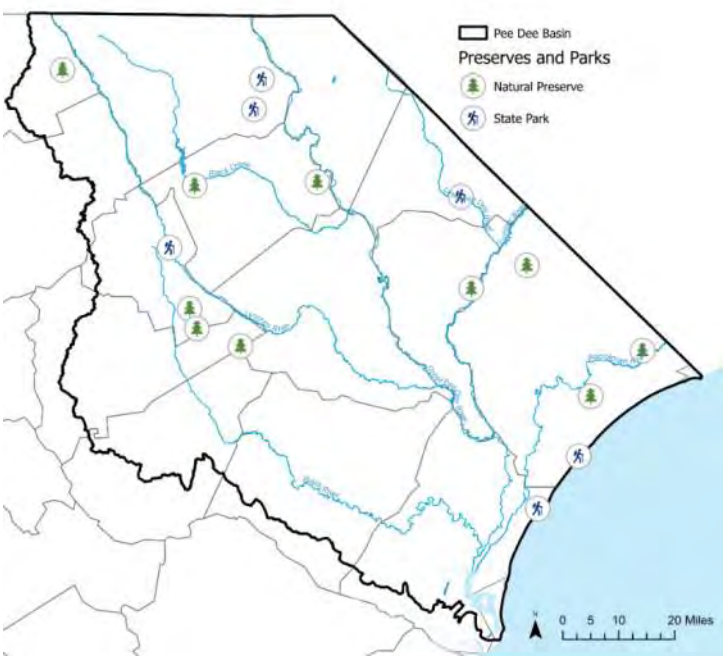


Figure 2-21. Natural preserves and state parks.

2.3.5 Land Protection

As South Carolina's population grows and land uses change, it will be important to preserve habitat, natural areas, historical sites, sites of unique ecological significance, forests, farmlands, wetlands, watersheds, open space, and urban parks. These land uses help maintain water quantity and quality as well as environmental attributes, recreational opportunities, and cultural assets.

Land protection provides a multitude of benefits to landowners and the public. From a water quantity perspective, preserved lands can maintain or enhance recharge to aquifers (both deep aquifers and alluvial aquifers) which help maintain groundwater supplies and can help attenuate flood flows. Preserved lands that maintain the historical function of wetland habitat and provide riparian buffers (land areas adjacent to a stream, lake, or wetland with naturally occurring vegetation) can filter runoff, attenuate flood flows, and help maintain water quality for both habitat and also downstream water users (thus reducing treatment costs). Protected lands also prevent habitat degradation as well as preserve greenways and open space.

The South Carolina Conservation Bank began evaluating ways to use open and protected land to enhance and protect water quality and watershed health back in 2000 through the Land Legacy Initiative. The initiative identified that offsetting urban lands with the preservation of greenways, open space, and parks help to "promote balanced growth and to promote the well-being and quality of life in South Carolina" (South Carolina Conservation Bank). Landscape-level land protection mechanisms such as conservation easements or State acquisition of real estate interests from willing sellers can preserve the historical attributes, uses, and functions of significant land areas and provide both ecological and human benefits at local and regional scales.

The Nature Conservancy maintains a database of lands that have been protected across South Carolina. Figure 2-22 shows the lands in the Pee Dee River basin that have been protected as of March 2024 through ownership by local, state, or federal agencies, conservation easements, and other mechanisms.

As indicated in Figure 2-22, protected lands in the Pee Dee River basin are owned and protected by a variety of entities and mechanisms. Table 2-12 summarizes the number of acres protected in the Pee Dee River basin by county, and Table 2-13 by owner or protection mechanism.

Table 2-12. Protected lands in each county of the Pee Dee River basin as of March 2024.

County	Area of Protected Land (acres)
Chesterfield	103,996
Clarendon	18,121
Darlington	19,901
Dillon	4,572
Florence	9,026
Georgetown	103,333
Horry	61,340
Kershaw	1,721
Lancaster	5,608
Lee	13,651
Marion	43,669
Marlboro	8,726
Sumter	24,497
Williamsburg	30,861
Total:	449,021

Table 2-13. Protected lands by category the Pee Dee River basin as of March 2024.

Category	Area of Protected Land (acres)
State	169,432
Private	157,717
Federal	103,197
Other Managed Land*	12,222
Local Government	6,453
Total:	449,021

* Other Managed Lands include lands held by non-traditional protection groups such as U.S. Dept. of Defense, U.S. Dept. of Energy, U.S. Army Corps of Engineers, or private entities

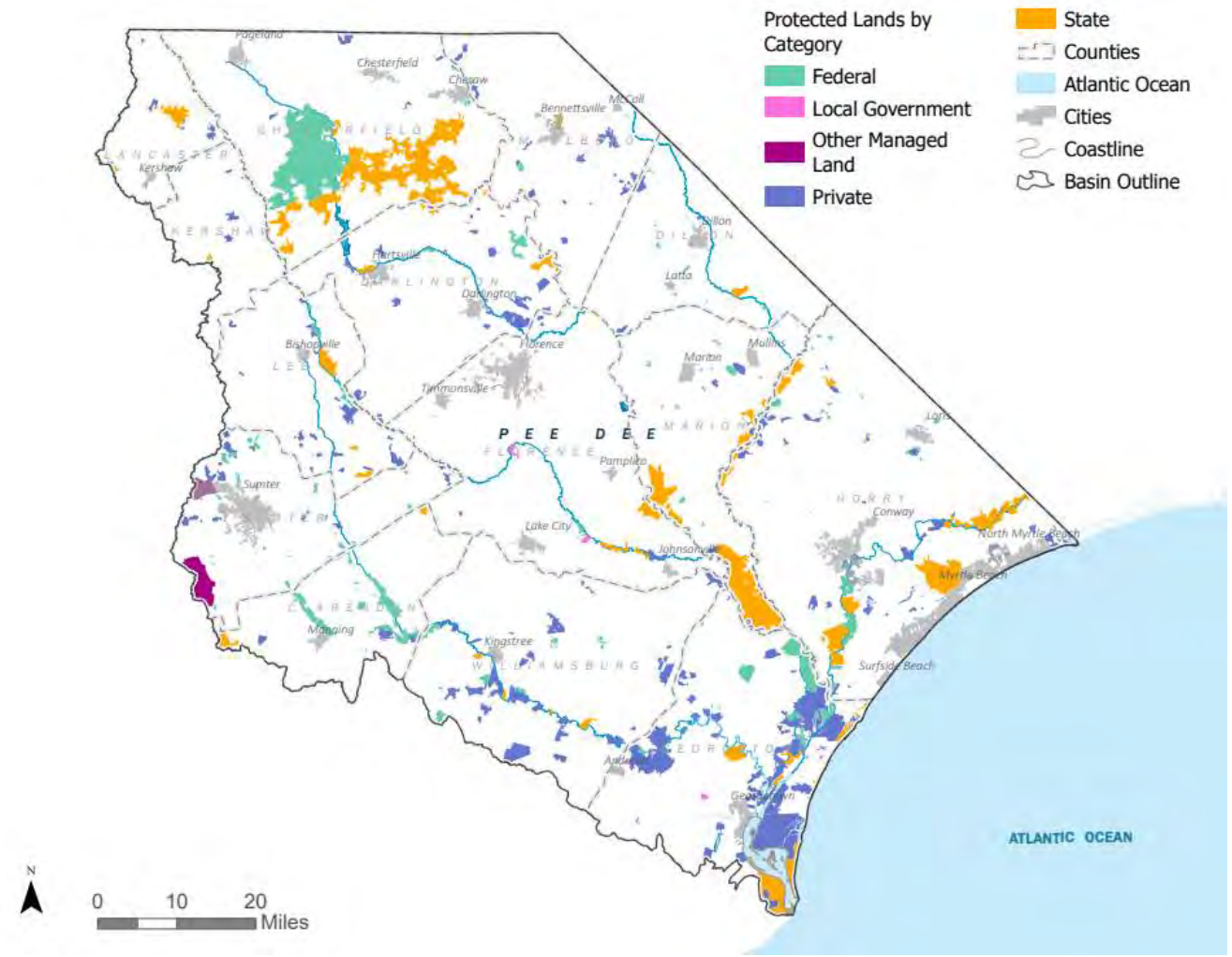


Figure 2-22. Protected Lands in the Pee Dee River basin as of March 2024.

The amount of protected land varies across the Pee Dee River basin, with some watersheds containing more protected land than others. Figure 2-23 illustrates the percentage of protected land by each of the HUC10 watersheds in the basin. While some watersheds have significant protected land areas, others contain less than 1.5 percent by area.

Figure 2-22 and Figure 2-23 along with Tables 2-12 and 2-13 show that lands have been protected throughout the Pee Dee River basin with concentrations in the northern end of the basin, coastal areas, and along major waterways including the Black River, Lynches, Little Pee Dee, and Waccamaw. Protection of lands in the northern part of the basin helps maintain the quality of the recharge that supplies the aquifers that provide groundwater for a variety of uses throughout the basin. Land protection and vegetated riparian buffers along waterways enhance habitat for fish and wildlife while protecting the quantity and quality of surface water supplies.

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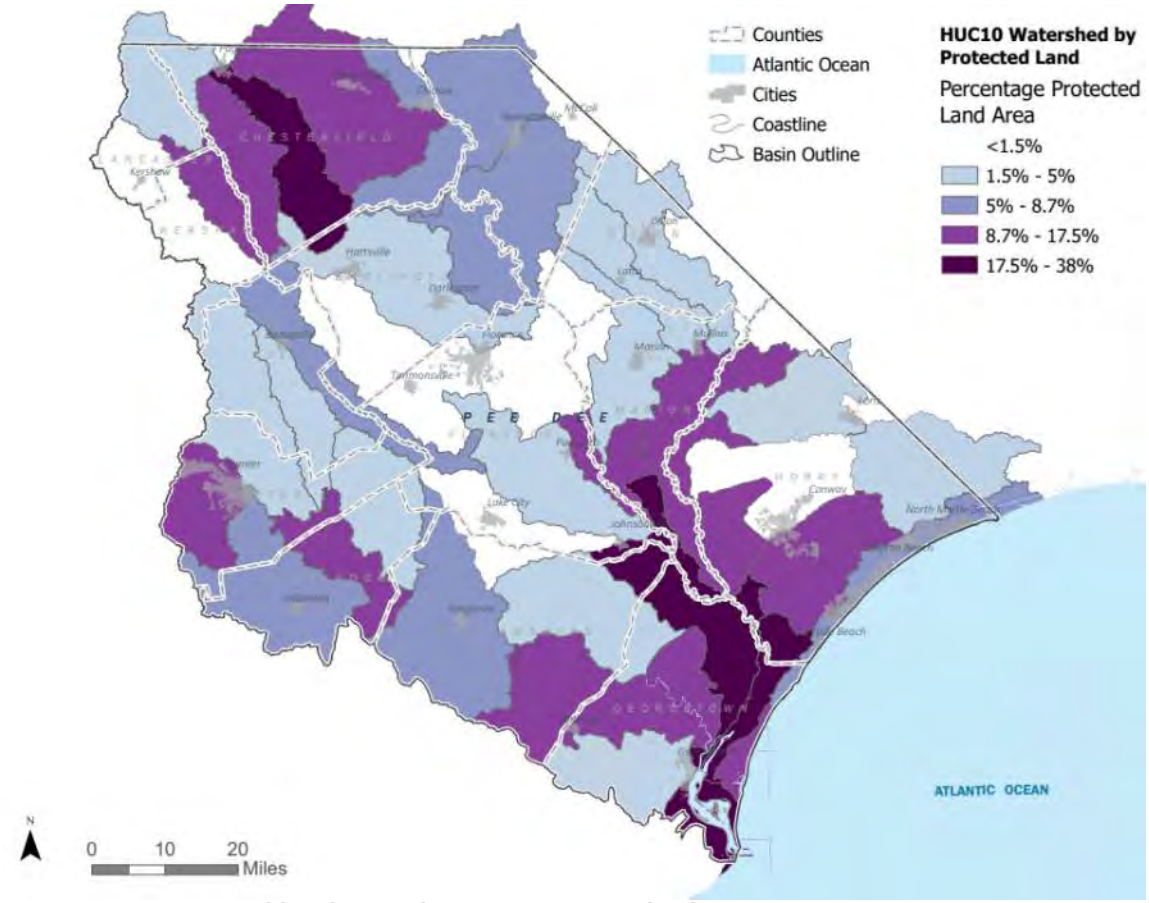


Figure 2-23. Protected land areas by HUC10 watershed.

The State of South Carolina has been actively working to preserve vital land areas across the state. In 2002, legislation was passed to form the South Carolina Conservation Bank. The bank pursues its mission of conserving significant sites through working with landowners who voluntarily sell their property or enter into conservation easements that retain the historical use of the land.

More information on the bank and their statewide conservation priorities can be found at:

https://sccbank.sc.gov/

2.4 Agricultural Resources

2.4.1 Agriculture and Livestock

Farmland makes up a significant portion of the Pee Dee River basin, and agricultural production is integral to the basin's economy. Figure 2-24 shows areas of the basin that are suitable for farmland as inventoried by the NRCS. While the northwest section of the basin has fewer areas suitable for farmland, the southern half of the basin is largely represented as farmland. Prime farmland is defined as the land with the best combinations of physical and chemical characteristics for producing food, feed, forage, fiber, and oilseed crops and is available for these uses. It has an adequate and dependable supply of moisture from precipitation or irrigation, a favorable temperature and growing season, a water supply that is dependable and of adequate quality, is not excessively erodible or saturated with water for long periods, and has slopes mainly ranging from 0 to 6 percent. Farmland of statewide importance is land that nearly meets the requirements of prime farmland and that can economically produce high-yield crops when treated and managed with acceptable farming methods. The distribution of the farmland types across the basin is shown in Figure 2-24 and Table 2-14.

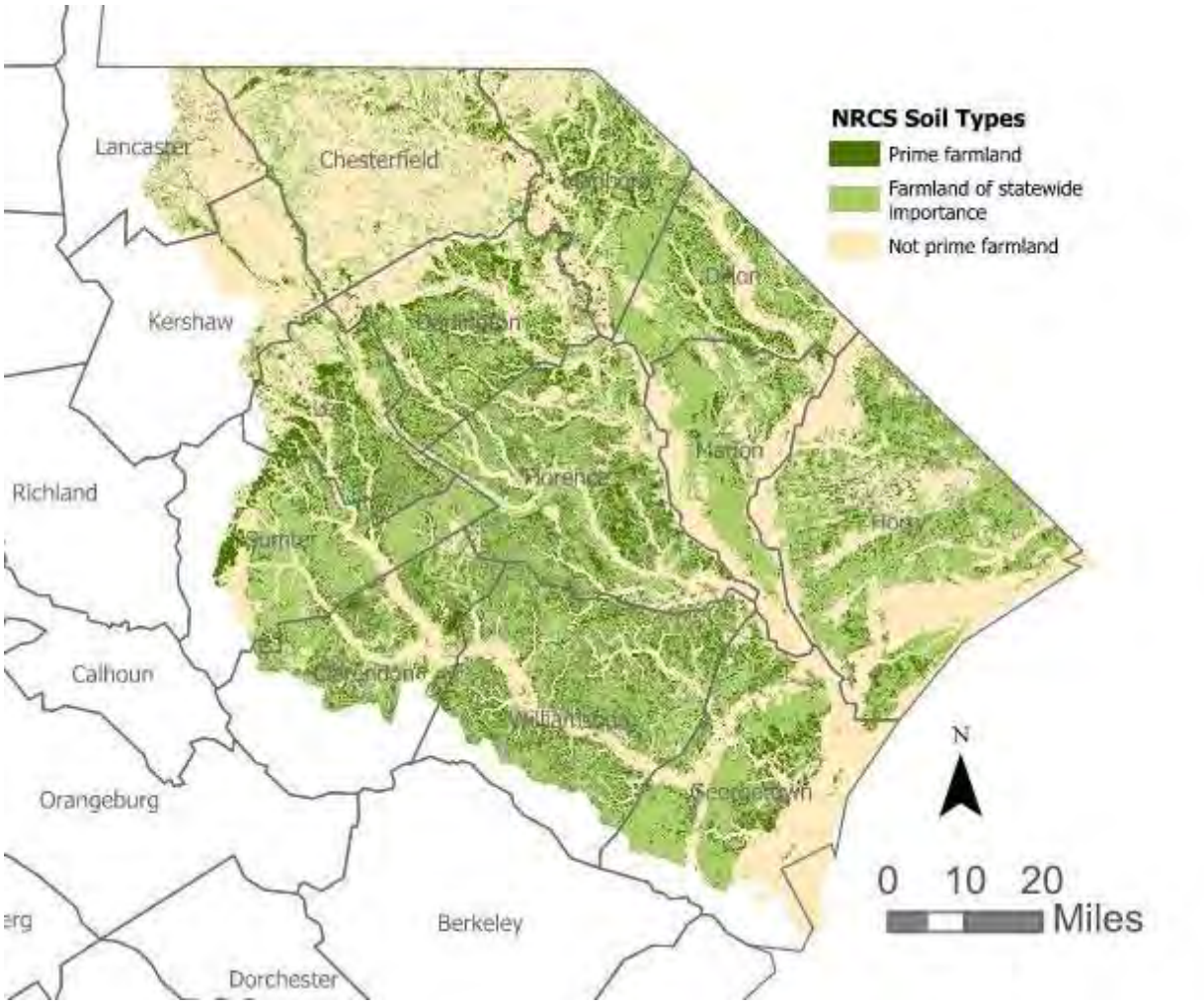


Figure 2-24. Location of NRCS-categorized farmland in the Pee Dee River basin.

Table 2-14. Area of NRCS-categorized farmland in the Pee Dee River basin.

Farmland Type	Area (acres)	Area (sq mi)	Percent of Basin
Prime farmland	1,253,833	1,959	24.9%
Prime farmland if drained	279,618	437	5.6%
Prime farmland if drained and either protected from flooding or not frequently flooded during the growing season	10,037	16	0.2%
Prime farmland if protected from flooding or not frequently flooded during the growing season	18,848	29	0.4%
Farmland of statewide importance	1,750,379	2,735	34.8%
Not Prime Farmland	1,714,678	2,679	34.1%
Total	5,027,393	7,855	100%

The Pee Dee River basin also contains significant livestock operations throughout the basin, which are shown in Figure 2-25 (SCDES).

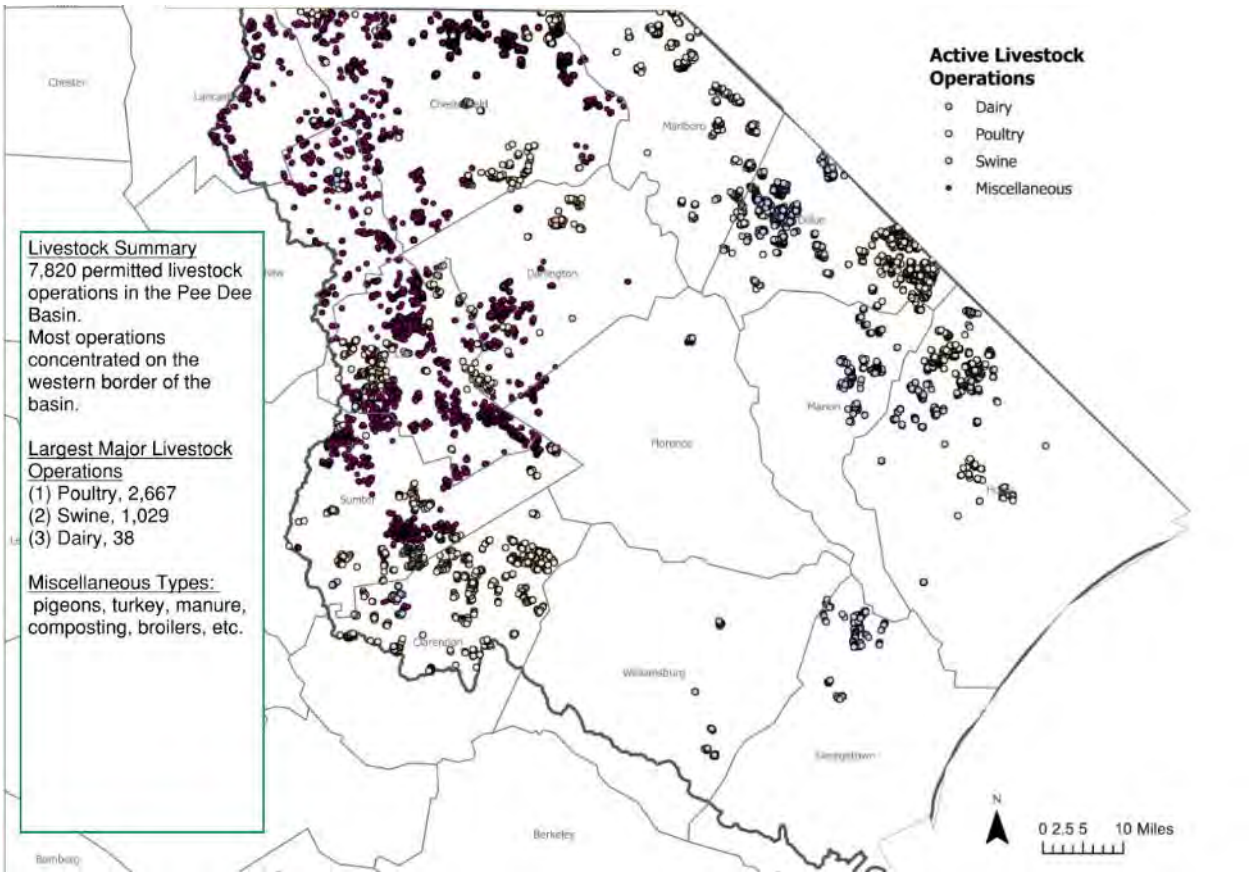


Figure 2-25. Livestock operations summary.

The number of farms in the state has generally increased since 1992, but growth has slowed and tapered since 2007. While the growth of farms has been variable and begun to decline slightly, irrigation has steadily increased. A comparison of these two trends is shown in Figure 2-26.

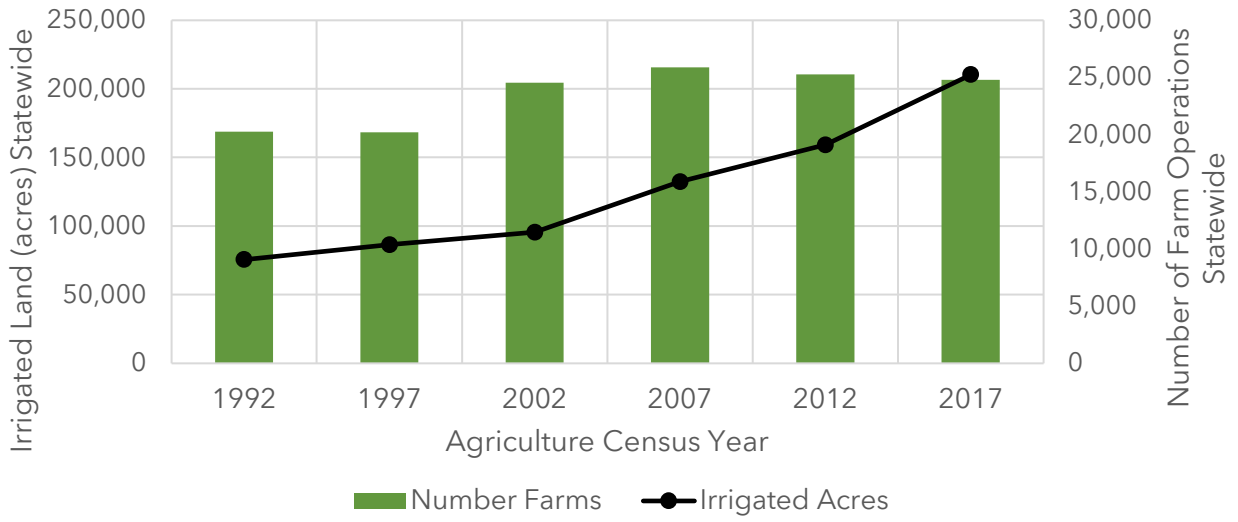


Figure 2-26. Number of farm operations and irrigated acreage statewide.

Table 2-15 shows the irrigated area for each of the fourteen counties in the basin. While not all of these counties are fully contained within the basin, the table provides context into the approximate magnitude of irrigation present in the Pee Dee River basin. Sumter County and Lee County, while not fully contained in the basin, both have the largest irrigated areas. As shown in Figure 2-25, the highest concentrations of active livestock operations are in those counties. Darlington County, which has the fourth highest irrigated acreage overall in Table 2-15, has the most irrigated acreage of the counties fully contained in the basin.

Table 2-15. 2017 Irrigated areas by county in the Pee Dee River basin.

County	2017 Irrigated Land (acres)
Chesterfield*	1,584
Clarendon	8,871
Darlington*	6,102
Dillon*	353
Florence*	1,324
Georgetown	196
Horry*	2,278
Kershaw	386
Lancaster	519
Lee	15,602
Marion*	490
Marlboro*	3,494
Sumter	19,133
Williamsburg	2,638

* County fully contained within the watershed

More specific data from the Census of Agriculture is presented in Figure 2-27 for three example counties within the Pee Dee River basin: Florence, Chesterfield, and Darlington. Figure 2-27 shows the number of farms and the irrigated acreage in these counties. In addition to Darlington, which was described above as having the largest irrigated acreage of the fully-contained counties, Florence and Chesterfield are two large counties contained within the basin, which both contain relatively average irrigated area for the watershed. The irrigation trends in Chesterfield and Florence are relatively steady over time, while Darlington's irrigated acreage significantly increased from 2002 through 2012. However, while the large changes in irrigated acreage occurred in Darlington, the figure shows that the number of farms remained relatively constant over the reporting period.

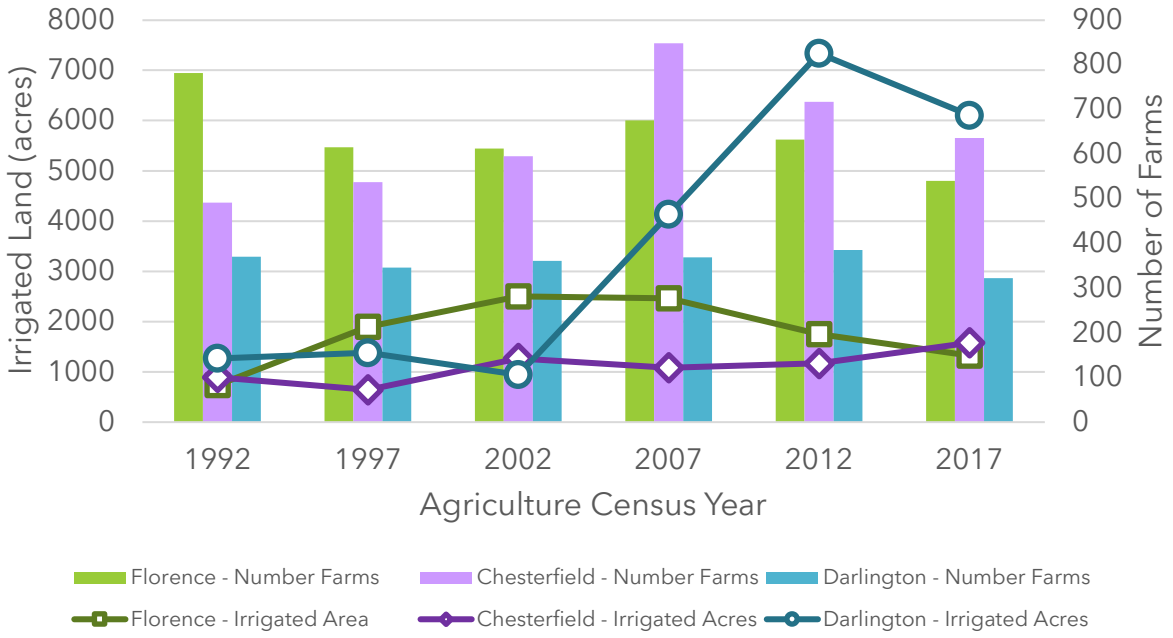
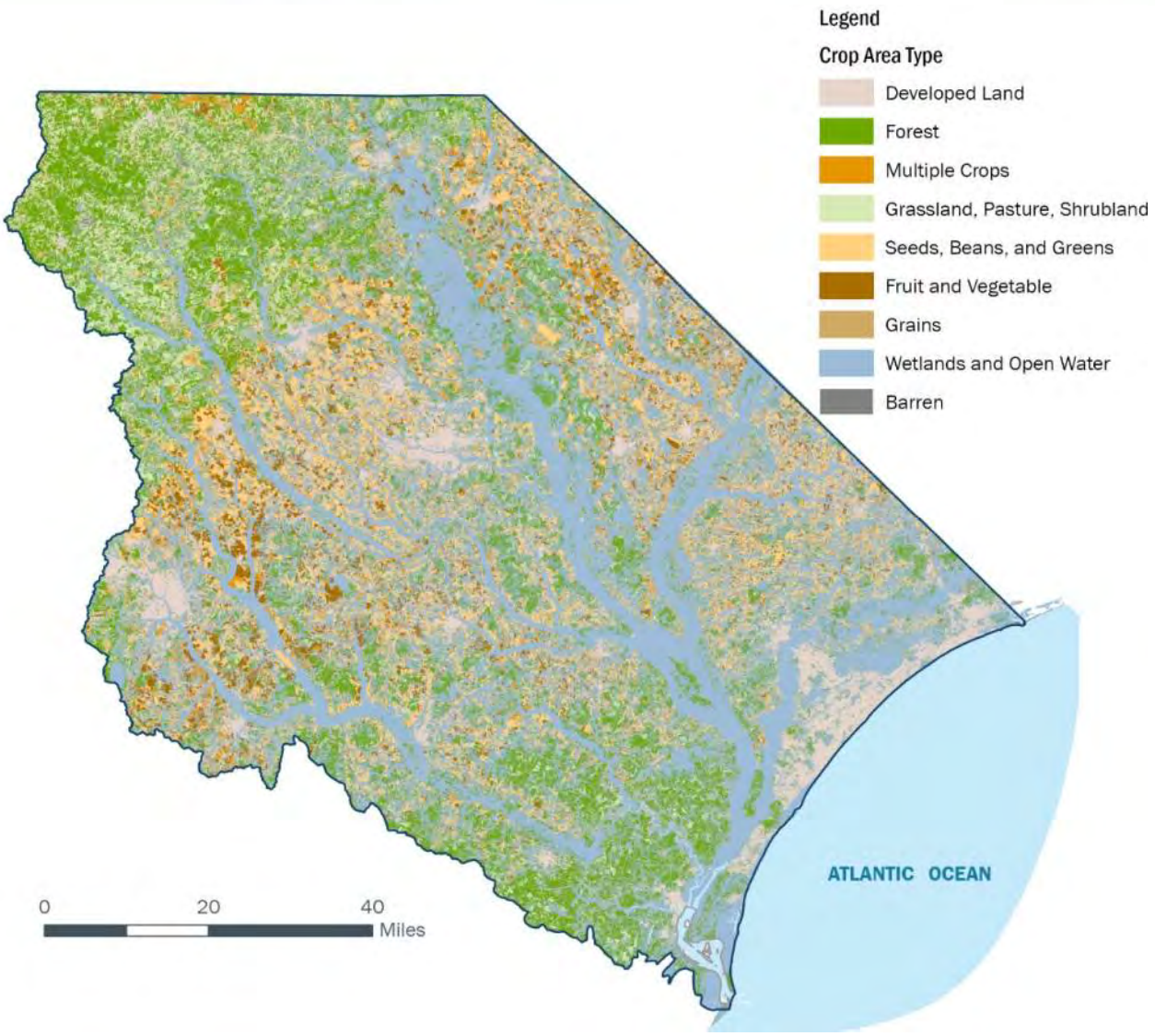


Figure 2-27. Number of farms and irrigated acreage in Florence, Chesterfield, and Darlington Counties.

Figure 2-28 shows farmland in the basin by general crop type as well as other land cover types. Similar to trends with livestock operations and irrigated lands, the central-western side of the basin and the northeastern side along the border with North Carolina both contain significant areas of cropland. The various crop types are relatively well distributed throughout the agricultural areas across the basin.



Cotton field in the Pee Dee River basin.
(Photo credit: Matt Lindburg)



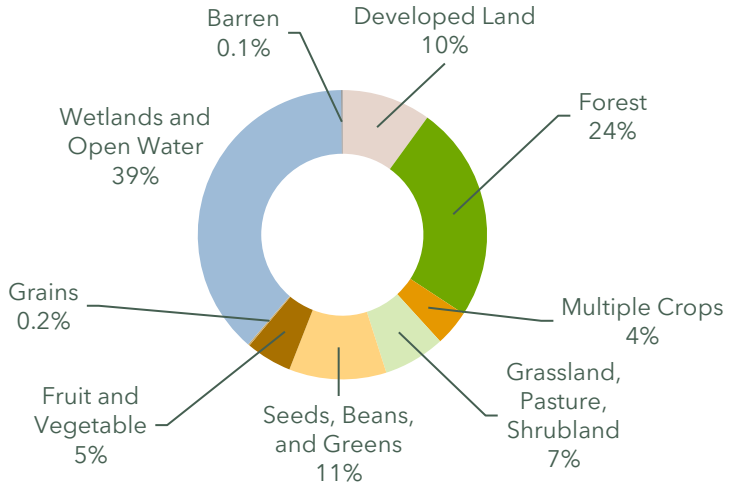


Figure 2-28. Crop areas (and other land uses) and associated percentages in the basin.

Irrigation surveys conducted by Clemson University from 1997 to 2000 identified several types of irrigation methods used in Pee Dee River basin counties, including sprinkler systems, gravity and flood systems, and low-flow or drip systems. The irrigation surveys provided a more comprehensive picture of the types of irrigation technologies used relative to other data sets. In the Pee Dee River basin, sprinkler systems are most numerous; specifically, center pivot irrigation systems are present throughout the basin. The percentage of sprinkler systems as compared to other types of irrigation, from 1997 to 2000, is shown in Figure 2-29. Note that basin wide information was computed using county-specific data. Irrigation systems in counties not fully within the Pee Dee River basin were assumed be distributed equally in areas within and outside of the basin.

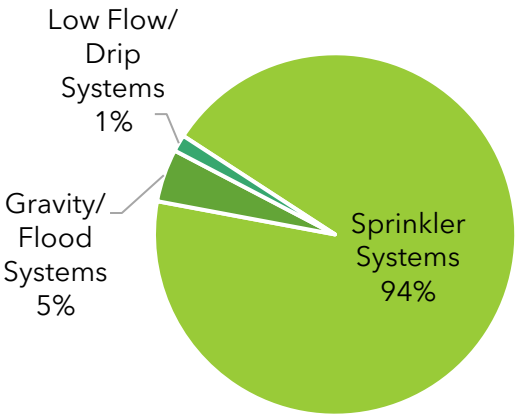


Figure 2-29. Irrigation system types in the Pee Dee River basin.

Figure 2-30 shows the location of center pivot irrigation systems throughout the basin (Pellet, 2020; Sekaran and Payero, 2023), which are most densely concentrated in Lee and Sumter counties.

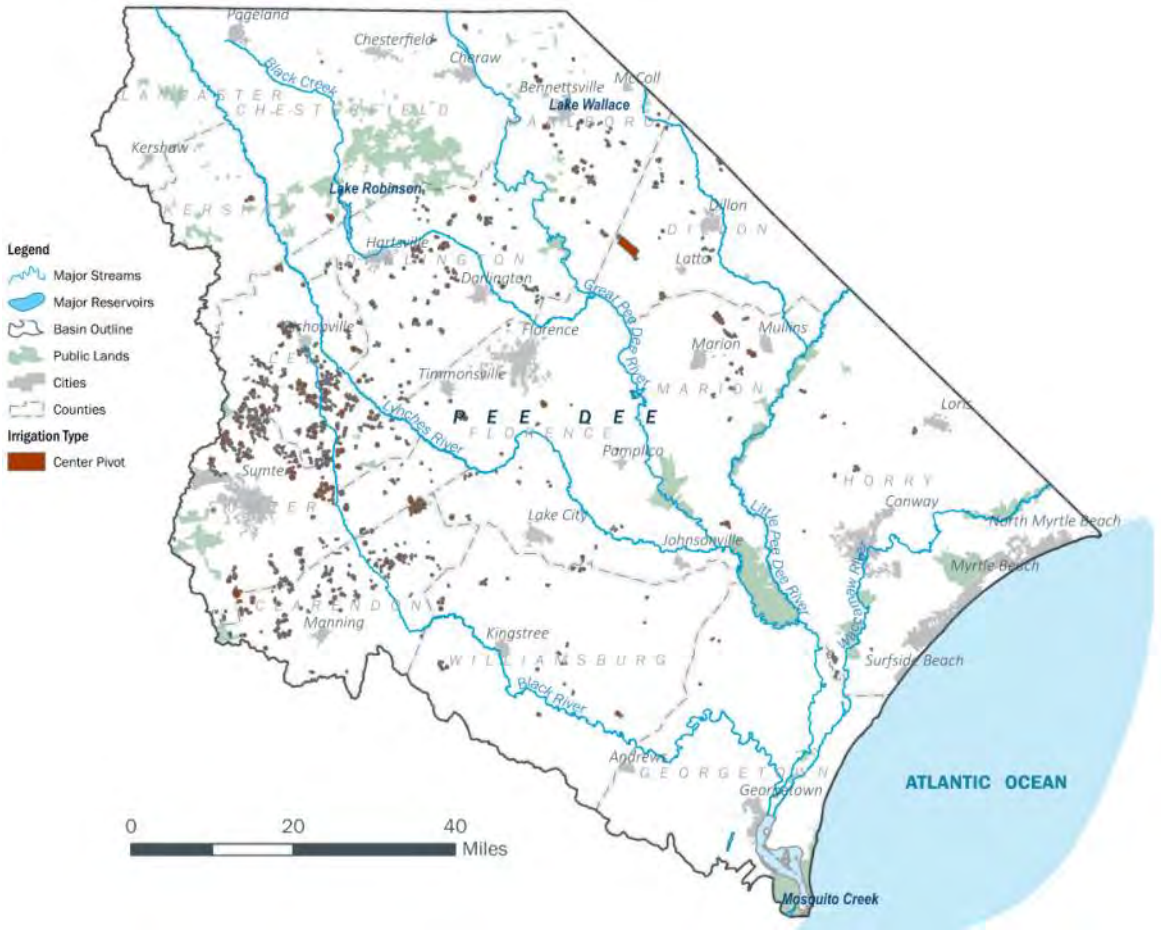


Figure 2-30. Location of center pivot irrigation systems in Pee Dee River basin.

2.4.2 Silviculture

Silviculture is a foundational component of South Carolina's economy. It contributes $21.2 billion annually to the economy and ranks first in jobs, second in labor income, and third in direct economic output compared to other leading industries in the state.

Table 2-16 shows harvested timber values for counties that are within or overlap the Pee Dee River basin. The Pee Dee River basin includes counties that overlap the basin and rank in the top 5 in South Carolina in terms of the value of harvested timber (Georgetown County at 2nd and Williamsburg County at 4th). Horry County and Chesterfield County, which are wholly within the basin, rank in the top 10 statewide.

Table 2-16. Value of timber delivered to South Carolina mills, 2017.

County	Acres of Forestland	Percent Forest	Harvested Timber Value		Statewide Rank
			Stumpage**	Delivered***	
Chesterfield*	372,982	73%	$16,353,705	$32,730,172	8
Clarendon	227,130	58%	$12,057,156	$26,252,963	15
Darlington*	159,574	45%	$9,485,720	$20,920,742	25
Dillon*	144,098	56%	$7,815,811	$15,583,687	34
Florence*	338,394	64%	$13,642,304	$28,966,817	13
Georgetown	416,817	73%	$26,171,471	$57,399,379	2
Horry*	468,514	63%	$14,573,239	$32,149,733	9
Kershaw	338,966	72%	$11,014,911	$25,364,228	16
Lancaster	266,882	76%	$8,838,992	$20,253,991	27
Lee	122,038	47%	$8,060,780	$17,244,602	30
Marion*	251,237	52%	$7,431,757	$14,789,467	35
Marlboro*	227,272	69%	$12,339,560	$25,197,815	17
Sumter	275,647	64%	$11,857,570	$26,948,229	14
Williamsburg	407,098	71%	$23,138,222	$48,877,501	4

* County fully contained within the watershed

** Stumpage is the value of standing trees or "on the stump"

*** Delivered is the value of the trees when they are delivered to the mill and considers all costs associated with cutting, preparing, and hauling timber to the plant.

2.4.3 Aquaculture

The 2017 Census of Agriculture ranks each county in the state by aquaculture production. Some counties were listed as having no aquaculture, while the remaining are assigned a rank. Seven out of the 14 counties in the watershed were listed as containing aquaculture, and Table 2-17 presents the ranks for these counties.

Table 2-17. Counties in the Pee Dee River basin with aquaculture and their relative rank in terms of production.

County	State Rank (out of 22)
Chesterfield	6
Lancaster	7
Horry	9
Darlington	11
Sumter	15
Clarendon	16
Kershaw	22

2.5 Socioeconomic Development

2.5.1 Population and Demographics

The Pee Dee River basin contains a mix of rural and urban areas. Large portions of the basin are rural in nature, and cities like Florence, Sumter, and Myrtle Beach contain more highly developed, urban, and population-dense areas. The 2020 population of the Pee Dee River basin was 1,089,700. Figure 2-31 shows the population density throughout the basin.

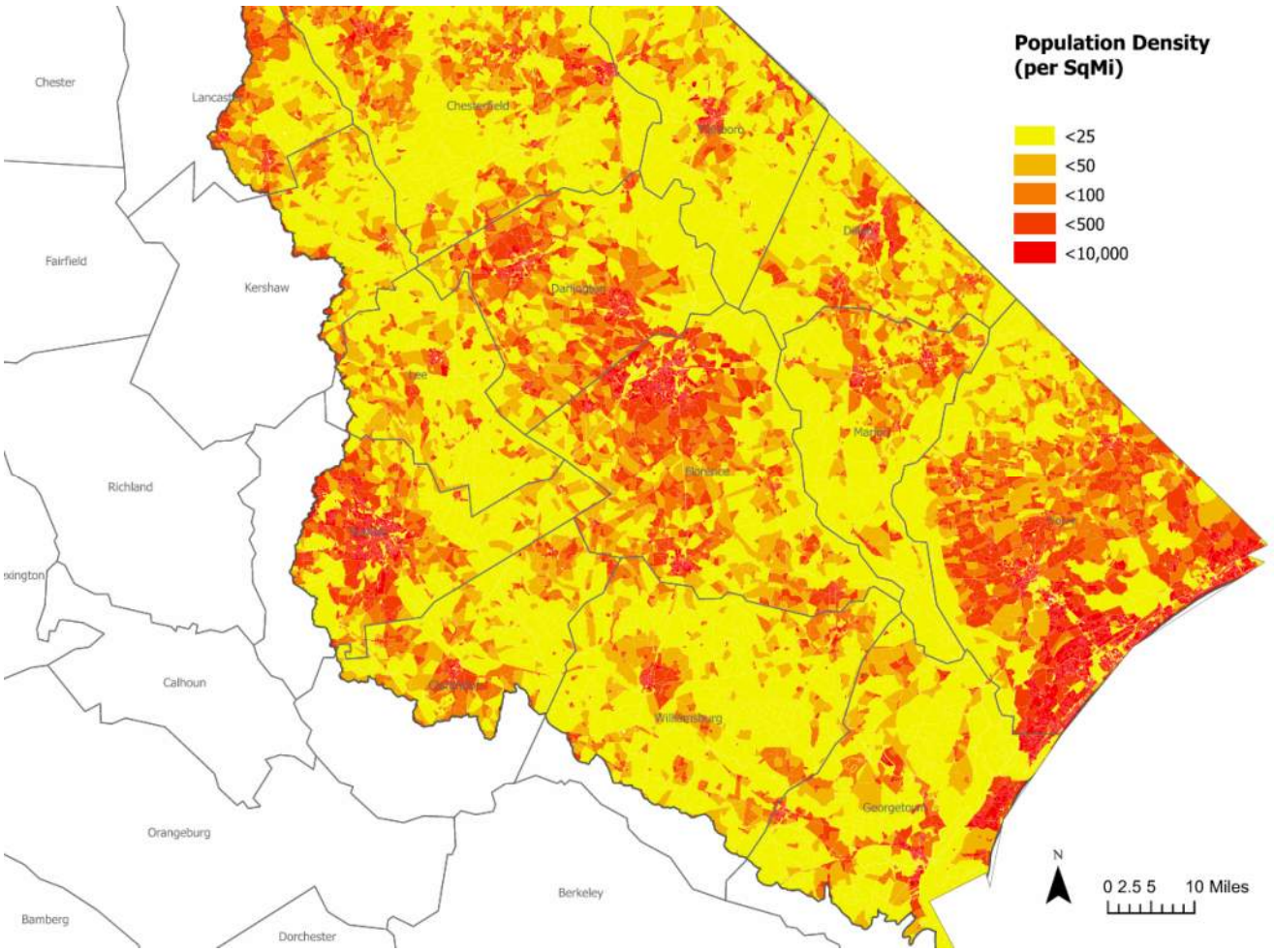


Figure 2-31. Population density of Pee Dee River basin (U.S. Census Bureau 2020).

According to the U.S. Bureau of Labor Statistics, the annual per capita income in South Carolina in 2022 was $57,836. The average per capita income across the fourteen counties in the Pee Dee River basin is approximately $50,100, which is below the statewide average. Chesterfield has the lowest per capita income in the basin of $39,047, and the highest is in Georgetown County, with an average per capita income of $63,946.

The population centers of the Pee Dee River basin have evolved over the past decade, as depicted in Figure 2-32. Most of the basin has stayed relatively consistent, if not decreasing in population slightly

over the decade, while more urbanized areas experienced more growth, particularly Horry County and the Myrtle Beach area.

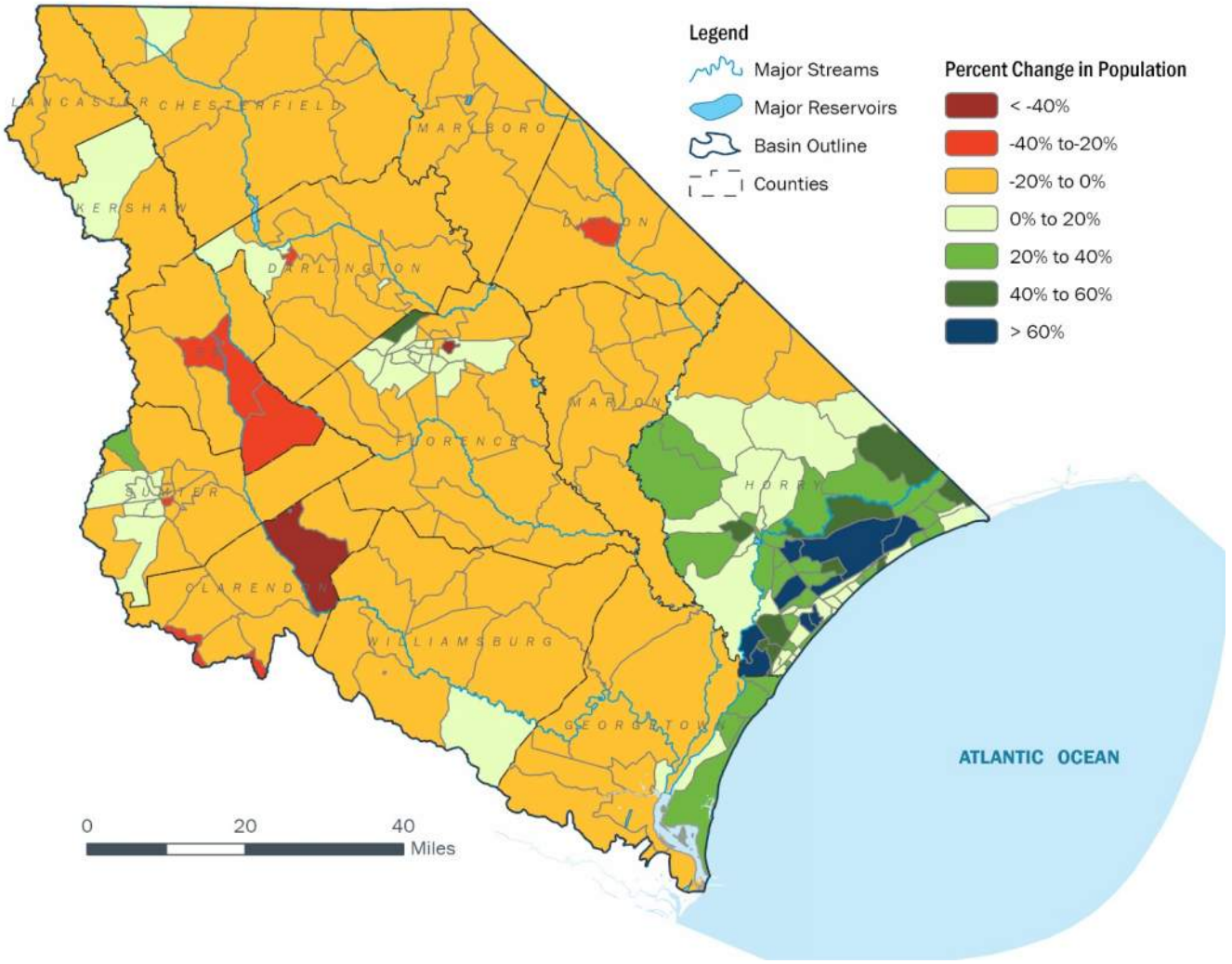


Figure 2-32. Population change in the Pee Dee River basin from 2010 to 2020 (U.S. Census Bureau).

2.5.2 Economic Activity

The 2021 gross domestic product (GDP) associated with a variety of sectors was collected from the South Carolina Regional Economic Analysis Project (REAP) and is shown in Figure 2-33. Data describing GDP was provided for each county by industry. Basin wide information was aggregated by assuming that the GDP is directly proportional to the area of a county present in the basin. For example, 55% of Clarendon County is located in the Pee Dee River basin. Therefore, the 55% of the county-wide GDP for Clarendon was attributed to the Pee Dee River basin.

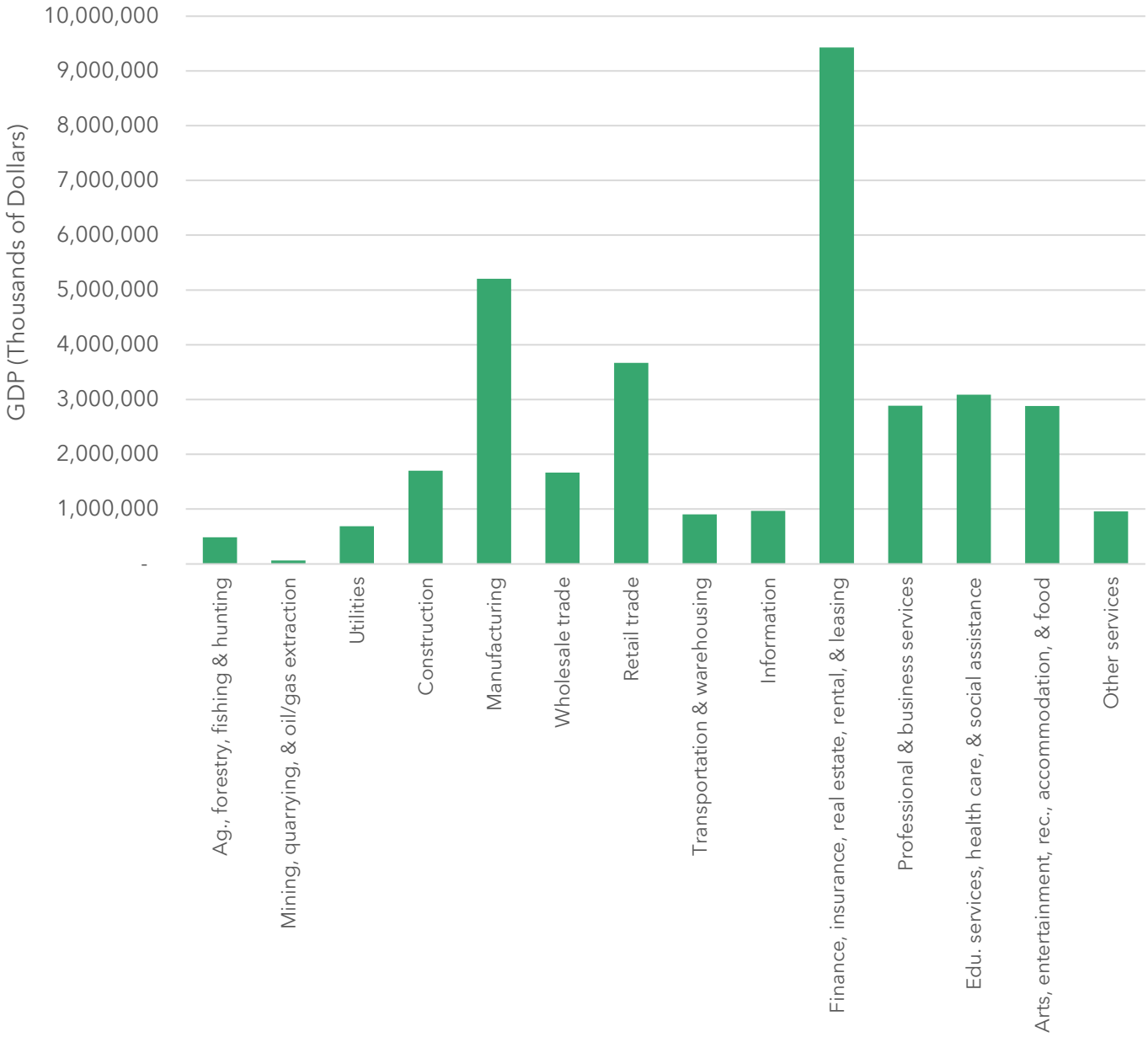


Figure 2-33. Gross domestic product by category for entire Pee Dee River basin.

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Chapter 3
Water Resources of the Pee Dee River Basin

3.1 Surface Water Resources

3.1.1 Major Rivers and Lakes

The mainstem of the Great Pee Dee River (Pee Dee River) is the dominant hydrologic feature of the basin. As shown in Figure 2-3, the river originates in North Carolina and receives most of its flow from drainage in North Carolina (SCDNR 2009). Other major rivers that flow into the Pee Dee River include the Little Pee Dee River, Lynches River, Black River, and Waccamaw River.

Streams in the upper part of the basin originate in or traverse the upper Coastal Plain. These streams, such as Black Creek and Cedar Creek, exhibit steady flows that are maintained by discharge from groundwater storage, particularly during periods of low rainfall. Most streams in this basin are associated with extensive swamp areas and follow indistinct channels that often divide and recombine. Lower Coastal Plain streams, such as Catfish Canal, exhibit more variable flow and typically are more dependent on rainfall and runoff than on groundwater discharge to support flows (SCDNR 2009).

Although the Pee Dee River in South Carolina is free-flowing, in North Carolina it is regulated by a series of six large reservoirs, the last of which, Blewlett Falls Lake, is located 15 miles upstream of the state border. The Pee Dee River basin has experienced limited surface-water development in South Carolina, consisting primarily of small-scale flood-control projects. The largest reservoir, Lake Robinson, is located on Black Creek and is owned and operated by Duke Energy Progress, LLC (SCDNR 2009).

Figure 3-1 shows the location of the major subbasins, the major estuarine and riverine wetlands, and small lakes and ponds in the Pee Dee River basin from the U.S. Fish and Wildlife Service (USFWS). Near the coast, the basin is dominated by estuarine and marine deepwater and wetlands, which are influenced by saltwater streams from border marshes and creeks. Freshwater emergent wetlands are present immediately upstream, and freshwater forested/shrub wetlands dominate the upper Coastal Plain.

The SC Watershed Atlas is a data-rich online tool with multiple layers of water-related mapping and functions. Users can explore mapping and information on topics such as surface and groundwater withdrawals, water use permits, public water supply intakes, water quality, and land cover. Users can add data, create layers from selected features, export attribute data, view watershed information at their current location, save their sessions, and restore sessions again later.

https://des.sc.gov/programs/bureau-water/watersheds-program/sc-watershed-atlas

SC Watershed Atlas

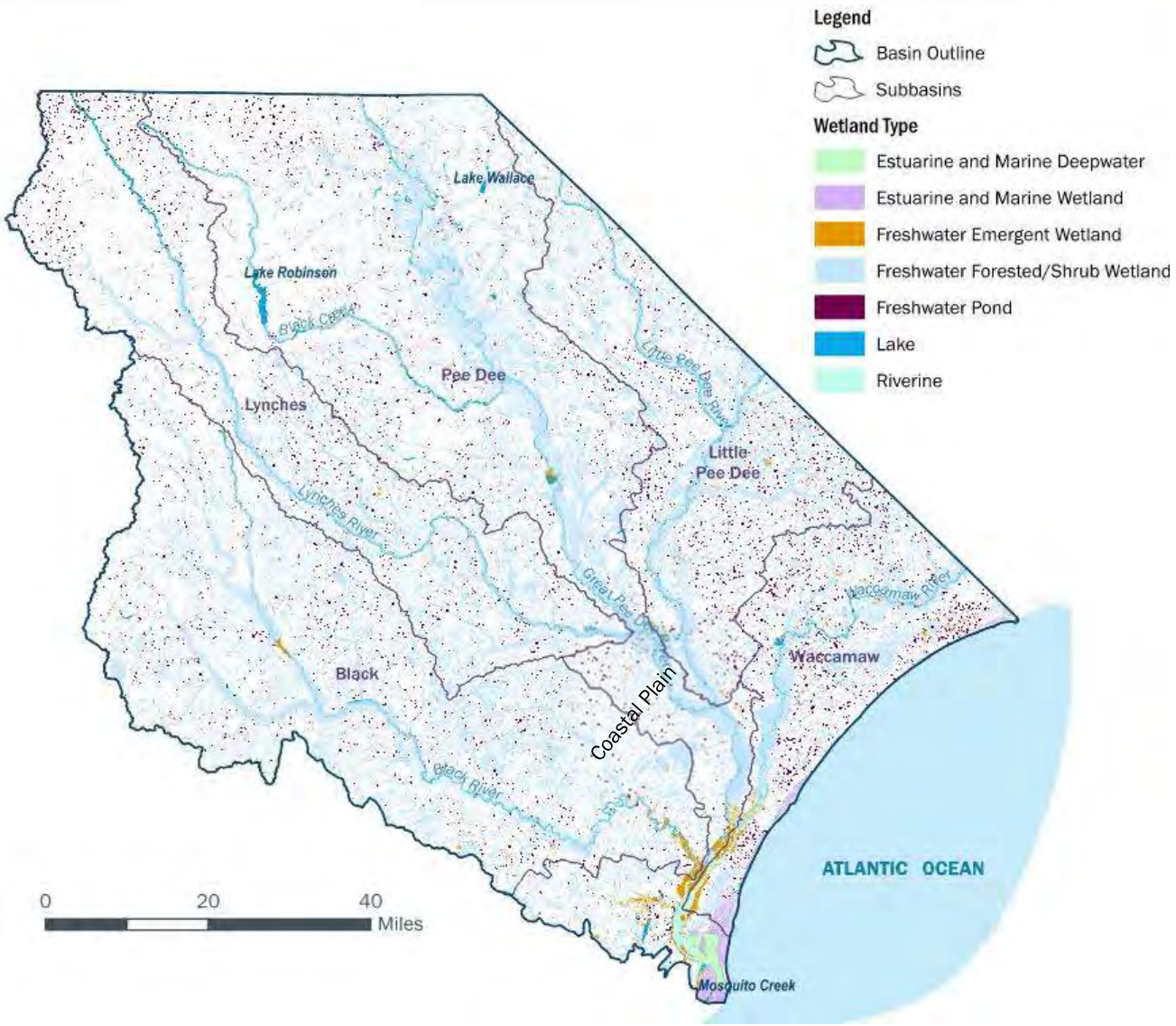


Figure 3-1. Wetland types of the Pee Dee River basin (USFWS 2023).

3.1.2 Surface Water Monitoring

Forty-seven USGS streamflow monitoring sites are active throughout the basin in South Carolina, encompassing the Pee Dee River, Little Pee Dee River, Black Creek, Black River, Lynches River, Little Lynches River, Waccamaw River, and Atlantic Intracoastal Waterway (AIW). A gaging station on the Pee Dee River outside the state near Cordova, NC, also provides useful flow data. Figure 3-2 shows a map with the active gaging stations in the Pee Dee River basin.

In addition, Table 3-1 summarizes streamflow characteristics at select stream gages. At these stream gages, median flows are lower than mean flows due to the influence of occasional short duration flood events which exceed the mean daily flows.

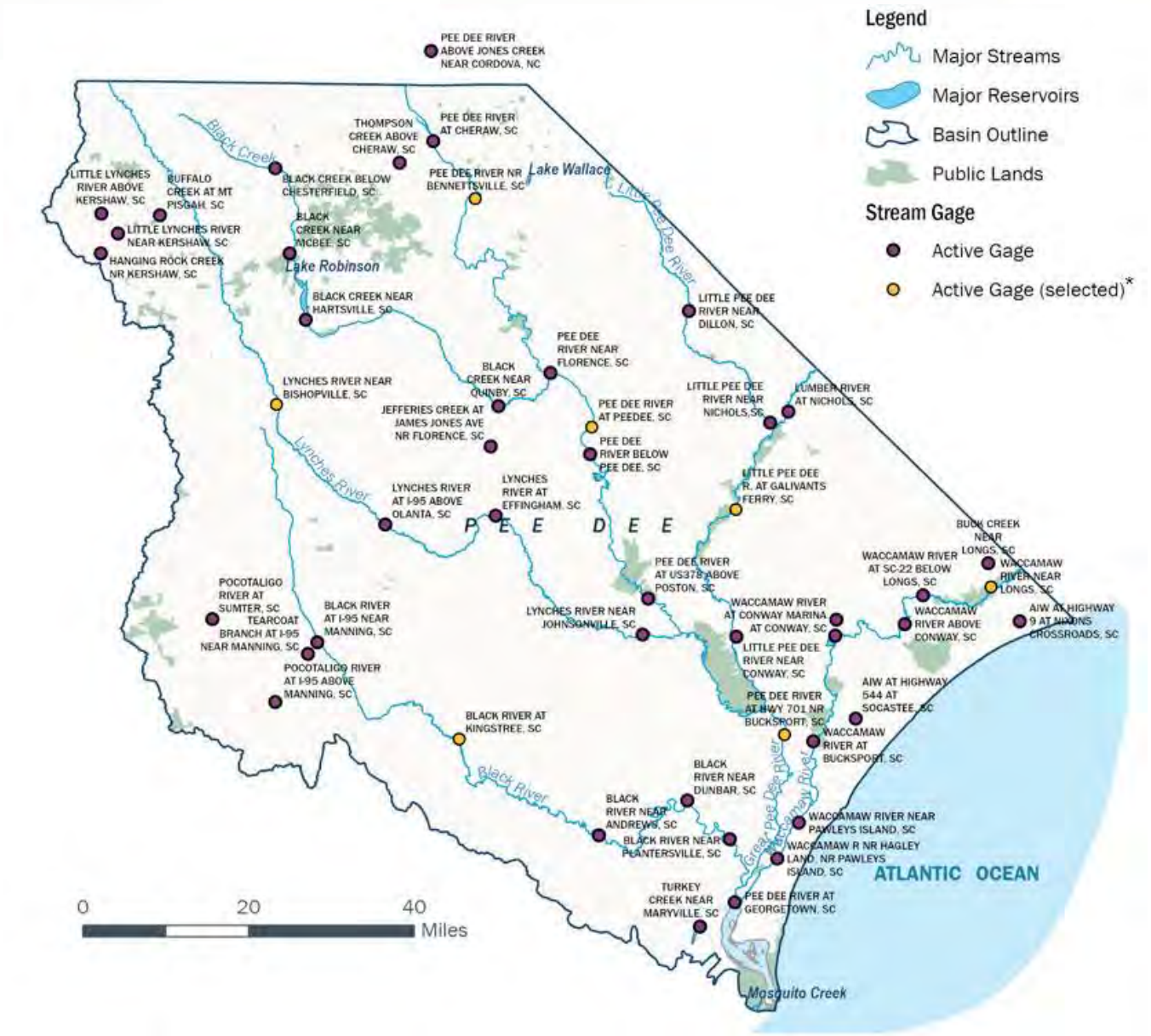
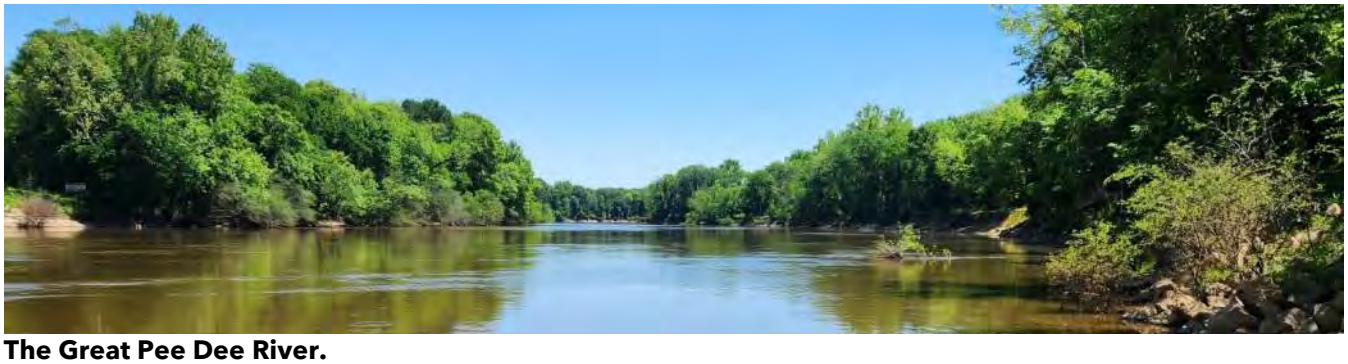


Figure 3-2. USGS streamflow gaging stations.
** Active Gage (selected) indicates gages that have streamflow characteristics summarized in Table 3-1.*



The Great Pee Dee River.
(Photo credit: Matt Lindburg)

Table 3-1. Streamflow characteristics at USGS gaging stations in the Pee Dee River basin.*

Gaging Station Name	Station Number	Period of Record	Minimum Daily Flow (cfs), (year)	Median Daily Flow (cfs)	Average Daily Flow (cfs)	75th percentile (cfs)	Maximum Daily Flow (cfs), (year)
Pee Dee River near Bennettsville	02130561	1990-2023	48 (2000)	5,060	7,934	9,340	173,000 (2018)
Pee Dee River at Peedee, SC	02131000	1938 - 2023	653 (2007)	6,820	9,504	12,100	217,000 (1945)
Pee Dee River at Hwy 701 NR Bucksport, SC	02135200	2001 - 2023	637 (2007)	9,670	13,285	16,450	137,000 (2018)
Little Pee Dee River at Galivants Ferry, SC	02135000	1942 -2023	73 (2002)	1,990	2,955	3,810	64,000 (2018)
Black River at Kingstree, SC	02136000	1929 – 2023	2 (1954)	462	945	1160	78,200 (2015)
Lynches River near Bishopville, SC	02131500	1942 - 2023	33 (2002)	459	701	824	27,300 (2003)
Waccamaw River Near Longs, SC	02110500	1950 – 2023	1 (1954)	700	1246	1610	53,700 (2018)

*Data gathered from USGS National Water Information System for data through June 23, 2023 to calculate statistics.

Duration hydrographs showing streamflow throughout the year at select gaging stations in the Pee Dee, Little Pee Dee, Lynches, Black, and Waccamaw subbasins are shown in Figure 3-3.

The hydrographs show similar seasonal patterns with normal flows at their highest in February through April, and the lowest flows in July through September. Flows along the Pee Dee River and Lynches River show more variability.

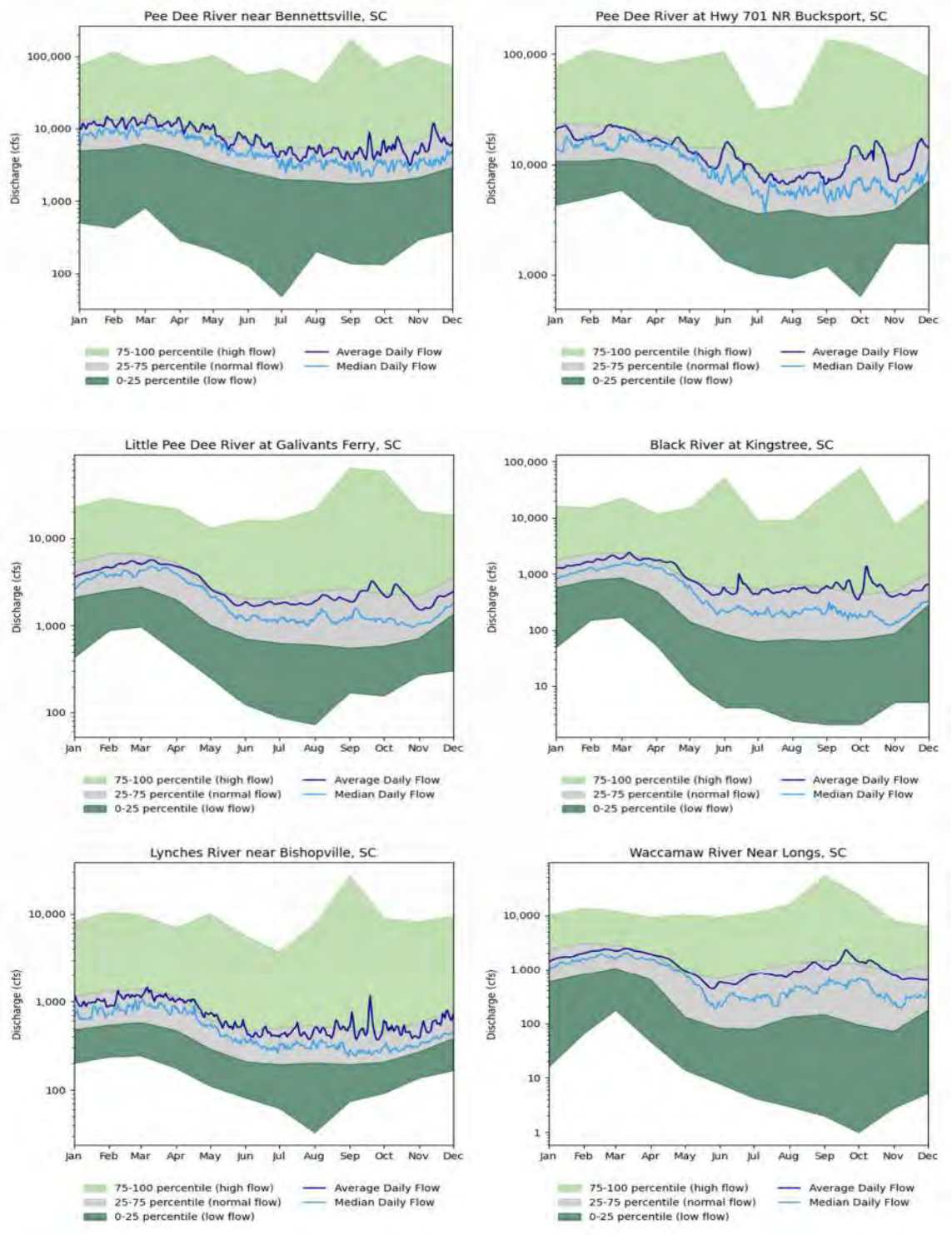
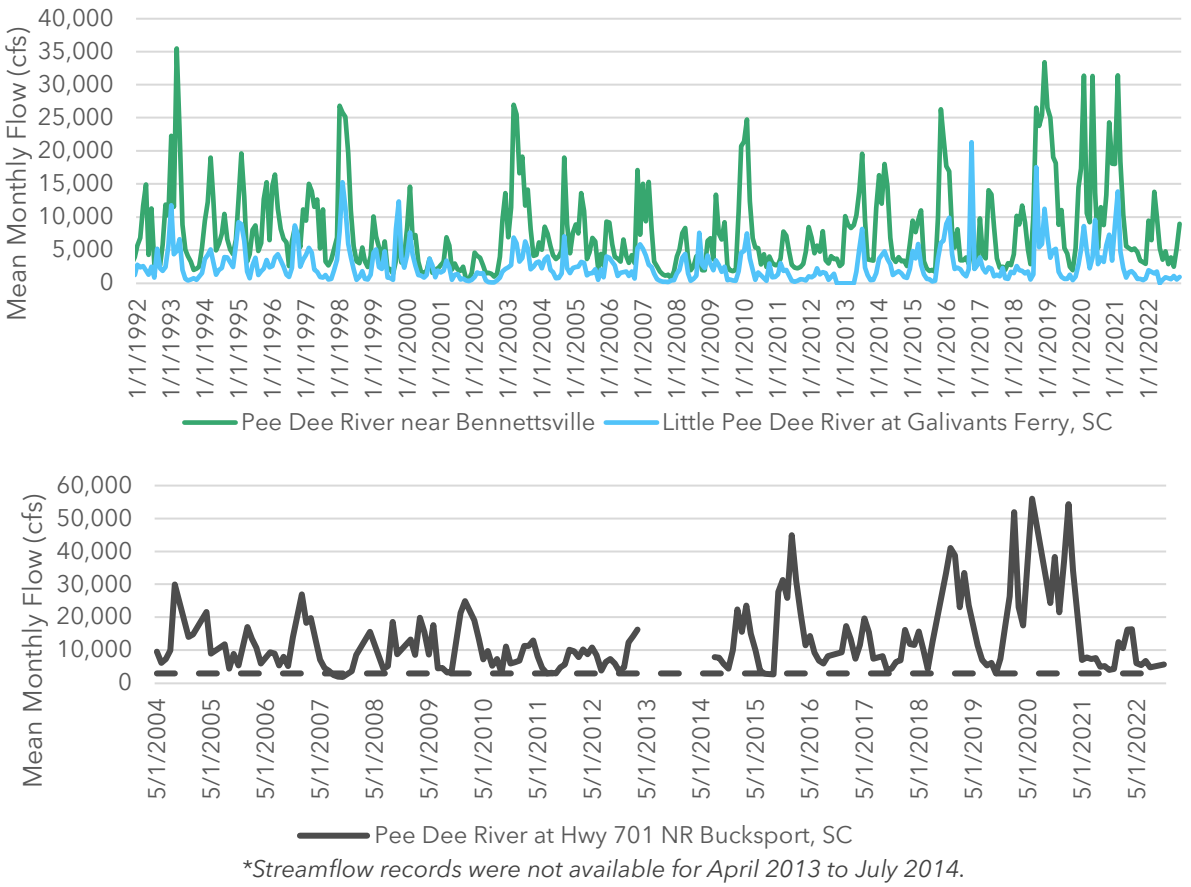


Figure 3-3. Duration hydrographs for select gaging stations on the Pee Dee River basin.

Although the Pee Dee River is free flowing in South Carolina, it is heavily regulated by a series of six reservoirs in North Carolina. The reservoirs, operated primarily for hydroelectric power generation, strongly influence flows in the Pee Dee River in South Carolina, particularly during low-flow periods (SCDNR 2009).

In 2015 and 2016, Duke Energy Progress, LLC and Cube Yadkin Generation, LLC received new Federal Energy Regulatory Commission (FERC) operating licenses for the Yadkin-Pee Dee Hydro Project (Tillery and Blewett Falls developments) and Yadkin Hydro Project (High Rock, Tuckertown, Narrows, and Falls developments), respectively. Both hydro projects are in North Carolina with the lowermost Blewett Falls Development providing regulated flows downstream into the South Carolina portion of the Pee Dee River. These new licenses reflected a collaborative effort to address a wide variety of stakeholder relicensing interests including instream flow requirements, power production, fish passage, water quality, recreation, endangered species, and cultural resources. Minimum flow requirements for downstream needs and drought-focused low inflow protocols were developed that have resulted in more stable downstream flows (Duke Energy, 2022).

Mean monthly flows at a few select gages are shown in Figure 3-4. The Little Pee Dee River at Galivants Ferry, SC and Pee Dee River near Bennettsville show similar patterns, with significant seasonal and annual variation and higher flows along the Pee Dee River throughout the 20-year period. The mean monthly flows at Pee Dee River at Hwy 701 NR Bucksport, SC include the 5th percentile of mean average flow. Low flows indicate drought periods and can result in saltwater intrusion in streams near the coast.



**Streamflow records were not available for April 2013 to July 2014.*

Figure 3-4. Mean monthly flows at select gaging stations in the Pee Dee River basin.

In addition to the USGS gaging stations, South Carolina Department of Environmental Services (SCDES) collects water quality data at 53 sites throughout the Pee Dee River basin as a part of their ongoing Ambient Surface Water Physical and Chemical Monitoring Program to assess the water's suitability for aquatic life and recreational use. The program includes ongoing fixed-location monitoring and statewide statistical survey monitoring. The fixed-location monitoring includes monthly collection and analysis of water from Base Sites in a uniform manner for the purpose of providing solid baseline water quality data. Figure 3-5 below shows the Base Sites in the Pee Dee River basin as of 2023. The Statistical Survey Sites are sampled once per month for one year and moved from year to year (SCDES 2023).

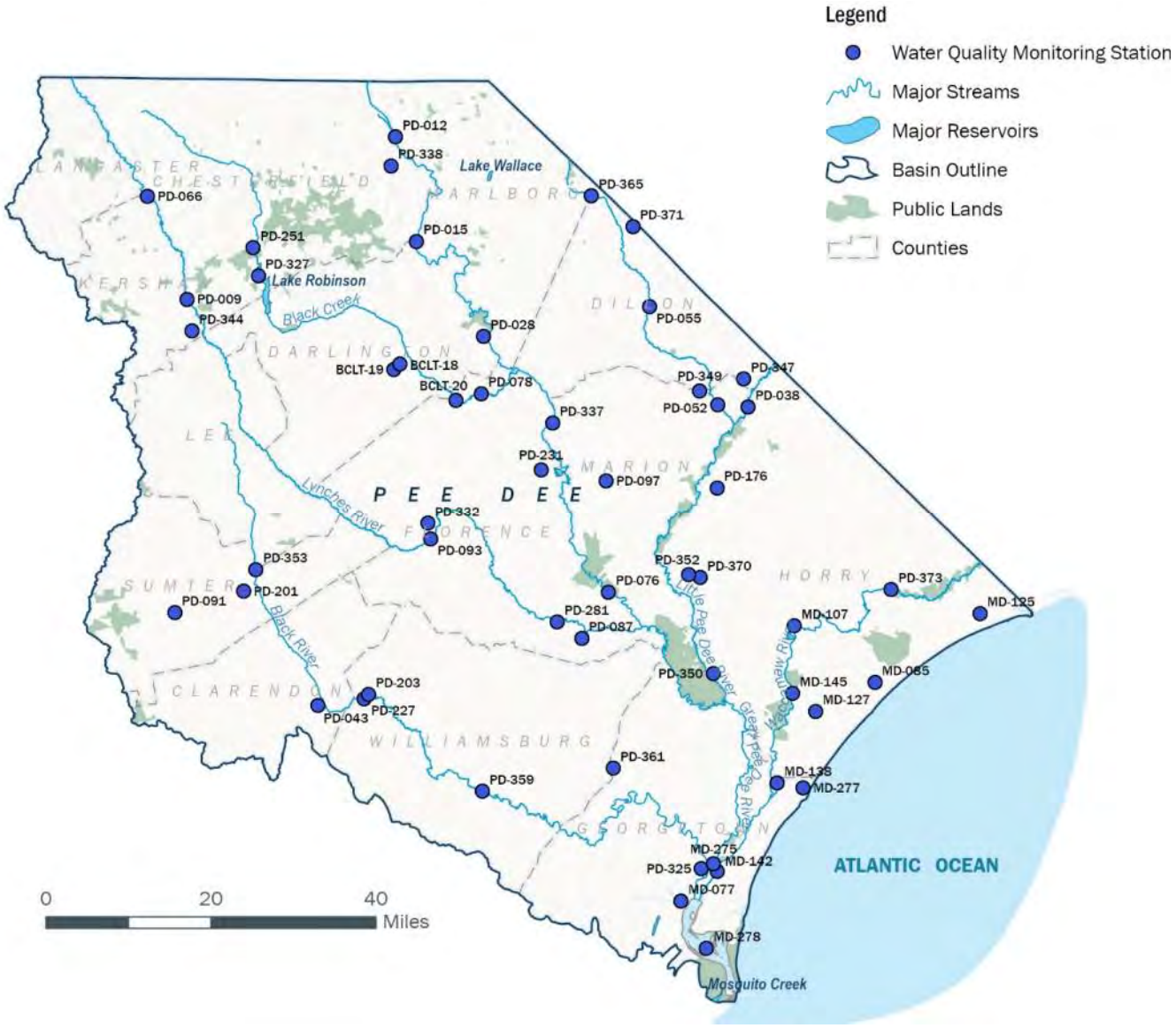


Figure 3-5. Active water quality monitoring sites in the Pee Dee River basin.

3.1.3 Surface Water Development

The Pee Dee River basin has experienced limited surface-water development in South Carolina, consisting primarily of small-scale flood-control projects. There are no active U.S. Army Corps of Engineers (USACE) navigation projects in the basin; howeverthe NRCS and USACE have completed several flood-control, drainage, and erosion projects in the basin (SCDNR 2009). Table 3-2 shows the number of regulated dams in the Pee Dee River basin categorized by flood hazard classification, and Figure 3-6 shows the locations of regulated dams throughout the basin.

Table 3-2. Regulated dams in the Pee Dee River basin.

Dam Type	Number of Dams	Description
High Hazard, Class 1	61	Structure where failure will likely cause loss of life and/or serious damage to infrastructure
Significant Hazard, Class 2	42	Structure where failure will not likely cause loss of life but infrastructure may be damaged
Low Hazard, Class 3	252	Structure where failure may cause limited property damage
Total	355	

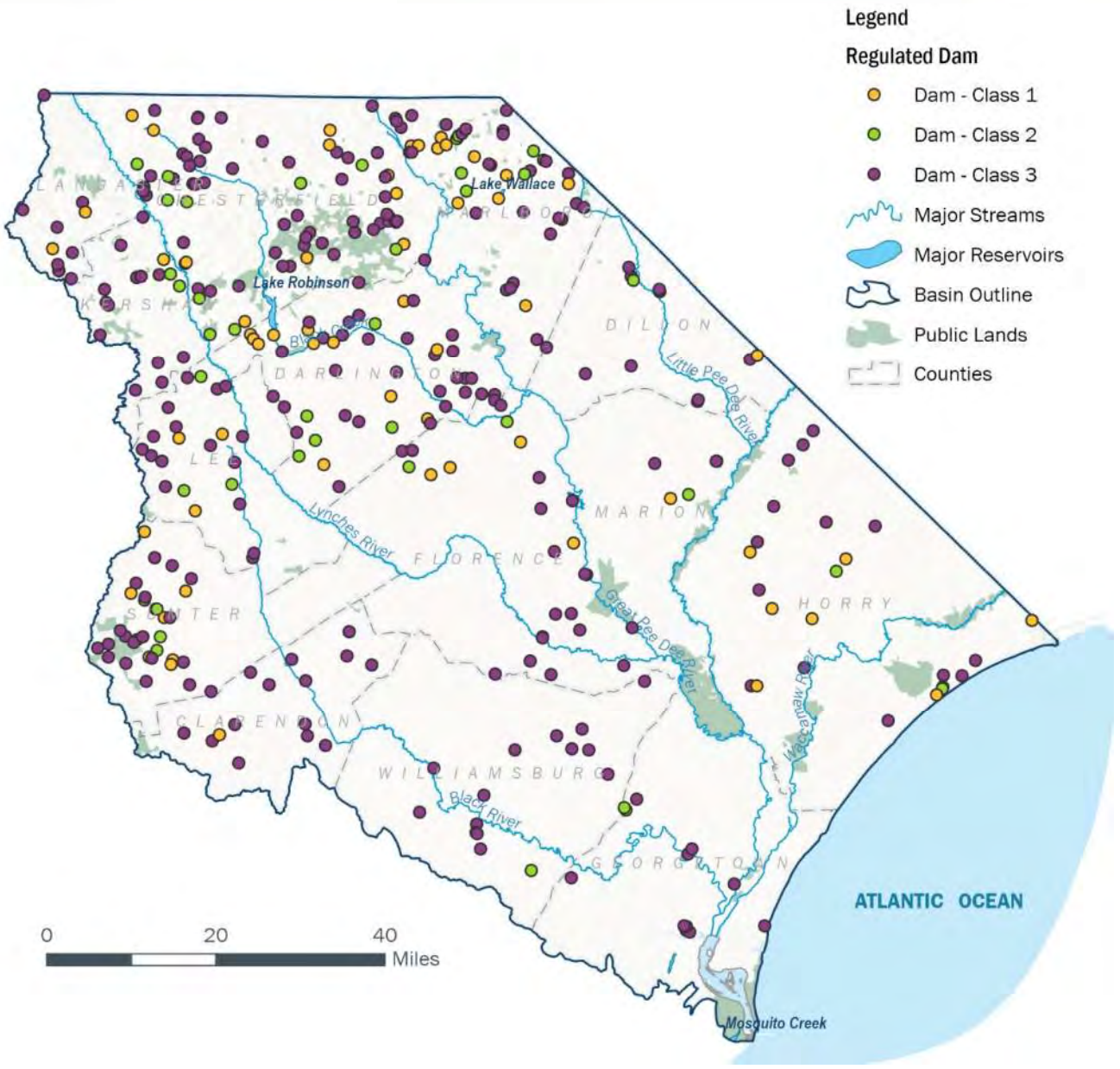


Figure 3-6. Regulated dams in the Pee Dee River basin.

3.1.4 Surface Water Concerns

The Lynches, Pee Dee, Little Pee Dee, and Waccamaw Rivers originate in North Carolina. The Black River originates in South Carolina. Flows on the Pee Dee River may be quite variable on a weekly basis due to hydropower discharges upstream in North Carolina; however, discharges from hydropower facilities in addition to groundwater support from the Upper Coastal Plain sustain relatively steady long-term flows (SCDNR 2009).

The water bodies in the Pee Dee Basin, except for Winyah Bay, are designated "freshwater." Winyah Bay is designated "tidal saltwater" (SCDNR 2009).

Stream and river reaches that do not meet water quality standards and do not support designated uses are a concern. The 2022 Section §303(d) Clean Water Act list of impaired waters documents 272 impaired waters in the basin. A summary of the designated uses, impairments, and causes is shown in Table 3-3. The cyclical nature of SCDES's permitting, monitoring, and data analysis results in a dynamic §303(d) listing that is updated biannually. As new waters are monitored, new impaired sites may be identified which require listing (SCDES 2022).

Table 3-3. 2022 303(d) Pee Dee River basin impairment summary.

Designated Use	Number of Stations with Impairments	Causes of Impairments (Number of Impairments)
Aquatic Life	118	Macroinvertebrate (7) Dissolved Oxygen (64) Turbidity (13) Ammonia-nitrogen (1) Chlorophyll-a, Total Phosphorus (2) pH (27) Metals (Lead, Mercury, Zinc, or Nickel) (9)
Fish Consumption	66	Mercury (62) Mercury, PCB (4)
Recreational Use	93	Escherichia coli (66) Enterococci (27)
Shellfish Harvesting	23	Fecal Coliform Bacteria (23)

** 27 stations had multiple impairments*

In breakout discussions at the June 27, 2023, RBC Meeting, participants identified surface water concerns and challenges. RBC members were interested in integrating water quality considerations with quantity-based surface water assessments and modeling. Water quality is becoming a bigger concern, and the Pee Dee RBC needs to understand its impacts to environment and recreation, both at high and low flows. In addition, development in coastal communities is continuing at a rapid pace, and the RBC expressed concern that surface water modeling tools do not extend to coastal areas with tidal influences.

3.2 Surface Water Assessment Tools

3.2.1 SWAM Model

The SWAM model was used to assess current and future surface water availability and to evaluate the effectiveness of proposed water management strategies. From 2014 to 2017, all eight South Carolina surface water quantity models were built in the SWAM platform, including the Pee Dee River basin model. The Pee Dee River basin SWAM model was updated in 2020. Updates included extending the period of record to 2018, adding new permits and registrations, and removing inactive users.

SWAM uses a framework composed of a network of river reaches, impoundments, withdrawals, and returns, in which water is routed hydrologically between nodes. The model focuses principally on mainstem rivers, along with primary and secondary tributaries, and often does not include smaller order

tributaries, whose flows are aggregated into flow estimates for primary and secondary tributaries. The model simulates basin hydrology at a daily or monthly timestep.

Inputs to the model include:

- Calculated and estimated "unimpaired flows" for the headwaters of the mainstem and tributaries included in the model. Unimpaired flows were calculated by mathematically removing historical influence of storage, withdrawals, and return flows from measured flow at USGS streamflow gaging stations. This allows the model to simulate either historical or hypothetical water use patterns for evaluating future conditions. Many of the unimpaired flow records were synthesized using standard statistical techniques where measured data were not explicitly available for river reaches or time periods.
- Reach Gain/Loss Factors, which are calibrated values used to increase flow as it moves downstream based on additional drainage area or decrease flow for losing river reaches.
- Locations of all withdrawals, return flows, and interbasin transfers (values of which are user-adjusted variables).
- Reservoir characteristics, such as capacity, bathymetry, constraints, and flexible operating rules.
- USGS daily flow records are embedded in the model for comparative purposes – simulation results can be compared with historical records.

Model variables, which can be modified by users to explore future conditions, include:

- Withdrawal targets (municipal, industrial, thermoelectric, agricultural, golf courses, hatcheries)
- Consumptive use, wastewater discharge, and other return flows (which can be estimated automatically)
- Interbasin transfers
- Reservoir operating rules and storage characteristics, if applicable
- Environmental flow targets

Using this information, the SWAM model calculates available water (physically available based on full simulated flows, and legally available based on permit conditions and other uses), withdrawals, storage, consumption, and return flows at user-defined nodes. The flow from the main river stem, as well as major branches and tributaries, are discretely quantified. Figure 3-7 shows the Pee Dee River basin SWAM model framework.

The model can be used to simulate current and future demands based on defined scenarios and identify potential shortages in water availability when compared to demands for withdrawals or instream flow targets. The scenarios that were evaluated specifically for the Pee Dee River basin are discussed in further detail in Chapter 4 - Current and Projected Water Demand and Chapter 5 - Comparison of Water Resource Availability and Water Demand.

As with all eight of the SWAM models for South Carolina, the Pee Dee model was calibrated and then tested to demonstrate reasonable ability to recreate historical hydrology and operational conditions. Historical water uses were added into the model to alter the estimated unimpaired flows, and simulated versus gaged flows were compared at key locations throughout the basin. An example verification test

result is shown in Figure 3-8. Full verification results and methods are discussed in the South Carolina Surface Water Quantity Models: Pee Dee Basin Model report (CDM Smith 2017).

While the SWAM model is capable of quantifying water balance calculations for free-flowing streams and reservoirs based on a number of inputs, it does have limitations. The model is not capable of performing rainfall-runoff or hydraulic routing calculations and cannot be used (by itself) to calculate natural flow in tidally-influenced reaches. Groundwater and its impacts are not explicitly modeled by the SWAM model; however, groundwater inputs and losses to streams and rivers are implicitly accounted for through incorporation of gage records and model calibration and verification. Water quality metrics also cannot be modeled by SWAM. Future climate scenarios can be explored with SWAM by adjusting the tributary input flows.

The model, as well as its Users Guide and the full report on the Pee Dee Basin Model development and calibration are publicly available for download at SCDES's website.

For more information on the models and associated documentation, see:

https://www.des.sc.gov/programs/bureau-water/hydrology/surface-water-program/surface-water-models/simplified-water-allocation-models-swam

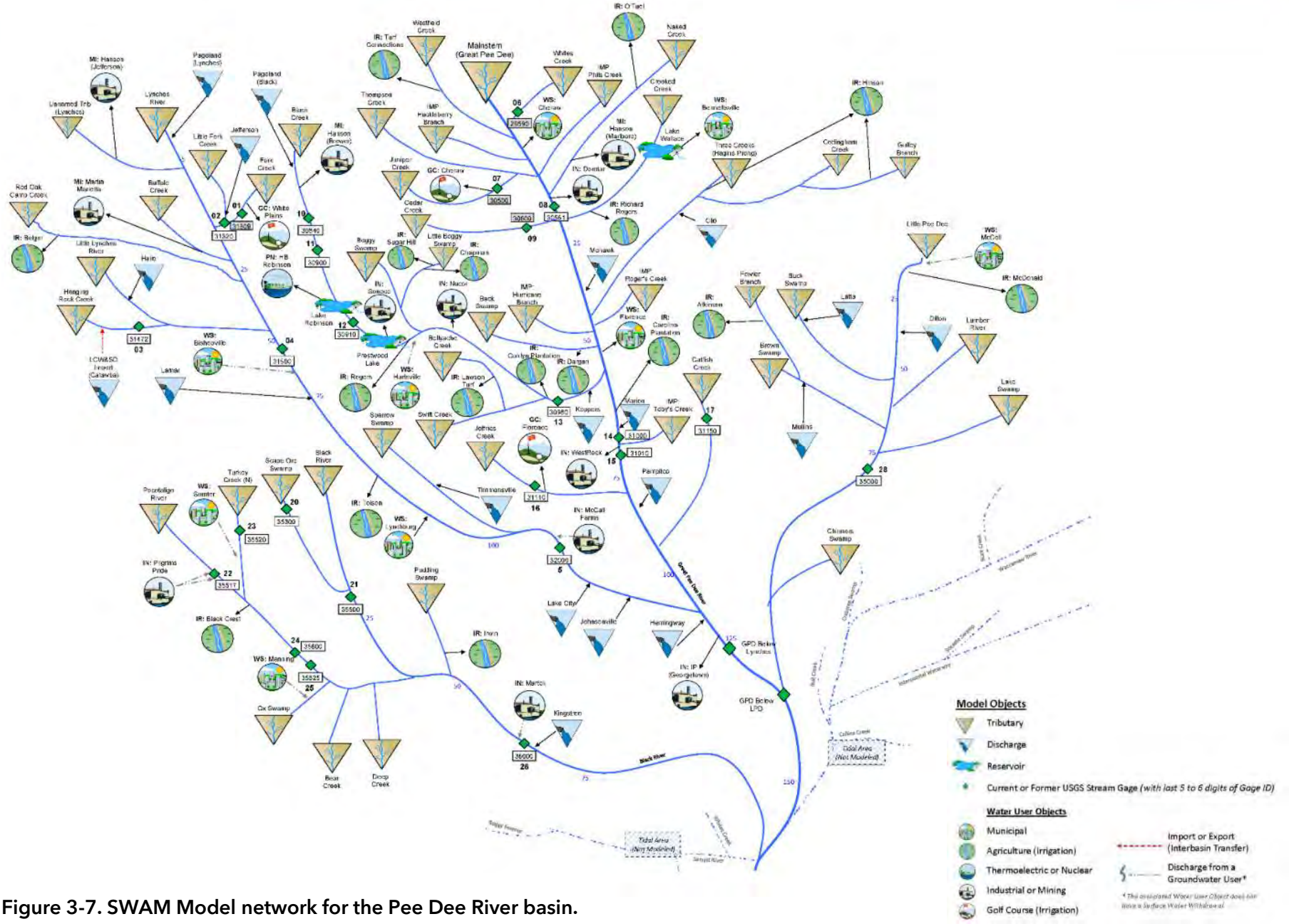


Figure 3-7. SWAM Model network for the Pee Dee River basin.

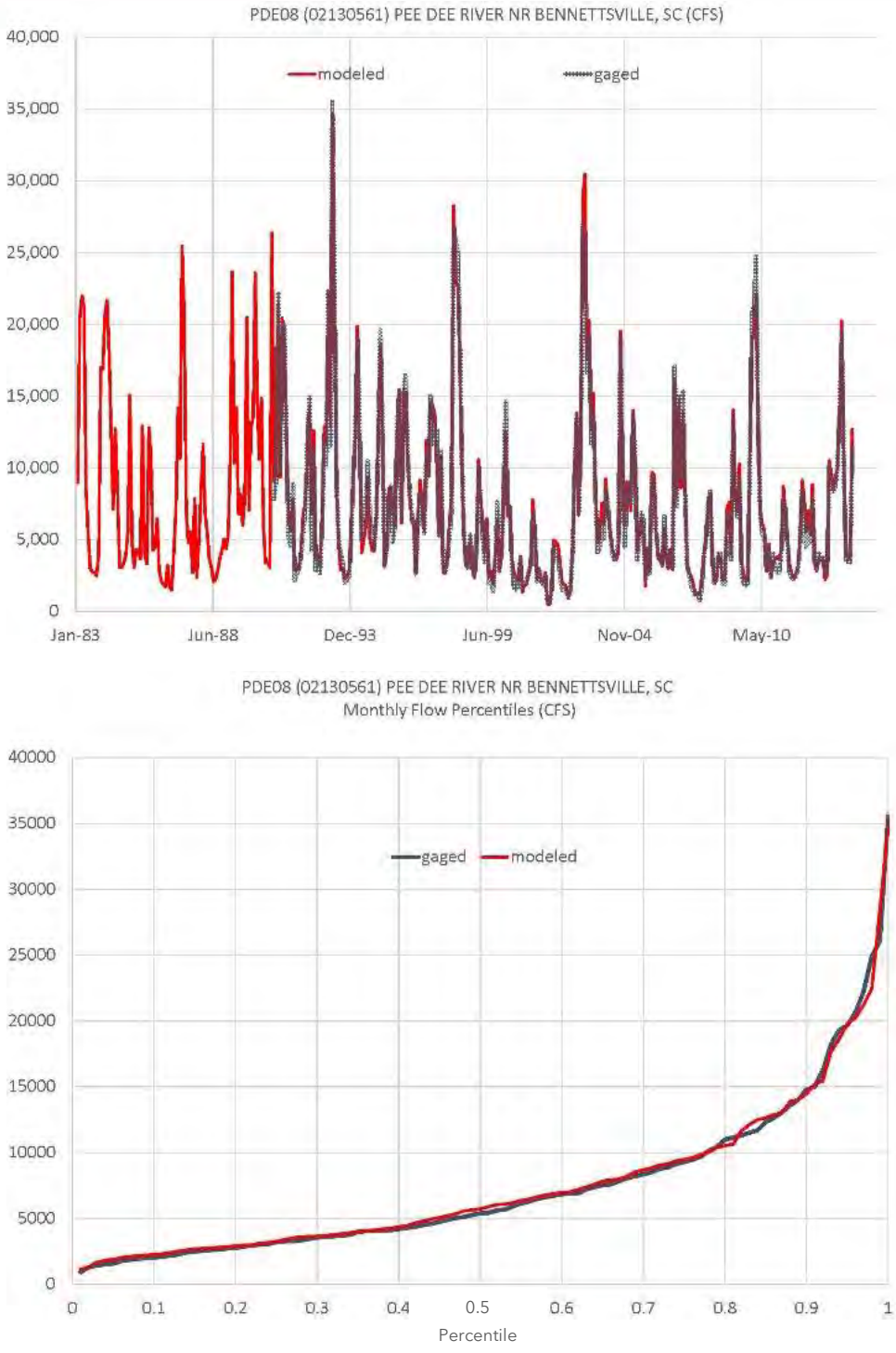


Figure 3-8. Representative Pee Dee River basin SWAM model verification graphs (CDM Smith 2017).

3.2.2 Other Surface Water Analyses

While the SWAM models focus on the hydrology of larger mainstem rivers and primary tributaries in the Pee Dee River basin and other South Carolina basins, other work has focused on the hydrology and flow characteristics in smaller headwater streams, specifically those that are classified as "wadeable." In part of an effort to formulate relationships between hydrologic metrics (flow patterns, statistics, and variability in these streams for both pulses and long-term averages) with ecological suitability metrics, daily rainfall/runoff modeling of small headwater streams throughout the state was accomplished with the WaterFALL® model (Watershed Flow ALLocation model), as described in Eddy et al (2022) and Bower et al (2022). The WaterFall® model is a semi-distributed rainfall runoff model that simulates daily streamflows at the catchment resolution, allowing for the simulation of the local watershed contribution at each stream segment.

Separately, as discussed in Bower et al (2022), biological response metrics were developed and combined with the hydrologic metrics from WaterFALL® to identify statistically significant correlations between flow characteristics and ecological suitability for fish and macroinvertebrates. The framework can be used to inform instream flow management and assess effects of flow alterations on riverine assemblages. Thus, the results are intended to help guide scientific decisions on maintaining natural hydrologic variations while also supporting consumptive water withdrawals.

As a component in the analysis, the WaterFALL® hydrologic modeling results augment the SWAM modeling results by providing similar hydrologic understanding of the smaller headwater streams not simulated explicitly or individually in SWAM.

3.3 Groundwater Resources

3.3.1 Groundwater Aquifers

The Pee Dee River basin, which includes South Carolina, North Carolina, and a small portion of Virginia, is underlain by aquifers belonging to the Coastal Plain and Piedmont – Blue Ridge crystalline rock aquifer systems. In South Carolina, the Pee Dee River basin is predominately underlain by the Coastal Plain aquifer system with a small portion of the Piedmont crystalline rock aquifer present in Chesterfield County (SCDNR 2022). The Coastal Plain aquifers are composed of permeable sands or limestone separted by clay confining units arranged in a wedge that begins at the Fall Line and thickens towards the coast, as shown in Figure 3-9. The most important aquifers in the Pee Dee River basin are the surficial, Crouch Banch, and McQueen Branch aquifers, which are seperated by confining units of the same name.

Surficial Aquifer
The surficial aquifer is unconfined and is referred to as the water-table aquifer. The surficial aquifer is comprised of quartz, gravel, sand, silt, clay, and shelly sand (Gellici and Lautier 2010). The flow direction and flow rate of groundwater in the surficial aquifer largely follow the ground surface topography (SCDNR 2009). Because the aquifer is unconfined, water levels fluctuate due to seasonal weather changes. The thickness of the surficial aquifer is typically tens of feet and the sediments are generally fine-grained near the coast. Well depths range from 20 to 100 feet, and well yields are generally low, ranging from 5 to 20 gallons per minute (gpm) due to the limited amount of available drawdown (SCDNR 2009). The surficial aquifer is most commonly used for domestic, light commercial, and small agricultural operations.

Crouch Branch Aquifer

The Crouch Branch aquifer underlies the surfical aquifer in the Pee Dee River basin. It is an important source of water for public supply and crop irrigation, and it is also used for industry and power production. The Crouch Branch aquifer covers the majority of the South Carolina Coastal Plain and consists of unconsolidated quartz sand and clay throughout (Figure 3-10). In the Pee Dee River basin, the top of the aquifer occurs at or near the surface in Chesterfield, Marlboro, and Darlington Counties and reaches a depth of over 700 feet in coastal Georgetown County. Aquifer thickness ranges from 0 feet near the Fall Line to about 400 feet at the coast. In locations close to the Fall Line, the aquifer is unconfined and the surficial aquifer and the Crouch Branch aquifer are connected. The presence of laminated sand and clay beds divide the aquifer into three aquifer zones, but the zones are assumed to be hydraulically connected to one another (Wachob and others 2017). The coarse sediments in the upper and middle basin become more fine-grained as the aquifer dips toward the coast, resulting in a wide range of yields from wells completed in the aquifer. In Darlington, Dillon, Florence, Marion, and Marlboro Counties the average well yield is approximately 700 gpm (Rodriguez and others 1994), whereas along the coast in Horry and Georgetown Counties, yields typically are between 100 to 500 gpm (Pelletier 1985). Recharge to the Crouch Branch aquifer occurs from rainfall within the unconfined portion of the aquifer in Marlboro, Chesterfield, and Lee Counties.

McQueen Branch Aquifer

The McQueen Branch aquifer underlies the Crouch Branch aquifer and is the most heavily used aquifer in the basin. The aquifer is primarily used for public water supply, crop irrigation, and industrial use. It consists of unconsolidated fine to coarse quartz sand and clay, and it covers most of the Coastal Plain and Pee Dee River basin (Figure 3-10). The aquifer outcrops near the Fall Line in Chesterfield and Kershaw Counties, and is recharged in its unconfined area when rainfall moves downward through the Crouch Branch aquifer to recharge the McQueen Branch. The top of the aquifer occurs close to the surface to near its outcrop and reaches a depth of over 950 feet in Georgetown County, with an aquifer thickness of about 200 feet in Horry and Georgetown Counties. Well yields in Darlington, Dillon, Florence, Marion, and Marlboro Counties average approximately 950 gpm (Rodriguez and others 1994). Yields generally decrease eastward (700 gpm in Williamsburg County) as the aquifer composition becomes more fine grained and less permeable (Pelletier 1985).

Charleston and Gramling Aquifers

The Charleston aquifer underlies the McQueen Branch aquifer and is composed of unconsolidated sand, clayey sand, and clay. In the Pee Dee River basin, the top of the Charleston aquifer occurs at depths ranging from 8 to 1,200 feet, and the aquifer is up to 100 feet thick. The Gramling aquifer lies beneath the Charleston aqufier, at the base of the Coastal Plain aquifer system in South Carolina and is composed of unconsolidated clayey sand with silt and clay that can inhibit water use. Because the Charleston and Gramling aquifers do not outcrop at the surface, they are recharged from the overlying McQueen Branch aquifer, and these aquifers experience much slower recharge than the Crouch Branch and McQueen Branch aquifers. Well yields of the Charleston aquifer are approximately 500 gpm (Gellici and Lautier 2010), but few wells in the Pee Dee River basin are completed soley in the Charleston aquifer; wells screened in the Charleston aquifer often are also screened in the McQueen Branch aquifer. Because of its depth and relatively low ability to yield water, few wells are completed in the Gramling aquifer in the Pee Dee River basin (SCDNR 2022).

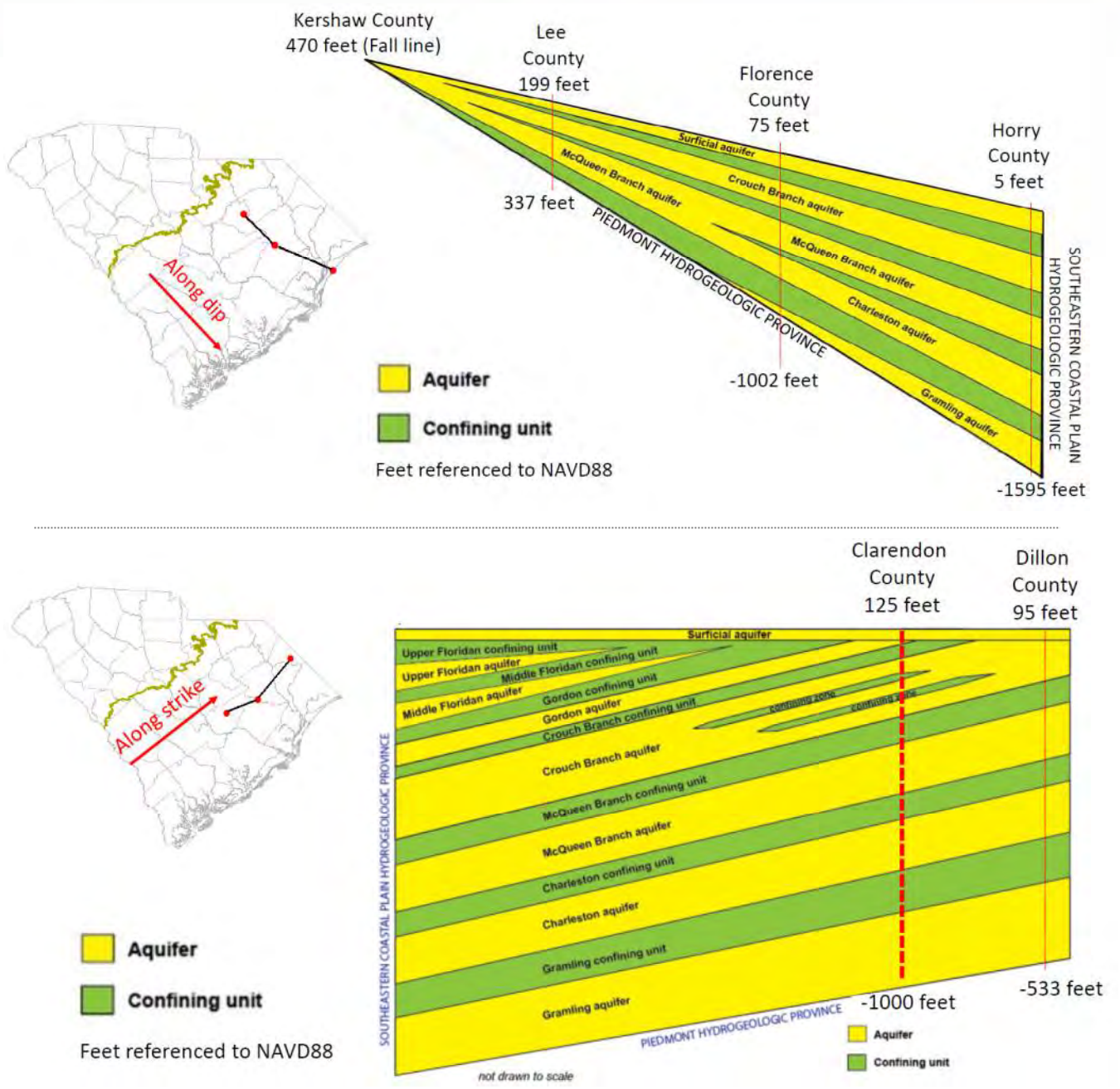


Figure 3-9. Coastal Plain aquifer system schematic cross sections (SCDNR 2022).

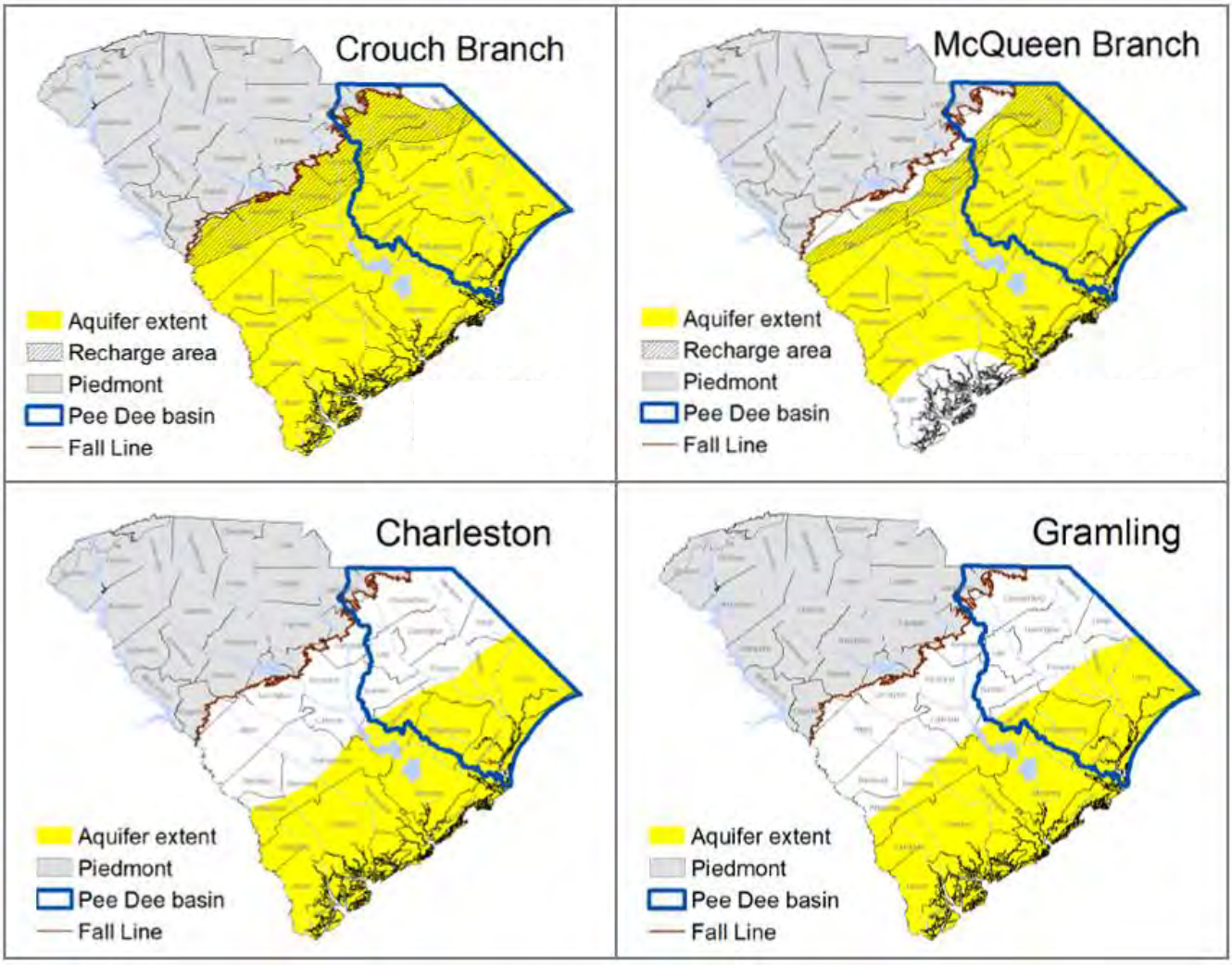


Figure 3-10. Aquifers underlying the Pee Dee River basin (SCDNR 2022).

3.3.2 Groundwater Monitoring

Groundwater monitoring is performed by the USGS and SCDES. Statewide, the groundwater monitoring network operated by SCDES has more than 180 wells as of 2022. The majority of the monitoring wells are in the Coastal Plain. Most wells have hourly data automatically recorded, and others are measured manually four to six times per year (SCDNR 2022c). The USGS maintains a groundwater-level monitoring network of an additional 21 wells in South Carolina. Groundwater monitoring wells are used to identify short- and long-term trends in groundwater levels and aquifer storage, and to monitor drought conditions. The majority of the wells have water level records dating to the 1990s with some dating back to 1955 (SCDNR 2022c).

The Pee Dee River basin has 54 monitoring wells, principally in the Crouch Branch and McQueen Branch aquifers (SCDES 2024). The locations of the wells monitoring groundwater levels in each aquifer are shown in Chapter 5 (see Section 5.4).

SCDES[1] routinely measures water levels in other, non-network wells in order to develop potentiometric maps for the major Coastal Plain aquifers. A potentiometric map is a contour map that illustrates the elevation to which groundwater will rise in a well open to a particular aquifer. Unlike monitoring wells, which provide continuous records of changing aquifer conditions at specific points, potentiometric maps provide "snapshots" of aquifer conditions over the full extent of the aquifer at one moment in time. Areas of relatively significant groundwater level declines are indicated on potentiometric maps by relatively lower potentiometric elevations, often seen as concentric loops of contours lines known as a cone of depression. Typically, SCDES produces new potentiometric maps for the Crouch Branch aquifer and the McQueen Branch aquifer every three years.

Examples of monitoring well hydrographs and potentiometric maps that can be created using monitoring well data are shown in Figure 3-11 and Figure 3-12, respectively. More detailed descriptions monitoring well data and potentiometric maps are included in Chapter 5.

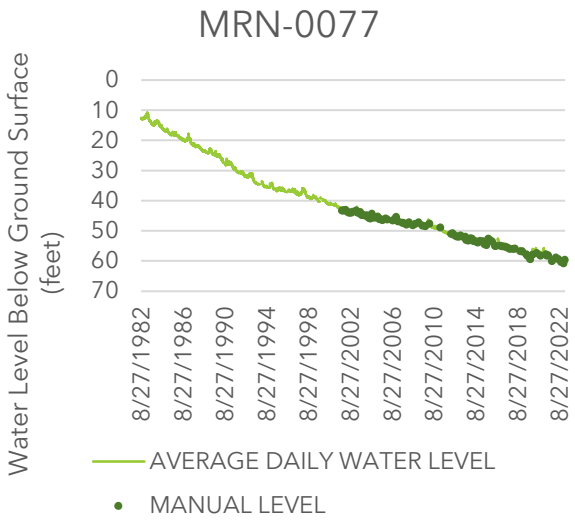


Figure 3-11. Example monitoring well hydrograph showing groundwater level trends in the Crouch Branch aquifer in Marion County.

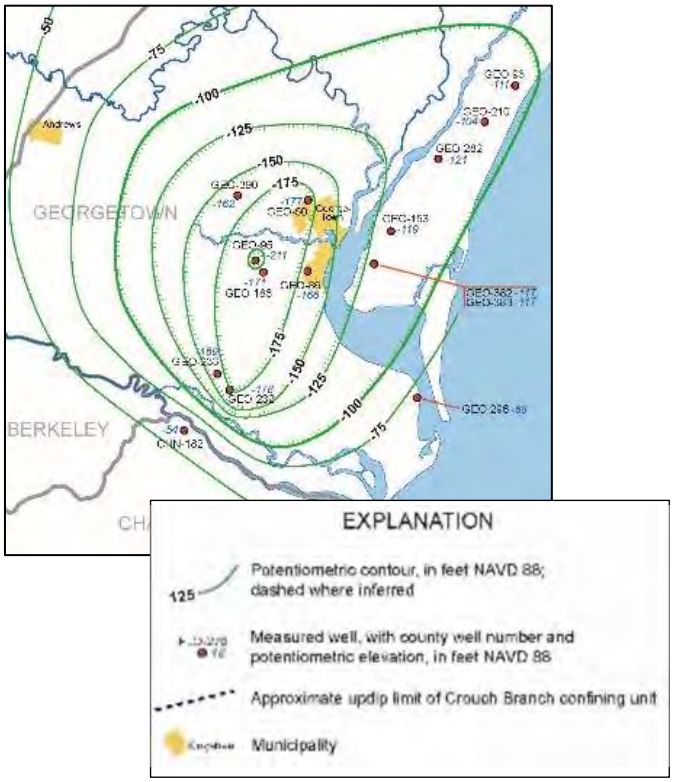


Figure 3-12. Example map showing the potentiometric surface of the Crouch Branch aquifer near Georgetown.

For more information on Potentiometric Mapping, see:

https://des.sc.gov/programs/bureau-water/hydrology/groundwater-program/potentiometric-mapping

[1] The state agency responsible for collecting and assessing groundwater level data recently changed. Water level data collected before July 1, 2024, was obtained by the SCDNR Hydrology Section. Water level data collected on or after July 1, 2024, was obtained by the SCDES Hydrology Section. In 2023, Senate Bill 399 (S.399) was enacted, effective July 1, 2024, leading to, among other things, the establishment of the SC Department of Environmental Services (SCDES). Furthermore, the Hydrology and Aquatic Nuisance programs of SCDNR were incorporated as sections within SCDES, conserving and consolidating the relevant powers and duties of the preceding agencies.

Over pumping of groundwater creates localized cones of depression that disrupt natural groundwater flow and can allow saltwater to move into aquifers along the coast. Saltwater intrusion has become a problem for some coastal areas.

SCDES manages a network of 10 coastal monitoring wells to measure and track saltwater intrusion. In the Pee Dee River basin, coastal monitoring wells are near Georgetown and Myrtle Beach. For more information, see:

https://des.sc.gov/programs/bureau-water/hydrology/groundwater-program/saltwater-intrusion-monitoring-network

3.3.3 Groundwater Development

Groundwater supplies have been developed in the Pee Dee River basin to serve municipalities, agriculture, industry, golf courses, and the energy sector. Currently, the average withdrawal of groundwater for all uses is approximately 111.9 million gallons per day (MGD) (or 40.9 billion gallons per year). This does not include relatively minor withdrawals from domestic and other wells which are below the reporting limit of 3 million gallons per month (MGM).

The public water supply sector is the largest user of groundwater, with current withdrawals averaging 65.7 MGD (or 24.0 billion gallons per year). Agricultural uses of groundwater average 34.3 MGD (12.5 billion gallons per year), and industrial uses of groundwater averge 9.4 MGD (3.4 billion gallons per year). Golf courses are supplied by groundwater sources, but their use is relatively small compared to other sectors at 1.5 MGD (0.5 billion gallons per year). Finally, the HB Robinson nuclear power plant uses approximately 1.0 MGD (0.3 billion gallons per year), though the vast majority of their water use is supplied from surface water sources.

Many of the Pee Dee River basin's municipal water providers, such as Sumter and a host of smaller communities are solely dependent on groundwater supplies. Some water providers like Florence, Grand Strand Water and Sewer Authority, and Georgetown use groundwater supplies but also have access to surface water supplies. Groundwater supplies have also been developed to serve industrial water users like Sonoco, McCall Farms (for canning and freezing operations), and Nan Ya Plastics Corporation. Some industries in the Pee Dee River basin depend solely on groundwater supplies while some, like Sonoco and NUCOR, use both groundwater and surface water supplies.

Some municipal water providers have implemented conjunctive water management strategies that use surface water supplies alongside groundwater supplies in an effort to mitigate aquifer level declines. For example, conjuctive water management strategies in Florence County have been successful at stabilizing groundwater level declines in the local aquifer and are described further in Chapter 6. In essence, surface water has been developed and utilized to support additional municipal water demand that has occurred since the mid-2000s. Groundwater withdrawals have remained relatively steady since that time. In another example, Grand Strand Water and Sewer Authority (GSWSA) has implemented an aquifer storage and recovery strategy to store surface water in aquifers when municipal usage is low and extract the stored water when demands are high.

3.3.4 Groundwater Concerns

Years of groundwater pumping from wells in the Pee Dee and neighboring basins have resulted in regional groundwater-level declines (SCDNR 2009). Although some areas have experienced recovery of groundwater levels, groundwater level declines are a concern. Three cones of depression are in the Pee Dee Basin, as indicated in potentiometric surface maps and as shown as blue dots in Figure 3-13. The severity of the cones is more prominent in the coastal region. When groundwater levels are at or below sea level, aquifers can experience saltwater intrusion. Declining groundwater levels can also reduce yields, and in extreme cases, can result in compaction and land subsidence.

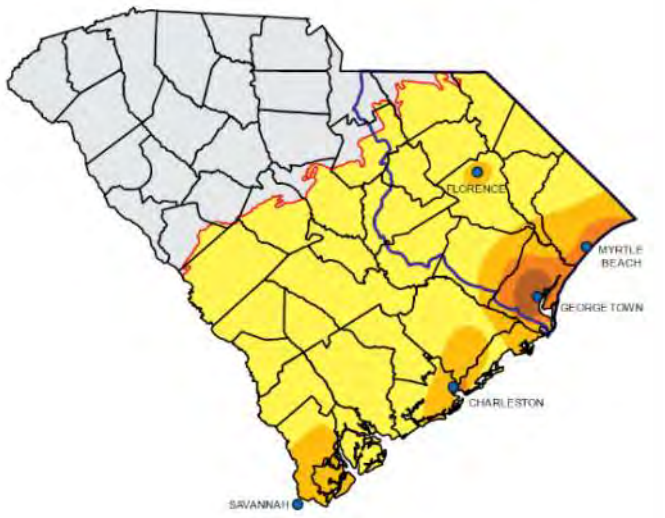


Figure 3-13. Cones of Depression in South Carolina (SCDNR 2022).

Three Capacity Use Areas (CUA) cover the basin (as described in Section 3.3.5). The groundwater management plans for those areas contain goals around the sustainable development of the groundwater resource by managing withdrawals, protecting groundwater from saltwater intrusion, and monitoring quality and quantity to evaluate changing conditions (SCDHEC 2023).

In breakout discussions at the June 27, 2023 RBC meeting, attendees identified groundwater concerns and challenges.

- Water supplies are generally adequate, but drought conditions create water supply risks. Planning for drought and managing limited water resources is important.
- Agriculture, which often relies on groundwater, is vulnerable to drought.
- Coastal regions continue to develop even though groundwater levels are declining.

3.3.5 Capacity Use Areas

In South Carolina, groundwater is managed and monitored by the South Carolina Department of Environmental Services (SCDES) within areas of the state designated as CUAs. According to the Groundwater Use and Reporting Act (Chapter 5, Section 49-5-60), a CUA is defined as an area where excessive groundwater withdrawal may adversely affect natural resources or pose a threat to public health, safety, or economic welfare, or where there is a significant threat to the long-term integrity of the groundwater resource. Within a designated CUA, groundwater users withdrawing three (3) million gallons or more of groundwater per month from a single well or from multiple wells within a one-mile radius must apply for and obtain a Groundwater Withdrawal Permit.

There are currently six designated CUAs in the Coastal Plain of South Carolina, the region east of the Fall Line to the coast, three of which are partially located within the Pee Dee River basin: the Waccamaw, Pee

Dee, and Santee-Lynches (see Table 3-4). For each CUA, SCDES, in collaboration with various stakeholders, has developed a Groundwater Management Plan (GWMP).

Table 3-4. Capacity Use Areas within the Pee Dee River basin.

Capacity Use Area	Year Designated	Counties
Waccamaw	1979	Georgetown and Horry
Pee Dee	2004	Darlington, Dillon, Florence, Marion, Marlboro, and Williamsburg
Santee-Lynches	2021	Chesterfield, Kershaw, Richland, Clarendon, Lee, and Sumter

The GWMPs for the Waccamaw and Pee Dee CUAs share the following goals:

1. Ensure sustainable development of the groundwater resource by management of groundwater withdrawals
2. The protection of groundwater quality from salt-water intrusion
3. Monitoring of groundwater quality and quantity to evaluate conditions

The goals of the Santee-Lynches GWMP are:

1. Ensure sustainable use of the groundwater resource by management of groundwater withdrawals
2. Monitor groundwater conditions to evaluate availability
3. Promote educational awareness of the resource and its conservation

The first goal described in the Waccamaw, Pee Dee, and Santee-Lynches GWMPs is achieved through SCDES's groundwater permitting cycles. Groundwater permits have a duration of five years, with a review and renewal in the fifth year. In the fourth year of the cycle, the CUA is evaluated to inform the upcoming renewal cycle. CUA evaluations analyze groundwater sources and use, aquifer conditions, and growth projections to issue recommendations for permitting. These recommendations are followed by SCDES staff when issuing new permits and renewals in the CUA.

Waccamaw CUA

The Waccamaw CUA, the first CUA to be designated, was established on June 22, 1979. It is comprised of Georgetown County and Horry County, both of which are entirely within the Pee Dee River basin. The Waccamaw CUA was established in response to several observed problems with groundwater supply, including declines in monitoring well water levels, saltwater intrusion, and dry wells. Water levels have declined since 1900 in all aquifers below the Waccamaw CUA, but of particular concern is the enduring cone of depression in the Crouch Branch aquifer and Middendorf Aquifer System below Andrews and Georgetown in southern Georgetown County. Groundwater monitoring wells near this cone document a decline of approximately 2 feet per year in the Crouch Branch aquifer (Kemmer and Wyant 2023). An additional concern is saltwater intrusion into freshwater zones of the aquifers as a result of the cone of depression lowering the pressure surface of the aquifer and concentrated, high-capacity water supply pumping. Water supply is the major water use (81 percent) in the Waccamaw CUA, followed by golf course irrigation (9 percent).

Pee Dee CUA

The Pee Dee CUA was designated on February 12, 2004. It includes most of the inland coastal plain counties in the Pee Dee River basin, including Marlboro, Dillon, Marion, Florence, Darlington, and Williamsburg Counties. Groundwater conditions vary based on location and aquifer; groundwater levels in the western area of the CUA have remained relatively stable, while groundwater levels in the eastern region have seen considerable decline. In particular, the Crouch Branch aquifer has declined across Dillon, Florence, Marion, and Williamsburg Counties, and the McQueen Branch aquifer has declined in Dillon, Florence, and Williamsburg Counties. A cone of depression developed in Florence County due to significant groundwater pumping. As of 2022, it had recovered by 70 feet from its lowest level at 92 feet below sea level, in large part due to conjunctive surface water use. Groundwater in the Pee Dee CUA is primarily used for water supply (65 percent) and agricultural irrigation (18 percent).

Santee-Lynches CUA

The Santee-Lynches CUA is the most recent CUA to be established; it was designated on July 15, 2021. The Santee-Lynches CUA overlaps with the Pee Dee River basin in the northeast parts of Clarendon and Sumter Counties, most of Lee County, and parts of Chesterfield and Kershaw Counties. This CUA was established in response to observations of declining groundwater levels. Beneath Sumter and Clarendon Counties, groundwater levels have fallen by at least 60 feet in the Crouch Branch aquifer and by 80 feet in the McQueen Branch aquifer. Groundwater in the Santee-Lynches CUA is used for water supply (49 percent) and agricultural irrigation (41 percent).

For more information on the Capacity Use Areas, see:

https://www.des.sc.gov/index.php/programs/bureau-water/groundwater-management-planning/groundwater-withdrawal-permitting-capacity-use-areas

3.4 Groundwater Assessment Tools

The primary tools used for the Pee Dee River Basin Plan to evaluate current and future groundwater supply conditions are the groundwater monitoring data and information, potentiometric maps, and current/projected groundwater use data described in Section 3.3 above.

Groundwater models are useful tools for simulating current and future groundwater level and supply trends as well as potential effects of groundwater management strategies. A regional groundwater model has been developed, and a localized version of the regional groundwater model focused on aquifers in the Pee Dee River basin is currently being developed (see Section 3.4.1 below for more information). Once completed the localized groundwater model can be used by the Pee Dee RBC to further evaluate groundwater supply issues and management strategies to mitigate supply risk.

3.4.1 Coastal Plain Groundwater Model

To support water planning in the river basins extending into the Coastal Plain of South Carolina, the USGS with assistance from SCDES is updating and re-calibrating the three-dimensional numerical groundwater flow model of the Atlantic Coastal Plain (ACP) aquifers and confining units. The original model, documented in the 2010 USGS report Groundwater Availability in the Atlantic Coastal Plain of North and South Carolina (USGS 2010), is a MODFLOW-2000 model that simulates groundwater flow in three dimensions by using a block-centered, finite-difference method. The model covers approximately 70,500 square miles including the entire South Carolina Coastal Plain and extends into North Carolina

and Georgia (see Figure 3-14). Numerous updates and improvements are being made to support water availability assessments and river basin planning in South Carolina. The major model updates include:

- Activating the entire surficial aquifer model layer
- Incorporating recharge from the Soil-Water Balance Model
- Updating the hydrogeologic framework and adding groundwater-related data collected from 2005 to 2020
- Refining the model grid from approximately 2 by 2 miles spacing to 2,000 by 2,000 foot spacing
- Incorporating a more detailed representation of the Fall Line area
- Incorporating new MODFLOW packages, including the Newton Formulation and Multi-Node Well Package
- Extending the stress periods that were originally from 1900 to 2004, to 2070

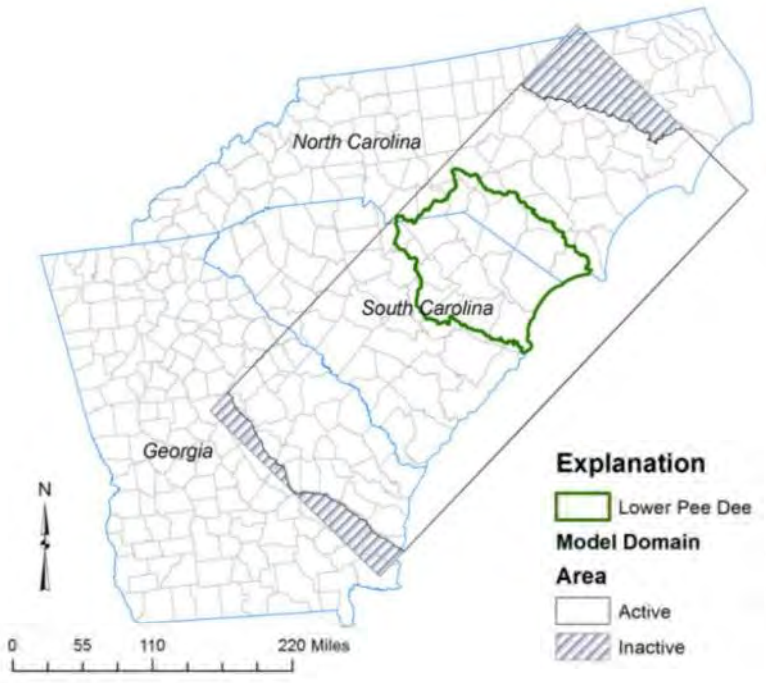


Figure 3-14. Coastal Plain groundwater model boundary and grid outline (SAWSC 2023).

For the Pee Dee River basin, the USGS with assistance from SCDES is transferring the model from MODFLOW-NWT to MODFLOW 6. The model transfer and updates include:

- Local grid refinement (smaller cell size)
- All groundwater use, water-level, stream baseflow, and recharge updated through 2022
- Shorter time steps
- Calibration using parameter estimation (PEST++ Version 5)
- Calibration period from 2002 to 2022 to take advantage of highest quality groundwater withdrawal and water-level data

Chapter 4
Current and Projected Water Demand

This chapter summarizes current and projected water demands over the 50-year planning horizon from 2020 to 2070 in the Pee Dee River basin. Demand projections are based on historical demands and published projection datasets for variables that influence water demand including population, economic development, and irrigated acreage. A statistical model was built to develop demand projections for each permitted and registered water withdrawer using reported withdrawals and, when available, driver variables. Two demand projection scenarios were developed: a Moderate Demand Scenario using median rates of water use and moderate growth, and a High Demand Scenario using high rates of water use and high growth. The demand projections were used to assess future water availability in the surface water model and in the groundwater evaluation as summarized in Chapters 5 and 6. The demands presented in this chapter include all demands, surface and groundwater.

4.1 Current Water Demand

Current water demands reflect the most recent withdrawal data, as reported to SCDES, that were available at the time of the analysis.

The withdrawals used for the demand estimates were reported to SCDES by permitted and registered water users in the Pee Dee River basin as required by state regulation. All users withdrawing more than 3 million gallons of surface water or groundwater in any month must either obtain a permit or register their use and report withdrawals to SCDES annually. Users withdrawing less than this threshold are not required to report their withdrawals; however, they may choose to report voluntarily. For surface water withdrawals over the threshold, agricultural water users must register their use while all other users must permit their use in accordance with SCDES's Regulation 61-119, Surface Water Withdrawal, Permitting, Use and Reporting. For groundwater withdrawals over the threshold, users withdrawing within a CUA must permit their use, while those withdrawing outside of a CUA must only register their use. Most groundwater users in the Pee Dee River basin are within CUAs and must therefore permit their use. Unpermitted and unregistered water uses were not quantified and were assumed to be negligible for the purposes of this plan (which is consistent with other River Basin Plans). This assumption may be revisited in future iterations of the Pee Dee River Basin Plan.

Surface Water Demands

Surface water demands were developed for the entire Pee Dee River basin. Some of the surface water demand occurs in river segments that were included in the SWAM model, while some occur in coastal communities along rivers that are tidally influenced and are beyond the SWAM model's downstream extent. The SWAM model, further described in Chapter 5, models surface water allocation across water use categories based on water availability in non-tidally influenced stream reaches. As a result, SWAM does not consider surface water intakes for coastal communities in tidally influenced stream reaches.

Current surface water demands (see Table 4-1) were summarized based on their inclusion in the SWAM model or whether they are for coastal communities with tidally influenced surface water intakes.

Groundwater Demands

Groundwater demands were generated for the groundwater model that is currently being updated by the USGS. Groundwater demands were developed for the entire Pee Dee River basin across the various water use sectors. Total current basinwide groundwater demands by sector are presented in Table 4-1. A portion of the total groundwater demand is incorporated in the SWAM model for communities or industries that use significant groundwater and discharge the return flow into surface streams. These groundwater demands include municipal and industrial water users such as Bishopville, Hartsville, Lynchburg, Manning, McColl, Sumter, McCall Farms, Martek, and Pilgrim's Pride.

Current Water Demands

The total current water demand in the basin is approximately 1,028.8 MGD on average. Of this withdrawal, 111.9 MGD is from groundwater and 916.9 MGD is from surface water. About 217 MGD (21 percent) of the water is consumptively used, and 811.8 MGD (79 percent) returns to the river after its use.

The nuclear power sector accounts for 72.5 percent of of the overall water demand. The water supply and industry sectors account for 13.9 percent and 9.4 percent of the total, respectively. The agriculture sector accounts for 3.6 percent of withdrawals, and the golf course and mining sectors account for 0.6 percent and less than 0.1 percent, respectively. The distribution by sector is summarized in Table 4-1 and shown in Figure 4-1. The distribution by sector, excluding nuclear, is shown in Figure 4-2. Appendix A includes a table of all water users along with the user's source (surface water or groundwater), including coastal water users, withdrawals, and discharges. For surface water modeling purposes, consumptive use percentages (i.e., the amount of water withdrawn that is not returned to surface water or groundwater) for each water user were calculated by comparing withdrawal and discharge amounts as reported to SCDES. In many instances, NPDES permit discharge locations associated with a unique water use were lumped together due to close proximity to one another. It is assumed that all golf course and agricultural irrigation is compsumptively used (no return flows).

Table 4-1. Current water demand in the Pee Dee River basin.

Water Use Category	Surface Water (MGD)			Groundwater (MGD)	Total (MGD)
	SWAM[1]	Coastal[2]	Total		
Agriculture	2.1	0.5	2.6	34.3	36.9
Golf	0.2	3.9	4.2	1.5	5.7
Industry	79.5	7.7	87.2	9.4	96.6
Mining	0.2	--	0.2	0.0	0.2
Nuclear	745.3	--	745.3	1.0	746.3
Water Supply	18.8	58.7	77.5	65.7	143.2
Total Demand	**846.2**	**70.8**	**916.9**	**111.9**	**1,028.8**

[1]Surface water demands considered in the SWAM model.
[2]Surface water demands for coastal communities downstream of SWAM model extent.
Note: Current water demands were based on the most up to date and available data at the time of analysis; 2022 for surface water demands and 2023 for groundwater demands.

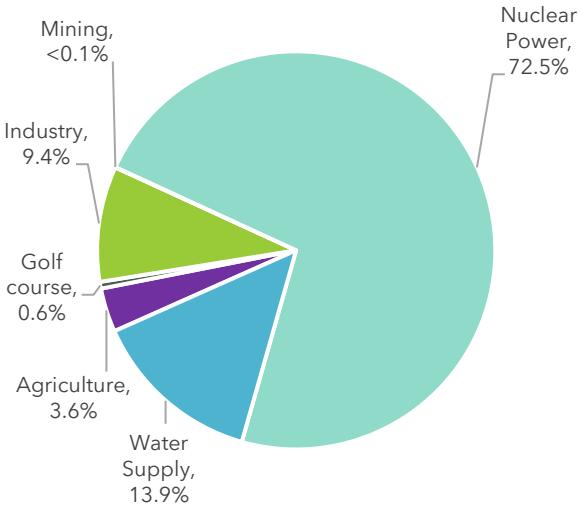


Figure 4-1. Current water use category percentages of total demand.

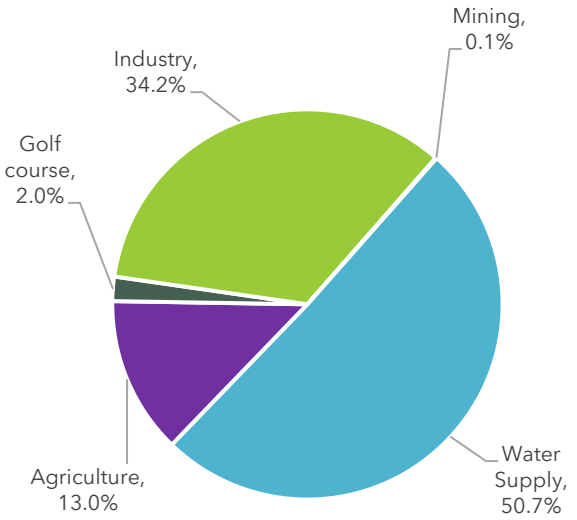


Figure 4-2. Current water use category percentages of total demand without nuclear power.

4.2 Permitted and Registered Water Use

In the Pee Dee River basin,1,452.5 MGD of surface water is permitted or registered as of March 2024. Of this total, 863.7 MGD is permitted or registered for nuclear power and 588.8 MGD has been permitted for other uses. Figure 4-3 shows the location of all permitted and registered surface water intakes and groundwater wells in the basin.

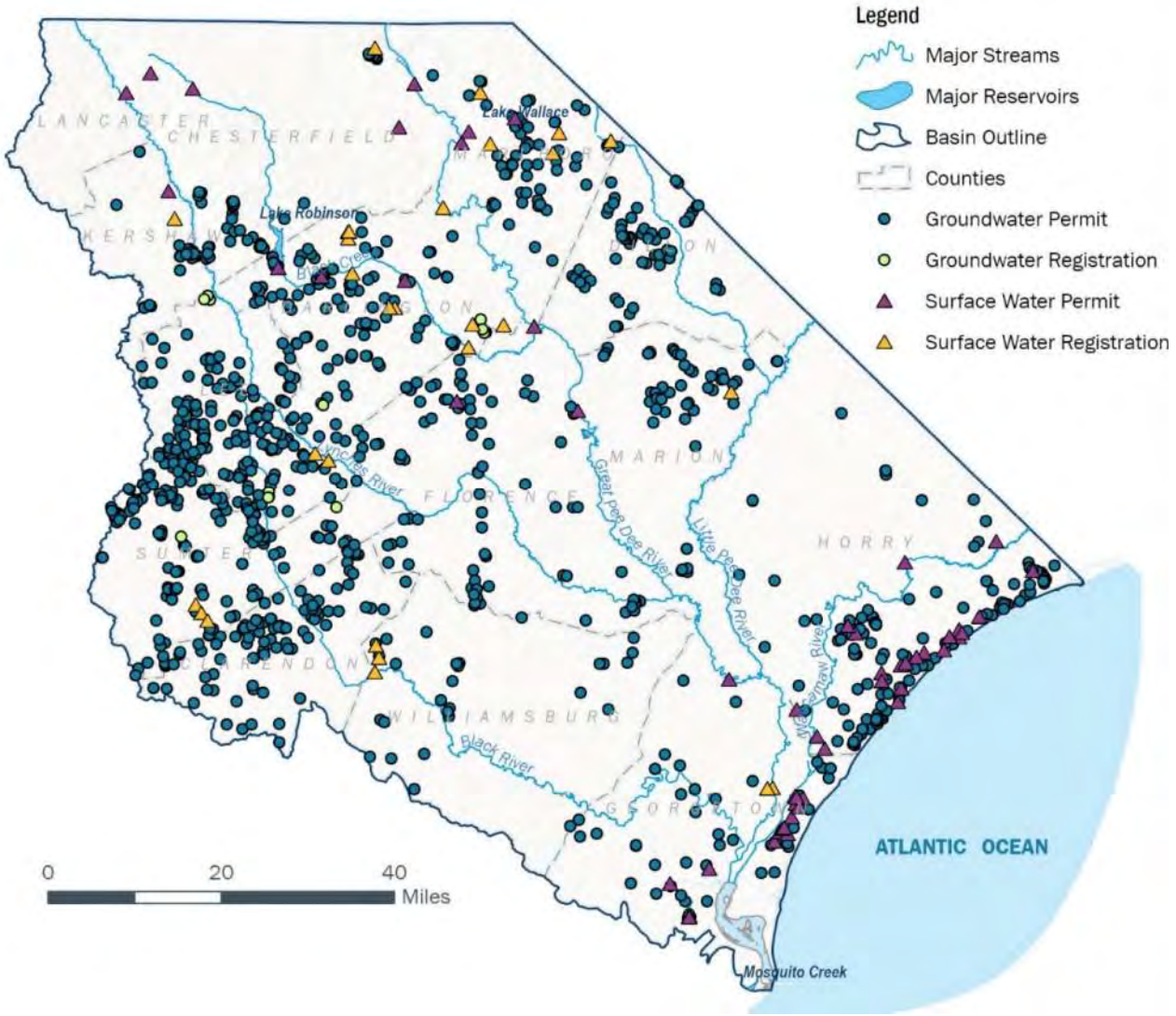


Figure 4-3. Locations of permitted and registered surface water intakes and groundwater wells in the Pee Dee River basin.

Since nearly all users are within CUAs, almost all groundwater use has been permitted. There are 10 agricultural, one golf course, and two water supply groundwater withdrawal registrations within the Pee Dee River basin. Permitted and registered groundwater withdrawals in the basin total 190.5 MGD.

Currently, only 63 percent (916.9 MGD) of the total permitted and registered surface water amount is withdrawn, and 59 percent (111.9 MGD) of the total permitted and registered groundwater amount is withdrawn. These low percentage use rates are in part due to the fact that agricultural surface water registrations and existing (prior to the enactment of Surface Water Regulation 61-119 in 2011) nonagricultural surface water permits do not require the user to demonstrate that the withdrawal is "reasonable" for the use. Such registrations and permits were granted prior to the river basin planning efforts, which represent an attempt to better understand and balance the actual availability of resources with the needs of current users and for future growth. Comparatively, new surface water permits and all groundwater permits must demonstrate reasonable use for the permitted withdrawal amount. Additionally, agricultural surface water registrations have no review period and are granted in perpetuity.

Comparatively, surface water permits are reviewed every 20 to 50 years and groundwater permits are reviewed every 5 years. The lack of reasonable use criteria and authority to revisit registered surface water withdrawals has resulted in permitted and registered withdrawal amounts that greatly exceed current use rates. Scenarios for both the current use patterns and the fully allocated river basin are explored with the modeling exercises discussed in Chapter 5, as are scenarios that represent moderate to substantial demand growth within this range. Details of the permitting and registration process for withdrawals in South Carolina can be found in Table 9-1 in Chapter 9.

Table 4-2 summarizes permitted and registered surface water withdrawals by water use category, and the percent of total permitted and registered water currently in use is shown in Table 4-3. Appendix A includes a table of all permitted or registered withdrawals for each user.

Table 4-2. Permitted and registered surface water totals by category in the Pee Dee River basin.

Water Use Category	Surface Water (MGD)			Groundwater (MGD)			Total (MGD)		
	Permit	Registration	Total	Permit	Registration	Total	Permit	Registration	Total
Agriculture	0.0	201.3	201.3	82.5	0.4	83.0	267.1	17.2	284.3
Golf	52.6	0.0	52.6	3.2	0.0	3.2	55.7	0.0	55.7
Industry	126.9	0.0	126.9	18.0	0.0	18.0	144.9	0.0	144.9
Mining	15.3	0.0	15.3	0.0	0.0	0.0	15.3	0.0	15.3
Nuclear	863.7	0.0	863.7	1.8	0.0	1.8	865.5	0.0	865.5
Water Supply	192.8	0.0	192.8	84.5	0.0	84.5	277.4	0.0	277.4
Total	**1,435.7**	**16.8**	**1,452.5**	**190.0**	**0.4**	**190.5**	**1,625.8**	**17.2**	**1,643.0**

[1]The agriculture water use category includes one permitted groundwater user for aquaculture.

Table 4-3. Percent of total permitted and registered water currently in use.

Water Use Category	Surface Water	Groundwater	Total
Agriculture	1%	12%	13%
Golf	8%	3%	10%
Industry	69%	6%	67%
Mining	1%	0%	1%
Nuclear	86%	0%	86%
Water Supply	40%	24%	52%
Total	**63%**	**59%**	**63%**

4.3 Projection Methodology

The methodology to calculate demand projections followed the guidance in *Projection Methods for Off-Stream Water Demand in South Carolina* (SCDNR 2019). SCDNR developed this document over several years in collaboration with the South Carolina Water Resources Center at Clemson University and the U.S. Army Corps of Engineers, with additional input from stakeholders including:

- South Carolina Water Works Association Water Utility Council
- South Carolina Farm Bureau Water Committee
- South Carolina Chamber of Commerce Environmental Committee
- South Carolina Water Quality Association
- PPAC

Following the guidance in the statewide projections report, SCDES developed demands for the Pee Dee River basin with only minor deviations from the framework. In the Pee Dee River basin, demand projections were developed for the agricultural, golf, industry, mining, nuclear, and water supply sectors. Golf courses and mining have minimal withdrawals and are assumed to remain at current levels over the planning horizon.

For the water use categories with projected increases in demands, the projection methodology varies by water use category. Each water use category has an associated driver variable that influences demand growth, as shown in Table 4-4. Projections for these driver variables come from a variety of published sources. Published values were extrapolated to 2070 to match the planning horizon of the River Basin Plan.

Table 4-4. Driver variables for each water use category.

Water Use Category	Driver Variable	Driver Variable Data Source	Moderate Scenario	High Demand Scenario
Agriculture	Irrigated acreage	Irrigated areas polygons	0.65% increase per year	0.73% increase per year
Industry	Economic production	Subsector growth rates from the U.S. Energy Information Agency (EIA)	Industry/manufacturing subsector growth with the minimum adjusted to 0% through 2035 and 0.3% beyond 2035	Industry/manufacturing subsector growth with the minimum adjusted to 2.1%[1]
Nuclear	Not applicable	Not applicable	Assumed constant	Assumed constant
Water Supply	Population	South Carolina Office of Revenue and Fiscal Affairs	Extend straight-line growth or assume constant population if the population projection is negative	Project using statewide or countywide growth rate, increased by 10%
Golf Course	Not Applicable	Not applicable	Assumed constant	Assumed constant
Mining	Not applicable	Not applicable	Assumed constant	Assumed constant

[1]2.1% is the total overall EIA economic growth projection increased by 10% (1.9% + 10% x 1.9% = 2.1%)

Two demand projections were developed: (1) the Moderate Water Demand Scenario (Moderate Demand Scenario) and (2) the High Water Demand Scenario (High Demand Scenario). The Moderate Demand Scenario was originally referred to as the Business-as-Usual Scenario in the Planning Framework. The Moderate Demand Scenario is based on median rates of water use and moderate growth projections, while the High Demand Scenario is based on the maximum monthly rates of water use in recent reporting and high growth projections. While it is unlikely that the conditions of the High Demand Scenario would occur for an extended time or universally across the basin, the scenario is useful for establishing an upper bound for the projected demand. The following subsections present additional details on the calculation of demand for each water use category.

High Growth Groundwater Demands

Although the High Demand Scenario for groundwater demands is presented in this chapter, it may be unrealistic to maintain the High Demand Scenario every single year for decades on end. Thus, a "High Growth" Scenario was developed using the Moderate calibration (median monthly demands) and the High Demand growth projections (for population, economic sectors, and irrigated area). The High Growth Scenario may be used or mixed with High Demand on alternating years for groundwater model simulations.

4.3.1 Agriculture Demand Projection Methodology

Agricultural surface water and groundwater demands were developed for the Pee Dee River basin. Multiple datasets indicate agricultural demands will increase over time, including National Agricultural Statistics Service data and State pumping records.

To assess where future additional irrigation may occur, a multi-step approach was used (Pellett 2024).

- First, irrigated fields/areas (i.e. polygons in GIS) were developed for the Pee Dee River basin. The irrigated areas are based on registered irrigation water withdrawal intake locations, and irrigated areas were visually identified at these locations using Google Earth and NAIP aerial imagery.
- Then, the irrigated areas were assessed for suitability to expand. It is assumed these lands would be irrigated via center pivot. Areas for potential expansion were constrained by several spatial characteristics that would limit future irrigation, such as:
  - Wetlands present
  - Slopes greater than 5 percent
  - Parcels less than 30 acres
  - Protected areas present
  - Developed areas present
  - Morphological opening/closing (not condusive to center pivot installation)
- The polygons were then ranked based on their proximity to existing irrigated areas and their overlap on existing cultivated agriculture. The highest-ranking polygons were selected for "projected growth". Other polygons that met some of the criteria, but were not highly ranked due to their lack of proximity to existing irrigated land and agriculture were labeled as "other opportunity".

Figure 4-4 shows the irrigated areas, projected growth, and other opportunities. The High Demand Scenario was used as an upper limit for the expansion of irrigated areas, and the Moderate expansion of irrigated areas was set lower than this. Although irrigated areas are projected to increase at a consistent rate per year for the Moderate and High Demand Scenarios, this does not necessarily correlate to an equivalent increase in water demand due to variation in irrigation practices and cropping patterns.

Areas of projected growth for irrigation are estimates only and reflect assumptions made for the purposes of the River Basin Plan regarding conditions that might foster growth. Projected growth areas and other opportunities areas do not indicate recommended locations for future growth nor do they indicate locations where irrigation may or may not be viable.

Note that members of the Pee Dee RBC had suggestions for future improvements to projecting additional lands that may be irrigated in the future, including conducting outreach with irrigators and irrigation equipment manufacturers (specifically, center pivot manufacturers).

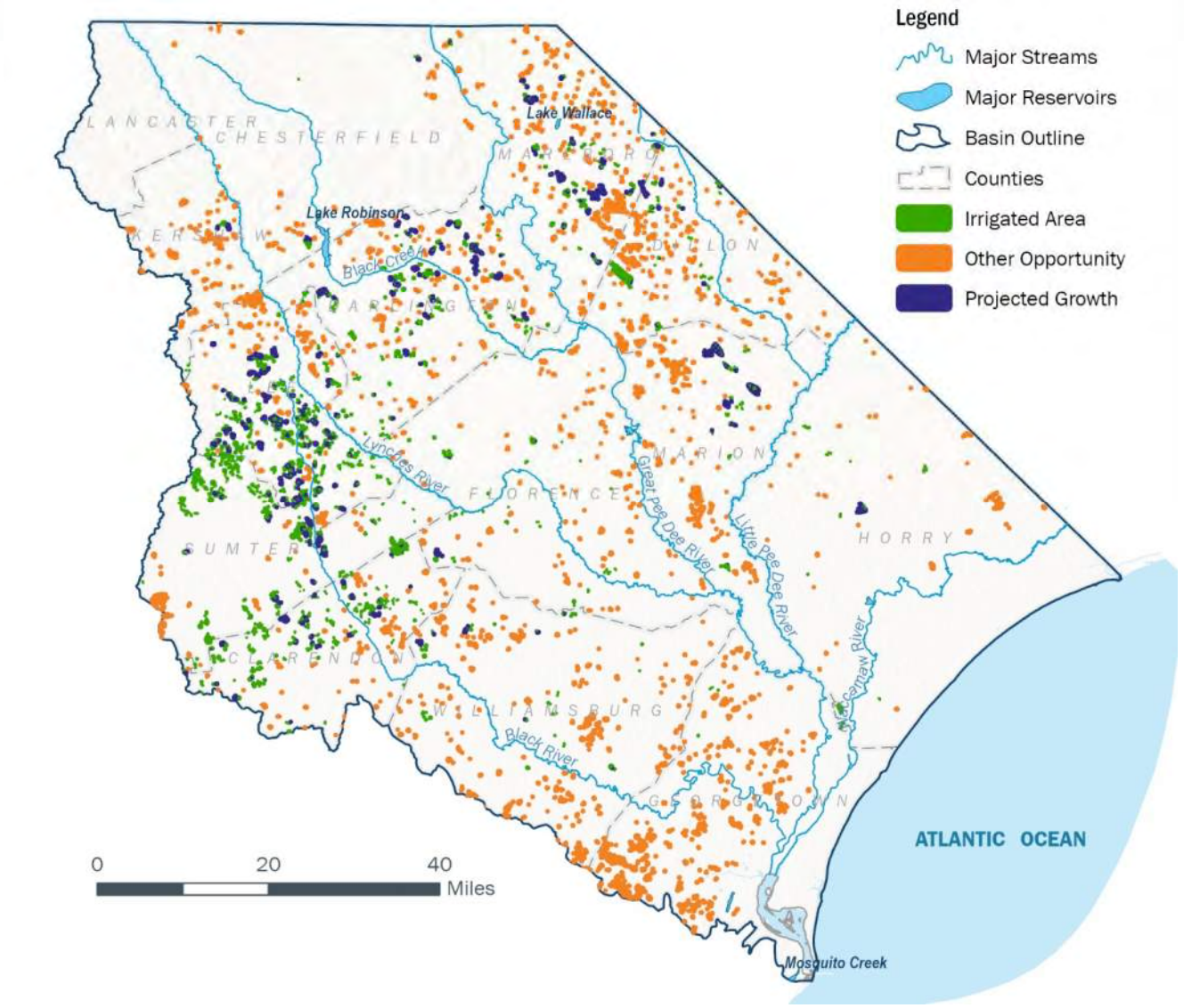


Figure 4-4. Irrigated areas, projected growth, and other opportunities in the Pee Dee River basin.

4.3.2 Public Supply Demand Projections Methodology

Public supply is the second largest water use sector in the Pee Dee River basin. Approximately 19 percent of public supply withdrawals are met with surface water. Demand projections for public supply were developed based on county-level population and water use projections. Population projections for the Moderate Scenario were taken from the South Carolina Office of Revenue and Fiscal Affairs (SC ORFA). These projections, which end in 2035, were extended to 2070. For the Moderate Demand Scenario, projections are extended linearly. If SC ORFA projections indicate a decline in population, then the extension to 2070 was flatlined at 2035 levels. For the High Demand Scenario, populations were projected to grow exponentially. If SC ORFA projected growth, then the exponential growth rate was increased by 10 percent. If the SC ORFA projection for a county was less than the statewide average, then the high scenario population projection was set at the state average plus 10 percent. As shown in Figure

4-5, some counties are projected to experience population declines while others may experience substantial growth in both the Moderate and High Demand Scenarios.

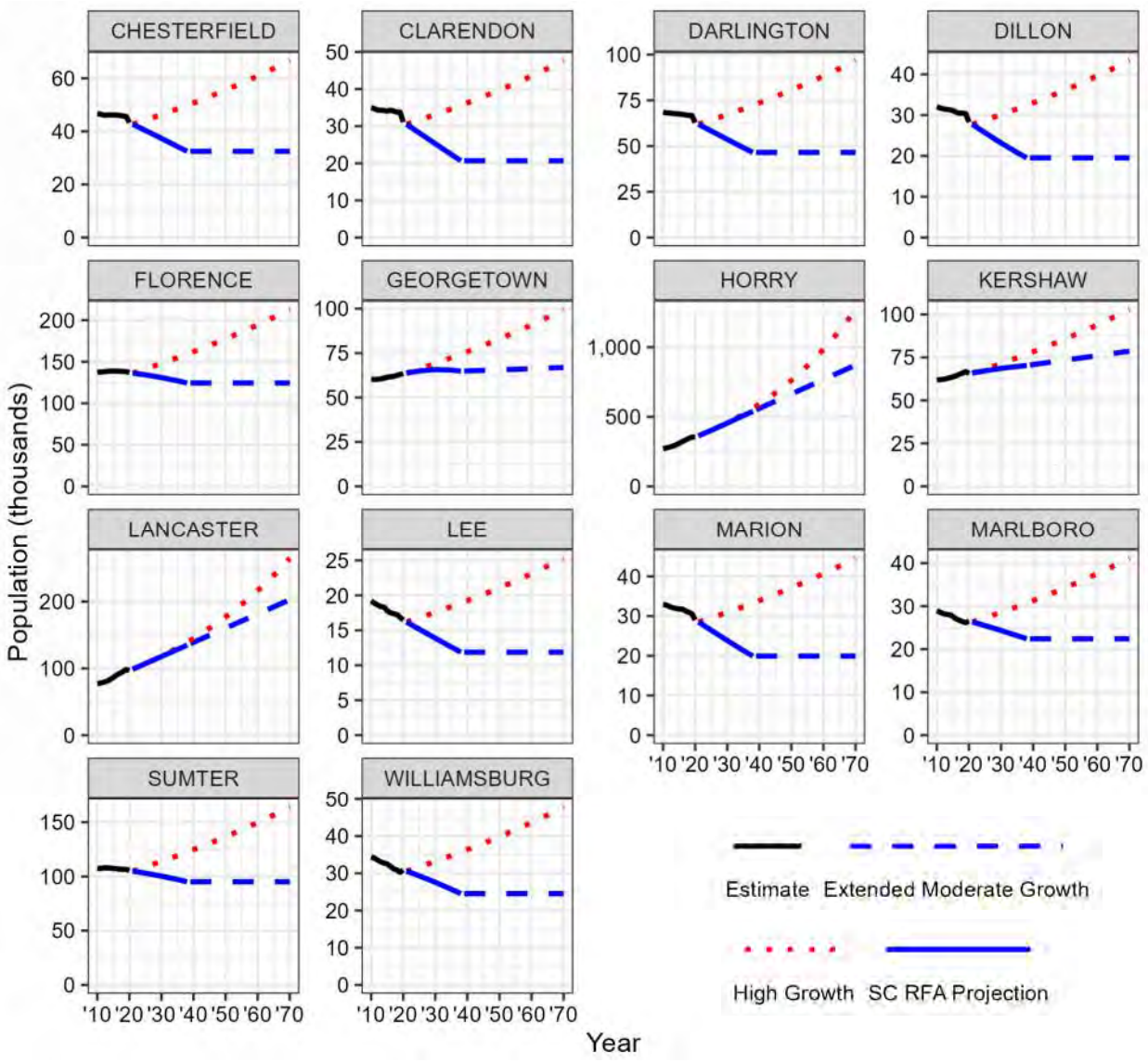


Figure 4-5. Population projections to 2070 for counties withdrawing from the Pee Dee River basin.

4.3.3 Industry Demand Projections Methodology

Industrial water supplies are used in the Pee Dee River basin to produce paper, packaging, and other paper-related products; manufacture and recycle steel; produce lumber, food products, and bottled water; and manufacture chemicals, among other uses. Surface water is used by industrial water users such as International Paper and Domtar. Groundwater supplies have been developed to serve industrial water users like Pilgrims Pride (food products), McCall Farms (for canning and freezing operations), and Nan Ya Plastics Corporation. Some industries use both groundwater and surface water supplies, like Sonoco, NUCOR, and West Rock Co.

Industrial demand projections were based on projected subsector growth rates from the U.S. Energy Information Agency (EIA), which ranged from -0.4 to 2.5 percent for the sectors present in the Pee Dee River basin (EIA 2020). For the Moderate Demand Scenario, negative projected growth rates were set to zero percent through 2035, and growth rates were set to a minimum of 0.3 percent beyond 2035; resulting in an overall growth rate less than 0.3 percent for those cases. For the High Demand Scenario, annual growth rates were set to a minimum of 2.1 percent, and annual growth rates higher than 2.1 percent were multiplied by 1.1 to increase them by 10 percent. The adjusted annual growth rates were applied for the entire projection period.

4.3.4 Other Projections Methodology

Other water withdrawals in the Pee Dee River basin support golf course irrigation and mining. Historically, golf has been in decline in the basin, and mining has been stable. Water use for these categories is low and assumed relatively constant into the future. Mining is projected to be 1.3 MGD and 2.0 MGD for the Moderate Demand and High Demand Scenarios, respectively. Golf course is projected to increase in coastal areas, with approximately 5.2 MGD for the Moderate Demand Scenario and 13.8 to 14.3 MGD for the High Demand Scenario.

Nuclear power is also projected to remain relatively constant into the future. The H.B. Robinson Nuclear Plant renewed their 40-year permit with no anticipated changes in use.

4.4 Projected Water Demand

From 2025 to 2070, total withdrawals are projected to increase by 12 percent (117.6 MGD) under the Moderate Demand Scenario and 34 percent (417.2 MGD) under the High Demand Scenario. In the Moderate Demand Scenario, groundwater and surface water demands are projected to increase 26.5 MGD and 91.1 MGD respectively. In the High Demand Scenario, groundwater demands are projected to increase 117.9 MGD, and surface water demands are projected to increase 299.3 MGD.

Table 4-5 and Figure 4-6 summarize projected surface water and groundwater demands over the planning horizon. Figure 4-6 represents a stacked area graph where total demand is shown as a thick black line and shaded areas show which portion of that demand comes from groundwater or surface water. Although the majority of the demands under both scenarios are attributable to surface water demands, it is projected that groundwater demands will increase at a higher rate than surface water demands.

In the Pee Dee basin scenarios, as in other basins, there are some differences between the Moderate Growth Projection Scenario and the Current Use Scenario. The Current Use Scenario is based on long-term average (mean) withdrawals. This is a reasonable way to represent the status quo, but mean averages can be biased by outliers and may not reflect recent efficiency improvements.

The Moderate Demand Scenario is based on recent median withdrawals. Median averages, the middle value of a set, are less affected by outlier values compared with mean averages. The High Demand scenario is based on the maximum monthly withdrawal, and it represents an extreme case when applied across all users in the basin.

Projected demands by water use category are summarized in Figure 4-7 and further described in the subsections that follow. Figure 4-8 shows projected demands, excluding nuclear power.

Table 4-5. Projected surface water and groundwater demands.

	Moderate Demand Scenario (MGD)			High Demand Scenario (MGD)		
Year	**Surface Water**	**Groundwater**	**Total**	**Surface Water**	**Groundwater**	**Total**
2025	892.8	102.1	994.9	1,032.8	177.6	1,210.4
2030	902.0	103.2	1,005.2	1,053.4	187.2	1,240.6
2035	910.8	104.4	1,015.2	1,076.4	197.6	1,274.0
2040[1]	917.9	106.3	1,024.2	1,099.6	208.8	1,308.4
2050	940.7	113.2	1,053.9	1,162.5	233.2	1,395.7
2060[1]	959.9	120.9	1,080.8	1,235.5	262.3	1,497.8
2070	983.9	128.6	1,112.5	1,332.1	295.5	1,627.6
% Change 2025-2070	**10%**	**26%**	**12%**	**29%**	**66%**	**34%**

[1]2040 and 2060 are leap years. When projections are constant into the future; the projected results may show some variation accounting for number of days in the year.

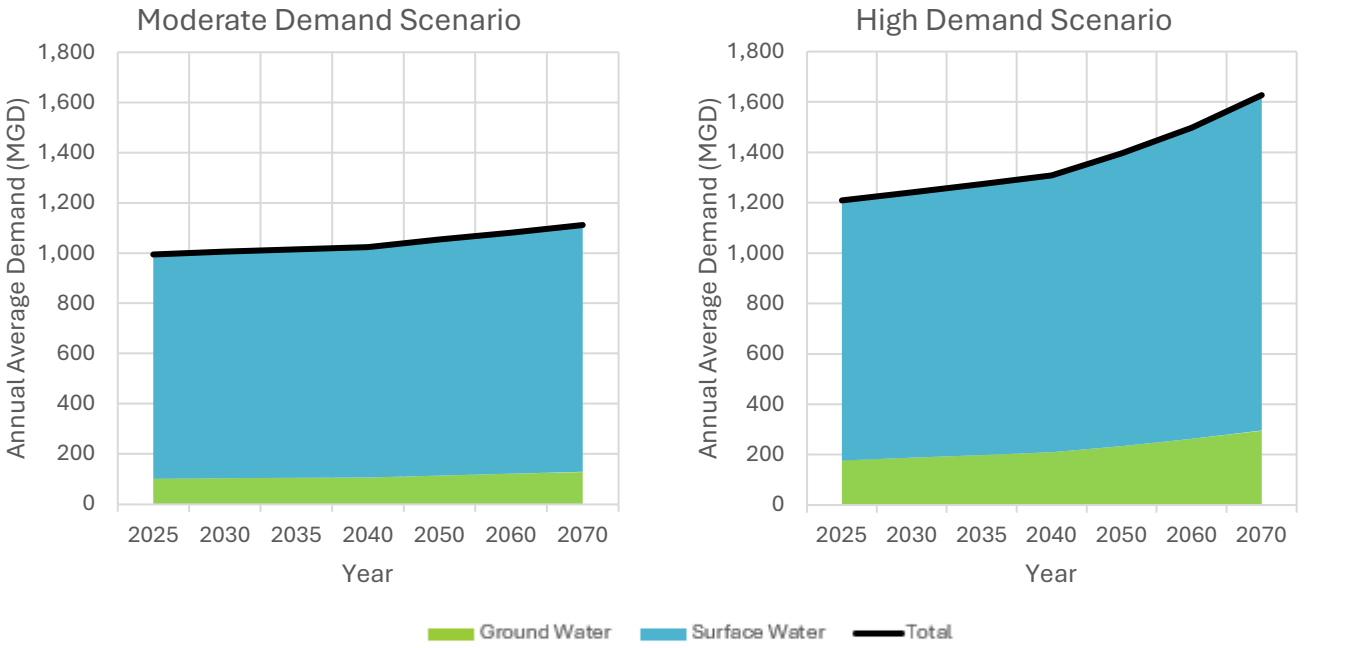


Figure 4-6. Demand projections by water source.

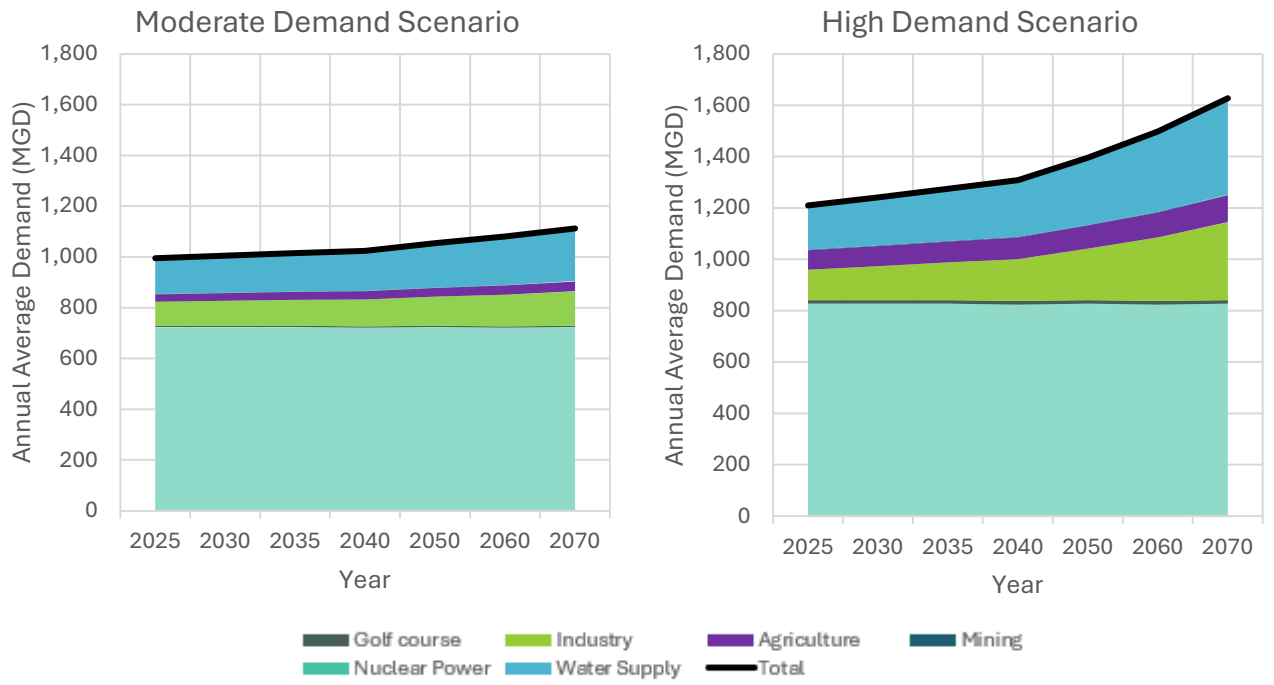


Figure 4-7. Demand projections by water use category.

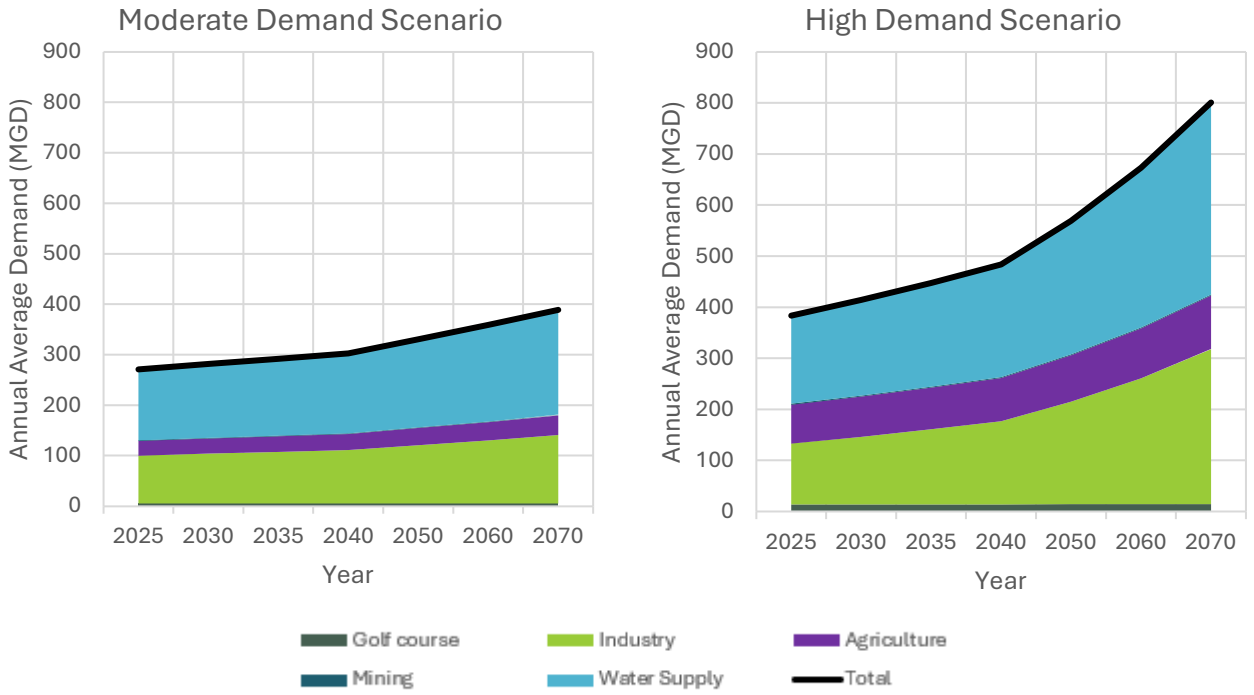


Figure 4-8. Demand projections by water use category without nuclear power.

4.4.1 Agriculture Demand Projections

Agricultural water demands are projected to increase by 34 percent between 2025 and 2070 (29.2 MGD to 39.1 MGD) in the Moderate Demand Scenario. In the High Demand Scenario, the agricultural water demands are projected to increase by 38 percent between 2025 and 2070 (76.0 MGD to 104.9 MGD). Groundwater demands account for most of the total projected agricultural demands. Agricultural demand projections by water source are shown in Figure 4-9 and Table 4-6.

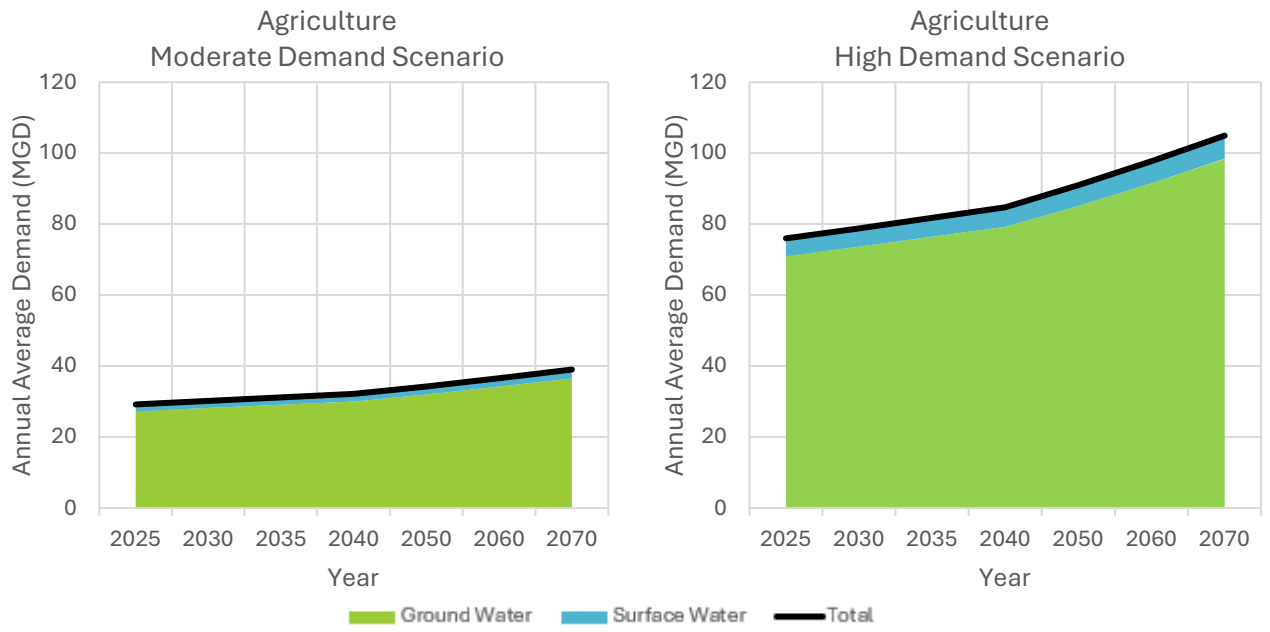


Figure 4-9. Projected agricultural water demands.

Table 4-6. Projected agricultural water demands.

	Moderate Demand Scenario (MGD)			High Demand Scenario (MGD)		
Year	**Surface Water**	**Groundwater**	**Total**	**Surface Water**	**Groundwater**	**Total**
2025	1.9	27.3	29.2	5.0	71.0	76.0
2030	2.0	28.2	30.2	5.2	73.6	78.8
2035	2.1	29.1	31.2	5.3	76.4	81.7
2040	2.1	30.0	32.1	5.5	79.2	84.7
2050	2.3	32.0	34.3	5.8	85.1	90.9
2060	2.4	34.2	36.6	6.1	91.5	97.6
2070	2.6	36.5	39.1	6.5	98.4	104.9
% Change 2025-2070	**31%**	**34%**	**34%**	**30%**	**39%**	**38%**

4.4.2 Public Supply Demand Projections

Public water supply demand is the second highest demand by sector in the Pee Dee River basin. Projected populations by county over time are presented in Table 4-7. In the Moderate Demand Scenario, public water supply demands are projected to increase by 47 percent from 2025 to 2070 (140.7 MGD to 207.6 MGD). In the High Demand Scenario, public water supply demands are projected to increase by 118 percent from 2025 to 2070 (172.6 MGD to 375.8 MGD). Approximately 33 percent and 38 percent of the total public water supply demand is projected to be supplied by groundwater in the Moderate and High Demand Scenarios, respectively, in 2070. Public water supply demand projections by water source are shown in Figure 4-10 and Table 4-8.

Table 4-7. Projected population increases (in thousands).

	County	2025	2030	2035	2040	2050	2060	2070
Moderate Demand Scenario	Chesterfield	40.4	37.3	34.3	32.5	32.5	32.5	32.5
	Clarendon	28.2	25.3	22.4	20.7	20.7	20.7	20.7
	Darlington	58.3	53.7	49.1	46.5	46.5	46.5	46.5
	Dillon	25.7	23.2	20.8	19.5	19.5	19.5	19.5
	Florence	134.3	131.0	127.0	124.4	124.4	124.4	124.4
	Georgetown	65.0	65.7	65.5	65.0	65.6	66.3	66.9
	Horry	402.4	454.6	508.0	560.4	664.2	768.0	871.8
	Kershaw	67.2	68.6	69.7	70.8	73.4	76.0	78.6
	Lancaster	107.2	117.7	128.3	139.1	160.3	181.5	202.7
	Lee	15.2	13.9	12.6	11.9	11.9	11.9	11.9
	Marion	26.4	23.8	21.4	19.9	19.9	19.9	19.9
	Marlboro	25.5	24.3	23.1	22.4	22.4	22.4	22.4
	Sumter	103.1	100.3	97.2	95.1	95.1	95.1	95.1
	Williamsburg	29.3	27.6	25.7	24.5	24.5	24.5	24.5
	Total	**1,128**	**1,167**	**1,205**	**1,253**	**1,381**	**1,509**	**1,637**
High Demand Scenario	Chesterfield	44.3	46.3	48.5	50.7	55.6	60.9	66.7
	Clarendon	31.6	33.1	34.7	36.3	39.7	43.5	47.7
	Darlington	64.2	67.2	70.3	73.6	80.6	88.3	96.7
	Dillon	28.8	30.1	31.5	33.0	36.2	39.6	43.4
	Florence	141.4	147.9	154.8	162.0	177.5	194.4	213.0
	Georgetown	66.1	69.2	72.4	75.8	83.0	90.9	99.6
	Horry	402.4	457.3	519.7	590.7	762.9	985.3	1,272.5
	Kershaw	68.3	71.5	74.8	78.3	85.8	94.0	102.9
	Lancaster	107.0	118.4	130.9	144.8	177.0	216.5	264.8
	Lee	16.8	17.6	18.4	19.3	21.1	23.1	25.3
	Marion	29.6	31.0	32.4	33.9	37.1	40.7	44.6
	Marlboro	27.3	28.6	29.9	31.3	34.3	37.6	41.1
	Sumter	108.8	113.9	119.2	124.8	136.7	149.7	164.0
	Williamsburg	31.7	33.2	34.7	36.4	39.8	43.6	47.8
	Total	**1,168**	**1,265**	**1,372**	**1,491**	**1,767**	**2,108**	**2,530**

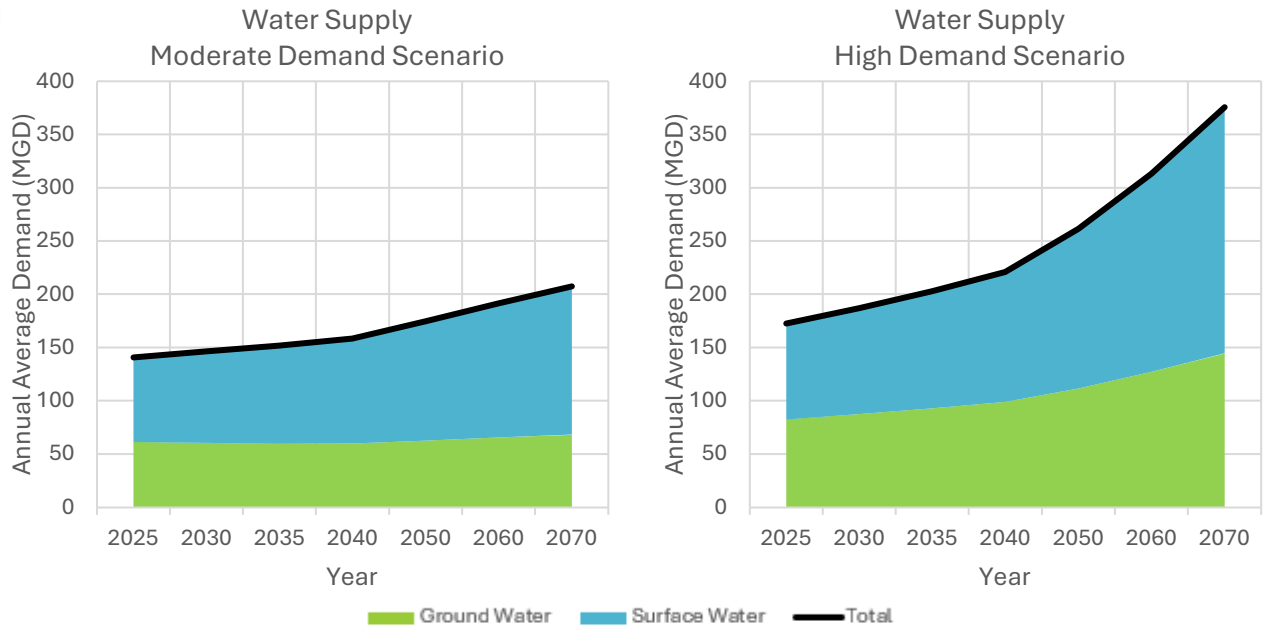


Figure 4-10. Projected public water supply demands.

Table 4-8. Projected public water supply demands.

	Moderate Demand Scenario (MGD)			High Demand Scenario (MGD)		
Year	**Surface Water**	**Groundwater**	**Total**	**Surface Water**	**Groundwater**	**Total**
2025	79.5	61.2	140.7	90.0	82.6	172.6
2030	85.9	60.4	146.3	99.4	87.6	187.0
2035	92.1	59.6	151.7	109.9	92.9	202.8
2040	98.7	59.7	158.4	121.9	98.9	220.8
2050	112.1	62.4	174.5	150.0	111.5	261.5
2060	126.0	65.5	191.5	186.2	127.0	313.2
2070	139.4	68.2	207.6	231.3	144.5	375.8
% Change 2025-2070	**75%**	**11%**	**47%**	**157%**	**75%**	**118%**

4.4.3 Industry Demand Projections

Industrial water demands are projected to increase by 43 percent from 2025 to 2070 in the Moderate Demand Scenario (94.8 MGD to 135.7 MGD). In the High Demand Scenario, industrial water demands are projected to increase by 155 percent from 2025 to 2070 (119.3 MGD to 303.8 MGD). While manufacturing has variable production day-to-day, the High Demand Scenario assumes maximum production and potential for new industries or facilities to develop. Industrial water demand projections by water source are shown in Figure 4-11 and Table 4-9.

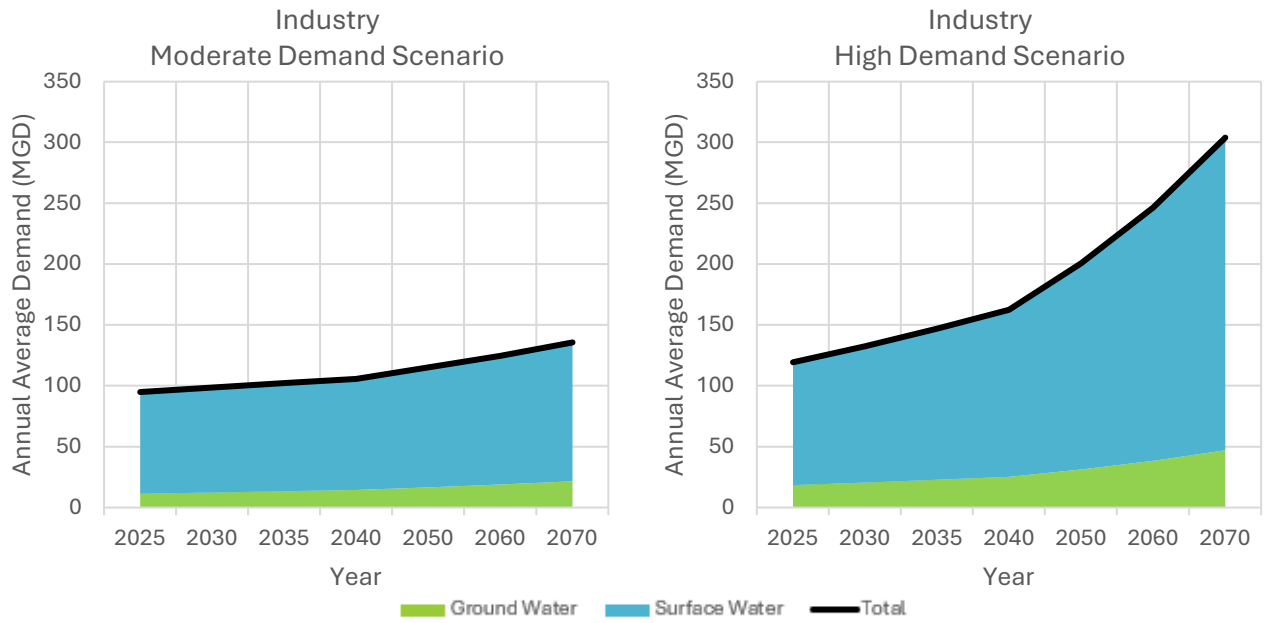


Figure 4-11. Projected industry water demands.

Table 4-9. Projected industry water demands.

	Moderate Demand Scenario (MGD)			High Demand Scenario (MGD)		
Year	**Surface Water**	**Groundwater**	**Total**	**Surface Water**	**Groundwater**	**Total**
2025	83.5	11.3	94.8	100.8	18.5	119.3
2030	86.3	12.3	98.6	111.8	20.5	132.3
2035	88.8	13.4	102.2	124.0	22.8	146.8
2040	91.2	14.3	105.5	137.3	25.2	162.5
2050	98.5	16.5	115.0	169.4	31.1	200.5
2060	105.6	18.9	124.5	208.0	38.3	246.3
2070	114.1	21.6	135.7	256.7	47.1	303.8
% Change 2025-2070	**37%**	**91%**	**43%**	**155%**	**155%**	**155%**

4.4.4 Other Demand Projections

Other demands are held constant into the future as described in Section 4.3.4. Mining demands are assumed to be 1.3 MGD and 2.0 MGD for the Moderate and High Demand Scenarios, respectively. All mining demands are projected to be met from surface water.

Golf course demands are approximately 5.2 to 5.3 MGD for the Moderate Demand Scenario and 13.8 to 14.3 MGD for the High Demand Scenario. Of these demands, approximately 77 percent of the demand is for surface water for the Moderate Demand Scenario, and 71 percent of demand is for surface water for the High Demand Scenario. Note that slight increases in golf course demand over the planning horizon were due to increases at a course that is associated with a drinking water permit (Founders Golf Club in Myrtle Beach).

In addition, nuclear power demands are assumed to be approximately 723.6 MGD and 826.7 MGD for the Moderate and High Demand Scenarios, respectively, with nearly 100 percent supplied by surface water. Other uses are too small to be reported and were not included in the demand projections.

Chapter 5
Comparison of Water Resource Availability and Water Demand

This chapter describes the methods used to assess surface water and groundwater availability in the Pee Dee River basin and underlying aquifers. A surface water model was used to evaluate water availability using current and projected water demands. Water availability was also assessed assuming surface water withdrawals at permitted and registered amounts. Groundwater was evaluated by examining historical water-level measurements and trends, potentiometric surface maps, reported water use, and projected water demand. The results of these assessments are presented and compared, and potential shortages, issues, and areas of concern are identified. Opportunities for mitigating issues and managing water supplies sustainably are described in subsequent chapters.

5.1 Methodology

5.1.1 Surface Water

Surface water planning scenarios were constructed and simulated using the previously developed Pee Dee River basin surface water quantity model (CDM Smith 2017). This model was developed with CDM Smith's SWAM software. It simulates river basin hydrology, water availability, and water use across a dendritic stream network and over an extended time series.

SWAM was designed to provide efficient planning-level analyses of surface water supply systems. Beginning with naturally occurring water flowing in the river reaches, it calculates physically and permitted or allowable water, diversions, storage, consumption, and return flows at user-defined nodes in a networked river system. A range of water user types can be represented in the model, including municipal water suppliers, agricultural irrigators, and industrial water users, with time-variable demands either prescribed by the user or, in some cases, calculated internally. Multiple layers of complexity are available as options in SWAM to allow for easy development of a range of systems, from the very simple to the more complex. As an example, SWAM's reservoir object can include only basic hydrology-dependent calculations (storage as a function of inflow, outflow, and evaporation) or can include operational rules of varying complexity: prescribed monthly releases, a set of prioritized monthly releases or storage targets, or a set of conditional release rules (dependent on hydrology). Municipal water conservation programs can similarly be simulated with sets of rules of varying complexity. The model user chooses the appropriate level of complexity given the modeling objectives and data availability.

The Pee Dee River basin SWAM model simulates 89 years of variable historic hydrology (October 1929 – December 2018) with either a monthly or daily user-specified calculation timestep (the surface water

scenarios presented in this chapter represent monthly analyses, unless noted otherwise). It is designed for three primary purposes:

- Accounting of current and past basin inflows, outflows, and consumptive uses
- Simulating streamflow and lake storage (if applicable) across a range of observed historical climate and hydrologic conditions, given current water use and operations
- Simulating future "what if" scenarios associated with changes in basin water use, management, and/or operations

The Pee Dee River basin model includes 9 municipal, 8 industrial, 3 golf course, 1 thermoelectric, 4 mining, and 17 agricultural (irrigation) water users. Some of the included water users only withdraw groundwater but discharge to surface water, thus their inclusion in the model. All water users with permitted withdrawals greater than 0.1 million gallons per day (MGD) are represented, either explicitly or implicitly. In the model, which represents current conditions, monthly water use is set equal to the average of a recent 10-year period (2009 to 2018) of reported use, with several exceptions. Exceptions include new surface water users and surface water users with recent demands that are significantly different than demands in the early part of the 10-year period. Water use patterns can also be adjusted by model users to explore future water management scenarios, as discussed in this chapter.

A total of 48 "tributary objects" (rivers and streams) are represented discretely in the model, including the mainstem Great Pee Dee River. Boundary condition (headwater) flows for each tributary object are prescribed in the model based on external analyses (see CDM Smith 2017), which estimated naturally-occurring historical flows "unimpaired" by human uses. Historic, current, and/or future uses can then be simulated against the same natural hydrology of the basin. Hydrologic flow gains (or losses) for each tributary are simulated in SWAM using lumped gain (or loss) factors, which are set based on a model calibration exercise, using gaged flow data, and/or guided by changes in reach drainage area. While there is no direct linkage between the SWAM model and the groundwater model (discussed below), SWAM implicitly accounts for interaction between groundwater and surface water through the assignment of the gain/loss factors in each stream reach.

The Pee Dee River basin SWAM model was used to simulate current and potential future scenarios to evaluate surface water availability. Detailed descriptions of the surface water scenarios and their results are provided in Chapter 5.3.

Several key terms are used throughout this section when presenting results of the surface water modeling. These key terms are introduced and defined below.

- **Physically Available Surface Water Supply** – the maximum amount of water that occurs 100 percent of the time at a location on a surface water body with no defined Surface Water Conditions applied on the surface water body.
- **Reach of Interest** – a stream reach defined by the RBC which experiences undesired impacts, environmental or otherwise, determined from current or future water-demand scenarios or proposed water management strategies. Such reaches may or may not have identified surface water shortages. The RBC did not identify any Reaches of Interest in the Pee Dee River basin.

- **Strategic Node** – a location on a surface water body designated to evaluate the cumulative impacts of water management strategies for a given model scenario and which serves as a primary point of interest from which to evaluate a model scenario's Performance Measures. Strategic Nodes are defined by the RBC.

- **Surface Water Condition** – a limitation, defined by the RBC, on the amount of water that can be withdrawn from a surface water source and which can be applied to evaluate Surface Water Supply for planning purposes. The RBC did not establish a Surface Water Condition for any location in the Pee Dee River basin.

- **Surface Water Shortage** – a situation in which water demand exceeds the Surface Water Supply for any water user in the basin.

- **Regulatory Shortage** – for the purposes of the Pee Dee River Basin Plan, a situation in which water demand exceeds the permitted or registered amount of a specific user (note that this term and definition are not in the Planning Framework).

- **Surface Water Supply** – the maximum amount of water available for withdrawal 100 percent of the time at a location on a surface water body without violating any applied Surface Water Conditions on the surface water source and considering upstream demands.

5.1.2 Groundwater

The methodology for comparing groundwater availability with groundwater demand presented in the Planning Framework relies on the use of the USGS Coastal Plain groundwater-flow model to calculate water-level declines in aquifers for the four water-use scenarios described in the Planning Framework. For each scenario, the groundwater model would simulate water levels in each aquifer throughout the basin over the 50-year planning horizon, allowing the RBC to identify areas of potential groundwater problems. The groundwater model also could be used to evaluate the effectiveness of proposed groundwater management strategies by estimating the impacts of those strategies on aquifer water levels.

After the USGS developed the Coastal Plain groundwater flow model that was used for the 2023 Edisto River Basin Plan, they identified problems with some water-use data that was used during the model calibration. Correcting the data and subsequently recalibrating the model delayed the model's availability to the extent that it would not be ready for use during the Pee Dee basin planning process without significantly delaying the release of the Pee Dee River Basin Plan. After the USGS's initial and unsuccessful efforts to rapidly update the model and a project delay of six months, the Pee Dee RBC decided to complete the River Basin Plan without the benefit of having a groundwater model.

Without a groundwater model, groundwater availability assessments could not be conducted as described in the Planning Framework. A different approach was needed. The RBC relied only on empirical data to evaluate groundwater conditions in the basin.

Groundwater level measurements, primarily collected from the SCDES monitoring well network, provide information about historical and current conditions in the major aquifers, showing how groundwater conditions in the basin have changed during the past several decades. Water levels collected for potentiometric mapping projects include data for many other wells not in the dedicated monitoring network, and the potentiometric maps themselves offer insights into how aquifer conditions have

changed over time. This collection of water-level data not only provides a good picture of current water-level conditions, but it also provides a good look at trends or changes in water levels over time.

In addition to water-level data, the RBC considered groundwater use throughout the basin as part of its groundwater availability assessment. Because groundwater withdrawals are the primary driver of groundwater-level declines, it is essential to understand both historical and current groundwater use, both quantitatively and spatially, to relate groundwater use to observed trends in groundwater levels. Reasonably good groundwater withdrawal data are available for most groundwater users in the basin for the past twenty years.

By reviewing both water-use and water-level data, the RBC identified areas within the basin where specific aquifers have already or are likely to see significant water-level declines that should be addressed through some management strategy. Similarly, the RBC identified other areas of the basin in which groundwater availability has not been negatively impacted by past water use.

Water-use projections for the standard four water-use scenarios described in the Planning Framework were still developed and will be ready for use in the groundwater model when it becomes available. Without the groundwater model, however, detailed descriptions of the impacts of each water-use scenario will not be available. Even without the model, however, the groundwater-use projections can inform planners of areas likely to see significant increases in groundwater use during the next several decades.

Without the groundwater model, the Pee Dee RBC relied on current and historical water-level and water-use data, as well as knowledge of aquifer hydrogeology, to identify Groundwater Areas of Concern and potential Groundwater Areas of Concern. A Groundwater Area of Concern is defined in the Planning Framework as "an area where current or future groundwater withdrawals from an aquifer are causing or are expected to cause unacceptable impacts to the resource or the public well-being". A "potential Groundwater Area of Concern" is similar to a Groundwater Area of Concern but is more speculative, in that it represents an area in which a problem is not yet known to occur but may develop or be confirmed in the future. Potential Groundwater Areas of Concern would be classified as Groundwater Areas of Concern if future groundwater modeling or field measurements substantiated the suspected problem.

Demand-side groundwater management strategies were developed and recommended by the RBC, but the effectiveness of those strategies cannot be tested with the groundwater model until a later date. Similarly, supply-side management strategies were developed and recommended, but without a technical evaluation, those recommendations are somewhat conceptual or generalized. Management strategies proposed by the RBC may be considered for inclusion in future iterations of Capacity Use groundwater management plans as well as the State Water Plan.

5.2 Performance Measures

Performance measures were developed as a means for comparing water resource impacts (negative and positive) of each scenario. A performance measure is a quantitative measure of change in a user-defined condition from an established baseline, used to assess the performance of a proposed water management strategy or combination of strategies. Performance measures establish an objective means with which to compare scenarios. Performance measures were selected collaboratively with the RBC.

5.2.1 Surface Water Performance Measures

Hydrologic-based Performance Measures

The hydrologic surface water performance measures used to evaluate and compare simulation results are presented in Table 5-1. For each simulated scenario, performance measures were calculated as a post-processing step in the modeling. All metrics were calculated for the entire simulation period. As noted above, changes in performance measures between scenarios were particularly useful for the planning process. The first set of performance metrics were calculated for model output nodes that were identified by the RBC as Strategic Nodes. These Strategic Nodes are distributed throughout the river basin. Strategic Nodes coincide with seven active streamflow gaging stations plus two additional locations on the Pee Dee River below the confluence with the Lynches River and below the confluence with the Little Pee Dee River. These Strategic Nodes were selected in collaboration with the RBC. All strategic node locations are shown in Figure 5-1.

Table 5-1. Surface water performance measures.

Strategic Node Metrics (generated for each Strategic Node)
Mean flow (cfs)
Median flow (cfs)
25th percentile flow (cfs)
10th percentile flow (cfs)
5th percentile flow (cfs)
Comparison to Minimum Instream Flows (MIFs)[1]
Basin-wide Metrics (generated in aggregate for the entire modeled river basin)
Total basin annual mean shortage (MGD) - Sum of the average shortage for all users over the simulation period
Maximum water user shortage (MGD) - The maximum monthly shortage experienced by any single user over the simulation period
Total basin annual mean shortage (% of demand) - Sum of the average shortage for all users over the simulation period divided by the sum of the average demand for all users over the simulation period
Average frequency of shortage (%) - The average frequency of shortage of all users who experience a shortage, where each user's frequency of shortage is calculated as the number of months with a shortage divided by the total months in the simulation (for a monthly timestep simulation)

[1] MIFs are discussed and used as performance measures in Chapter 6 – Water Management Strategies.

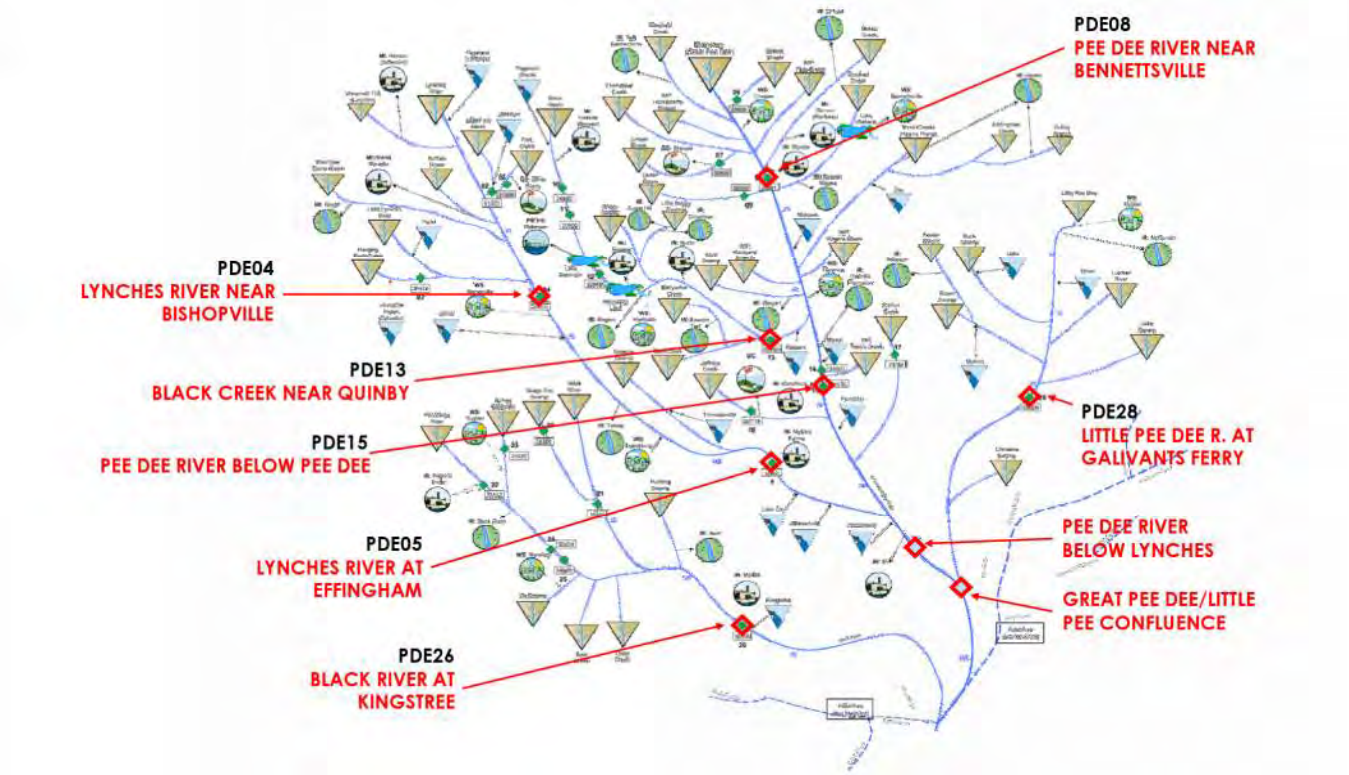


Figure 5-1. Strategic node locations.

Biological Response Metrics

As referenced in Chapter 3 and discussed in Bower et al. (2022) and The Nature Conservancy et al. (2023), biological response metrics were developed and combined with hydrologic metrics to identify statistically significant correlations between flow characteristics and ecological suitability for fish and macroinvertebrates. Select flow-ecology metrics (hydrologic metrics found to be most correlated to biological diversity) were used then as performance measures to help guide RBC discussions and recommendations for the Pee Dee River basin. This section provides discussion of the relevant, selected biological response metrics and related hydrologic metrics (sometimes referred to as the "flow-ecology metrics"), and Chapter 5.3.7 presents their values and interpretation in the context of the Pee Dee River basin.

The metrics were calculated at key downstream nodes in four of the primary tributaries to the Pee Dee River: Black Creek, Lynches River, Black River, and Little Pee Dee River. They represent a general assessment of how aquatic life will be impacted by changes in flow based on SWAM scenarios. Results should not be considered as necessarily uniform throughout each subbasin. Local conditions may vary along the length of streams. Metrics were based on flow-ecology relationships calculated using data from streams and small rivers with watershed areas equal to or less than 2,715 square miles. Because streams of this size comprise 86 percent of all surface water in South Carolina, results are broadly applicable across the basin. However, the results should not be extrapolated to large rivers or reservoirs.

Of the 14 biological response metrics identified in Bower et al. (2022), the following biological response metrics were used in the Pee Dee River basin because of the relevance and strong correlation to

hydrologic statistics that could be readily extracted from the SWAM model (descriptions from The Nature Conservancy et al. 2023):

- **Species richness**: the number of fish and macroinvertebrate species found at a given site
- **Tolerant species**: the average tolerance index for taxa

Hydrologic statistics that correlated well to these biological metrics included four metrics that could be easily extracted from SWAM model results (The Nature Conservancy et al. 2023). These flow metrics, intended to support flow-ecology relationships, expand on the hydrologic metrics discussed in Chapter 5.2.1, which were used specifically for hydrologic comparisons. The four flow metrics that emerged as having the greatest impact on aquatic ecosystem health in the Pee Dee River basin are:

- **Mean daily flow** (MA1) is the mean (average) daily flow of the stream in cfs over the period of record.
- **Base flow** (ML17) is the seven-day minimum flow divided by mean annual daily flow averaged across all years.
- **Frequency of low flow** (FL1) is the annual average of the number of low events below the 25th percentile of all daily values over the period of record.
- **Timing of lowest observed flow** (TL1) is the (Julian) date of the annual minimum flow, converted to Julian date (a number from 1 to 365).

Mapped together, these hydrologic metrics were used to estimate changes in the biological response metrics, which characterized the ecological integrity of the subbasins. Table 5-2 helps illustrate the flow-ecology relationships for the Southeastern Plains Perennial Runoff (SE 1) and Mid-Atlantic Coastal Plains Perennial Runoff (M1) stream types, which are two of the three dominant stream types in the Pee Dee River basin (The Nature Conservancy et al. 2023). Chapter 5.3.7 presents and provides discussion of the application of the biological response metrics for the Pee Dee River basin.

Table 5-2. Relationship of hydrologic and biological response metrics.

Hydrologic Metric (Output from SWAM Scenarios)	Biological Response Metrics with High Conditional Importance (Bower et al. 2022)	Type of Evaluation
Mean Daily Flow	Fish Species Richness	Ecological Integrity
Base Flow	Macroinvertebrate Richness	Ecological Integrity
Frequency of Low Flow	Tolerant Fish Species and Fish Species Richness	Ecological Integrity and Tolerance
Timing of Low Flow	Tolerant Fish Species	Tolerance

5.2.2 Groundwater Performance Measures

As defined in the Planning Framework, performance measures are used to compare the results from various groundwater modeling simulations and to evaluate the effectiveness of potential groundwater management strategies. Examples of groundwater performance measures include changes in water levels in the major aquifers, groundwater levels falling below the top of a confined aquifer, changes in water budgets of the aquifers, and groundwater discharge to streams from the surficial aquifer.

Because this initial Pee Dee basin planning effort will not use a groundwater model, the Pee Dee RBC did not establish any specific groundwater performance measures.

5.3 Scenario Descriptions and Surface Water Simulation Results

Four scenarios were used to evaluate surface water availability and to identify anticipated surface water shortages: the Current Surface Water Use Scenario (Current Scenario); the Permitted and Registered Surface Water Use Scenario (P&R Scenario); the Moderate Water Demand Scenario (Moderate Scenario); and the High Water Demand Scenario (High Demand Scenario). The Moderate Scenario was originally referred to as the Business-as-Usual Scenario in the Framework. A fifth scenario, the Unimpaired Flow Scenario (UIF Scenario) was requested by the RBC and a model simulation was completed. The UIF Scenario removes all surface water withdrawals and discharges and simulates conditions prior to any surface water development. The scenarios described below were simulated over the approximately 89-year period of variable climate and hydrology spanning October 1929 to December 2018. All simulation results, except where noted, are based on model simulations using a monthly timestep.

5.3.1 Current Surface Water Use Scenario

The Current Scenario represents current operations, infrastructure, and water use in the Pee Dee River basin. Water demands were generally set based on reported water usage in the 10-year period spanning 2009 to 2018, with several minor exceptions. This simulation provides information on the potential for surface water shortages that could immediately result under a repeat of historic drought conditions in the basin and highlights the need for short-term planning initiatives including the development of strategies to mitigate shortages and/or increase surface water supply.

Simulation results for the Current Scenario are summarized in Table 5-3 through Table 5-5. Table 5-3 lists only the surface water users with one or more months of a simulated Surface Water Shortage over the 89-year (1,071-month) simulation. Also shown are the average annual demand for each water user; the minimum physically available (monthly average) flow at the point of withdrawal; the maximum (monthly average) shortage; and the frequency of shortage. The locations of these water users, as depicted on the SWAM model framework, are shown in Figure 5-2.

Table 5-3. Identified surface water shortages, Current Scenario.

Water User Name	Source Water	Average Annual Demand (MGD)	Minimum Physically Available Flow (MGD)	Maximum Shortage (MGD)	Frequency of Shortage (%)
IR: Turf Connections	Westfield Creek	0.1	0.6	0.1	33.3%
IR: O'Tuel[1]	Naked Creek	0.2	0.4	0.3	0.4%
GC: Florence	Jeffries Creek	0.1	0.0	0.1	0.3%
GC: White Plains	Fork Creek	0.1	0.0	0.1	7.0%
MI: Hanson (Jefferson)	Unnamed Trib (Lynches)	0.04	0.0	0.05	6.1%
IR: Atkinson	Fowler Branch	0.01	0.0	0.05	1.2%

IR = agricultural (irrigation) water user; GC = golf course water user; MI = mining water user
[1] BFP Agriculture 4 recently took over IR: O'Tuel's property and has a new registration for a surface water withdrawal. The Current Use Scenario withdrawal was based on IR: O'Tuel's historical withdrawal amount.

Turf Connections (agricultural irrigator), which withdraws water from Westfield Creek, has a simulated regulatory shortage frequency of 33.3 percent and maximum simulated regulatory shortage of 0.1 MGD. While this user's water demand exceeds their registration amount one-third of the time, there is enough (physical) water in each month throughout the simulation's entire period of record to meet the water user's demand 100 percent of the time. Atkinson (agricultural irrigator) and two golf course water users (Florence and White Plains) withdraw water from small impoundments which are not included in the model; therefore, even during times when the stream is simulated to have low or no flow, the impoundment may provide enough stored water to prevent shortages. Because it is on an ungaged tributary with flows typically less than 1 MGD, there is significant uncertainty associated with the simulated stream flows that supplies water to the Hanson (Jefferson) mining operation.

Table 5-4 presents the mean flow, median flow, and Surface Water Supply at each strategic node. Also presented are the 25th, 10th, and 5th percentile flows, which are useful in characterizing low flows. Table 5-5 presents the basin wide performance metrics. As noted above, the model very likely over-predicts the number, degree, and frequency of surface water shortages on the small, ungaged tributaries, where multiple intake locations have been aggregated and where ponds, which are not simulated in the model, provide water storage that would often prevent a shortage. Table 5-5 provides a summary of the Current Scenario shortages in the basin overall, without groundwater users included.

Table 5-4. Surface water model simulation results at Strategic Nodes, Current Scenario.

Strategic Node	Mean Flow (cfs)	Median Flow (cfs)	Surface Water Supply (cfs)	Percentile Flows (cfs)		
				25th	10th	5th
PDE08 Pee Dee River near Bennettsville	7,935	6,154	991	3,707	2,548	2,020
PDE15 Pee Dee River below Pee Dee	9,463	7,384	1,105	4,510	3,058	2,437
Pee Dee River Below Lynches River Confluence	11,568	8,913	1,362	5,500	3,632	2,968
Great Pee Dee River below Little Pee Dee Confluence	14,795	11,521	1,670	7,093	4,637	3,778
PDE13 Black Creek near Quinby	527	452	56	279	191	151
PDE04 Lynches River near Bishopville	752	525	46	280	177	139
PDE05 Lynches River at Effingham	1,006	716	71	388	251	197
PDE28 Little Pee River at Galivants Ferry	2,917	2,190	190	1,223	745	599
PDE26 Black River at Kingstree	999	662	38	314	180	129

Table 5-5. Basin-wide surface water model simulation results, Current Scenario.

Performance Measure	Result[1]
Total basin annual mean shortage (MGD)	0.01 [2]
Maximum water user shortage (MGD)	0.3
Total basin annual mean shortage (% of demand)	0.03%
Percentage of water users experiencing shortage	18.8%
Average frequency of shortage (%)	1.5%

[1] Results shown do not include groundwater users.
[2] Includes only physical shortages and omits the regulatory shortage at Turf Connections.

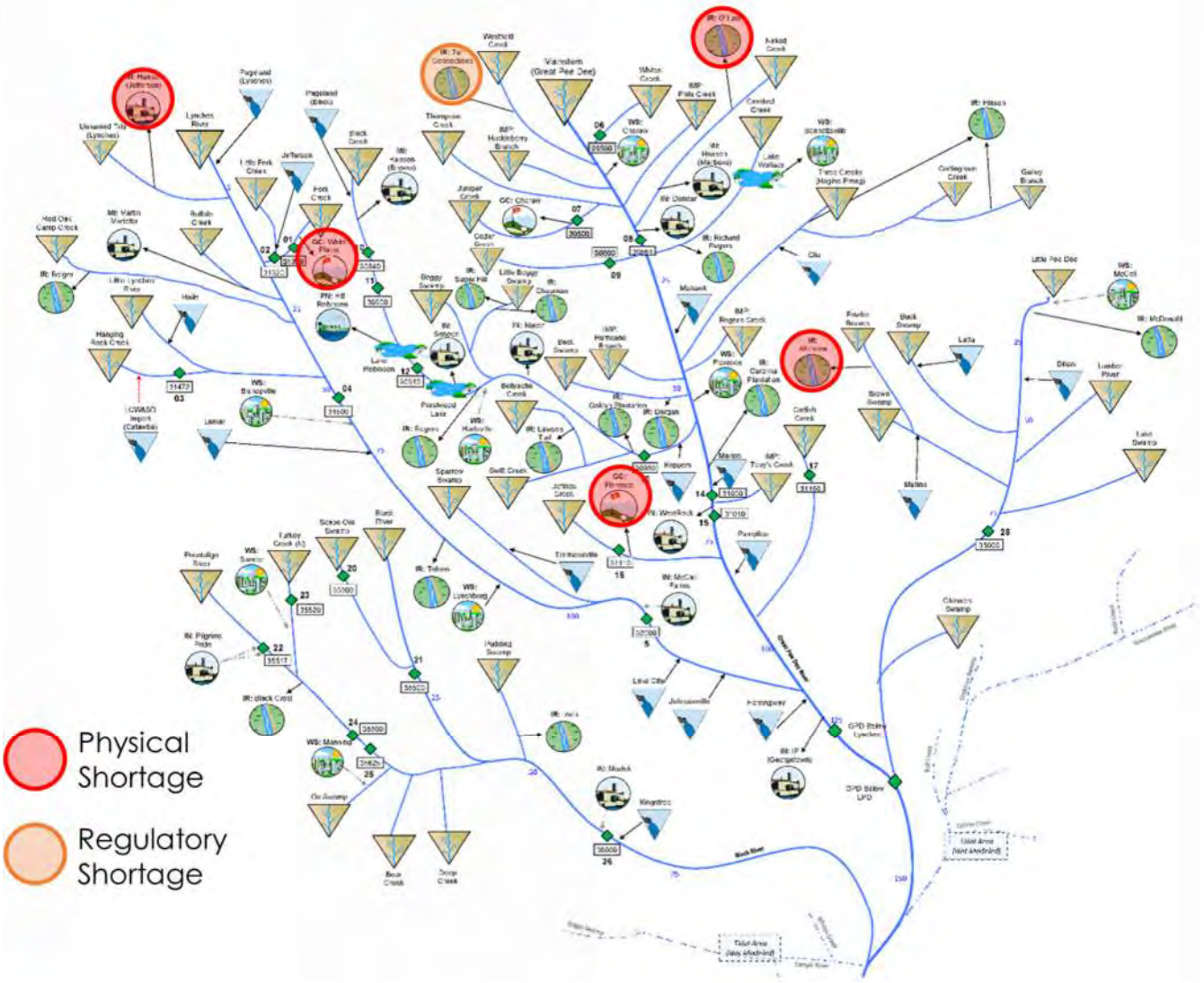


Figure 5-2. Water users with surface water shortages, Current Scenario.

5.3.2 Permitted and Registered Surface Water Use Scenario

In the P&R Scenario, modeled demands are set to permitted or registered values for all water users. In other words, this simulation explored the question of, "what if all water users used the full volume of water allocated through permits and registrations?" The scenario provides information to determine whether surface water is currently over-allocated in the basin. As such, it is a hypothetical scenario which does not necessarily reflect a projection of likely water use. The total permitted and registered amount of surface water (in the non-tidally influenced, modeled portion of the Pee Dee Basin) is 1,324 MGD, or more than twice the Current Use Scenario surface water demands of 576 MGD.

The P&R Scenario accounts for increased wastewater discharge for municipal and industrial surface water users with associated increases in simulated usage but does not account for the increase in wastewater discharges to surface water that might occur if all municipal and industrial groundwater users in the basin were withdrawing groundwater at their permitted or registered amount and returning the non-

consumptively used portion (after treatment) to surface water. As such, the P&R scenario presents a worst-case simulation for surface water availability.

Simulation results for the P&R Scenario are summarized in Table 5-6 through Table 5-9. In this scenario, river flows are predicted to decrease, compared to the Current Scenario, throughout the basin, resulting in surface water shortages for approximately a third of the surface water users. Table 5-6 lists only the surface water users with one or more months of a simulated surface water shortage. The locations of these water users are shown on the SWAM model framework in Figure 5-3.

A recent surface water registration on Black Creek was issued by SCDHEC to Oaklyn Plantation (registered as an agricultural irrigator) for an amount of 5,400 million gallons per month (MGM) and 64,800 million gallons per year (MGY). To put the size of the registration in perspective, it is 42 percent larger than the three highest permitted or registered amounts in the Pee Dee River basin combined (which are IR: Sonoco, WS: Florence and IR: WestRock). Because Oaklyn Plantation has no reported use, this demand was only applied to the P&R Scenario and no demands were applied to the Current Use, 2070 Moderate Demand, or 2070 High Demand Scenarios. The P&R simulation results show that Oaklyn Plantation would have a frequency of shortage of 31.5 percent and a maximum shortage of 146.3 MGD.

Sonoco (industrial water user) is simulated to have a maximum shortage of 35.5 MGD under the P&R Scenario because of Prestwood Lake emptying during certain times in the simulation. No operating rules were included in the model for Lake Robinson to allow for larger releases from its dam and provide more water for Sonoco's intake on Prestwood Lake. Additional releases from the much larger Lake Robinson may be possible (without appreciably lowering its lake level) to maintain enough water in Prestwood Lake so that there are no shortages in this scenario.

The percent decrease in P&R Scenario flow statistics compared to the Current Scenario are shown in Table 5-8. Modeled reductions are most pronounced during low flow periods. Simulation results indicate that the P&R demand from the Oaklyn Plantation water user results in an approximately 95 percent reduction of flow on Black Creek during drought periods. Mean and median flows at the most downstream site of the mainstem (Great Pee Dee River below Little Pee Dee Confluence) are predicted to decrease by approximately 3 percent if all upstream (South Carolina) surface water users withdrew water at their permitted or registered amount. The impact of withdrawals at their fully permitted and registered amount on downstream water users is evident in the predicted increase in mean annual water shortage and the increase in the number and frequency of water users experiencing a shortage during the simulation period, as shown in Table 5-9. Despite the low likelihood of the P&R Scenario, the results demonstrate both the surface water resources of the basin are over-allocated based on existing permit and registration amounts.

Table 5-6. Identified surface water shortages, P&R Scenario.

Water User Name	Source Water	Average Annual Demand (MGD)	Minimum Physically Available Flow (MGD)	Maximum Shortage (MGD)	Frequency of Shortage (%)
IR: O'Tuel[1]	Naked Creek	2.3	0.4	1.8	12.1%
MI: Hanson (Marlboro)	Naked Creek	4.4	0.4	3.9	23.2%
IR: Hinson	Gulley Branch	0.7	0.4	0.3	5.9%
MI: Hanson (Brewer)	Black Creek	6.8	2.1	4.5	7.3%
IN: Sonoco	Black Creek	42.6	0.0	35.5	4.4%
IR: Oaklyn Plantation	Black Creek	177.7	27.9	146.3	31.5%
GC: Florence	Jeffries Creek	1.6	0.0	1.6	0.7%
GC: White Plains	Fork Creek	1.6	0.0	1.6	81.2%
MI: Martin Marietta	Buffalo Creek	3.2	0.4	2.8	7.7%
IR: Belger	Red Oak Camp Creek	3.0	0.1	2.9	46.8%
MI: Hanson (Jefferson)	Unnamed Trib (Lynches)	0.9	0.0	0.9	84.1%
IR: Atkinson	Fowler Branch	0.3	0.0	0.3	40.6%

IR = agricultural (irrigation) water user; GC = golf course water user; MI = mining water user; IN = industrial water user

[1] BFP Agriculture 4 recently took over IR: O'Tuel's property and has a new registration for a surface water withdrawal. The Current Use Scenario withdrawal was based on IR: O'Tuel's historical withdrawal amount.

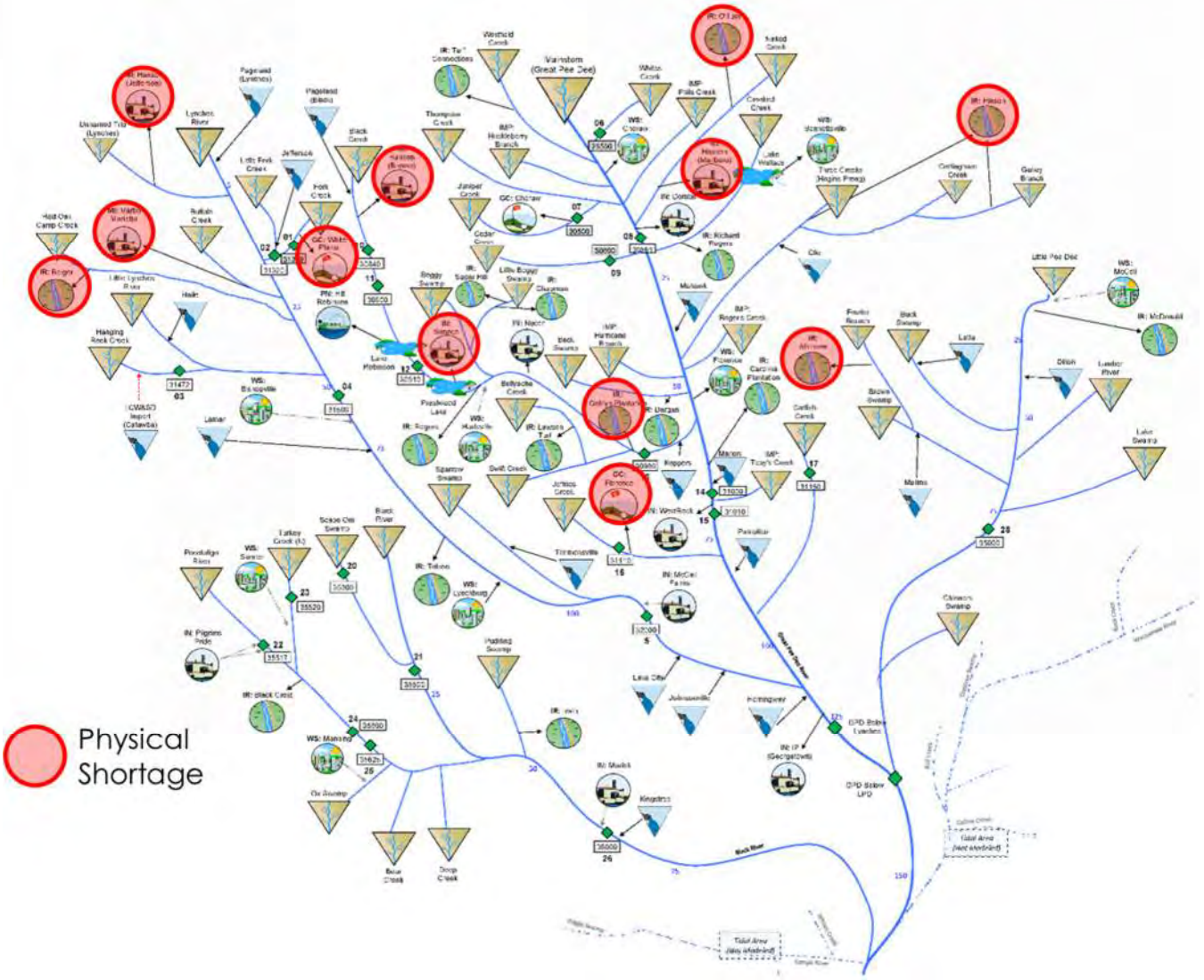


Figure 5-3. Water users with surface water shortages, P&R Scenario.

Table 5-7. Surface water model simulation results at Strategic Nodes, P&R Scenario.

Strategic Node	Mean Flow (cfs)	Median Flow (cfs)	Surface Water Supply (cfs)	Percentile Flows (cfs)		
				25th	10th	5th
PDE08 Pee Dee River near Bennettsville	7,921	6,141	984	3,692	2,533	2,009
PDE15 Pee Dee River below Pee Dee	9,029	6,935	901	4,078	2,687	2,107
Pee Dee River Below Lynches River Confluence	11,182	8,520	1,210	5,110	3,329	2,729
Great Pee Dee River below Little Pee Dee Confluence	14,446	11,157	1,549	6,750	4,359	3,520
PDE13 Black Creek near Quinby	249	141	2	12	9	7
PDE04 Lynches River near Bishopville	743	514	46	272	172	135
PDE05 Lynches River at Effingham	996	708	70	381	245	192
PDE28 Little Pee River at Galivants Ferry	2,917	2,189	190	1,222	744	598
PDE26 Black River at Kingstree	994	657	36	309	177	125

Table 5-8. Percent change in P&R Scenario flows at Strategic Nodes relative to Current Scenario flows.

Strategic Node	Mean Flow (cfs)	Median Flow (cfs)	Surface Water Supply (cfs)	Percentile Flows (cfs)		
				25th	10th	5th
PDE08 Pee Dee River near Bennettsville	-0.2%	-0.2%	-0.7%	-0.4%	-0.6%	-0.5%
PDE15 Pee Dee River below Pee Dee	-4.6%	-6.1%	-18.5%	-9.6%	-12.1%	-13.5%
Pee Dee River Below Lynches River Confluence	-3.3%	-4.4%	-11.2%	-7.1%	-8.3%	-8.0%
Great Pee Dee River below Little Pee Dee Confluence	-2.4%	-3.2%	-7.2%	-4.8%	-6.0%	-6.8%
PDE13 Black Creek near Quinby	-52.8%	-68.8%	-96.4%	-95.7%	-95.3%	-95.4%
PDE04 Lynches River near Bishopville	-1.2%	-2.0%	0.0%	-2.7%	-3.0%	-2.6%
PDE05 Lynches River at Effingham	-1.0%	-1.1%	-1.4%	-1.9%	-2.4%	-2.7%
PDE28 Little Pee River at Galivants Ferry	0.0%	0.0%	0.0%	-0.1%	-0.1%	-0.1%
PDE26 Black River at Kingstree	-0.5%	-0.8%	-5.3%	-1.5%	-1.5%	-3.2%

Table 5-9. Basin-wide surface water model simulation results, P&R Scenario.

Performance Measure	Result[1]
Total basin annual mean shortage (MGD)	21.5
Maximum water user shortage (MGD)	146.3
Total basin annual mean shortage (% of demand)	4.6%
Percentage of water users experiencing shortage	36.4%
Average frequency of shortage (%)	10.5%

[1] Results shown do not include groundwater users.

5.3.3 Moderate Water Demand Projection Scenario

For the Moderate Scenario, modeled demands were set to projected 2070 levels based on an assumption of moderate population and economic growth, as described in Chapter 4.3. Projected 2070 surface water demands for the Moderate Scenario are 846 MGD, which is equal to the Current Use Scenario surface water demands. The Moderate Scenario explores a plausible future where water demands increase with moderate population growth and agricultural expansion, and climate change impacts are negligible, in both the short and long term. For agricultural expansion, the specific locations for future new or expanded farms are not known, so a lumped spatial representation was applied in the model. Existing agricultural users' current demands were kept constant, and projected increases in demands for the agricultural sector were aggregated at the base of each subwatershed. The increase in demands was assigned proportionally to each subwatershed node according to the distribution of 2020 agricultural demands.

The Moderate Scenario simulation results for the 2070 planning horizon are summarized in Table 5-10 through Table 5-13. Table 5-10 lists only the surface water users with one or more months of a simulated Surface Water Shortage. The locations of these water users are shown on the SWAM model framework in Figure 5-4. The agricultural water users with shortages in the Current Scenario (Table 5-3) had the exact same shortages in the Moderate Scenario because their monthly demands were not increased. As noted above, new agricultural withdrawals were applied at the outlet to certain watersheds (not to existing agricultural water users). All new agricultural withdrawals are downstream of existing agricultural water users that experienced a simulated shortage. Furthermore, there are no non-agricultural withdrawals upstream of any of the agricultural water users that experienced a simulated shortage. The average annual demands from Sonoco (industrial water user) and Martin Marietta (mining water user) are larger in the Moderate 2070 scenario compared to current use, resulting in shortages for these water users.

Table 5-10. Identified surface water shortages, Moderate 2070 Scenario.

Water User Name	Source Water	Average Annual Demand (MGD)	Minimum Physically Available Flow (MGD)	Maximum Shortage (MGD)	Frequency of Shortage (%)
IR: O'Tuel[1]	Naked Creek	0.2	0.4	0.3	0.4%
IN: Sonoco	Black Creek	21.0	0.0	9.2	0.3%
GC: Florence	Jeffries Creek	0.04	0.0	0.03	0.3%
GC: White Plains	Fork Creek	0.04	0.0	0.1	6.3%
MI: Martin Marietta	Buffalo Creek	1.2	0.4	1.1	1.0%
MI: Hanson (Jefferson)	Unnamed Trib (Lynches)	0.03	0.0	0.04	5.0%
IR: Atkinson	Fowler Branch	0.01	0.0	0.05	1.2%

IR = agricultural (irrigation) water user; IN = industrial water user; GC = golf course water user; MI = mining water user

[1] BFP Agriculture 4 recently took over IR: O'Tuel's property and has a new registration for a surface water withdrawal.

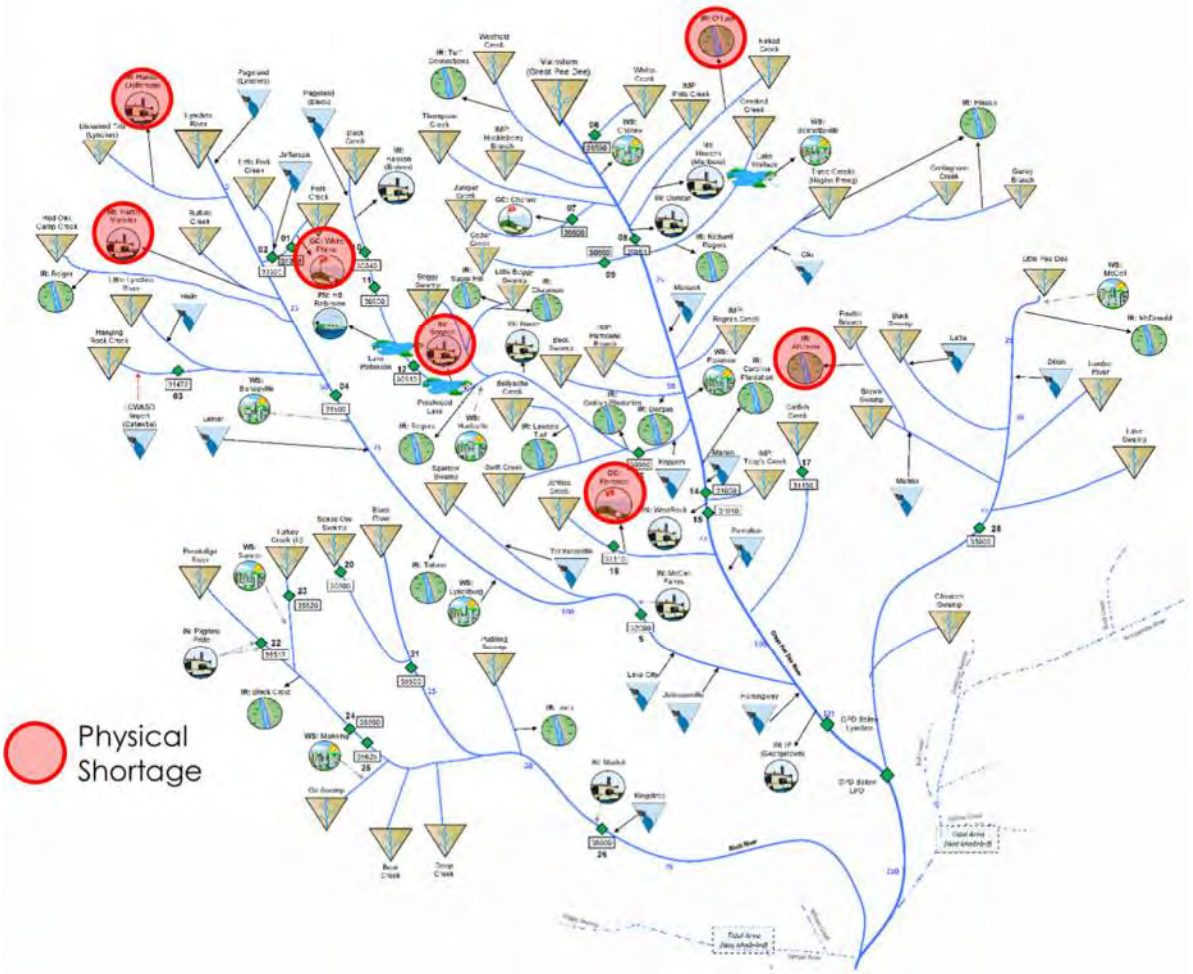


Figure 5-4. Water users with surface water shortages, Moderate 2070 Scenario.

In the Moderate Scenario, flows are predicted to decrease modestly, compared to the Current Use Scenario, throughout the basin. Modeled reductions are most pronounced during low flow periods. At the most downstream Strategic Node (Great Pee Dee River below Little Pee Dee Confluence), mean and median flows are predicted to decrease by approximately 1 percent, and low flows by about 3 percent, by 2070 if population and economic growth is moderate and climate change impacts are negligible. Calculated water user shortages remain essentially unchanged, relative to the Current Scenario. The percent of users experiencing a shortage decreases due to the addition of agricultural users in the model assigned at the 7 HUC outlets, which represent future increased agricultural demand in the basin. Given current climate conditions and existing basin management and regulatory structure, basin surface water supplies are predicted to be adequate to meet increased demands resulting from moderate economic and population growth, and assuming the continued use of farm ponds that, while not simulated, are likely to prevent many of the observed Current and Moderate Scenario agricultural shortages.

Table 5-11. Surface water model simulation results at Strategic Nodes, Moderate 2070 Scenario.

Strategic Node	Mean Flow (cfs)	Median Flow (cfs)	Surface Water Supply (cfs)	Percentile Flows (cfs)		
				25th	10th	5th
PDE08 Pee Dee River near Bennettsville	7,792	6,018	989	2,416	1,880	2,416
PDE15 Pee Dee River below Pee Dee	9,285	7,203	1,093	2,879	2,292	2,879
Pee Dee River Below Lynches River Confluence	11,391	8,717	1,351	3,435	2,785	3,435
Great Pee Dee River below Little Pee Dee Confluence	14,628	11,389	1,658	4,472	3,618	4,472
PDE13 Black Creek near Quinby	523	448	56	186	147	186
PDE04 Lynches River near Bishopville	751	524	46	176	137	176
PDE05 Lynches River at Effingham	1,004	714	70	248	196	248
PDE28 Little Pee River at Galivants Ferry	2,917	2,190	190	745	599	745
PDE26 Black River at Kingstree	997	661	36	177	128	177

Table 5-12. Percent change in Moderate 2070 Scenario flows at Strategic Nodes relative to Current Scenario flows.

Strategic Node	Mean Flow (cfs)	Median Flow (cfs)	Surface Water Supply (cfs)	Percentile Flows (cfs)		
				25th	10th	5th
PDE08 Pee Dee River near Bennettsville	-1.8%	-2.2%	-0.2%	-3.3%	-5.2%	-6.9%
PDE15 Pee Dee River below Pee Dee	-1.9%	-2.4%	-1.1%	-3.7%	-5.9%	-5.7%
Pee Dee River Below Lynches River Confluence	-1.5%	-2.2%	-0.8%	-3.1%	-5.4%	-6.1%
Great Pee Dee River below Little Pee Dee Confluence	-1.1%	-1.1%	-0.7%	-2.5%	-3.5%	-4.2%
PDE13 Black Creek near Quinby	-0.6%	-0.6%	1.8%	-0.8%	-1.7%	-1.6%
PDE04 Lynches River near Bishopville	-0.2%	-0.1%	0.0%	-0.6%	-0.8%	-1.2%
PDE05 Lynches River at Effingham	-0.2%	-0.2%	-1.4%	-0.6%	-1.2%	-0.7%
PDE28 Little Pee River at Galivants Ferry	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
PDE26 Black River at Kingstree	-0.2%	-0.2%	-5.3%	-0.6%	-1.5%	-0.9%

Table 5-13. Basin-wide surface water model simulation results, Moderate 2070 Scenario.

Performance Measure	Result[1]
Total basin annual mean shortage (MGD)	0.03
Maximum water user shortage (MGD)	9.2
Total basin annual mean shortage (% of demand)	0.02%
Percentage of water users experiencing shortage	17.5%
Average frequency of shortage (%)	0.4%

[1] Results shown do not include groundwater users.

5.3.4 High Water Demand Projection Scenario

For the High Demand Scenario, modeled demands are set to the 90th percentile of variability in reported withdrawals for each user, and the projections are based on aggressive growth within the range of uncertainty of the referenced driver variable projections, as described in Chapter 4. Projected 2070 surface water demands for the High Demand Scenario are 1,094 MGD and are 29 percent higher than the Current Use Scenario surface water demands of 846 MGD. This set of scenarios represents the combined impacts of all sectors experiencing high growth and all water users experiencing conditions of high water demand. These assumptions are intended to represent an unlikely maximum for total water demand; it is very unlikely these demands would occur month after month and year after year for all water users. The purpose of this scenario is to provide the RBC with information on which to base

conservative management strategies. Other methods and assumptions used in constructing the High Demand Scenario were the same as for the Moderate Scenario.

The High Demand Scenario simulation results for the 2070 planning horizon are summarized in Table 5-14 through Table 5-17. The same water users with shortages in the Moderate Scenario (see Figure 5-4) also had shortages in the High Demand Scenario, and no additional users were simulated to have shortages under the High Demand Scenario.

Table 5-14. Identified surface water shortages, High Demand 2070 Scenario.

Water User Name	Source Water	Average Annual Demand (MGD)	Minimum Physically Available Flow (MGD)	Maximum Shortage (MGD)	Frequency of Shortage (%)
IR: O'Tuel[1]	Naked Creek	0.2	0.4	0.3	0.4%
IN: Sonoco	Black Creek	29.8	0.0	21.0	1.3%
GC: Florence	Jeffries Creek	0.10	0.0	0.1	0.3%
GC: White Plains	Fork Creek	0.06	0.0	0.1	8.2%
MI: Martin Marietta	Buffalo Creek	1.4	0.4	1.1	1.3%
MI: Hanson (Jefferson)	Unnamed Trib (Lynches)	0.04	0.0	0.1	7.1%
IR: Atkinson	Fowler Branch	0.01	0.0	0.05	1.2%

IR = agricultural (irrigation) water user; IN = industrial water user; GC = golf course water user; MI = mining water user

[1] BFP Agriculture 4 recently took over IR: O'Tuel's property and has a new registration for a surface water withdrawal.

In the High Demand Scenario, river flows are predicted to decrease modestly, compared to the Current Scenario, throughout the basin. Modeled reductions are most pronounced during low flow periods. Mean and median flows at the most downstream site of the mainstem (Great Pee Dee River below Little Pee Dee Confluence) are predicted to decrease by approximately 3 percent, and low flows by 5 to 8 percent, by 2070. Calculated water user shortages increase slightly, in terms of both duration and intensity, for the 2070 planning horizon, compared to the Current Scenario results.

Table 5-15. Surface water model simulation results at Strategic Nodes, High Demand 2070 Scenario.

Strategic Node	Mean Flow (cfs)	Median Flow (cfs)	Surface Water Supply (cfs)	Percentile Flows (cfs)		
				25th	10th	5th
PDE08 Pee Dee River near Bennettsville	7,639	5,842	974	3,430	2,231	1,709
PDE15 Pee Dee River below Pee Dee	8,964	6,858	928	4,007	2,547	1,974
Pee Dee River Below Lynches River Confluence	11,122	8,447	1,236	5,067	3,139	2,500
Great Pee Dee River below Little Pee Dee Confluence	14,418	11,191	1,538	6,694	4,244	3,443
PDE13 Black Creek near Quinby	521	443	53	274	184	144
PDE04 Lynches River near Bishopville	750	523	46	278	176	137
PDE05 Lynches River at Effingham	1,005	715	71	387	249	196
PDE28 Little Pee River at Galivants Ferry	2,918	2,190	190	1,223	745	599
PDE26 Black River at Kingstree	1,011	674	47	325	189	141

Table 5-16. Percent change in High Demand 2070 Scenario flows at Strategic Nodes relative to Current Scenario flows.

Strategic Node	Mean Flow (cfs)	Median Flow (cfs)	Surface Water Supply (cfs)	Percentile Flows (cfs)		
				25th	10th	5th
PDE08 Pee Dee River near Bennettsville	-3.7%	-5.1%	-1.7%	-7.5%	-12.4%	-15.4%
PDE15 Pee Dee River below Pee Dee	-5.3%	-7.1%	-15.9%	-11.1%	-16.6%	-18.9%
Pee Dee River Below Lynches River Confluence	-3.8%	-5.2%	-9.2%	-7.8%	-13.5%	-15.7%
Great Pee Dee River below Little Pee Dee Confluence	-2.5%	-2.8%	-7.8%	-5.6%	-8.4%	-8.8%
PDE13 Black Creek near Quinby	-0.8%	-1.2%	-3.6%	-1.2%	-2.7%	-4.2%
PDE04 Lynches River near Bishopville	-0.3%	-0.3%	0.0%	-0.6%	-0.8%	-1.2%
PDE05 Lynches River at Effingham	-0.1%	-0.1%	0.0%	-0.3%	-0.8%	-0.7%
PDE28 Little Pee River at Galivants Ferry	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
PDE26 Black River at Kingstree	1.2%	1.8%	23.7%	3.6%	5.2%	9.2%

Table 5-17. Basin-wide surface water model simulation results, High Demand 2070 Scenario.

Performance Measure	Result[1]
Total basin annual mean shortage (MGD)	0.14
Maximum water user shortage (MGD)	21.0
Total basin annual mean shortage (% of demand)	0.05%
Percentage of water users experiencing shortage	17.5%
Average frequency of shortage (%)	0.5%

[1] Results shown do not include groundwater users.

5.3.5 Unimpaired Flow Scenario

The SWAM model was used to simulate unimpaired flows throughout the Pee Dee River basin. For this simulation, all water demands and discharges in the model were set to zero. Simulation results represent river hydrologic conditions without the impact of surface water withdrawals, discharges, and reservoirs, as modeled. In other words, results represent "naturalized" surface water conditions in the basin.

Inflows from North Carolina on the Pee Dee River and Lumber River were provided by HDR Inc., using the OASIS model, and were based on naturalized conditions (no reservoirs and no surface water use or discharges). The process used by the OASIS model to generate the unimpaired daily inflow timeseries for the Pee Dee River resulted in approximately 600 days (or 1.8 percent of the total days in the timeseries) with negative flows. Negative flows can be generated as part of the unimpairment process for several reasons. One example is when historical withdrawal and discharge data are only available on a monthly timestep but the data are applied to daily, gaged flows, and another is the travel time associated with large releases from upstream reservoirs. CDM Smith performed a simple correction of the negative daily flows by replacing them with flows based on a simple linear interpolation between the preceding and ensuing positive daily flows. The corrected daily flows were then used to calculate the monthly inflow time series used in the UIF Scenario.

UIF Scenario monthly simulation results are summarized in Table 5-18 and Table 5-19. Because of the negative flows in the UIF Scenario inflow dataset for the Pee Dee River (which were removed by CDM Smith, and replaced with positive, interpolated flows), the minimum flows on the Pee Dee River for the UIF scenario should be ignored, and no comparisons should be made to minimum flows of other scenarios.

The differences in performance measures at Strategic Nodes between the UIF Scenario and the Current Use Scenario are relatively small, indicating that current net withdrawals and discharges are not appreciably altering the current flow regime, compared to naturalized conditions. Current Use Scenario flows are larger than the UIF Scenario flows on the Lynches, Little Pee Dee, and Black Rivers because of water users that withdraw from ground water and discharge to surface water. There is also an import of water from the Catawba River Basin to the Lynches River. At the furthest downstream strategic node (Great Pee Dee River below Little Pee Dee Confluence), mean and median unimpaired flows are only approximately 0.5 percent higher than Current Scenario flows. At this same location, UIF low flows (10th – 5th percentile) are approximately 3 to 7 percent higher than Current Scenario flows.

Table 5-18. Surface water model simulation results at Strategic Nodes, UIF Scenario.

Strategic Node	Mean Flow (cfs)	Median Flow (cfs)	Surface Water Supply (cfs)	Percentile Flows (cfs)		
				25th	10th	5th
PDE08 Pee Dee River near Bennettsville	8,046	6,129	Minimum Flows Not Applicable Due to Correction of Negative Flows from NC Headwaters	3,703	2,699	2,229
PDE15 Pee Dee River below Pee Dee	9,673	7,457		4,638	3,263	2,796
Pee Dee River Below Lynches River Confluence	11,732	9,070		5,641	3,836	3,277
Great Pee Dee River below Little Pee Dee Confluence	14,892	11,561		7,065	4,787	4,051
PDE13 Black Creek near Quinby	540	463		294	207	165
PDE04 Lynches River near Bishopville	751	524		279	177	138
PDE05 Lynches River at Effingham	1,001	712		384	247	193
PDE28 Little Pee River at Galivants Ferry	2,883	2,162		1,197	721	577
PDE26 Black River at Kingstree	984	647		299	166	115

Table 5-19. Percent change in UIF Scenario flows at Strategic Nodes relative to Current Scenario flows.

Strategic Node	Mean Flow (cfs)	Median Flow (cfs)	Surface Water Supply (cfs)	Percentile Flows (cfs)		
				25th	10th	5th
PDE08 Pee Dee River near Bennettsville	1.4%	-0.4%	Minimum Flows Not Applicable Due to Correction of Negative Flows from NC Headwaters	-0.1%	6.0%	10.4%
PDE15 Pee Dee River below Pee Dee	2.2%	1.0%		2.8%	6.7%	14.7%
Pee Dee River Below Lynches River Confluence	1.4%	1.8%		2.6%	5.6%	10.4%
Great Pee Dee River below Little Pee Dee Confluence	0.7%	0.4%		-0.4%	3.2%	7.2%
PDE13 Black Creek near Quinby	2.4%	2.5%		5.1%	8.5%	9.2%
PDE04 Lynches River near Bishopville	-0.1%	-0.2%		-0.3%	-0.4%	-0.6%
PDE05 Lynches River at Effingham	-0.5%	-0.6%		-1.1%	-1.7%	-2.2%
PDE28 Little Pee River at Galivants Ferry	-1.2%	-1.3%		-2.1%	-3.2%	-3.7%
PDE26 Black River at Kingstree	-1.5%	-2.3%		-4.7%	-7.8%	-11.3%

5.3.6 Comparison of Low Flows

Model simulations using a daily timestep were performed to more closely evaluate the differences in simulated low flows between scenarios, compare to 7Q10 flows, and to support the application of biological response metrics described in Chapter 5.3.7.

The model's daily simulation results were first used to compare low flows simulated during the drought of record. In this instance, the drought of record is generally defined by the period of lowest recorded streamflow since data collection began. Streamflow in the Pee Dee Basin was typically lowest in the summer of 2002, and therefore it is generally considered as the drought of record for the basin. However, at some locations in the basin, streamflow was similarly low or lower during the early summer and fall of 2001.

The hydrographs in Figure 5-5 depict model-simulated daily streamflow for the Current Use, UIF, P&R, 2070 Moderate Demand, and 2070 High Demand Scenarios during the summer of 2002 at strategic nodes on the Little Pee Dee River, Black River, and Great Pee Dee River. Each hydrograph tells a slightly different story, as noted below.

- On the Little Pee Dee River (top hydrograph), simulated P&R Scenario flows are slightly lower (about 10 cfs) than Current Use, Moderate Demand 2070, and High Demand 2070 Scenario flows. There is no discernable difference in flows between the Current Use, Moderate Demand 2070, and High Demand 2070 Scenarios. The UIF flows are appreciably higher in the UIF Scenario, reflecting the larger difference in surface water withdrawals in the North Carolina portion of the basin for naturalized versus current-day and projected 2070 conditions.

- On the Black River (middle hydrograph), simulated UIF Scenario flows are the lowest of the four scenarios and the 2070 High Demand Scenario flows are the highest. This is because there are several municipal and industrial groundwater users upstream of this strategic node that discharge to surface water. Their increasing withdrawals from groundwater also equate to increasing wastewater discharges.

- On the Great Pee Dee River (bottom hydrograph), there is significant variability in the UIF Scenario flows because of the previously mentioned issues with negative flows in the UIF inflow timeseries that was provided for North Carolina. Accordingly, the daily UIF flows should generally be ignored. The P&R Scenario flows are approximately 100 cfs lower than the Current Use, Moderate Demand 2070, and High Demand 2070 Scenario flows. There is no discernable difference in the low flows of the Current Use, Moderate Demand 2070, and High Demand 2070 Scenario flows, reflecting the fact that the cumulative impact of surface water withdraws and returns (from both surface water and groundwater), do not appreciably alter the flow regime at the bottom of the basin, as represented by this Strategic Node.

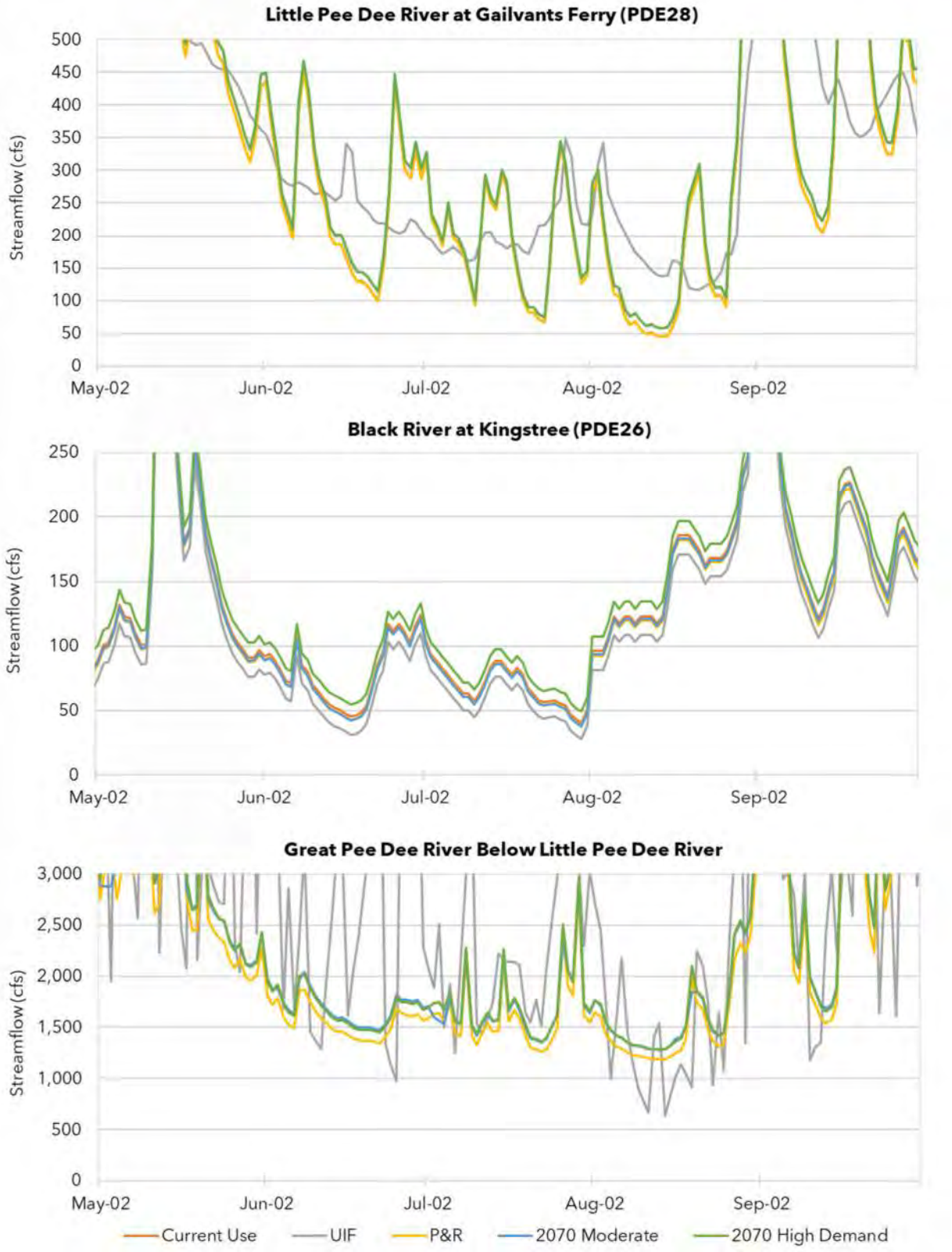


Figure 5-5. Comparison of daily timestep simulation results for all Scenarios during the drought of record at three Strategic Nodes.

The daily timestep simulations were also used to compare scenario flows to calculated 7Q10 flows. The 7Q10 flow is defined as the lowest 7-day average flow that occurs (on average) once every 10 years. 7Q10 flows are calculated from actual USGS gaging station records that correspond to the Strategic Nodes used in the SWAM model. The 7Q10 flow is a commonly used low-flow metric.

Table 5-20 shows the frequency (as a percentage) that simulated daily flows at each strategic node, for each scenario, were below the calculated 7Q10 flows. There is generally very little difference in the frequency of simulated flows below the calculated 7Q10 flow between scenarios, at most locations. One notable exception is at the Black Creek near Quinby (PDE13) Strategic Node. Here, P&R Scenario flows are considerably lower, with 45 percent of the days in the simulation experiencing a flow below the 7Q10 flow, compared to an approximately 1 percent frequency for the other scenarios. This is because of the very large (and unrealistic), upstream withdrawal representing the IR: Oaklyn Plantation registration. As previously noted, this water user has not reported any water use.

Table 5-20. Low-flow frequency comparison to 7Q10 flows.

Strategic Node	Gage Length of Record (years)	7Q10 (cfs)	UIF	Current	2070 Moderate Demand	2070 High Demand	Permitted and Registered
PDE08 Pee Dee River near Bennettsville	32.4	801	3.5%	0.0%	0.0%	0.0%	0.0%
PDE15 Pee Dee River below Pee Dee	26.5	1,061	2.3%	0.0%	0.1%	0.5%	0.6%
PDE13 Black Creek near Quinby	21.5	74	0.6%	1.1%	0.8%	0.6%	44.9%
PDE04 Lynches River near Bishopville	50.2	93	2.9%	2.8%	2.9%	3.0%	3.1%
PDE05 Lynches River at Effingham	93.6	117	1.8%	1.5%	1.6%	1.6%	1.6%
PDE28 Little Pee Dee River at Galivants Ferry	81.3	224	0.5%	0.6%	0.4%	0.4%	0.6%
PDE26 Black River at Kingstree	93.6	7.9	0.0%	0.0%	0.0%	0.0%	0.0%

5.3.7 Application of Biological Response Metrics

The biological response metrics developed by Bower et al. (2022) were correlated to model-simulated daily flows from the various planning scenarios to assess the potential for ecological risk, as described in The Nature Conservancy et al. (2023). Results of this assessment are not presented in their entirety, but rather illustrated by example for the various biological response metrics used.

The consistent methodology used is discussed in Bower et al. (2022) and summarized in this plan in Chapter 5.2.1. Fundamentally, the four selected hydrologic metrics (mean daily flow, base flow, frequency of low flow, and timing of low flow) are compared to current conditions and expressed as a percentage change relative to future demand scenarios. This percentage change is converted into a percentage change in the biological response metric using the pre-developed correlation relationships between these factors and plotted on a risk scale. Table 5-21 and Figure 5-6 illustrate the process.

Table 5-21. Example of calculating changes in the biological metrics at the Black Creek near Quinby Strategic Node.[1]

Demand Scenario	Current Scenario Flow (cfs)	Projected Demand Scenario Flow (cfs)	Percentage Change in Flow Metric	Biometric	Percentage Change in Biometric	Standard Error
UIF	537	550	2.34	Richness	1.63	0.107
Moderate 2070		533	-0.82	Richness	-0.57	0.107
High Demand 2070		531	-1.16	Richness	-0.81	0.107
P&R		267.3	-50.23	Richness	-35.0	0.107

[1]This table is one example, extracted from the analysis at the Black Creek near Quinby Strategic Node, and looks at the single hydrologic metric of mean daily flow (MA1) and its correlation with the single biological metric of species richness for fish taxa.

Once the changes in flow-ecology relationships are quantified via machine learning techniques, they are converted into a risk chart. The three risk categories, high, medium, and low, are determined by sudden and significant changes in biological health, driven by the change in the hydrologic metric, as shown in Figure 5-6.

Biological response metrics were applied at Strategic Nodes on four major tributaries to the Pee Dee River: Black Creek, Lynches River, Black River, and Little Pee Dee River. Figure 5-7 presents representative results for some of the combinations of hydrologic metrics and biological response metrics on the four major tributaries. These results do not constitute the full array of results for all locations and all metrics but are offered to help support understanding of the process, the results themselves as shared with the RBC, the consistency of results, and the interpretations that follow.

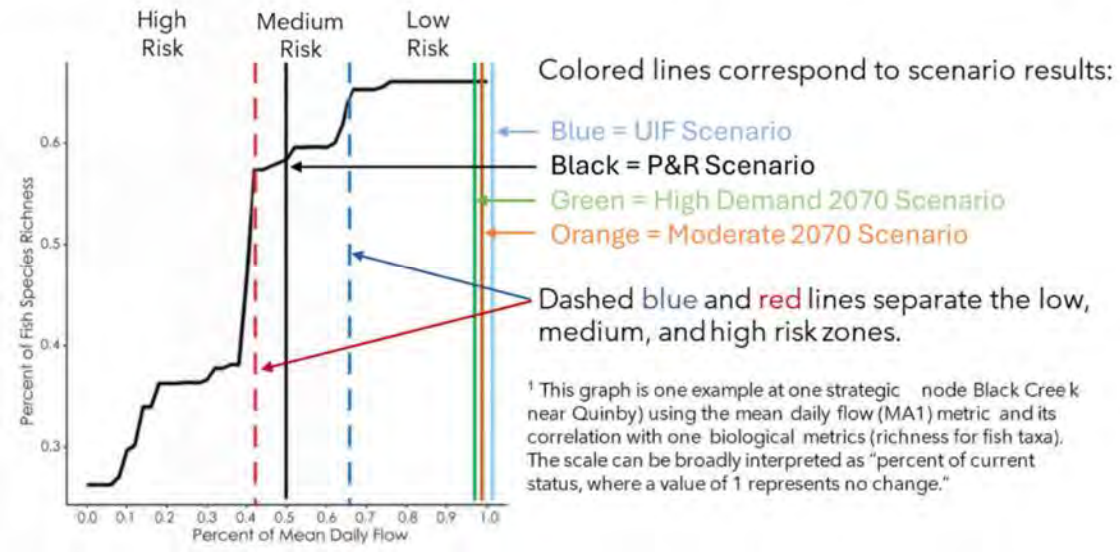


Figure 5-6. Example of the conversion of changes in biological metrics into risk[1].

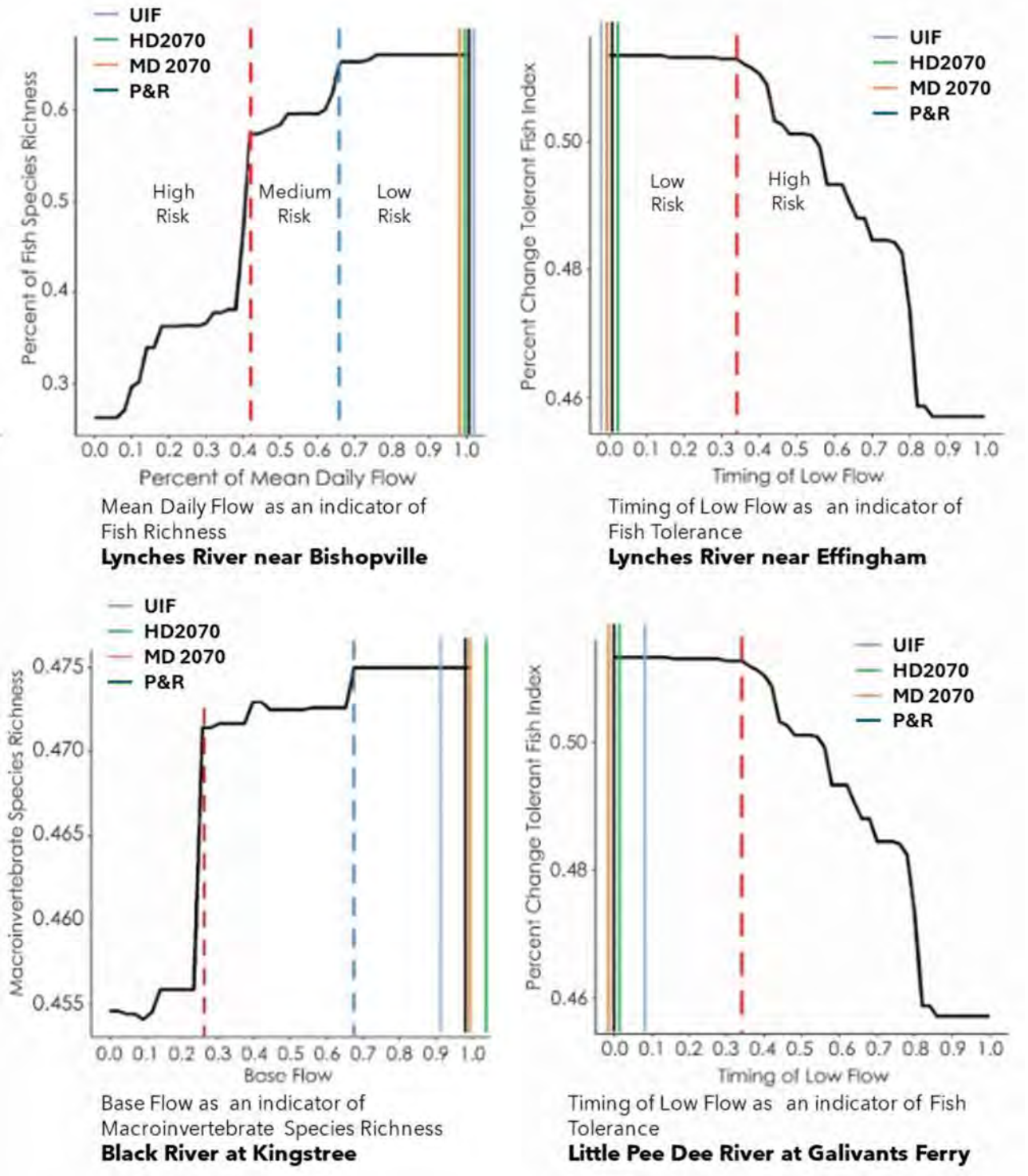


Figure 5-7. Selected biological risk level results for various biological metrics and Strategic Node locations (The Nature Conservancy et al. 2023).

As illustrated in Figure 5-6, a large change in mean daily flow for the P&R Scenario is predicted to reduce the number of fish species by 35 percent at the Black Creek near Quinby location. In no other locations was mean daily flow simulated to change significantly from the Current Use Scenario to the Moderate 2070 Scenario, High Demand 2070, or P&R Scenario.

Considering the timing of low flow (Figure 5-7, bottom right graph), the greatest change was projected under the unimpaired flow regime at the Little Pee Dee River at Galivants Ferry where the timing of low flow was altered by 7.5 percent relative to current conditions, resulting in a 16.7 percent reduction in the mean tolerant fish index. No other SWAM scenario projected large changes (>1 percent) in the timing of low flow, thus remaining in the low-risk zone.

Considering the metric of the frequency of low flow, the greatest shift was projected under unimpaired flow scenario at the Little Pee Dee River at Galivants Ferry. A reduction in low flow frequency was reduced 36.1 percent relative to current conditions, resulting in a 28.5 percent reduction in the mean tolerant fish index. No other SWAM scenario projected large changes (>1 percent) in the timing of low flow, thus remaining in the low-risk zone.

In general, these results suggest that while projected water use scenarios are a low risk to stream biodiversity, high water withdrawals, especially the fully permitted and registered allocation water use scenarios, could pose a medium to high risk to fish species and could result in large losses in the number of fish species. The findings do not rule out all potential risks to ecological integrity or aquatic biodiversity related to other metrics or flow alterations. For proper context, the following are some important limitations of the work:

- Biological response metrics and associated risks were only calculated at select nodes, principally at the downstream end of primary tributaries. There may be other locations in the river network that are more susceptible to flow changes or where changes in flow would result in significantly different conditions than existing. This could lead to more significant impacts to associated ecological integrity and tolerance in these unexamined locations.
- Processing biological samples from wadable sampling locations and hydrologic records throughout the Pee Dee River basin via machine learning techniques derived the relationships between hydrologic metrics and biological responses. Wadable access, while more limited downstream and in larger tributaries, is the most widespread form of surface water across the basin.
- The assessment was limited to the hydrologic and biological response metrics selected by the principal investigators, and for which biologically meaningful correlation had been established. This limited the use of these metrics to four hydrologic metrics and three biological metrics. The findings do not rule out potential risks for ecological integrity or tolerance related to other flow metrics or other forms of flow changes.
- Because the SWAM model focuses principally on primary and secondary tributaries, the study did not examine impacts on smaller headwater streams, which may be more vulnerable to flow management changes, but which are also less likely to be affected by large-scale changes in their flow regimes. Since the SWAM model includes all streams where significant flow management occurs (i.e., permitted and registered withdrawals and major discharges), the likelihood of significant flow alteration on non-modeled streams is low.

The demand scenarios are based solely on potential future changes on withdrawals, and do not consider other human impacts that affect instream flow. Increased development of the landscape from forest or agricultural land cover to suburban/urban development will continue to degrade the flow regime, which will exacerbate the effects of water withdrawals on the ecological integrity of streams and rivers in the basin. As such, the estimates of potential biodiversity loss are likely underestimated. Additionally, the flow metrics used to estimate flow-ecology relationships were estimated based on precipitation, temperature, land cover, etc. within a recent period of record. Future changes in these factors will affect the shape and magnitude of flow-ecology relationships. Accordingly, incorporating future climate and land use projections would likely alter our estimates of future water withdrawals impact on aquatic biodiversity.

5.4 Groundwater Conditions

Groundwater conditions in the Pee Dee River basin were evaluated based on available data from groundwater monitoring data, potentiometric mapping, and estimates of future water demand. A description of SCDES's groundwater monitoring and mapping program is included in Section 3.3.2.

In the Pee Dee River basin, groundwater monitoring data in the Crouch Branch and McQueen Branch aquifers show a general decline in groundwater levels over time due to groundwater extraction exceeding recharge rates. Declining groundwater levels are important because as of 2021, groundwater withdrawals from these aquifers represent 45 percent of the basin's reported water withdrawals (without consideration of withdrawals for energy generation). Public water supply and agricultural irrigation represent 89 percent of the use in the basin with well intakes distributed across the entire basin. Reported withdrawals between 2011 to 2023 generally showed an increasing trend but cannot be attributed to use alone due to better reporting in response to additional reporting regulations beginning in 2021 (SCDNR 2024).

Several wells completed in the Crouch Branch and McQueen Branch aquifers were selected to illustrate the major trends observed in the aquifers of the Pee Dee River basin. Figures 5-8 and 5-9 show the locations of trend network and synoptic network wells completed in each aquifer. Where spatial resolution of trend network wells (those with a daily average time series) were lacking, synoptic network wells (those with periodic manual measurements) are used together to create potentiometric maps. Evaluating these datasets together, along with reported water use and estimates of water demand projections, provide the basis for assessing current and historical groundwater conditions in the water source.

Water level trends in the Crouch Branch and McQueen Branch aquifers differ spatially from the upper to lower basin primarily due to distance from the recharge zone, the degree of confinement from the overlying geology, and aquifer characteristics. Recharge of the Crouch Branch and McQueen Branch occurs in the basin's upper reaches mainly in Marlboro, Chesterfield, and the northernmost portions of Darlington and Lee Counties. Water levels close to this highly permeable zone fluctuate with climate patterns. Where the aquifer is unconfined, water levels follow topography and interact with surface water bodies. Farther away from the recharge zone, the aquifers increase in depth but also in volume beneath confining units composed of clays.

Moving coastward, highly productive coarse grain sands grade to a finer grain sand and silt, with clay beds frequently occurring. These finer grain sediments reduce the aquifer's ability to transmit water. Therefore, recharge is slower and cases where groundwater extraction exceeds recharge, such as the cone of depression located at Georgetown County, become more likely.

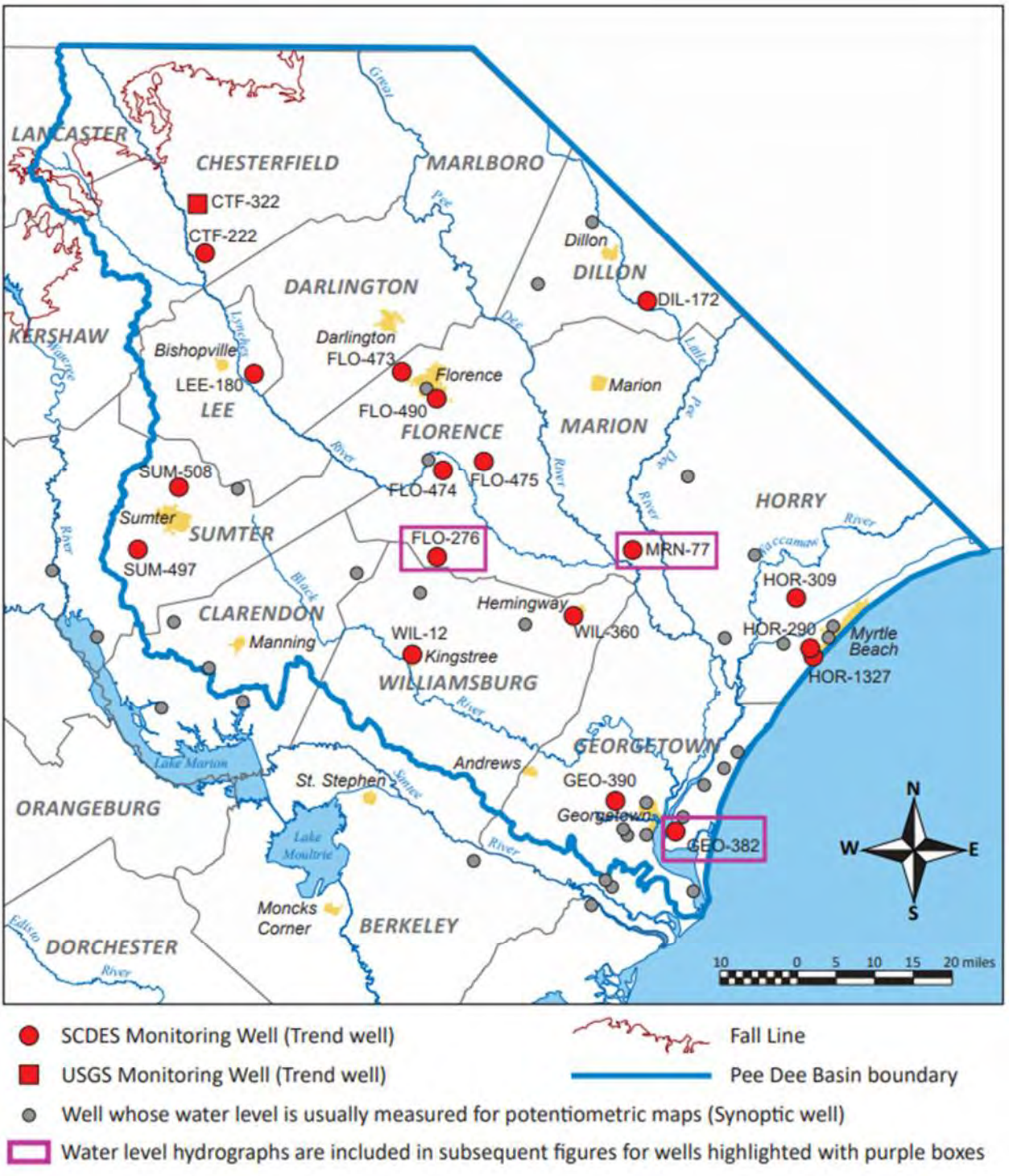


Figure 5-8. Locations of trend and synoptic wells completed in the Crouch Branch aquifer.

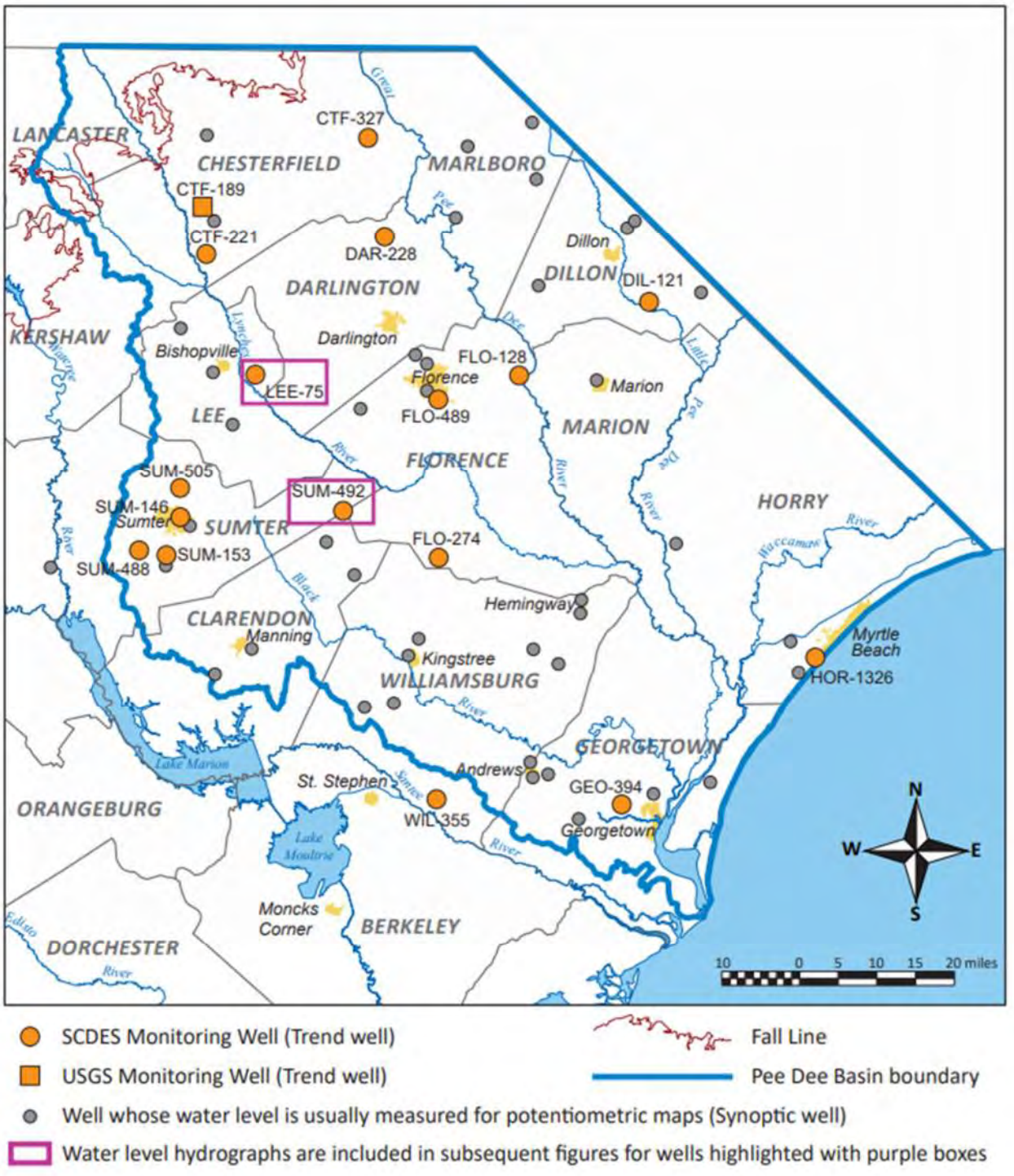


Figure 5-9. Locations of trend and synoptic wells completed in the McQueen Branch aquifer.

Groundwater levels in the Crouch Branch aquifer at monitoring sites in Florence County (FLO-0276) and Marion Country (MRN-0077) are shown in Figure 5-10. Both sites show a downward trend that is characteristic of the Crouch Branch in the Pee Dee River basin. Site FLO-0276 is located closer to the Fall

Line and receives more recharge. The site shows an irrigation well signal, with recharge in the winter and pumping in the summer; however, there is a steady decline in groundwater levels. Site MRN-0077 is located farther from the Fall Line, and the site shows less seasonal variability. Similarly, this site shows a downward trend in groundwater levels.

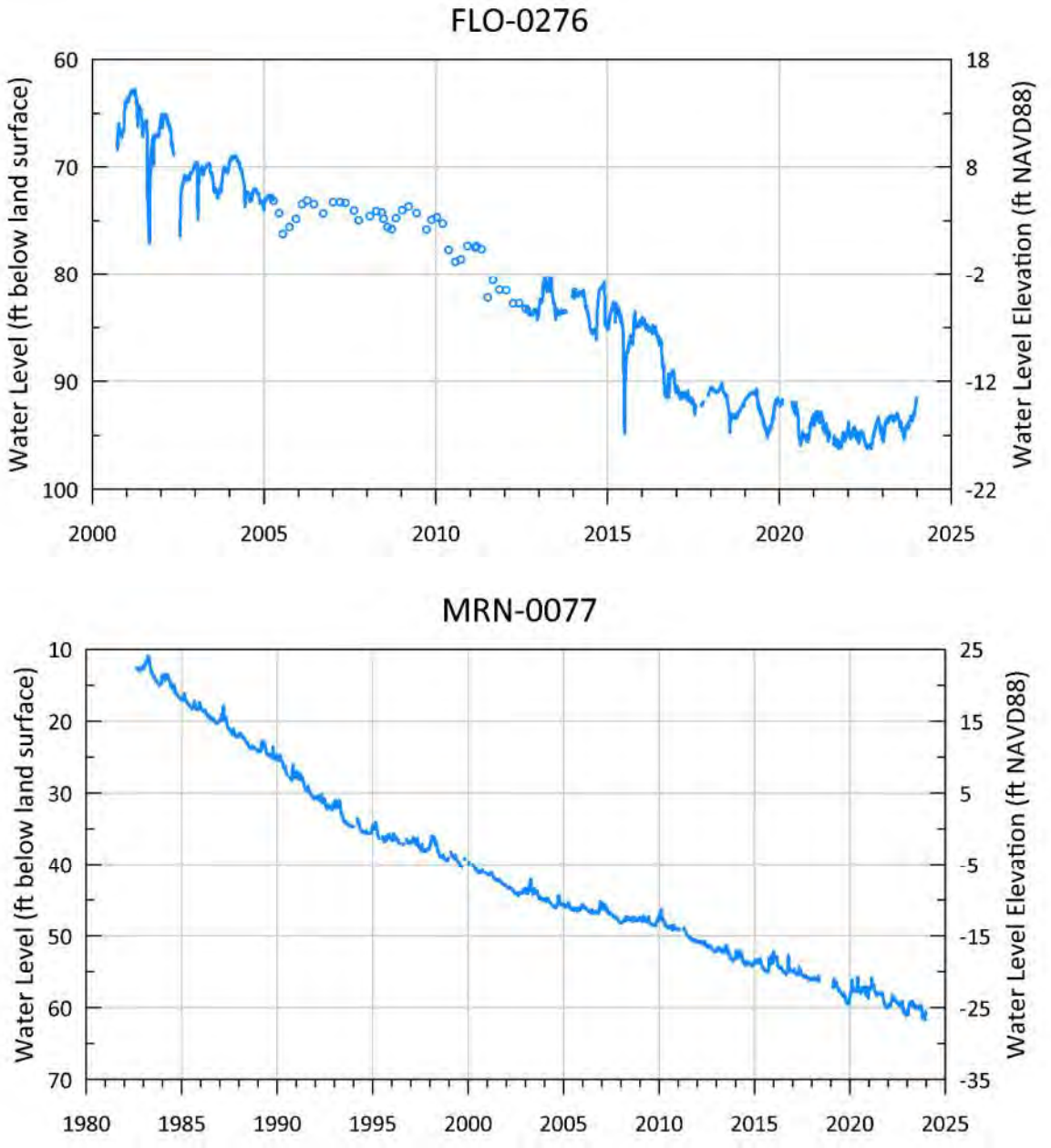


Figure 5-10. Groundwater levels in Crouch Branch aquifer in Florence and Marion counties.

Groundwater levels in the McQueen Branch aquifer at monitoring sites in Lee County (LEE-0075) and Sumter County (SUM-0492) are shown in Figure 5-11. The figure shows daily average and manual water level readings in feet below land surface. Both sites are in agricultural areas where groundwater is used for irrigation. Site LEE-0075 shows an irrigation well signal, where groundwater levels decline in the summer months due to irrigation pumping and then rise in the winter months due to recharge and less

pumping. The increasing magnitude of summer drawdowns at LEE-0075 since 2014 indicate an increase in agricultural pumping in that area in recent years. Because LEE-0075 is close to the recharge area near the Fall Line, groundwater levels at this site recover each year. Site SUM-0492 also shows an irrigation well signal due to its proximity to several high-yielding irrigation wells.

Because the aquifer at SUM-0492 is deeper and is farther from the recharge zone than LEE-0075, the water level does not rebound to the level of the previous growing season, which results in a consistent downward trend. This reduction of head of about 1 foot per year since 2010 indicates a declining resource. Downward trends in groundwater levels are present aquifer-wide in areas not near the recharge zone.

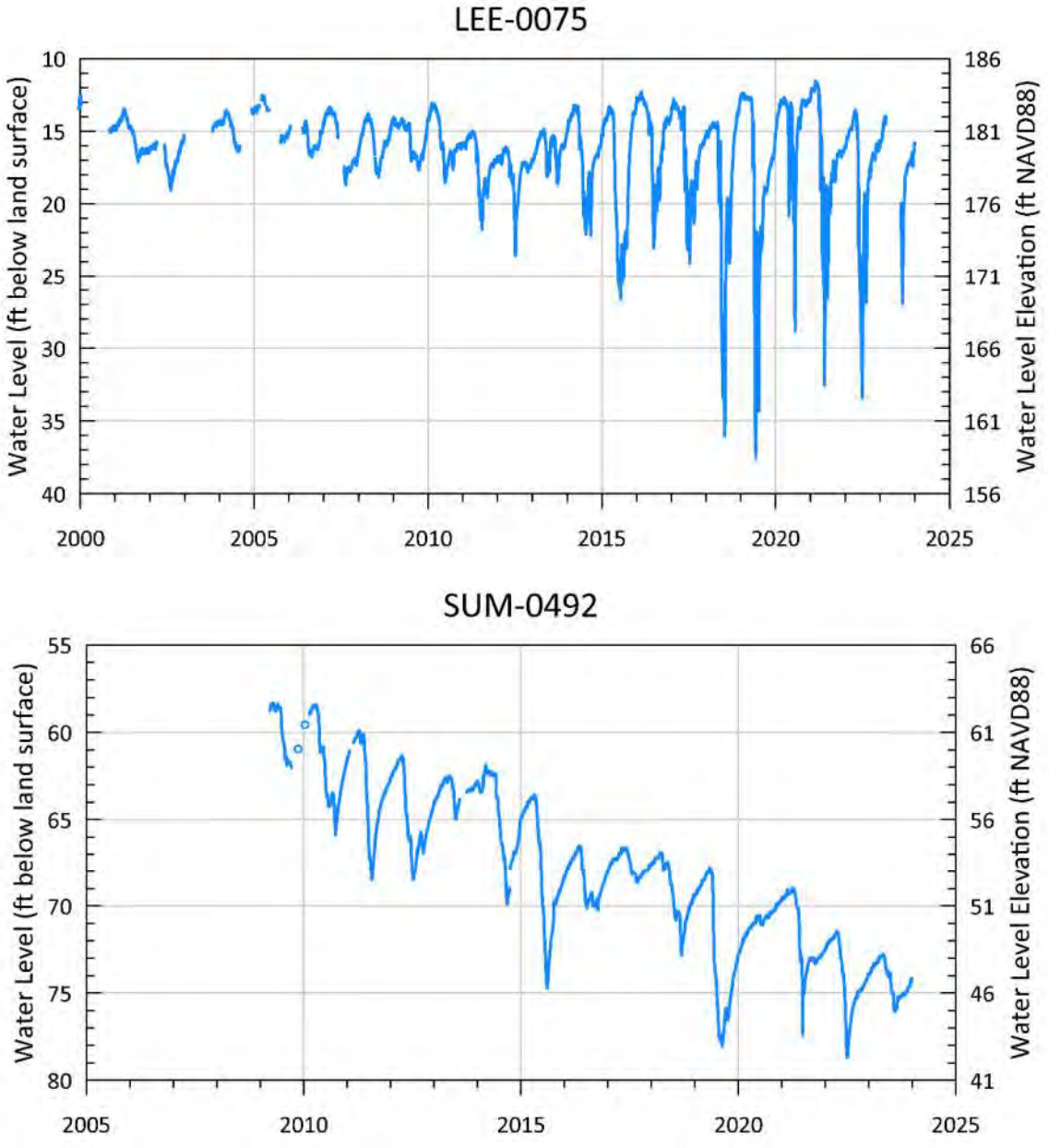


Figure 5-11. Groundwater levels in McQueen Branch aquifer in Lee and Sumter counties.

A majority of permitted agricultural irrigation wells are in the upper to middle portions of the Pee Dee Basin. Irrigation in these areas is projected to continue or increase over the planning horizon (see Figure 4-4). Agricultural water use is seasonal and tied to regional climate, which allows the aquifer to recover during the non-irrigation season and during wet years. While aquifer declines are observed with increasing distance from the recharge zone, it is expected that future declines in aquifer levels in these areas will not have the same severity as those in the lower portion of the basin.

Groundwater levels in a Crouch Branch aquifer well near Georgetown are shown in Figure 5-12. This well is located near the coast and shows a general decline in groundwater level associated with the large cone of depression in Georgetown County. Water levels have fallen at a rate of almost 2 feet a year between 2014 and 2023. Recovery in late 2023 may be the result of a reduction in pumping in Georgetown. This decline is consistent with declines observed in the aquifer for many years and is discussed in the following section. Declines are observed in both the Crouch Branch and McQueen Branch aquifers.

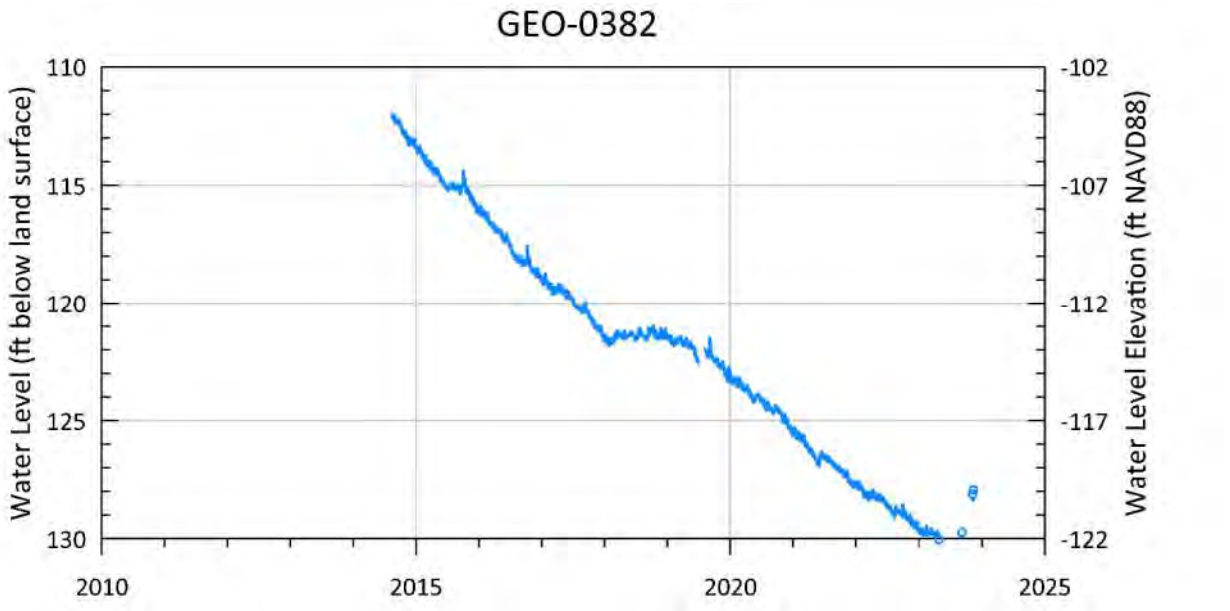


Figure 5-12. Groundwater levels in Crouch Branch aquifer in Georgetown County.

Potentiometric maps, which illustrate the surface elevation contours to which groundwater levels will rise in wells completed in the aquifer, indicate a general groundwater flow direction towards the coast. Potentiometric surfaces of the major aquifers present in the basin (and in South Carolina, overall) are shown in Figure 5-13 and Figure 5-14, based on interpretation of groundwater-level data collected in a campaign approach usually during the months of November and December. The resulting maps identify cones of depression where groundwater levels have declined. The greatest declines are centered at pumping wells, and the zone of influence can be narrow or spread out for tens of miles (SCDNR 2022). The largest cone of depression in the Pee Dee River basin is in Georgetown, and cones of depression are present in Myrtle Beach and Florence (SCDNR 2022). These cones of depression are discussed in more detail in the following sections, along with discussions of how future groundwater use may affect groundwater levels in these areas.

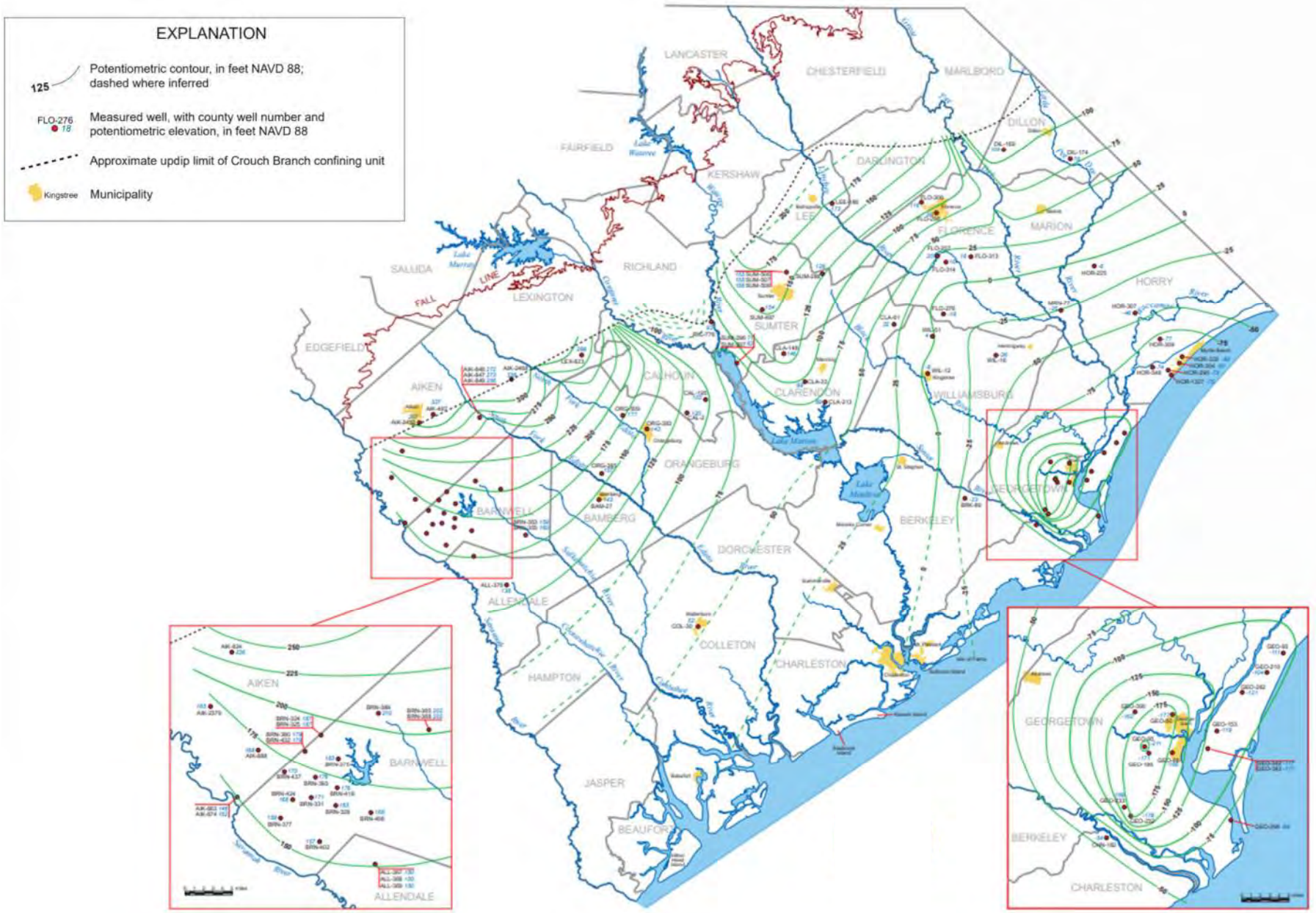


Figure 5-13. Potentiometric surface map of the Crouch Branch aquifer in November – December 2020.

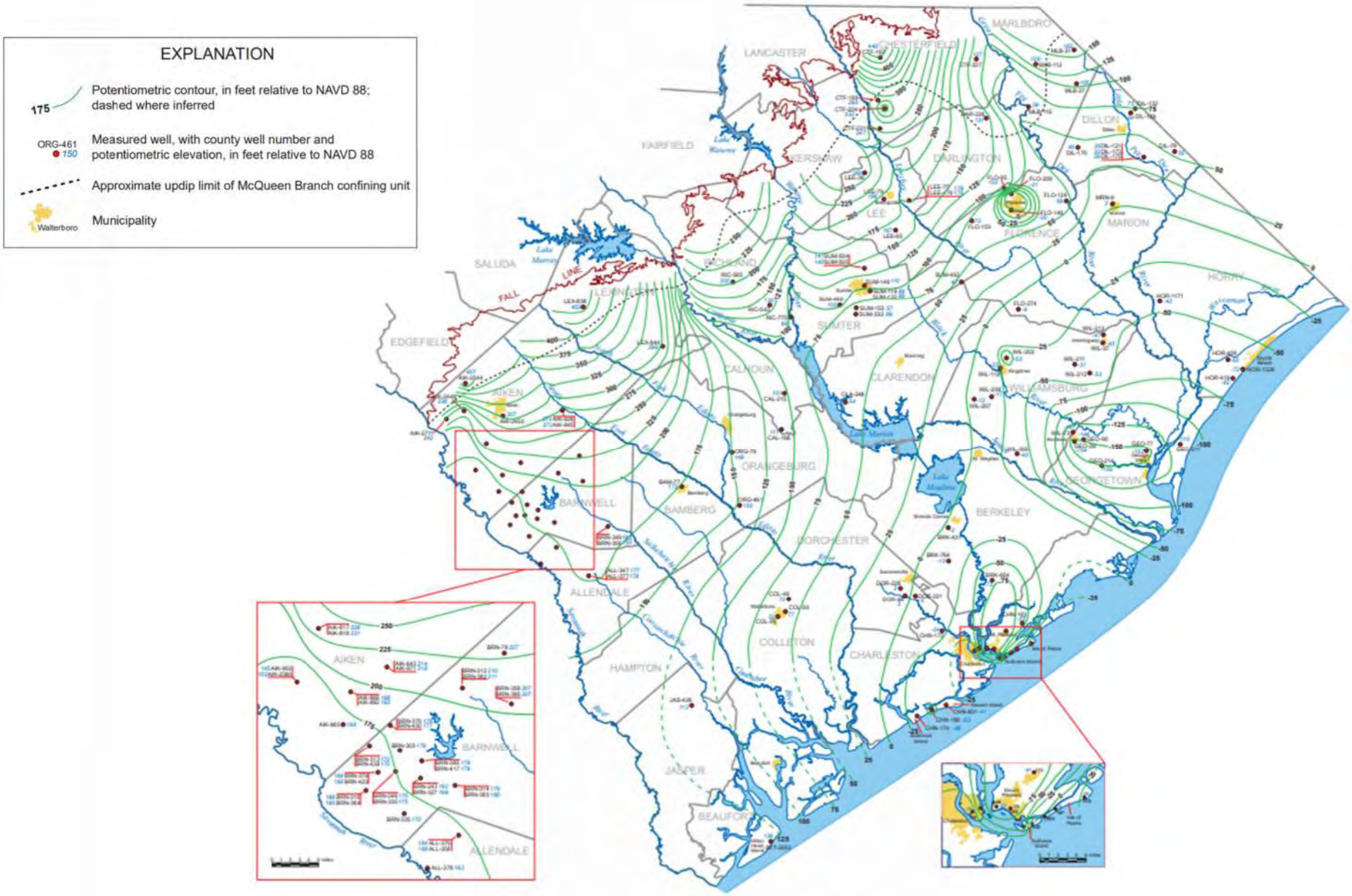


Figure 5-14. Potentiometric surface map of the McQueen Branch (and Charleston) aquifer, November – December 2022.

5.4.1 Coastal Cone of Depression

In the upper Coastal Plain, groundwater levels appear to be generally stable, and no significant long-term decline in aquifer water levels has been observed. In the lower Coastal Plain, however, there is a trend of groundwater levels declining at a rate of about one foot per year in Williamsburg and Horry counties, and as much as two feet per year in parts of Georgetown County. This decline is seen in both the Crouch Branch and McQueen Branch aquifers.

Much of the groundwater use in these counties is for public water supply. In 2022, reported withdrawals from water supply wells in Georgetown and Horry counties (Waccamaw CUA) was 81 percent of the overall annual reported groundwater use (3,139 million gallons out of an overall use of 3,866 million gallons). Water supply wells screened solely in the Crouch Branch and across both the Crouch Branch and McQueen Branch aquifers provide the largest portion supply followed by wells completed solely in the McQueen Branch aquifer. It is difficult to assess water use by aquifer in these areas due to this diversity of well construction.

Groundwater use for the water supply sector in Georgetown and Horry counties has remained relatively stable since 2013. The average county-wide reported water supply use between 2013 and 2023 was 2.8 MGD and 5.5 MGD for Georgetown and Horry counties, respectively (see Figure 5-15). During this same period, both continuous and periodic groundwater levels collected in the region declined at a rate of approximately 2 feet per year. Figure 5-12 illustrates this decline in a groundwater monitoring well in Georgetown County.

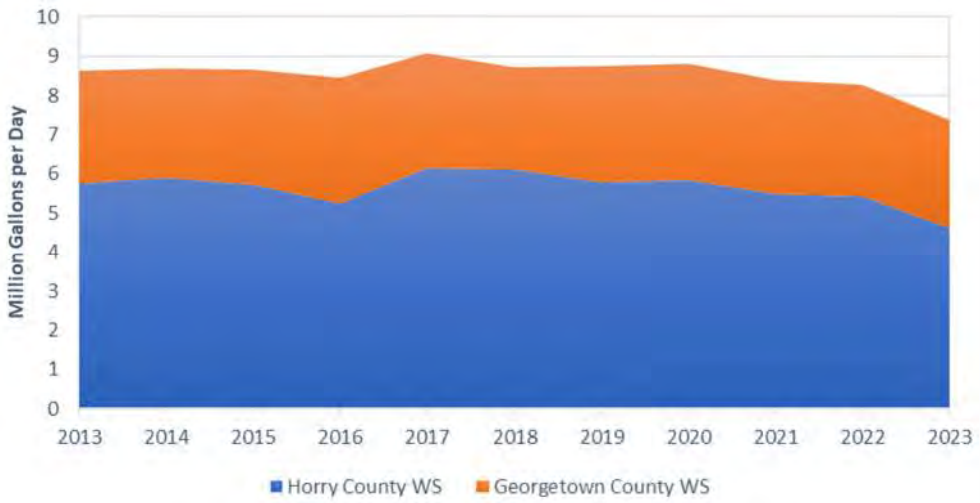


Figure 5-15. Reported groundwater use for water supply in the Waccamaw Capacity Use Area between 2013 and 2023.

The declining groundwater level in Figure 5-12 is symptomatic of a large cone of depression observed in the Crouch Branch and McQueen Branch aquifers that is centered over Georgetown County. The cone of depression has been forming for many years. In fact, potentiometric maps dated as early as 1975 show water level declines in the Crouch Branch aquifer of 125 feet when compared to predevelopment levels (Pelletier 1985). Since that time, subsequent water level maps constructed from water levels collected in 2004, 2016, and 2020 in the Crouch Branch aquifer have shown a steady decline in water levels near Georgetown to depths of approximately 250 feet below predevelopment levels. The cone has spread for tens of miles away from the pumping center due to finer sediments in the aquifer near the coast in contrast to the coarse-grained sediments in the upper basin further to the north and west.

While the cone of depression near Georgetown County is acute, the entire coastal region encompassing both Georgetown and Horry counties has seen lowered potentiometric pressure in the Crouch Branch

aquifer with declines of around 100 feet or more. Figure 5-16 shows different depictions of the Crouch Branch potentiometric surface over time since pre-development and illustrates the historical declines in coastal groundwater pressure in the Crouch Branch aquifer. The McQueen Branch aquifer in the same region has experienced similar declines but not at the same rate and with less severity.

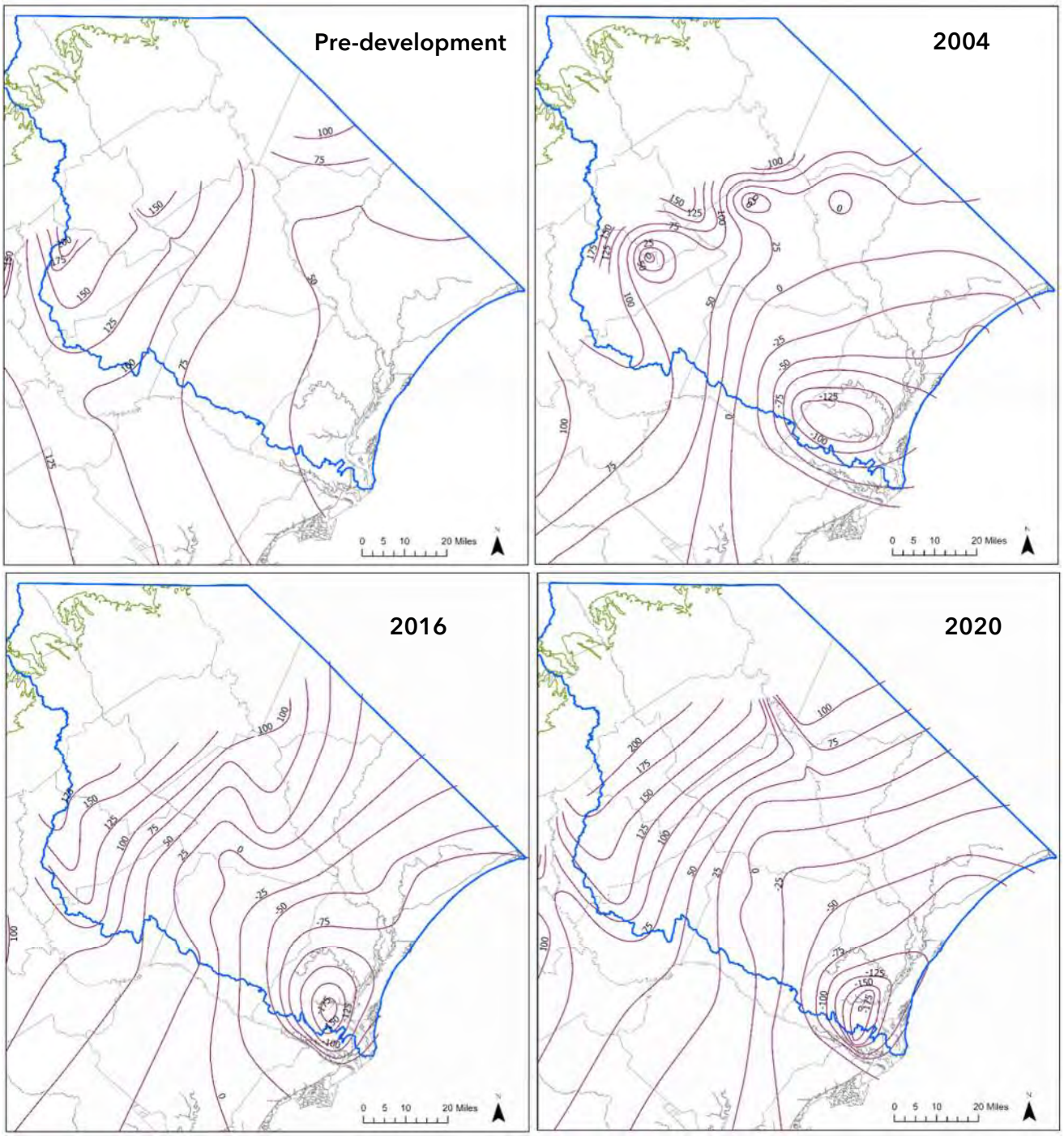


Figure 5-16. Potentiometric surface maps of the Crouch Branch aquifer over time (prior to groundwater development, 2004, 2016, 2020).

Georgetown and Horry counties are expected to see additional growth in water demand driven by anticipated population increases along the coast. In Georgetown County, projections suggest that by 2070, water demand will increase by 105 percent under the Moderate Scenario. Current and projected Georgetown County water supply demands are shown in Figure 5-17. Reported use in 2023 was 42.1 MGD (39.3 MGD was from surface water sources, and 2.8 MGD was from groundwater). By 2070, the Moderate Scenario projects water demand to increases to 86.5 MGD (82 MGD from surface water and 4.5 MGD from groundwater). Most of the future demand (95 percent) is anticipated to be supplied by surface water sources. However, demands supplied by groundwater sources are anticipated to increase by 60 percent (from 2.8 MGD to 4.5 MGD) over the planning horizon.

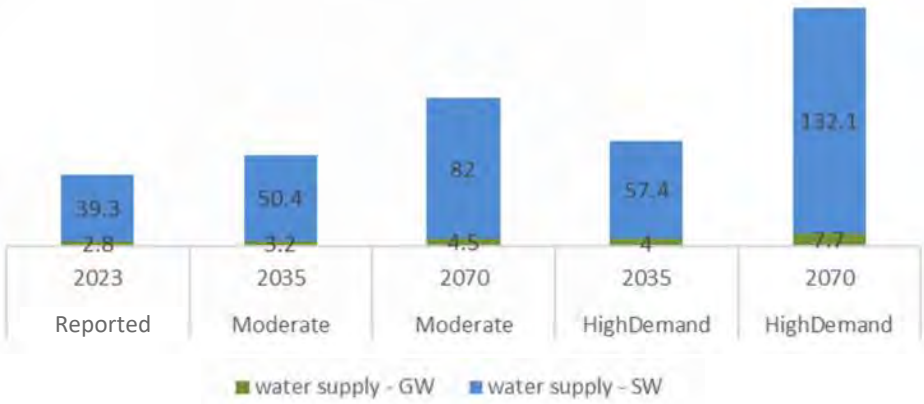


Figure 5-17. Water demand projections (in MGD) by source of supply for Georgetown County.

In Horry County, projections suggest that by 2070, water demand will increase by 109 percent under the Moderate Scenario. Current and projected Horry County water supply demands are shown in Figure 5-18. Reported use in 2023 was 25.4 MGD (19.4 MGD was from surface water sources, and 6 MGD was from groundwater. By 2070, the Moderate Scenario projects water demand to increases to 53 MGD (41 MGD from surface water sources and 12 MGD from groundwater). Most of the future demand (71 percent) will be supplied by surface water sources. Demands supplied by groundwater sources are anticipated to double (from 6 MGD to 12 MGD) over the planning horizon.

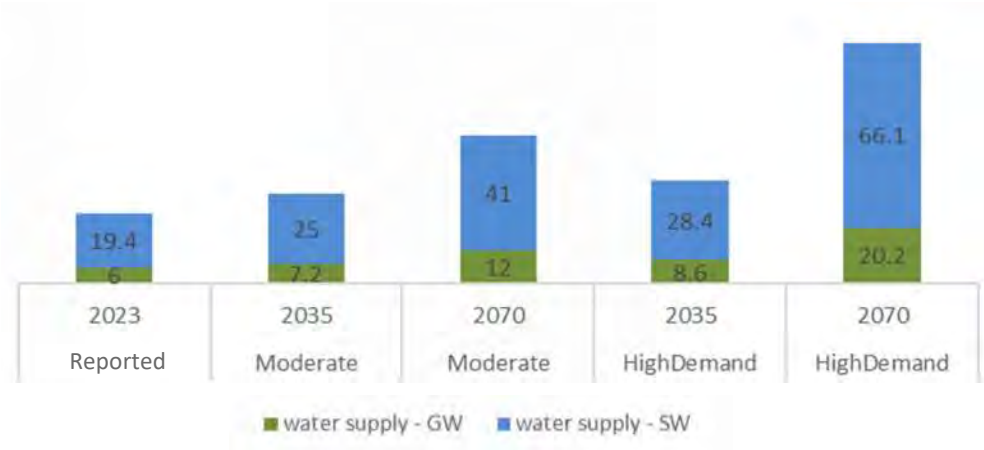


Figure 5-18. Water demand projections (in MGD) by source of supply for Horry County.

While much of the future growth in Georgetown and Horry counties will be supplied by surface water sources, increases in groundwater use could exacerbate existing declines in groundwater supplies. Water providers in Georgetown and Horry counties recognize the groundwater supply risk and have been implementing conjunctive surface water and groundwater management practices that utilize aquifer storage and recovery strategies.

If groundwater use continues at its current rate and distribution in the basin, this trend will likely continue, and over the 50-year planning horizon, groundwater levels in the major aquifers of Williamsburg County and Horry County will decline about 50 feet from current levels, and possibly as much as 100 feet in parts

of Georgetown County. If that happens, water levels in the Crouch Branch aquifer in these counties will likely fall below the top of the aquifer, which could lead to irreversible damage to the aquifer as well as possible land subsidence. Because of its depth, water levels in the McQueen Branch aquifer would still be several hundred feet above top of that aquifer.

It is worth noting that the above discussion relates to static water levels. Because water levels in the vicinity of actively pumped wells may be significantly lower than the regional static water level, water levels in the Crouch Branch aquifer near pumping centers may reach critical levels years earlier than elsewhere in the basin.

5.4.2 Florence County Cone of Depression

Long-term use of groundwater from the McQueen Branch aquifer in Florence County has caused a cone of depression. The potentiometric contour maps of the McQueen Branch aquifer in Figure 5-14 and also in Chapter 6 (Figure 6-4) show a steeply contoured cone of depression in the potentiometric surface centered in Florence County. The cone of depression and high use of groundwater for municipal needs has been a cause of concern for stakeholders in the county.

It is unclear whether future groundwater uses in Florence County will impact the cone of depression. In Florence County under the Moderate Scenario, overall municipal water demand is anticipated to decrease by 18 percent due to potentially declining population. Reported municipal water use for Florence County in 2023 was 18.4 MGD (7 MGD for surface water and 11.4 MGD for groundwater). By 2070, the Florence County water demand is anticipated to decline to 15.1 MGD (5.4 MGD for surface water and 9.7 for groundwater) under the Moderate Scenario. While groundwater demand is expected to decrease by 15 percent in the Moderate Scenario, it will still be the primary source of supply (1.8 times more than surface water). In the High Demand Scenario, municipal water use in Florence County is anticipated to increase.

In contrast to potentially declining future municipal demands, industrial demand for surface and groundwater supplies is anticipated to increase by 53 percent by 2070 in the Moderate Scenario. Reported use for the industrial sector in 2023 was 14.8 MGD (13 MGD for surface water and 1.8 MGD for groundwater). By 2070, industrial water demand is anticipated to increase to 22.6 MGD (17.9 MGD for surface water and 4.7 MGD for groundwater) under the Moderate Scenario. Significantly more surface water than groundwater is used in the industry sector currently, but groundwater is anticipated to have a disproportional future increase in use. Over the planning horizon, the demand from surface water supplies is anticipated to increase by 37 percent, but the demand for groundwater supplies is anticipated to grow by 161 percent.

In the Moderate Scenario, a decline in municipal water demand for groundwater of 1.7 MGD will potentially be offset by an increase in demand for groundwater supplies by the industrial sector of 2.9 MGD. Impacts to the cone of depression, if any, will depend on the location of new groundwater use and the aquifer from which groundwater is extracted. In addition, a recently implemented conjunctive water management strategy involving greater use of surface water supplies to relieve stress on groundwater supplies has reversed long term aquifer declines in some parts of Florence County (see Chapter 6, Section 6.2.3 for more information). The RBC recommends that groundwater uses and aquifer levels continue to be monitored in the Florence County area to inform the potential need for additional water management strategies to mitigate groundwater supply risks, should they arise.

5.5 Summary of Water Availability Assessments

The application of the surface model using current and projected rates of water withdrawals resulted in the identification of several key observations and conclusions regarding the availability of surface water resources in the Pee Dee River basin. Several observations and conclusions were also identified for groundwater resources. Although lacking a model to simulate current and future groundwater demand scenarios, the approach of using current and historical water level and water use trends resulted in the identification of areas where water management strategies have been successfully employed through regulatory action that has maintained the current supply. Areas were also identified that are lacking information for a thorough assessment. The approach for evaluating groundwater resources was developed to be data-ready when the groundwater model becomes available.

The key conclusions from water availability assessments, presented below, led to the RBC identifying and evaluating a suite of water management strategies to protect surface water supply and maintain adequate river flows, especially during low flow conditions, as well as address potential groundwater issues. The evaluation and selection of water management strategies is presented in Chapter 6 – Water Management Strategies.

The results and conclusions are based on surface water modeling that assumed historical climate patterns. As stated earlier, groundwater-related results and conclusions were not based on modeling. In subsequent phases of river basin planning, the RBC may decide to evaluate potential impacts to water supply availability resulting from changing climate conditions such as increasing temperatures and more variable precipitation. In addition, the RBC intends to further evaluate groundwater-related issues using the groundwater model when it is complete.

5.5.1 Key Surface Water Observations and Conclusions

The surface water availability modeling suggests a minimal risk of water supply shortages under reasonable future demand scenarios. It suggests there could be shortages for agricultural users in small headwater streams that do not have storage ponds; however, these shortages would be infrequent.

Specific observations and conclusions relative to each planning scenario are presented below.

- Physical surface water shortages were identified in the Current Scenario for 2 agricultural water users, 2 golf courses, and a mining operation in the SWAM model, ranging in frequency from 0.3 to 7 percent of months of the 89-year simulation period. However, many if not all the simulated shortages in this scenario are likely to be significantly tempered or avoided because of the on-site storage available from existing ponds which were not included in the model. The ponds provide much-needed storage during low flow conditions that occur during a drought.

- In the P&R Scenario (i.e., surface water withdrawals at fully permitted and registered amounts), river flows are predicted to decrease compared to the Current Scenario resulting in surface water shortages for just over one-third of the surface water users. The total permitted and registered amount of surface water (in the non-tidally influenced, modeled portion of the Pee Dee Basin) is 1,324 MGD, or more than twice the Current Use Scenario surface water demands of 576 MGD. The P&R Scenario represents an unrealistic scenario; however, it demonstrates that the surface water resources of the basin are over-allocated based on existing permit and registration amounts.

- In the Moderate Scenario, river flows are predicted to decrease only slightly, compared to the Current Use Scenario, throughout the basin. Modeled reductions are most pronounced during low flow periods. Calculated water user shortages remain essentially unchanged, relative to the Current Scenario. Surface water supplies are predicted to be adequate to meet increased demands resulting from moderate economic and population growth.

- In the High Demand Scenario, river flows are also predicted to decrease modestly, compared to the Current Scenario, throughout the basin. Modeled reductions are most pronounced during low flow periods. Median flows in the Pee Dee River at the USGS gaging station below Pee Dee are predicted to decrease by 7.1 percent and minimum flows by up to 15.9 percent by 2070, compared to the Current Use Scenario flows if population and economic growth is high and given a hotter and drier climate. Calculated water user shortages increase only slightly, in terms of both duration and intensity, from the Moderate and Current Use Scenarios.

- The differences in performance measures (flow statistics) at Strategic Nodes between the UIF Scenario and the Current Use Scenario are relatively small, indicating that current net withdrawals and discharges are not appreciably altering the current flow regime, compared to naturalized conditions. Current Use Scenario flows are larger than the UIF Scenario flows on the Lynches, Little Pee Dee, and Black Rivers because of water users that withdraw from groundwater and discharge to surface water.

- The application of biological response metrics and the development of flow-ecology relationships at Strategic Nodes demonstrated that while projected water use of the Current, Moderate and High Demand Scenarios are a low risk to stream biodiversity, high water withdrawals, especially the fully permitted and registered allocation water use scenarios, could pose a medium to high risk to fish species and could result in large losses in the number of fish species. The findings do not rule out potential risks for ecological integrity or tolerance related to other metrics or flow changes.

5.5.2 Key Groundwater Observations and Conclusions

The groundwater evaluation demonstrates that both the Crouch Branch and McQueen Branch aquifers can transmit large volumes of groundwater to support water demand withdrawals in most regions of the Pee Dee River basin. In the absence of testing the demand scenarios with a calibrated groundwater model, it is difficult to predict if groundwater supply shortages will exist under reasonable future demand scenarios.

Specific observations and conclusions relative to the groundwater assessment are presented below.

- Water level trends in wells near the recharge areas of the Crouch Branch and McQueen Branch aquifers have remained stable over time despite groundwater pumping. This demonstrates a pattern of consistent and sufficient recharge to both aquifers. It is likely that no groundwater supply shortages will occur under modeled projected use scenarios.

- Groundwater levels decline moving farther toward the coast from the recharge zone, which is consistent in both the Crouch Branch and McQueen Branch aquifers. In most cases, water levels



are declining approximately 1 foot a year. The declines in the Crouch Branch aquifer observed near Georgetown are about 2 feet year.

- Groundwater gradients in both aquifers are influenced by pumping at the coast. It is possible that recharge is not reaching the coast because it is withdrawn up dip (or further inland). Finer sediments in the coastal counties do not transmit water as easily, further exacerbating declines.
- The continued growth and expansion of a cone of depression in the potentiometric surfaces of groundwater in the Crouch Branch and McQueen Branch aquifers in Georgetown County has been monitored for years. While groundwater pumping is a driver, the specific reasons for the degree and nature of the decline are not fully understood and may include under or unreported withdrawals and geologic factors.
- At current rates of groundwater use, by 2070, groundwater levels in Williamsburg and Horry counties may decline an additional 50 feet, and in parts of Georgetown County, as much as 100 feet, bringing water levels in the Crouch Branch aquifer to critically low levels.
- Groundwater levels should be monitored routinely, particularly in the lower Coastal Plain and coastal counties. In addition to the measurement of static water levels, water levels in actively pumping wells should occasionally be measured.
- The updated Coastal Plain groundwater model is needed to make better projections of potential future groundwater levels and to evaluate strategies to mitigate groundwater supply risks.
- While not described in this chapter, Chapter 6 highlights conjunctive surface and groundwater management strategies that were implemented in Florence County and the resulting stabilization of groundwater levels.
- While conjunctive water management strategies have been very beneficial for slowing and reversing declining groundwater levels associated with the cone of depression in Florence County, groundwater levels should continue to be monitored to evaluate potential groundwater supply risks that may occur if future uses increase.

Chapter 6
Water Management Strategies

This chapter summarizes the evaluation of potential water management strategies identified by the Pee Dee RBC. The Framework identifies a two-step process to evaluate water management strategies. As a first step, proposed management strategies are simulated using the available models to assess their effectiveness in eliminating or reducing identified shortages or increasing surface water or groundwater supply. For strategies that are deemed to be effective, their feasibility for implementation is addressed during a second step. The Framework identifies multiple considerations for determining feasibility, including cost and benefits, consistency with state regulations, reliability, environmental and socioeconomic impacts, and potential interstate or interbasin impacts.

Under the Framework, a surface water management strategy is any water management strategy proposed to eliminate a surface water shortage, reduce a surface water shortage, or generally increase surface water supply to reduce the probability of future shortages. Strategies include demand-side management strategies that reduce supply gaps by reducing demands, as well as supply-side strategies that reduce supply gaps by directly increasing supply.

6.1 Overview of Strategies

The Pee Dee RBC reviewed and discussed a portfolio of various demand-side strategies consisting of agricultural water efficiency practices and municipal, industrial, and thermoelectric water conservation practices as listed in Tables 6-1 through 6-5, respectively. While these demand-side strategies were first identified and evaluated for surface water withdrawers, they also apply to groundwater withdrawers.

Table 6-1. Agricultural/Irrigation water efficiency practices.

Agricultural/Irrigation Conservation Practices	
Water Audits and Nozzle Retrofits	Crop Variety, Crop Type, and Crop Conversions
Irrigation Scheduling and Smart Irrigation	Irrigation Equipment Changes
Cover Cropping, Conservation Tillage, Mulch	Drip/Trickle Irrigation (for select crops)

Table 6-2. Golf course water efficiency practices.

Golf Course Conservation Practices	
Wetting Agents to Reduce Water Use	Soil Moisture Monitoring
Water Loss Control and Regular Maintenance	Low-Water Use Landscaping
Time of Day Watering Practices	

Table 6-3. Municipal water conservation and efficiency practices.

Municipal Conservation Practices	
Development, Update, and Implementation of Drought Management Plans	Residential Water Audits
Conservation Pricing Structures	Reclaimed Water Programs
Public Education on Water Conservation	Car Wash Recycling Programs
Leak Detection and Water Loss Control Program	Time of Day Watering Limits
Low Flow Fixtures, Toilets, and Appliances	Landscape Irrigation Programs and Codes
Water Efficiency Standards for New Construction	Xeriscaping

Table 6-4. Industrial water conservation and efficiency practices.

Industrial Conservation Practices	
Water Reuse and Recycling	Leak Detection and Water Loss Control Program
Water Efficient Processes	Low Flow Fixtures, Toilets, and Appliances
Drought Management Best Practice Collaboration	

Table 6-5. Thermoelectric water efficiency practices.

Thermoelectric Conservation Practices	
Reclaimed Water	Energy Saving Appliances
Switch to Combined-Cycle Natural Gas	

Surface water supply-side strategies reviewed and discussed by the RBC include conjunctive use of groundwater with surface water, increasing storage, water reclamation and reuse, conveyance, and desalination of seawater. Table 6-6 lists these strategies and example practices considered by the RBC. These strategies do not represent an exhaustive list of possible strategies that could be implemented by surface water users in the Pee Dee River basin. The most appropriate strategies for a water withdrawer will depend on their location, end use, water source, financial resources, and other constraints or opportunities.

Table 6-6. Supply-side strategies and example practices.

Supply-side Strategy and Practices
New or Increased Storage (new impoundments, reservoirs, and tanks; dredging to deepen impoundments; raising dam heights to expand impoundments; aquifer storage and recovery [ASR])
Water Reclamation (non-potable water reuse systems and stormwater capture and treatment)
Conjunctive Use (using groundwater to augment or replace surface water, especially during low flow periods)
Conveyance (interconnections with neighboring utilities, regional water systems, and interbasin transfers)
Desalination (desalination of seawater)

These strategies do not represent an exhaustive list of possible strategies that could be implemented by water users in the Pee Dee River basin. Similarly, not all these strategies will be applicable to all users in the basin. The most appropriate strategies for a water withdrawer will depend on their location, end use, water source, financial resources, and other constraints or opportunities.

The following sections present the surface water management strategies identified by the RBC, a technical evaluation of their potential effectiveness, and an assessment of their feasibility.

6.1.1 Demand-Side Strategies

6.1.1.1 Agricultural Water Efficiency Demand-Side Strategies

The agricultural water efficiency practices considered as part of the toolbox of strategies are further described below. These demand-side strategies also apply to groundwater users.

Water Audits and Nozzle Retrofits

Water audits monitor water use in an agricultural irrigation system to identify potential opportunities for water efficiency improvements. Water audits consider water entering the system, water uses, water costs, and existing water efficiency measures. They gather information on the size, shape, and topography of the agricultural field, depth to groundwater, vulnerability to flooding, pumping equipment, irrigation equipment, and past and present crop use and water use (Texas Water Development Board 2013).

Across the state, Clemson University Cooperative Extension Service specialists and researchers have held meetings to talk with farmers about center pivot irrigation and discuss the Clemson Center Pivot Irrigation Test Program, a type of water audit offered by the Clemson Extension Water Resources, Agronomic Crops, and Horticulture Teams. These audits measure irrigation uniformity—the consistency of irrigation depth across the irrigated area. Without irrigation uniformity, some crops may experience overirrigation and some may experience underirrigation, leading to wasted water and profit losses. The Center Pivot Irrigation Test Program can provide growers with a map of irrigation depths, observed issues such as leaks and clogs, estimated costs of over- or underwatering, estimated costs for nozzle retrofits, and design versus observed flow rates and system pressure (Clemson Cooperative Extension 2022a). After the audit, a report is provided that includes an estimated cost of under- and overirrigation based on crop types. This cost of suboptimal irrigation is compared to the estimated cost of a sprinkler retrofit.

The South Carolina Mobile Irrigation Laboratory pilot project is another example water audit program. This project was the result of a partnership with South Carolina Department of Agriculture (SCDA) and Aiken Soil and Water Conservation District. The audits identified areas of over- and underwatering, suggest energy savings opportunities, and recommend upgrades or operational changes (SCDNR 2019c). The project provided no-cost water and energy audits on 24 agricultural center pivot irrigation systems throughout South Carolina over 3 years (SCDNR 2020b).

Irrigation Scheduling and Smart Irrigation

Irrigation scheduling refers to the process of scheduling when and how much to irrigate crops based on the needs of the crops and the climatic/meteorological conditions. It ensures that crops are receiving the correct amount of water at the right time. The three main types of irrigation scheduling methods include

soil water measurement, plant stress sensing, and weather-based methods. To measure soil water, farmers can use soil moisture sensors at varying depths. There are two different types of soil moisture sensors: (1) sensors that measure volumetric water content and (2) sensors that measure soil tension (University of Minnesota Extension 2024). Water application can be controlled and limited by identifying precise periods of time when irrigation is needed by using soil moisture measurements coupled with other factors such as soil temperature, crop growth stage, localized evapotranspiration, and even weather forecasts. For weather-based methods, farmers can research regional crop evapotranspiration reports to develop an irrigation schedule. Additionally, farmers can use thermal sensors to detect plant stress (Freese and Nichols, Inc. 2020). The use of thermal and/or moisture sensors to automatically schedule irrigation is referred to as *smart irrigation*. Advanced irrigation scheduling and use of sensors and smart irrigation technology may reduce water use by 15 percent on average (Smart Irrigation, 2019).

A Clemson study on Intelligent Water and Nutrient Placement (IWNP) combines smart watering strategies with smart fertilizer applications. IWNP uses smart sensing with model-based decision support systems to determine the irrigation water and nutrient application required by crops at a given time (Clemson College of Agriculture, Forestry and Life Sciences 2021). The IWNP systems are installed on existing overhead irrigation systems as a retrofit. The program first seeks to develop the system, then develop a training program to teach farmers how to use the system.

Feedback from the Pee Dee RBC on this strategy was that irrigation scheduling can be a useful tool, but it needs to be conducted correctly to be effective. Also, it is a strategy that can be used in both agricultural and municipal settings (though the specific approaches and technologies may be different).

Soil Management

Soil management includes land management strategies such as conservation tillage, furrow diking, and the use of cover crops in crop rotations. The USDA defines conservation tillage as "any tillage or planting system that covers 30 percent or more of the soil surface with crop residue, after planting, to reduce soil erosion by water" (USDA 2000). Conservation tillage can conserve soil moisture, increase water use efficiency, and can decrease costs for machinery, labor, and fuel. Types of conservation tillage include:

- No-Till – The soil is left undisturbed from harvest to planting except for nutrient injection. With this type of practice, planting is done in narrow seedbeds and a press wheel may be used to provide firm soil–seed contact (Janssen and Hill 1994).
- Strip Till – This practice involves tilling only the seed row prior to planting, disturbing less than one-third of the row width (CTIC 1999).
- Ridge Till – This practice involves planting into a seedbed prepared on ridges using sweeps, disk openers, coulters, or row cleaners. Residue is left on the surface between ridges to reduce soil loss (Janssen and Hill 1994).
- Mulch Till – This practice uses chisel flows, field cultivators, disks, sweeps, or blades to till soil in such a way that it does not invert the soil but leaves it rough and cloddy (Janssen and Hill 1994).
- Furrow Diking – The practice of creating small dams or catchments between crop rows to slow or prevent rainfall runoff and increase infiltration. Increased water capture reduces supplemental irrigation needed, resulting in a direct water savings. The RBC noted that this is a vendor-specific technology for certain types of crops, limiting its applicability within the Pee Dee River basin.

- Cover Crops – This practice involves planting cover crops, such as brassicas (either singly or in a mix) along with cereal grains or legumes, following the harvest of summer crops. Such cover crops use unused nutrients and protect against nutrient runoff and soil erosion. They can increase infiltration and water-holding capacity of the soil, which may indirectly result in water savings due to more efficient use of applied water.

Crop Variety, Crop Type, and Crop Conversion

Changing crop type from those that require a relatively large amount of water to crops that require less water can save significant amounts of irrigation water. Exact savings vary by crop but could potentially be on the order of 15.8 acre-inches per acre (Freese and Nichols, Inc. 2020). Switching the variety of a particular crop may also act as a water conservation strategy. For example, switching from full/mid-season corn to short-season corn could result in a 3.7 acre-inches per acre savings. However, such a change could also result in substantial yield loss, making it an unviable option for some growers (Freese and Nichols, Inc. 2020).

In South Carolina, transitioning away from corn and small grains, such as wheat, rye, oats, and barley, and increasing cotton crops can reduce water use. However, because the choice of crops is market-driven and certain machinery, infrastructure, and skills are specific to different crops, changing crop type may not make economic sense for growers, especially in the Pee Dee River basin. Conversion programs that offer growers incentives may be necessary.

Irrigation Equipment Changes and Drip/Trickle Irrigation

Changing from low efficiency irrigation equipment to higher efficiency equipment can reduce water use but requires significant financial investment. Irrigation methodologies may include mid-elevation, low elevation, low elevation precision application, or drip/trickle irrigation. These methodologies have application efficiencies of 78, 88, 95, and 97 percent, respectively (Amosson et al. 2011).

6.1.1.2 Golf Course Water Efficiency Demand Side-Side Strategies

The water efficiency practices for golf courses that are considered as part of the toolbox of strategies are further described below. These demand-side strategies also apply to golf courses that use groundwater for irrigation.

Wetting Agents to Reduce Water Use

Adding wetting agents can reduce the surface tension of water, allowing irrigation water to penetrate deeper into the root zone. Also known as soil surfactants, wetting agents can be applied for a number of different reasons including preventing localized dry spots, improving moisture uniformity, increasing water infiltration to the root zone, and improving moisture retention.

Water Loss Control and Regular Maintenance

Water loss control and irrigation system maintenance is a best management practice that reduces loss of water from irrigation system breaks and leaks. This can take the form of routine and frequent inspections of sprinkler heads and along irrigation system pipe routes to identify leaks. Sprinkler heads that are

damaged by mowers or other equipment should be replaced immediately. Repairs, if not done correctly using proper materials, can result in recurring leaks.

Time of Day Watering Practices

Time of day watering practices limit water loss to evaporation, which is greatest during the middle part of the day and into the afternoons, when temperatures are at their highest. Generally, early morning watering is performed to minimize evaporation and prevent fungal growth that might occur after evening or nighttime watering.

Soil Moisture Monitoring

Irrigation efficiency of turfgrass can be improved by implementation of soil moisture sensors. Properly calibrated soil moisture sensors can help prevent over-irrigation, and if used properly, can help optimize the amount of water applied to turfgrass and provide a more consistent playing surface.

Low-Water Use Landscaping

Low water use landscaping is a best management practice for golf courses that can help limit the need for irrigation. Turfgrasses, groundcovers, shrubs, and trees can be specifically selected based on their water needs. Mulching around shrubs and in flower beds can reduce water loss through evaporation.

Low-water use, warm-season turfgrasses need to be drought tolerant while maintaining sufficient quality when mowed short to provide the playability needed by golfers. In a recent study of water requirements for warm-season turf grasses in several states, certain newer bermudagrass cultivars (TifTuf and Tahoma 31) showed increased drought resistance compared to older cultivars and outperformed other grasses in terms of lower irrigation requirement and acceptable turf quality. Newer and older cultivars of zoysiagrass were also evaluated and, in some cases, exhibited acceptable turf quality under drought conditions, but generally required more irrigation than bermudagrass varieties. The success and response of different turfgrass species are dependent on local climate and cultivar. Prior to selecting a low-water use turfgrass, the study recommended that golf courses establish test plots to assess the response of different species to less irrigation over a series of growing seasons (Serena, et al. 2023).

6.1.1.3 Municipal Water Efficiency and Conservation Demand-Side Strategies

Municipal water efficiency practices considered as part of the toolbox of strategies are further described in this subchapter. These demand-side strategies also apply to groundwater users.

Development, Update, and Implementation of Drought Management Plans

This strategy is already ongoing in the basin, because public suppliers were required to develop drought management plans as part of the Drought Response Act of 2000. Each drought management plan has a set of measurable triggers indicating when conditions have entered one of three phases of drought and corresponding response actions to reduce demand by a target percentage. Chapter 8 provides detailed description of the drought management plans in the Pee Dee River basin. The RBC recognizes the importance of these drought management plans for reducing demand and conserving water during

critical low-flow periods. Under this strategy, public suppliers would continue to implement their drought management plans during drought conditions as well as keep their plans up to date to reflect any changes to the system.

Conservation Pricing Structures

Conservation pricing structures increase the unit cost of water as consumption increases. Utilities may have pricing structures that have a flat rate for customers, a unit use rate that varies with consumption, or some combination of the two. Conservation pricing sets higher unit use rates for customers whose usage exceeds set thresholds. This strategy assumes that consumers will curtail their personal use to avoid paying higher prices. The extent of demand reduction depends on the magnitude of the price increase as well as the local price elasticity of demand for water usage.

Under the Extreme Drought Phase of their Drought Management Plan, the City of Bennettsville has the option to implement an excessive use rate schedule if voluntary reductions in residential usage are not successful. These excessive use rates are tiered by usage, extending as high as three times the regular rate. The City's Drought Plan also outlines the option to implement a drought surcharge, which is a fee imposed on water use in excess of 7,500 gallons/household/month during a water supply shortage. The Town of Cheraw and Marlboro Water Company also have the option to implement an excessive use rate schedule and levy surcharges during drought conditions.

Public Education of Water Conservation

Water conservation education could occur through public schools, civic associations, or other community groups. Local governments could create informational handouts, social media campaigns, and/or include additional water conservation information on water utility bills. For this strategy to remain effective, public outreach would need to continued regularly to maintain public engagement and motivation.

Leak Detection and Water Loss Control Program

A water loss control program identifies and quantifies water uses and losses from a water system through a water audit. Once identified, sources of water loss can be reduced or eliminated through leak detection, pipe repair or replacements, and/or changes to standard program operations or standard maintenance protocols. Following these interventions, the water loss program can evaluate the success of the updates and adjust strategies as needed (EPA 2013).

Automated meter reading (AMR) and advanced metering infrastructure (AMI) are technologies that can assist with leak detection. AMR technology allows water utilities to automatically collect water-use data from water meters, either by walking or driving by the property. AMI systems automatically transmit water usage data directly to the utility, without requiring an employee to travel to the property. AMI systems collect data in real time. Both technologies reduce the staff time required to read meters and allow utilities to more frequently analyze actual consumption (as opposed to predicted usage based on less frequent manual meter readings). Higher than expected readings then can be noted and flagged as potential leaks. Because of their ability to collect data more frequently, AMI systems may detect consumption anomalies sooner than AMR. This allows for earlier detection of smaller leaks so that repairs can be made before major pipe breaks. AMI systems are more expensive to install than AMR systems

and, therefore, may not be economical for smaller utilities. Hybrid systems on the market allow for future migration from AMR to AMI.

An example of a basin-wide water audit and water loss control program is that of the Catawba-Wateree Water Management Group (CWWMG), which is undertaking a significant water audit project to identify real (leaks) and apparent (meter inaccuracy) water losses throughout the basin. This project identified 17 billion gallons of non-revenue water that could be managed to increase utility revenue by $16.8 million (CWWMG n.d.). Subsequent phases involve conducting economic analyses and identifying water loss goals for each CWWMG member, and the entire group. A similar effort could be pursued within the Pee Dee River basin.

Georgia is one of the few states that have implemented statewide water loss control requirements. In 2010, the Georgia Water Stewardship Act was signed into law. The Act set water loss control requirements that apply to public water systems serving populations over 3,300 that include:

- Completing an annual water loss audit using American Water Works Association (AWWA) M36 methodology
- Developing and implementing a water loss control program
- Developing individual goals to set measures of water supply efficiency
- Demonstrating progress toward improving water supply efficiency

The Pee Dee RBC discussed some of the challenges that water providers may face in implementing water loss control programs. In some instances, inadequate metering data be a barrier to identifying specific locations where leaks and losses are occurring. If a water provider identifies needed repairs and upgrades to reduce water loss, funding may not be available to implement loss reduction work. Rate increases to fund loss reductions need to be implemented responsibly and in a manner that is affordable to customers. Federal and other funding assistance for water loss reduction activities should be investigated and used where appropriate.

Replacing Low Flow Fixtures, Toilets, and Appliances

Residents can be incentivized to replace household appliances and fixtures with low-flow alternatives that meet standards and requirements such as Leadership in Energy and Environmental Design (LEED) or the U.S. Environmental Protection Agency's (EPA) WaterSense. For example, toilet rebate programs offer rebates for applicants who replace old, inefficient toilets with water-efficient ones. If a toilet being replaced uses 3.5 gallons per flush (gpf) and the replacement toilet uses 1.28 gpf, there will be a savings of 2.22 gpf per rebate. Assuming a use rate of five flushes per day per person (DeOreo et al. 2016) and an average of 2.5 persons per household results in savings of 27.8 gallons per household per day for each rebate.

Water Efficiency Standards for New Construction

Local ordinances can require that renovations and new construction meet established water efficiency metrics. These ordinances may either be set by the local government or rely on existing water efficiency certification programs such as LEED or EPA's WaterSense. These programs have set water efficiency requirements for all household fixtures, such as a maximum rating of 2.5 gallons per minute (gpm) flow rate for showers and maximum rating of 1.6 gallons per flush for toilets (Mullen n.d.).

Residential Water Audits

Residential water audits allow homeowners to gain a better understanding of their personal water use and identify methods to reduce water use. Homeowners can perform these audits themselves using residential water audit guides or water utilities may provide free residential water audits to their customers. Residential water audits involve checking both indoor uses (e.g., toilets, faucets, showerheads) and outdoor uses (e.g., lawn sprinklers). Based on the results of the audit, homeowners may invest in low flow systems, repair leaks, and/or adjust certain personal water use behaviors.

Reclaimed Water Programs

Reclaimed water programs reuse highly treated wastewater for other beneficial purposes, reducing demands on surface water and groundwater. Water can be reclaimed from a variety of sources then treated and reused for beneficial purposes such as irrigation of crops, golf courses, and landscapes; industrial processes including cooling water; cooling associated with thermoelectric plants; and environmental restoration. The quality of reuse water would need to be matched with water quality requirements of the end use, and emerging contaminants of concern (e.g., per- and polyfluoroalkyl substances [PFAS] and microplastics) would need to be considered.

Car Wash Recycling Ordinances

In-bay automatic car wash systems use approximately 35 gallons of water per vehicle. Touch-free car wash systems, which rely solely on chemicals and high-pressure spray rather than on the gentle friction of a soft-touch wash, use approximately 70 gallons of water per vehicle. Assuming one bay and 100 customers per day, these two common types of systems use between 3,500 and 7,000 gallons of water per day. To reduce water usage, car wash recycling ordinances require all new car washes to be constructed to include recycled water systems. Recycled water systems allow for water used in washing or rinsing to be captured and reused. Ordinances can set a percentage of recycled water to total water used. Typical ordinances require at least 50 percent use of recycled water.

Time-of-Day Watering Limit

A time-of-day watering limit prohibits outdoor watering during the hottest part of the day, usually 10 a.m. to 6 p.m. This practice reduces water loss from evaporation.

Landscape Irrigation Program and Codes

Landscape irrigation programs or water-efficient landscaping regulations can encourage or require homeowners to adopt water-efficient landscaping practices. Such practices seek to retain the natural hydrological role of the landscape, promote infiltration into groundwater, preserve existing natural vegetation, and ultimately conserve water. Water-efficient landscaping may include the incorporation of native plants or low water–use plants into landscape design (City of Commerce, CA 2021).

Local governments can require the use of these water efficiency measures through municipal codes or encourage them through incentives or educational programs. Potential practices include:

- Smart Irrigation Controller Rebate – Utilities may offer rebates to homeowners who replace their existing irrigation controllers with smart irrigation controllers that adjust irrigation according to soil

moisture levels (soil-moisture-based or SMS) and precipitation and/or evapotranspiration rates (weather-based or WBIC). Controllers can be WaterSense certified by meeting EPA criteria.

- Turf Replacement Rebate – Utilities may offer rebates to homeowners or businesses who replace irrigable turf grass with landscaping that requires minimal or no supplemental irrigation.
- Developer Turf Ordinance – Ordinances can be set that require new developments to have reduced irrigable turf grass area. Such development may be required to have low flow or microirrigation in plant beds, spray or rotor heads in separate zones for turf grass, or smart irrigation controllers to manage remaining turf area.
- Education Programs – Programs could be offered for homeowners to learn about water-efficient landscaping practices. Some examples of landscape irrigation improvements include:
  - Verifying the best irrigation schedule for the climate and soil conditions
  - Verifying the recommended nozzle pressure in sprinklers
  - Adjusting sprinkler locations to ensure water falls on lawns or gardens (not on sidewalks or other impervious surfaces)
  - Using a water meter to measure water used in landscape irrigation
  - Replacing high-water use landscape vegetation with native plants that naturally need less water and/or xeriscaping

Xeriscaping

Xeriscaping is a method of landscape design and maintenance that requires minimal water use. The principles of xeriscaping include using appropriate plants for the region, improving the soil to hold moisture, using mulches to limit evaporation, using no irrigation or efficient irrigation systems such as soaker hoses and drip systems.

6.1.1.4 Industrial Water Efficiency and Conservation Demand-Side Strategies

Industrial water efficiency practices considered as part of the toolbox of strategies are largely the same as the municipal efficiency practices. These practices include leak detection and water loss control programs; low flow fixtures, toilets, and appliances; and identification of drought-related best management practices. Although the Drought Response Act does not require the development of drought management plans for industrial surface water (or groundwater) users, implementation drought-related best management practices by industries would further extend surface water resources during times of drought at and downstream of industrial surface water withdrawals. While industry actively works to save water (and costs) during drought, sharing information among industrial water users regarding best management practices would be beneficial. Two additional strategies are further described in this subchapter. These demand-side strategies also apply to groundwater users.

Water Reuse and Recycling

Reclaimed water programs reuse highly treated wastewater for other beneficial purposes, reducing demands on surface water and groundwater. Water can be reclaimed from a variety of sources then

treated and reused for beneficial purposes such as irrigation of crops, golf courses, and landscapes; industrial processes including cooling water; cooling associated with thermoelectric plants; and environmental restoration. The quality of reuse water would need to be matched with water quality requirements of the end use, and emerging contaminants of concern (e.g., per- and polyfluoroalkyl substances [PFAS] and microplastics) would need to be considered.

Water Efficient Processes

Industrial water users in the basin are generally thought to be efficient users of water supplies. Additional means for conservation should be explored, but their impact on the water supplies of the basin is limited due to the conservation practices by industrial users that are already in practice, and their efforts to minimize water losses. New industrial facilities in the Pee Dee River basin, especially large water users, would be expected to implement water efficient processes.

6.1.1.5 Thermoelectric Water Efficiency Strategies

Thermoelectric water efficiency practices considered as part of the toolbox of strategies largely relate to reducing thermoelectric energy demand. Reductions in energy demand reduce the cooling water withdrawals required to operate thermoelectric plants. Methods for reducing this demand include encouraging energy users to install energy-saving appliances, as well as switching to combined-cycle natural gas, solar power, or wind sources.

Another conservation approach is to use reclaimed water produced by upstream facilities as cooling water, in lieu of withdrawing directly from waterbodies. While this approach may reduce surface water withdrawals, it also reduces returns and therefore does not decrease the overall water use within the basin. It can provide a cooling water source of more constant temperature and quality, which can be more efficient in terms of cooling efficiency and therefore reduce energy losses (Ahlberg 2016).

6.1.2 Supply-Side Strategies

The Pee Dee RBC identified and considered five potential supply-side water management strategies: new or increased storage, water reclamation, conjunctive use, conveyance strategies, and desalination. These are discussed in this subchapter.

New or Increased Storage

Reservoirs and small impoundments add storage to improve resiliency to drought. An offline or online reservoir, which would divert and store water during high flow periods and release water to augment flows during low flow conditions in the Pee Dee River or major tributaries, was considered. Small impoundments are common in the Pee Dee River basin and provide storage needed to maintain (primarily agricultural) surface water intakes on small streams. There are currently 355 regulated dams in the basin that impound water, and countless smaller unregulated impoundments. Any dam constructed for a new reservoir or impoundment would be regulated by the State of South Carolina if it is 25 feet or greater in height, if it impounds 50 acre-feet or more of storage, or if its failure may cause loss of human life. Additional county-specific provisions may apply if a proposed dam could affect the designated floodplain of a river, or for other reasons, and USACE would have additional regulatory input on dams constructed in waters of the United States. The storage in existing reservoirs could also be expanded by raising dam heights, while smaller impounded pounds could be expanded through dredging.

Another method of increasing storage is aquifer storage and recovery (ASR). ASR technology allows for storing treated surface water underground during periods of low demand, to be used during peak consumption periods. This approach is especially valuable in areas where water demands or supplies fluctuate greatly. For example, in the Grand Strand area, summer tourists increase water demand well beyond the average daily demand. To provide additional water during these periods, the city of Myrtle Beach implemented an ASR program in the 1990s (SCDNR 2009). Under the program, periodically more surface water is treated than is needed to meet demand when demands are low, and the additional treated water is injected into the aquifer using ASR wells. When demands are high, the injected water is extracted for use. The additional treated water stored underground would have otherwise been discharged to the ocean and lost if not for the ASR program. The Grand Strand Water and Sewer Authority now operates this ASR program, which consists of 17 ASR wells in operation or under development (GSWSA 2023). Up to 11 MGD of treated water can be withdrawn from these ASR wells.

Water Reclamation

Water reclamation is the process of using wastewater or stormwater for a variety of purposes, both potable and non-potable. Water reuse systems were discussed earlier as an industrial demand-side strategy but can also be implemented to supplement water supplies for a variety of purposes, including agricultural and landscaping irrigation, boilers and cooling systems, and toilets.

Direct potable reuse involves treating wastewater to drinking water standards, rather than returning treated wastewater to the environment. This approach reduces nutrient loads on waterbodies and provides a safe drinking water source that is less dependent on weather conditions. South Carolina currently has no statutes or regulations related to direct (wastewater treatment to water treatment without an environmental buffer like a lake or river between) or indirect (using an environmental buffer like a lake before drinking water treatment) potable reuse (Payne 2017); however, a South Carolina Section of WateReuse was established in December 2021 to advance water recycling programs and regulations in the state. Several water utility representatives from the Pee Dee River basin currently serve as Director's At-Large of the South Carolina Section.

Stormwater capture and reuse reduces flooding and strain on stormwater collection systems, while providing an additional supply of water. It should be noted that stormwater (precipitation that reaches the ground) tends to require more advanced treatment than rainwater (precipitation that is collected prior to reaching the ground) due to contamination from roads and soil (WateReuse 2023).

Conjunctive Use

Conjunctive use is the combination of multiple sources of water to improve the resilience of the overall water supply. At the basin scale, conjunctive use of both groundwater and surface water is already occurring. Excluding water that is used for generating energy, about 56 percent of water withdrawn in the basin comes from surface water sources and 44 percent comes from groundwater sources (SCDNR, 2022). Types of conjunctive use include:

- **Full conjunctive use** is the ability of a water user to meet 100 percent of water demands from either groundwater or surface water.
- **Partial conjunctive use** is the ability of a water user to meet a portion of demands from either groundwater or surface water.

- **Noncentralized conjunctive use** occurs when a water user relies on surface and groundwater sources but does not have the ability to replace one with the other because of separate systems of delivery.

In the Pee Dee River basin, some municipal and agricultural surface water users also have one or more groundwater sources (wells). The City of Florence, for example, operates 29 wells which produce an average of about 10.5 MGD. This is supplemented by about 4.5 MGD of surface water from the Great Pee Dee River. For this basin planning process, the evaluation of conjunctive use focused on the use of groundwater to supplement surface water supplies during periods when stream flow is low as well as using surface water to supplement groundwater supplies where aquifers are declining.

The Pee Dee RBC noted that developing groundwater to supplement surface water sources can be beneficial for providing emergency supply during flooding conditions when surface water quality is poor or if surface water intakes are damaged.

Conveyance Strategies

Conveyance strategies can be used to supplement water supply when there are localized periods of high demand or interruptions to other water supply sources. Regional water systems and utility interconnections may provide additional supply to meet demand; however, the effectiveness of this approach is limited when water shortage is widespread impacting the entire region and/or all utilities in the area.

Establishing infrastructure and agreements for interbasin transfers provides the capability to source water from outside the basin. In South Carolina, permits are required for interbasin transfers and are conditioned on the availability of water in both the losing and receiving basins and if the transfer will negatively impact instream uses. Lake Marion Regional Water Authority/Santee Cooper is permitted to transfer up to 20 MGD from the Santee Basin to the Black (within the Pee Dee River basin), Edisto, and Combahee-Coosawhatchie subbasins (SCDNR 2009). There are no other interbasin transfers permitted for the Pee Dee River basin.

Desalination

Desalination treatment removes salt from seawater or brackish groundwater, enabling its use for freshwater applications. Technologies include distillation (boiling seawater and capturing the steam as condensate) and reverse osmosis (removing salt molecules using a semi-permeable membrane), which are both energy-intensive methods. Outside of the Pee Dee River basin, reverse osmosis has been used on Hilton Head Island to treat brackish groundwater which has begun to intrude the Upper Floridian Aquifer (Seacord 2015), and by Mount Pleasant Waterworks to treat brackish groundwater from the Charleston Aquifer.

6.2 Evaluation of Surface Water Strategies

The effectiveness of potential demand-side surface water management strategies in the Pee Dee River basin were simulated using the SWAM surface water model. No supply-side strategies were evaluated since no significant shortages were simulated in the Current Use, Moderate, or High Demand planning

scenarios. Modeled shortages for the several agricultural and golf courses users in the planning scenarios were not expected to occur or not expected to occur at a very high frequency because of the presence of impoundments and ponds that were not included in the model.

Nine demand-side scenarios (Scenarios 1, 2a, 2b, 2c, 3a, 3b, 3c, 4, and 5) were developed to evaluate a range of potential actions that could be used to reduce water demands and increase surface water flows. These scenarios are listed in Table 6-7 and described below. All nine scenarios were simulated using the High Demand 2070 Scenario water demand projections.

Table 6-7. Summary of surface water model scenarios evaluating demand-side water management strategies.

Scenario Name	Municipal Conservation?	Agricultural Conservation?	Industrial Conservation?	Supply-side Mitigation Measures
Scenario 1: Agricultural Conservation	No	Yes – 10% reduction	No	None
Scenario 2a: Municipal Surface Water Users Conservation (Low)	Yes – 10% reduction for surface water users	No	No	None
Scenario 2b: Municipal Surface Water Users Conservation (Medium)	Yes – 15% reduction for surface water users	No	No	None
Scenario 2c: Municipal Surface Water Users Conservation (High)	Yes – 20% reduction for surface water users	No	No	None
Scenario 3a: Municipal Surface Water and Groundwater Users Conservation (Low)	Yes – 10% reduction for surface water and groundwater users	No	No	None
Scenario 3b: Municipal Surface Water and Groundwater Users Conservation (Medium)	Yes – 15% reduction for surface water and groundwater users	No	No	None
Scenario 3c: Municipal Surface Water and Groundwater Users Conservation (High)	Yes – 20% reduction for surface water and groundwater users	No	No	None
Scenario 4: Industrial Conservation	No	No	Yes – 5% reduction for all industrial users except mining	None
Scenario 5: Agricultural Conservation; Municipal Surface Water and Groundwater Users Conservation (Low); and Industrial Conservation	Yes – 10% reduction for surface water and groundwater users	Yes – 10% reduction	Yes – 5% reduction for all industrial users except mining	None

The demand-side strategies were evaluated by assuming the projected municipal, industrial, and agricultural water demands would decrease because of implementing one or more strategies from the portfolio of demand-side strategies. There is high uncertainty regarding the effective reduction in demand for individual demand-side management strategies, as their effectiveness depends on the extent of implementation and the magnitude of impact for each instance of implementation. For example, water savings associated with irrigation equipment changes will depend on the number of water users who change their equipment, the level of efficiency of their existing equipment, the level of efficiency of the new equipment, the water demand of the crops to be irrigated, the irrigated acreage, and the individual's adjustment of irrigation scheduling in response to the increased efficiencies.

- **Scenario 1** evaluated the impact of agricultural conservation strategies that result in a 10 percent reduction in agricultural water demands. The 10 percent reduction was applied to both existing agricultural users and to future agricultural demands, as simulated at the outlet of select subbasins.
- **Scenarios 2a, 2b, and 2c** evaluated the impact of municipal conservation strategies that result in a 10, 15 or 20 percent reduction in municipal water demands from surface water. The percent reductions were applied to the three existing surface water users in the model domain (Bennettsville, Cheraw, and Florence).
- **Scenarios 3a, 3b, and 3c** evaluated the impact of municipal conservation strategies that result in a 10, 15 or 20 percent reduction in municipal demands from both surface water and groundwater. The percent reductions were applied to the three existing surface water users in the model domain (Bennettsville, Cheraw, and Florence) and to the 14 municipal groundwater users that discharge treated wastewater to surface water. The effect of demand reductions for municipal groundwater users is a reduction (by 10, 15 or 20 percent) in treated wastewater discharging to surface water. This will lower stream flows, and thus have the opposite of the intended effect, but may help improve groundwater levels and extend groundwater availability.
- **Scenario 4** evaluated the impact of industrial conservation strategies that result in a 5 percent reduction in industrial water demands, not including mining operations. The 5 percent reduction was applied to industries that withdrawal either surface water or groundwater.
- **Scenario 5** evaluated the cumulative impact of conservation strategies for all three water use sectors examined. A 10 percent reduction in agricultural water demands, 10 percent reduction in municipal demands, and 5 percent reduction in industrial demands was evaluated. The reductions in municipal and industrial demands were applied to both surface and groundwater users.

The effectiveness of the conservation strategies was examined at six Strategic Nodes identified in Figure 6-1. The nodes were selected to be representative cumulative impacts to flows along the Pee Dee River and its major tributaries. Table 6-8 provides the minimum, mean, and 5th percentile flows at the six Strategic Nodes for the High Demand 2070 Scenario. These flow statistics served as the basis for comparison to simulated flows in scenarios 1 through 9. Table 6-9 provides the minimum, mean, and 5th percentile flows at the six Strategic Nodes for all nine scenarios, and lists the percent difference of these flow statistics, compared to the High Demand 2070 Scenario flows in Table 6-8. A positive percent difference means that the flow statistic increased compared to the same High Demand 2070 Scenario flow statistic. These cells are shaded light green in the table. A negative percent difference means that a flow statistic decreased. These cells are shaded a light red in the table. No red or green shading indicates there was less than 0.1 percent difference in flow. Negative percent differences are a result of reductions

in demand for municipal and/or industrial groundwater users which result in a similar decrease in treated wastewater discharge to surface water.

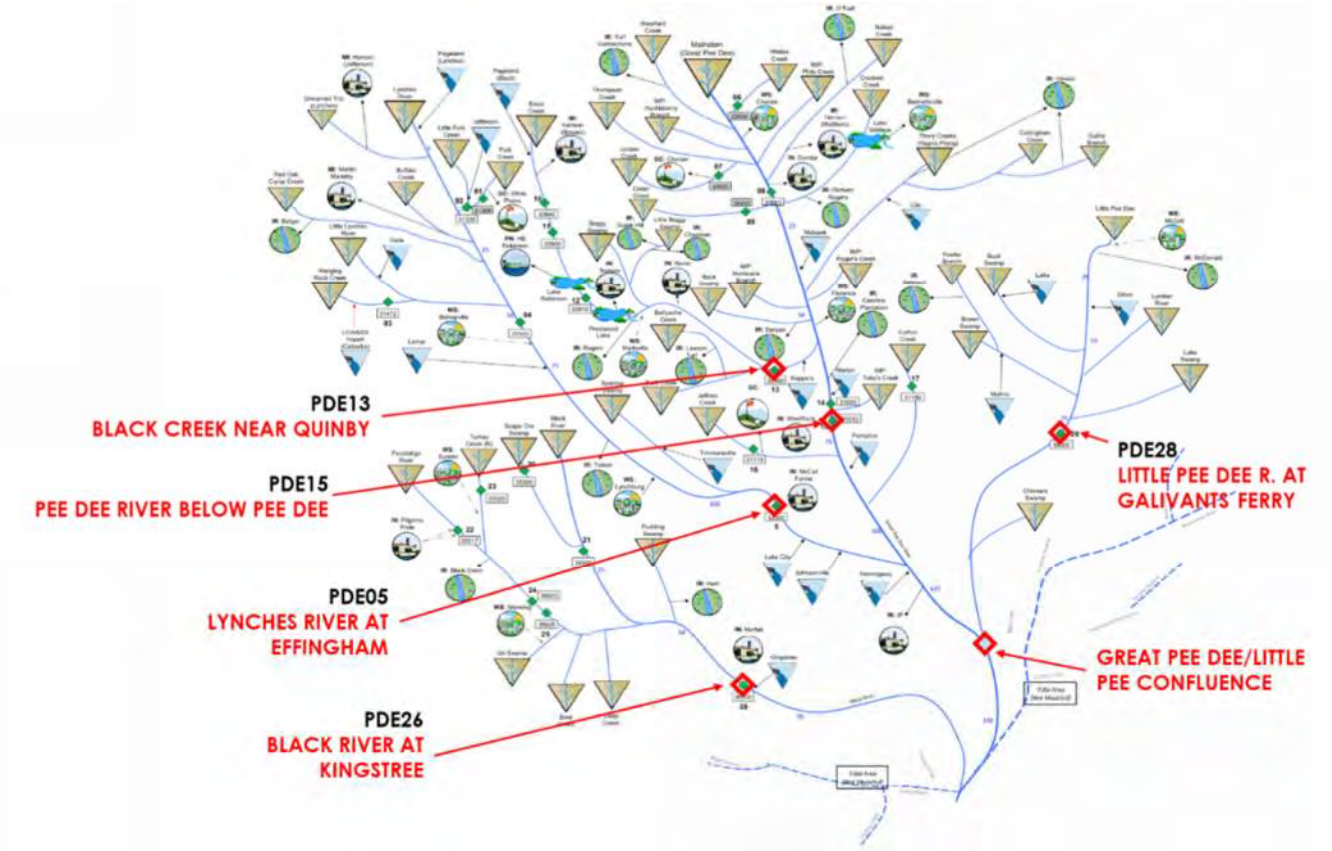


Figure 6-1. Location of Strategic Nodes used to evaluate stream flow following implementation of conservation strategies.

Table 6-8. Flow statistics for the High Demand 2070 Scenario.

Strategic Node	Minimum Flow (cfs)	5th Percentile Flow (cfs)	Mean Flow (cfs)
PDE15 Pee Dee River below Pee Dee, SC	928	1,974	8,964
Great Pee Dee / Little Pee Dee Confluence	1,547	3,464	14,450
PDE13 Black Creek near Quinby, SC	53	144	521
PDE05 Lynches River at Effingham, SC	71	196	1,005
PDE28 Little Pee Dee River at Galivants Ferry, SC	198	619	2,941
PDE26 Black River and Kingstree, SC	47	141	1,011

Table 6-9. Flow statistics for conservation scenarios and percent difference compared to the High Demand 2070 Scenario.

Strategic Node	Minimum Flow (cfs)	5th Perc. Flow (cfs)	Mean Flow (cfs)	Minimum Flow (% change)	5th Perc. Flow (% change)	Mean Flow (% change)
Scenario 1 - 10% Agriculture Demand Reduction						
PDE15 Pee Dee River below Pee Dee, SC	929	1,974	8,965	0.1%	0.0%	0.0%
Great Pee Dee / Little Pee Dee Confluence	1,548	3,464	14,451	0.1%	0.0%	0.0%
PDE13 Black Creek near Quinby, SC	54	145	521	0.5%	0.1%	0.0%
PDE05 Lynches River at Effingham, SC	71	196	1,005	0.1%	0.0%	0.0%
PDE28 Little Pee Dee River at Galivants Ferry, SC	198	619	2,941	0.0%	0.0%	0.0%
PDE26 Black River and Kingstree, SC	48	141	1,011	1.1%	0.0%	0.0%
Scenario 2a - 10% Municipal Demand Reduction (Surface Water Users Only)						
PDE15 Pee Dee River below Pee Dee, SC	932	1,978	8,968	0.4%	0.2%	0.0%
Great Pee Dee / Little Pee Dee Confluence	1,548	3,465	14,451	0.1%	0.0%	0.0%
PDE13 Black Creek near Quinby, SC	53	144	521	-0.5%	-0.2%	0.0%
PDE05 Lynches River at Effingham, SC	71	196	1,005	0.0%	0.0%	0.0%
PDE28 Little Pee Dee River at Galivants Ferry, SC	198	619	2,941	0.0%	0.0%	0.0%
PDE26 Black River and Kingstree, SC	47	141	1,011	0.0%	0.0%	0.0%
Scenario 2b - 15% Municipal Demand Reduction (Surface Water Users Only)						
PDE15 Pee Dee River below Pee Dee, SC	934	1,980	8,970	0.7%	0.3%	0.1%
Great Pee Dee / Little Pee Dee Confluence	1,549	3,466	14,452	0.2%	0.1%	0.0%
PDE13 Black Creek near Quinby, SC	53	144	520	-0.7%	-0.3%	-0.1%
PDE05 Lynches River at Effingham, SC	71	196	1,005	0.0%	0.0%	0.0%
PDE28 Little Pee Dee River at Galivants Ferry, SC	198	619	2,941	0.0%	0.0%	0.0%
PDE26 Black River and Kingstree, SC	47	141	1,011	0.0%	0.0%	0.0%

Table 6-9 (continued). Flow statistics for conservation scenarios and percent difference compared to the High Demand 2070 Scenario.

Strategic Node	Minimum Flow (cfs)	5th Perc. Flow (cfs)	Mean Flow (cfs)	Minimum Flow (% change)	5th Perc. Flow (% change)	Mean Flow (% change)
Scenario 2c - 20% Municipal Demand Reduction (Surface Water Users Only)						
PDE15 Pee Dee River below Pee Dee, SC	936	1,982	8,972	0.9%	0.4%	0.1%
Great Pee Dee / Little Pee Dee Confluence	1,550	3,466	14,452	0.2%	0.1%	0.0%
PDE13 Black Creek near Quinby, SC	53	144	520	-0.9%	-0.3%	-0.1%
PDE05 Lynches River at Effingham, SC	71	196	1,005	0.0%	0.0%	0.0%
PDE28 Little Pee Dee River at Galivants Ferry, SC	198	619	2,941	0.0%	0.0%	0.0%
PDE26 Black River and Kingstree, SC	47	141	1,011	0.0%	0.0%	0.0%
Scenario 3a - 10% Municipal Demand Reduction (Surface Water and Groundwater Users)						
PDE15 Pee Dee River below Pee Dee, SC	931	1,977	8,967	0.4%	0.2%	0.0%
Great Pee Dee / Little Pee Dee Confluence	1,546	3,463	14,449	0.0%	0.0%	0.0%
PDE13 Black Creek near Quinby, SC	53	144	520	-1.1%	-0.4%	-0.1%
PDE05 Lynches River at Effingham, SC	70	196	1,004	-0.6%	-0.2%	0.0%
PDE28 Little Pee Dee River at Galivants Ferry, SC	197	618	2,940	-0.3%	-0.1%	0.0%
PDE26 Black River and Kingstree, SC	45	139	1,008	-5.4%	-1.9%	-0.3%
Scenario 3b - 15% Municipal Demand Reduction (Surface Water and Groundwater Users)						
PDE15 Pee Dee River below Pee Dee, SC	933	1,979	8,969	0.6%	0.2%	0.1%
Great Pee Dee / Little Pee Dee Confluence	1,546	3,462	14,449	0.0%	0.0%	0.0%
PDE13 Black Creek near Quinby, SC	52	143	520	-1.7%	-0.6%	-0.2%
PDE05 Lynches River at Effingham, SC	70	196	1,004	-0.8%	-0.3%	-0.1%
PDE28 Little Pee Dee River at Galivants Ferry, SC	197	618	2,940	-0.4%	-0.1%	0.0%
PDE26 Black River and Kingstree, SC	43	137	1,007	-8.1%	-2.8%	-0.4%

Table 6-9 (continued). Flow statistics for conservation scenarios and percent difference compared to the High Demand 2070 Scenario.

Strategic Node	Minimum Flow (cfs)	5th Perc. Flow (cfs)	Mean Flow (cfs)	Minimum Flow (% change)	5th Perc. Flow (% change)	Mean Flow (% change)
Scenario 3c - 20% Municipal Demand Reduction (Surface Water and Groundwater Users)						
PDE15 Pee Dee River below Pee Dee, SC	935	1,980	8,970	0.8%	0.3%	0.1%
Great Pee Dee / Little Pee Dee Confluence	1,546	3,462	14,448	0.0%	0.0%	0.0%
PDE13 Black Creek near Quinby, SC	52	143	519	-2.2%	-0.9%	-0.3%
PDE05 Lynches River at Effingham, SC	70	196	1,004	-1.1%	-0.4%	-0.1%
PDE28 Little Pee Dee River at Galivants Ferry, SC	197	618	2,940	-0.5%	-0.2%	0.0%
PDE26 Black River and Kingstree, SC	42	136	1,005	-10.8%	-3.8%	-0.6%
Scenario 4 - 5% Industrial Demand Reduction (Surface Water and Groundwater Users)						
PDE15 Pee Dee River below Pee Dee, SC	939	1,986	8,976	1.3%	0.6%	0.1%
Great Pee Dee / Little Pee Dee Confluence	1,550	3,467	14,454	0.2%	0.1%	0.0%
PDE13 Black Creek near Quinby, SC	53	145	522	0.0%	0.3%	0.2%
PDE05 Lynches River at Effingham, SC	71	196	1,005	-0.1%	0.0%	0.0%
PDE28 Little Pee Dee River at Galivants Ferry, SC	198	619	2,941	0.0%	0.0%	0.0%
PDE26 Black River and Kingstree, SC	47	141	1,011	-0.1%	0.0%	0.0%
Scenario 5 - 10% Agricultural, 5% Industrial, and 10% Municipal Demand Reduction (Surface Water and Groundwater Users)						
PDE15 Pee Dee River below Pee Dee, SC	944	1,989	8,980	1.8%	0.8%	0.2%
Great Pee Dee / Little Pee Dee Confluence	1,551	3,467	14,453	0.3%	0.1%	0.0%
PDE13 Black Creek near Quinby, SC	53	144	521	-0.6%	0.0%	0.0%
PDE05 Lynches River at Effingham, SC	71	196	1,004	-0.5%	-0.2%	0.0%
PDE28 Little Pee Dee River at Galivants Ferry, SC	197	618	2,940	-0.3%	-0.1%	0.0%
PDE26 Black River and Kingstree, SC	45	139	1,008	-4.4%	-1.9%	-0.3%

In all conservation scenarios, increases in mean flows compared to the High Demand 2070 Scenario were very small, as would be expected given that only 5 to 20 percent reductions in demands were evaluated. At some Strategic Nodes, mean flows decreased for certain scenarios which assumed reductions in groundwater demands for municipal and industrial users and a corresponding decrease in wastewater discharges.

Changes in the 5th percentile flows (a low flow performance measure) were only slightly larger than changes in mean flows, when comparing the conservation strategy scenarios to the High Demand 2070 Scenario. The increase in 5th percentile flows was less than 1 percent at all Strategic Nodes. The Black Creek, Black River, Lynches River, and Little Pee Dee River Strategic Nodes' 5th percentile flows decreased in certain scenarios, owing to the reduction in groundwater demands and corresponding decrease in wastewater discharges.

Changes in the minimum flow (a low flow performance measure) simulated over the entire hydrologic period of record ranged from -10.8 percent (Scenario 3c, Black River Strategic Node) to 1.8 percent (Scenario 5, Pee Dee River Strategic Node). The -10.8 percent change in flow reflects the 20 percent reduction in groundwater demands for municipal users Sumter and Manning, and their corresponding 20 percent reduction in treated wastewater discharge to surface water. The largest, beneficial impacts to surface water flows from conservation strategies were observed in Scenario 5, which included conservation by agricultural, municipal, and industrial water users, but the impact was limited to the Strategic Nodes on the Pee Dee River. At that location, the Scenario 5 minimum flow was 944 cfs, compared to 928 cfs for the 2070 High Demand Scenario (a 1.8 percent increase).

While some reductions in stream flows may occur due to additional water conservation because of reduced wastewater discharges, the reductions in stream flow are very minor and would not be expected to pose additional risk to the ecological health of the streams. It's also worth noting that the assumed reduction in stream flows from lower discharges from groundwater-dependent communities is probably conservative given that conservation measures applied to outdoor water needs would not necessarily reduce wastewater discharges.

Benefits of Water Efficiency and Conservation Strategies

Although the level of conservation and water efficiency strategies evaluated resulted in relatively small impact on stream flows, these strategies are still worth pursuing for several important reasons:

- **Mitigate potential localized shortages:** Water users that withdraw surface water from small tributaries, and especially near the headwaters, may experience shortages during prolonged and/or severe drought, regardless of whether they have impoundments that provide storage. Implementing conservation strategies even before drought occurs will help extend their supply and reduce the risk of a water shortage.
- **Reduce water costs:** In an agricultural setting, water efficiency and conservation strategies can reduce costs of water for irrigation and possibly improve crop yields. In a municipal setting, they can lower costs of water for homeowners and reduce or delay a municipality's need to develop more water supplies.
- **Increase sustainability of groundwater supplies:** Conservation in groundwater dependent communities may be important for sustaining groundwater supplies.

6.2.1 Feasibility of Surface Water Management Strategies

The Pee Dee RBC assessed the feasibility of the water management strategies and practices described above with regard to consistency with regulations, reliability of water source, environmental impacts, socioeconomic impacts, potential interstate or interbasin impacts, and water quality impacts. This assessment is presented in Table 6-10 for demand side strategies and Table 6-11 for supply-side strategies. Agricultural/irrigation and golf course practices are presented first, followed by municipal, industrial, and thermoelectric practices which are generally evaluated as a single group of practices.

Color coding is used to identify an expected effect of the strategy within each category, ranging from moderate to high adverse effects to moderate to high positive effects. The selection of effects, whether it be adverse, neutral, or positive, was largely subjective and based on professional judgement and feedback from the RBC.

Color Coding for Assigning Expected Effects in Tables 6-10 and 6-11

Potential Moderate/High Adverse Effect	Potential Low Adverse Effect	Likely Neutral Effect (either no effect, or offsetting effects)	Potential Low Positive Effect	Potential Moderate/High Positive Effect

Table 6-10. Demand-side water management strategy feasibility assessment.

Water Management Strategy	Strategy Type	Consistency with Regulations	Reliability of Water Source	Environmental Impacts and Benefits[1]	Socioeconomic Effects	Potential Interstate or Interbasin Effects	Other Water Quality Considerations
Demand-Side Agricultural/Irrigation Practices							
Water Audits and Nozzle Retrofits	Demand-side - Agriculture	Consistent	Strategy reduces demand and extends supply, increasing water source reliability for other demands	**Impacts:** None anticipated **Benefits:** Prevention of overwatering may limit runoff, erosion, and sedimentation	No to low anticipated effects – Financial gains from reduced delivery and pumping costs likely outweigh costs of audit and nozzle retrofits	No anticipated effects	See Environmental Benefits
Irrigation Scheduling and Smart Irrigation	Demand-side - Agriculture	Consistent	Strategy reduces demand and extends supply, increasing water source reliability for other demands	**Impacts:** None anticipated **Benefits**: May reduce over fertilization and prevention of overwatering may limit runoff, erosion, and sedimentation	Low to moderate effects – Initial costs of advanced technology may be partially offset by savings from reduced water and nutrient use	No anticipated effects	See Environmental Benefits
Cover Cropping, Conservation Tillage, Mulch	Demand-side - Agriculture	Consistent	Strategy reduces demand and extends supply, increasing water source reliability for other demands	**Impacts:** Low anticipated impacts – Increase in herbicides may be required **Benefits:** May improve soil quality and reduce runoff	Low to moderate effects – Initial costs of new equipment plus training and O&M costs. Costs may be partially offset by reduction in soil, water, and nutrient loss	No anticipated effects	No to low anticipated impacts – Conservation tillage may increase potential leaching of nitrogen or pesticide to groundwater. See also Environmental Benefits

Table 6-10 (continued). Demand-side water management strategy feasibility assessment.

Water Management Strategy	Strategy Type	Consistency with Regulations	Reliability of Water Source	Environmental Impacts and Benefits[1]	Socioeconomic Effects	Potential Interstate or Interbasin Effects	Other Water Quality Considerations
Crop Variety, Crop Type, and Crop Conversions	Demand-side - Agriculture	Consistent	Strategy reduces demand and extends supply, increasing water source reliability for other demands	**Impacts:** Low anticipated impacts – Variation in chemical application for different crops must be considered	Medium to high anticipated effects – Potential profit loss from switching to lower demand crop or from a full season to short season crop	No anticipated effects	No anticipated impacts
Irrigation Equipment Changes, including Drip/Trickle Irrigation	Demand-side - Agriculture	Consistent	Strategy reduces demand and extends supply, increasing water source reliability for other demands	**Impacts:** Low anticipated impacts – Changing equipment may disturb environmentally sensitive areas	Low anticipated effects – Initial costs of equipment changes may be partially offset by water use savings. Investments in drip/trickle irrigation may not be economical for low value crops.	No anticipated effects	No anticipated impacts
Demand-Side Golf Course Practices							
Wetting Agents to Reduce Water Use	Demand-side – Golf Course	Consistent	Strategy reduces demand and extends supply, increasing water source reliability for other demands	**Impacts:** None assuming bio-degradable and environmentally friendly surfactants are used. **Benefits**: Prevention of overwatering may limit runoff, erosion, and sedimentation	Low to no effects – Effective use of wetting agents can result in water and energy savings, reducing overall cost.	No anticipated effects	Low to none assuming bio-degradable and environmentally friendly surfactants are used

Table 6-10 (continued). Demand-side water management strategy feasibility assessment.

Water Management Strategy	Strategy Type	Consistency with Regulations	Reliability of Water Source	Environmental Impacts and Benefits[1]	Socioeconomic Effects	Potential Interstate or Interbasin Effects	Other Water Quality Considerations
Water Loss Control and Regular Maintenance	Demand-side – Golf Course	Consistent	Strategy reduces demand and extends supply, increasing water source reliability for other demands	**Impacts:** None anticipated **Benefits**: Prevention of overwatering may limit runoff, erosion, and sedimentation	Low positive effects – Prevention and quick repair of leaks can result in water and energy savings, reducing overall cost.	No anticipated effects	No anticipated impacts
Time of Day Watering Practices	Demand-side – Golf Course	Consistent	Strategy reduces demand and extends supply, increasing water source reliability for other demands	**Impacts:** None anticipated **Benefits**: Prevention of overwatering may limit runoff, erosion, and sedimentation	Low positive effects – Limiting evaporation results in less water use and lower water and energy cost	No anticipated effects	No anticipated impacts
Soil Moisture Monitoring	Demand-side – Golf Course	Consistent	Strategy reduces demand and extends supply, increasing water source reliability for other demands	**Impacts:** None anticipated **Benefits**: Prevention of overwatering may limit runoff, erosion, and sedimentation	No to low positive effects – Initial costs of equipment plus training and O&M costs may be offset by reduction in water and energy cost	No anticipated effects	No anticipated impacts
Low-Water Use Landscaping	Demand-side – Golf Course	Consistent	Strategy reduces demand and extends supply, increasing water source reliability for other demands	**Impacts:** None anticipated **Benefits**: Prevention of overwatering may limit runoff, erosion, and sedimentation. Use of native vegetation where appropriate can benefit pollinators and wildlife.	Low positive effects – Using landscaping that requires less water results on lower water and energy costs	No anticipated effects	No anticipated impacts

Table 6-10 (continued). Demand-side water management strategy feasibility assessment.

Water Management Strategy	Strategy Type	Consistency with Regulations	Reliability of Water Source	Environmental Impacts and Benefits[1]	Socioeconomic Effects	Potential Interstate or Interbasin Effects	Other Water Quality Considerations
Demand-Side Municipal, Industrial, and Thermoelectric Practices							
Conservation Pricing Structures	Demand-side - Municipal	Consistent	Strategy reduces demand and extends supply, increasing water source reliability for other demands	**Impacts:** None anticipated	Moderate anticipated effects – Customers that cannot reduce water use may face economic hardship. Reduced billing revenue for utilities may cause financing issues or lead to further rate increases	No anticipated effects	No anticipated impacts
Public Education of Water Conservation	Demand-side - Municipal	Consistent	Strategy reduces demand and extends supply, increasing water source reliability for other demands	**Impacts:** None anticipated	Low to no anticipated effects – Effects to utility revenue if demand reductions are substantial. Positive effect to residential users from reduced water bills (if billed at unit rate)	No anticipated effects	No anticipated impacts
Leak Detection and Water Loss Control	Demand-side – Municipal, Industrial, and Thermo-electric	Consistent	Strategy reduces demand and extends supply, increasing water source reliability for other demands	**Impacts**: None anticipated	Cost of program implementation could result in rate increase, no impact, or potential rate decrease, depending on circumstances. Rate increases should be made responsibly and consider customer affordability.	No anticipated effects	No anticipated impacts
Low Flow Fixtures, Toilets, and Appliances	Demand-side – Municipal, Industrial, and Thermo-electric	Consistent	Strategy reduces demand and extends supply, increasing water source reliability for other demands	**Impacts:** Low anticipated impacts – Minor additional waste from discarded inefficient toilets, fixtures, and appliances.	Low anticipated Effects – Positive benefit for homeowners from upgrading appliances for lower cost and reduced water billings (if billed at unit rate). Adverse effect due to need to hire implementation and compliance staff which would contribute to rate increase.	No anticipated effects	No anticipated impacts

Table 6-10 (continued). Demand-side water management strategy feasibility assessment.

Water Management Strategy	Strategy Type	Consistency with Regulations	Reliability of Water Source	Environmental Impacts and Benefits[1]	Socioeconomic Effects	Potential Interstate or Interbasin Effects	Other Water Quality Considerations
Water Efficiency Standards for New Construction	Demand-side - Municipal	Consistent	Strategy reduces demand and extends supply, increasing water source reliability for other demands	**Impacts:** None anticipated	Low anticipated effects – Efficiency standards may make renovations or construction more expensive and limit access to renovate or build. The need to hire implementation and compliance staff would contribute to rate increase	No anticipated effects	No anticipated impacts
Residential Water Audits	Demand-side - Municipal	Consistent	Strategy reduces demand and extends supply, increasing water source reliability for other demands	**Impacts:** None anticipated	No to low anticipated effects – Revenue effects to utility from reduced demand may be offset by lower delivery costs. Effects to homeowners from repairs may be offset by reduced water bills (if billed at unit rate). The need to hire implementation and compliance staff would contribute to rate increase	No anticipated effects	No anticipated impacts

Table 6-10 (continued). Demand-side water management strategy feasibility assessment.

Water Management Strategy	Strategy Type	Consistency with Regulations	Reliability of Water Source	Environmental Impacts and Benefits[1]	Socioeconomic Effects	Potential Interstate or Interbasin Effects	Other Water Quality Considerations
Reclaimed Water Programs/ Water Reuse and Recycling (a demand- and supply-side strategy)	Demand-side – Municipal, Industrial, and Thermo-electric	SCDES regulates reclaimed wastewater systems for irrigation use with public contact; there are no laws or regulations pertaining to indirect potable reuse or direct potable reuse	Strategy reduces demand and extends supply, increasing water source reliability for other demands	**Impacts:** Low to moderate anticipated impacts: Depending on the extent of reclaim demand, reduced discharge from wastewater treatment facilities may reduce low flow levels **Benefits:** Depending on the extent of reclaim demand, reduced discharge from wastewater treatment facilities may results in improved receiving water quality	Moderate anticipated effects – Higher initial water bills to finance a reclaimed water program may be offset by long-term savings from postponing the need for new supplies and raw water treatment facilities. The need to hire operations staff could contribute to rate increase	No anticipated effects	See Environmental Benefits Need to match end use with quality of reclaimed water. Consider emerging contaminants of concern (e.g., PFAS and microplastics)
Car Wash Recycling Ordinances	Demand-side - Municipal	Consistent	Strategy reduces demand and extends supply, increasing water source reliability for other demands	**Impacts:** Low anticipated impacts – renovation or construction may impact sensitive areas **Benefits:** Positive environmental benefit of reduced pollutant runoff	Low anticipated effects – Financial burden to developer or owner of car wash for construction/renovation. The need to hire implementation and compliance staff would contribute to rate increase	No anticipated effects	See Environmental Benefits

Table 6-10 (continued). Demand-side water management strategy feasibility assessment.

Water Management Strategy	Strategy Type	Consistency with Regulations	Reliability of Water Source	Environmental Impacts and Benefits[1]	Socioeconomic Effects	Potential Interstate or Interbasin Effects	Other Water Quality Considerations
Time-of-Day Watering Limit	Demand-side - Municipal	Consistent	Strategy reduces demand and extends supply, increasing water source reliability for other demands	**Impacts**: None anticipated	The need to hire implementation and compliance staff would contribute to rate increase	No anticipated effects	No anticipated impacts
Landscape Irrigation Program and Codes	Demand-side - Municipal	Consistent	Strategy reduces demand and extends supply, increasing water source reliability for other demands	**Impacts:** None anticipated **Benefits:** Water quality of receiving waters may be improved by reducing runoff from landscaping	Low anticipated effects – Mandates to meet standards may cause financial hardship for homeowners. No anticipated effects to homeowners from educational programs. The need to hire implementation and compliance staff would contribute to rate increase.	No anticipated effects	See Environmental Benefits
Xeriscaping	Demand-side - Municipal	Consistent	Strategy reduces demand and extends supply, increasing water source reliability for other demands	**Impacts:** None anticipated **Benefits:** Water quality of receiving waters may be improved by reducing runoff from landscaping. Use of native vegetation can benefit pollinators and wildlife.	No to low anticipated effects – Cost to retrofit a landscape and/or implement xeriscaping. Energy and water savings would be realized long-term.	No anticipated effects	See Environmental Benefits
Water Efficient Processes	Demand-side – Industrial	Consistent	Strategy reduces demand and extends supply, increasing water source reliability for other demands	**Impacts**: None anticipated	Low to moderate positive effects from long-term economic savings of reduced water pumping, treatment, and management	No anticipated effects	No anticipated impacts

Table 6-10 (continued). Demand-side water management strategy feasibility assessment.

Water Management Strategy	Strategy Type	Consistency with Regulations	Reliability of Water Source	Environmental Impacts and Benefits[1]	Socioeconomic Effects	Potential Interstate or Interbasin Effects	Other Water Quality Considerations
Energy Saving Appliances	Demand-side – Thermo-electric	Consistent	Strategy reduces energy demand and could lead to less residential water demand, extending supply and increasing water source reliability for other demands	**Impacts**: None anticipated	Low to no anticipated effects – Cost to purchase energy saving appliances falls on residents; however, rebates can help mitigate impact.	No anticipated effects	No anticipated impacts

Table 6-11. Supply-side water management strategy feasibility assessment.

Water Management Strategy	Strategy Type	Consistency with Regulations	Reliability of Water Source	Environmental Impacts and Benefits[1]	Socioeconomic Effects	Potential Interstate or Interbasin Effects	Other Water Quality Considerations
New or Increased Storage	Supply-side	Consistent	Moderate to high reliability – Reliability depends on climatological factors like precipitation, evaporation, contributing stream flow, and seepage to groundwater	**Impacts:** Moderate to high anticipated impacts – Construction of new or increased storage may disturb existing stream habitat. Reductions in stream flow may adversely impact aquatic species. **Benefits**: New ponds and impoundments may create new habitat	Moderate anticipated effects – Costs of design, construction, and any permitting can be significant. Depending on dam size and classification, permitting requirements may be significant. Costs of inspections and maintenance in keeping with regulations and BMPs	No anticipated effects	Moderate anticipated impacts – Small impoundments may impact water quality of streams due to reduced stream flow. Algae growth may also be a concern

Table 6-11 (continued). Supply-side water management strategy feasibility assessment.

Water Management Strategy	Strategy Type	Consistency with Regulations	Reliability of Water Source	Environmental Impacts and Benefits[1]	Socioeconomic Effects	Potential Interstate or Interbasin Effects	Other Water Quality Considerations
Reclaimed Water Programs/ Water Reuse and Recycling (a demand- and supply-side strategy)	Demand-side – Municipal, Industrial, and Thermo-electric	SCDES regulates reclaimed wastewater systems for irrigation use with public contact; there are no laws or regulations pertaining to indirect potable reuse or direct potable reuse	Strategy reduces demand and extends supply, increasing water source reliability for other demands	**Impacts:** Low to moderate anticipated impacts: Depending on the extent of reclaim demand, reduced discharge from wastewater treatment facilities may reduce low flow levels **Benefits:** Depending on the extent of reclaim demand, reduced discharge from wastewater treatment facilities may results in improved receiving water quality	Moderate anticipated effects – Higher initial water bills to finance a reclaimed water program may be offset by long-term savings from postponing the need for new supplies and raw water treatment facilities. The need to hire operations staff could contribute to rate increase	No anticipated effects	See Environmental Benefits Need to match end use with quality of reclaimed water. Consider emerging contaminants of concern (e.g., PFAS and microplastics)
Conjunctive Use	Supply-side	Consistent – Wells that withdraw more than 3 MGD on average are required to apply for a permit under CUA requirements	Expected High reliability but depends on the reliability of the groundwater supply which varies by location and depth of well.	**Impacts:** Low anticipated impacts – Expected to be temporary, but extensive and prolonged pumping may draw down groundwater levels potentially leading to aquifer compaction, reduction in well yield, and land subsidence **Benefits:** May increase flow in streams during low flow periods	Moderate anticipated effects – The cost of drilling a new groundwater supply well will vary with local conditions and depth. The effect on a specific operation will depend on its size and financial capacity. Cost is also associated with conveyance and treatment infrastructure to allow switching and or blending of the primary and conjunctive sources.	No anticipated effects	Low to moderate anticipated impacts – Extent of impact depends on quality of local groundwater. Acidic groundwater may not be ideal for crop growth. Hard groundwater may reduce life or irrigation equipment from mineral precipitation

Table 6-11 (continued). Supply-side water management strategy feasibility assessment.

Water Management Strategy	Strategy Type	Consistency with Regulations	Reliability of Water Source	Environmental Impacts and Benefits[1]	Socioeconomic Effects	Potential Interstate or Interbasin Effects	Other Water Quality Considerations
Conveyance	Supply-side	Consistent	Strategy does not impact reliability of the water source, but connects the use to a source	**Impacts:** Low to moderate anticipated impacts due to construction, especially if it occurs in sensitive environments.	Moderate anticipated effects – Higher initial water bills to finance a conveyance project may be offset by long-term savings from postponing the need for new supplies and raw water treatment facilities. The need to hire operations staff could contribute to rate increase	No anticipated effects	No anticipated impacts
Desalination	Supply-side	Consistent	Source reliability (seawater) is considered high	**Impacts:** Moderate to high anticipated impacts due to discharge of brine, which can be toxic, and alteration of seabed during pipeline construction. **Benefits:** Reduces demand on (fresh) surface and groundwater sources	Moderate to high – The cost of desalination can be a factor of 10 higher than treatment of freshwater sources.	No anticipated effects	Brine effluent will impact quality of the receiving seawater

6.2.2 Cost-Benefit Analysis of Surface Water Management Strategies

Available information related to costs and benefits in terms of potential savings of water or dollars for each strategy is summarized below. These are generalized values from literature or other locations and should be considered for planning-level assessment only, to help screen and understand the alternatives. Implementation planning would require more specific analysis. The information is presented for relative comparison purposes, so that the potential benefits, risks, and impacts of the alternatives can be understood more completely, and decision-makers can make more informed decisions about priorities.

6.2.2.1 Demand-Side Agricultural Strategies

Water Audits and Nozzle Retrofits

The cost of a Clemson Center Pivot Irrigation Test Program audit is $125.00 per pivot. Costs of other water audits vary significantly depending on whether they are conducted internally, by a consultant, or by a government entity. While the process of conducting a water audit does not alone provide benefits, if improvements such as nozzle retrofits are made, benefits can include increased water efficiency and energy savings. An approximately 15 percent reduction in water use could be expected from nozzle retrofits made following a center pivot sprinkler audit (Walther, pers. comm. 2021).

A sample audit report provided by Clemson Cooperative Extension estimates the cost of a retrofit sprinkler package at $5 per foot of pivot length (Clemson Cooperative Extension 2022b). In this example, the total cost to retrofit is estimated at $2,982. Using an assumed crop value, irrigation need, and cost of under- or overirrigation, the estimated suboptimal irrigation cost is $4.39/acre. With an irrigated area of 37.4 acres, this comes out to an estimated loss of $164. Over the estimated 23.6-year lifespan of the retrofit, this equates to $3,875 in savings compared to the total cost of $3,107 ($2,982 cost of the retrofit plus the $125 cost of the initial audit).

Irrigation Scheduling and Smart Irrigation

According to the 2021 Texas Panhandle Water Plan, the cost of a typical smart irrigation system ranges from $6.50 to $12.00 per acre and benefits amount to approximately 10 percent of the water used on each crop seasonally (Freese and Nichols, Inc. 2020). Other studies suggest that irrigation scheduling may reduce water use by 15 percent on average (Smart Irrigation 2019). The overall cost savings is hard to quantify, given the variability in irrigation rates, the cost of pumping, the potential increase in crop yield that results from optimizing irrigation, and other factors. A simple example assuming a center pivot irrigated area of 81 acres, a cost of $648 for a smart irrigation system ($8 per acre), and an annual cost of $1,374 ($16.96 per acre) for energy associated with pumping (NC State University 2007), suggests that if a smart irrigation system is able to reduce water use by 15 percent, then the $648 capital cost of the system will be recovered in just over 3 years.

Cover Cropping, Conservation Tillage, Mulch (Soil Management)

The 2021 Texas Panhandle Water Plan assumed a 1.75 acre-inches per acre of water savings from soil management strategies (Freese and Nichols, Inc. 2020). While conservation tillage may result in savings from reduced machine, fuel, and labor costs, depending on the conservation type implemented, it also has initial costs to transition from conventional to conservation tillage, including the purchase of new

equipment and any chemical control costs (herbicides or pesticides). For example, ridge tilling requires specially designed equipment such as a ridge cultivator or ridge planter.

Implementing furrow diking can range from less than $2,000 to several thousand dollars. Per crop per season per acre estimates range from $5 to $30. The Texas Water Development Board estimates water savings of 3 inches per season (0.2 acre-feet per acre), but savings will vary by field and season. Using the irrigation of corn with a 113-day growing season as an example, a reduction in 3 inches per season would be expected to lower the seasonal irrigation need from 9.9 inches to 6.9 inches, assuming average seasonal precipitation of 16 inches, and an average seasonal corn crop watering need of 25.9 inches. The reduction of 3 inches would save approximately $10 per acre in irrigation system operating cost.

Crop Variety, Crop Type, and Crop Conversion

The cost of implementation and the actual reduction in irrigation water used will depend on numerous local factors including market pricing, cost of seed, cost of harvesting, and the value of crops.

If farmers are encouraged to switch from long season varieties to short season varieties, they may experience loss in yield and therefore revenue. However, they will also see a cost savings from reduced pumping and water use costs along with potential savings in product handling.

Irrigation Equipment Changes and Drip/Trickle Irrigation

Irrigation equipment changes may focus on lowering the elevation of nozzles on center pivot systems. Total replacement of a system (assumed 125-acre, 30-inch spacing) with a new 60-inch spacing system is estimated at $151.20 an acre, including labor and new hoses, heads, and weights. Conversion instead of full replacement of the same system is estimated at $44 per acre. Costs assume that the system is converting from low elevation spray application (LESA) or mid-elevation spray application (MESA) systems to low elevation precision application (LEPA) systems (Freese and Nichols, Inc. 2020). This transfer in irrigation practice may result in a 7 to 17 percent increase in irrigation efficiency and, consequently, decreased water usage. In most cases, irrigation equipment changes will be a combination of replacement and conversion.

Drip irrigation systems can cost between $500-$1,200 per acre (Simonne et al, 2024). Drip irrigation can improve the efficiency of both water and fertilizer applications, lowering the cost associated with pumping water and lowering fertilizer cost. Nutrient applications may also be better timed to meet plant needs. Drip systems can also be easily automated, lowering labor costs. One Texas cotton grower reported increasing their yield to 3 bales of cotton per acre using 16 inches of drip system water, compared to only 2.25 bales of cotton per acre using 16 inches of water from a center pivot system (Toro 2010). A Kansas corn grower who installed a drip system on 4,000 acres experienced a combined savings considering fuel, labor, chemical/fungicide, fertilizer, and cultivation of $160.05 per acre, compared to flood irrigation. At an initial capital cost of $1,200 per acre, the payback period for the drip system was 3.6 years (Toro 2007).

6.2.2.2 Demand-Side Golf Course Strategies

Wetting Agents to Reduce Water Use

Effective wetting agent programs can yield overall water savings. One study resulted in an approximately 20 percent savings the first season of application, and an average annual savings of $12,500 to $15,000 (USGA, 2024). Turfgrass loss during the summer was reduced to a level that allowed for the elimination of

annual fairway overseeding, saving an additional $15,000 per year. The combined savings of water and seed completely offset the cost of the wetting agent program.

6.2.2.3 Demand-Side Municipal and Industrial Strategies

Conservation Pricing Structures

The implementation of conservation pricing structures is a cost-effective option for utilities as there are no direct costs to them to achieve a reduction in demand. However, reduction in billing revenue associated with decreased customer usage must be considered. On average, in the United States, a 10 percent increase in the marginal price of water in the urban residential sector can be expected to diminish demand by about 3 to 4 percent in the short run (Olmstead and Stavins 2009). An example application in the Texas Panhandle assumed 10 percent of households would respond and change their water consumption behavior resulting in 6,000 gallons saved per household per year (Freese and Nichols, Inc. 2020).

Public Education of Water Conservation

Building water conservation awareness will not only save water but will save money on operational and production costs. Savings are estimated at 5,000 gallons per household per year for 30 percent of households targeted. Public education and outreach costs more per person in smaller communities than in larger ones ($2.75 per person per year for communities less than 20,000 and $1.80 per person per year for communities with more than 20,000) (Freese and Nichols, Inc. 2020).

Leak Detection and Water Loss Control Program

EPA estimates that the average water loss in water systems is 16 percent, with up to 75 percent of the water loss potentially recoverable through a water loss control program (EPA 2013). Since 2010, Georgia's public water systems have reported, on average, between 13.5 and 17.4 percent water loss; however, 43 of 263 systems reported over 30 percent average annual water loss since 2010. Costs of a water loss control program would be associated with the time spent conducting the water audit and the costs of needed repairs, which would depend on the system. However, water audits have generally been proven to be cost-effective practices. The AWWA M36 Manual of Water Audits and Loss Control Programs includes an example of a utility with a $79,000 water audit cost, which, in 2022 dollars, translates to a unit cost $310/mile water main (AWWA 2016).

As another example, the Red Star Water District, a small water system in Leedey, Oklahoma conducted a water loss audit and found real loss levels of 28.9 million gallons per year, valued at $71,962 and representing 25.2 percent of total water supplied to the system. After identifying 29 leaks, the District adopted an aggressive program of leak repair, and was able to repair all leaks, saving the system 26 million gallons of water per year at a value of $71,000 annually (Oklahoma DEQ 2021).

Low Flow Fixtures, Toilets, and Appliances

Rebate programs to encourage use of low flow fixtures, toilets, and appliances have been used to lower residential water demand. The costs to the utility or local government are based on the rebate amount per fixture, toilet, or appliance, plus any program management costs. Reduced total water use in the community results in lower operating costs for the utility but may also result in lower billing revenue depending on the fee structure used.

An example of an existing rebate requires customers to purchase a toilet using 1.1 gallons per flush or less to receive a $75 rebate (Metropolitan North Georgia Water Planning District 2022). Metro Atlanta utilities have proven toilet rebate programs can be successful by replacing more than 150,000 toilets with low flow models between 2008 and 2019. Assuming an average water savings of just 2.4 gallons per flush, this equates to a savings of 360,000 gallons per flush. Since the average household flushed about 5 times per day, the combined water savings of these 150,000 low flow toilet replacements is a staggering 657 million gallons over the span of one year.

Toilets made prior to 1980 typically used 5.0 to 7.0 or high gallons per flush and toilets made from the early 1980s to 1992 typically used 3.5 gallons per flush or more. The current federal standard is 1.6 gallons per flush.

Water Efficiency Standards for New Construction

High efficiency toilets can save more than $100 per family per year (Mullen n.d.). EPA estimates that fixtures meeting the WaterSense requirements can save approximately 700 gallons of water per year per household (EPA 2021). The costs associated with implementing local ordinances outlining water efficiency standards is low. There are numerous examples that can be used to guide ordinance development and implementation.

Residential Water Audits

Residential water audits may result in the implementation of various strategies, retrofits, and other measures that save up to 20 to 30 gallons of water per day. Costs are associated with the cost of the water audit (if applicable) and the costs of replacements or repairs to the household system.

Reclaimed Water Programs

The benefits of water recycling and reuse programs include increased water supply, increased reliability, and reduced effluent disposal. Initial costs may be substantial and include construction/retrofit costs to wastewater facilities for full reuse capabilities and construction of distribution lines to end users. Benefits may result by lowering demand on highly treated potable water, thereby extending the source of supply and delaying the need for future upgrades to treatment processes or procuring additional water sources. The overall cost-benefit is dependent on the system, the end user, the cost of treatment, and many other factors. Utilities and others that have implemented reclaimed water programs have typically done so after careful analysis and planning to demonstrate the long-term financial viability of a reclaimed water program.

Car Wash Recycling Ordinances

Costs of this practice are associated with purchase and installation of a recycled water system by the car wash owner or developer. The initial cost for a water recycling system can range between $20,000 and $40,000 (in 2022 dollars) depending on the car wash size and requirements (Taylor 2013). Operating costs would be higher than a nonrecycled wash water system because of increased energy usage, replacement of filters and membranes, and other factors. Depending on whether the water was obtained from a public water system or (private) well, there would be a reduction in raw water costs since water demand would be reduced. Ordinances can set a percentage of recycled water to total water used. Typical ordinances require at least 50 percent use of recycled water.

Time-of-Day Watering Limit

Setting a time-of-day watering limit may save up to 1,000 gallons of water per household per year, depending on the amount of irrigated landscape. Costs are associated with enforcement and can vary depending on the size of the utility but are expected to be low. Utilities may benefit from reduced water use and a reduction in peak demands if a time-of-day water limit restricts usage before typical morning peak demands.

Landscape Irrigation Program and Codes

If water efficiency measures are required, costs would be associated with enforcement. If not required, costs will be associated with incentives or education programs. If programs include rebate offerings, the cost of the rebate itself and the administration of the program must be considered. Smart irrigation controllers with an EPA WaterSense certification are commercially available for between $120 and $280. These costs assume there is already a compatible irrigation system in place. Costs to the homeowner would be greater if irrigation system installation or renovation is required. Irrigation with a smart irrigation meter rather than a standard irrigation meter may result in a water use efficiency reduction of 30 percent. An example of a turf replacement rebate is from California's Metropolitan Water District, which offers a $2 per square foot rebate for up to 5,000 square feet. Ultimately, the cost to the utility or municipality would be dependent on the rebate rate and percent uptake by customers.

Xeriscaping

The cost of xeriscaping can vary substantially, depending on whether it is a new installation or retrofit of an existing landscape, the size, and the type and density of plants used. Professionally installed xeriscapes mat range between $5 and $20 per square foot, with a typical price range of about $15,120 to $18,400 (Caayao, 2024).

Water Efficient Processes

Industry has made the use of water efficient processes commonplace over the last several decades. Industrial water managers have realized that the cost of purchasing treated water and/or withdrawing and treating raw water can be minimized by using water efficiently. Retrofitting water-intensive processes to use less water, or treat and reuse water, is likely to result in long-term cost savings.

Energy Saving Appliances

While there are no specific studies documenting the net impact of energy saving appliances on lowering water demands associated with energy production, the cumulative impact of energy saving appliances undoubtedly reduces overall energy demand. It could be assumed that lower energy demand helps extend the time when new, potentially expensive, sources of energy are required.

6.2.2.4 Supply-Side Strategies

New or Increased Storage

As described in Chapter 3, the Pee Dee River in South Carolina is free flowing, though flows are regulated by upstream reservoirs in North Carolina. The Pee Dee River basin in South Carolina only has limited surface water development, consisting primarily of one large reservoir, small-scale flood control projects, and on-site storage ponds for agriculture and golf courses. The largest reservoir in the basin, Lake Robinson, is located on Black Creek and is operated by Duke Energy Progress, LLC. As described in

Chapter 5, small on-site storage ponds have been very useful in mitigating local surface water supply shortages in the past and will be useful for mitigating local shortages in the future.

Costs for building new water storage ponds, impoundments, or reservoirs or increasing the volume of existing storage can vary significantly, depending on the type and size of project. Some examples are provided below.

Estimated costs for raising the dam height of Lake Whelchel in Cherokee County, South Carolina by 3 and 5 feet were $27 million and $31 to $35 million, respectively (adjusted to 2022 dollars) (AECOM 2019). This estimate included earth excavation and fill, concrete spillway construction, bridge and roadway work, and engineering and permitting. This equates to approximately $182 per 1,000 gallons of additional raw water storage (assuming a 3-foot increase in dam height).

Costs to construct a new reservoir would include, but be not limited to, construction of an earth-filled dam embankment and spillways, transmission pipelines, and pump stations, as well as roadway and utility relocations, environmental mitigation, permitting, administration and operations, and land acquisition of the reservoir location and any transmission easements. The range of potential cost for developing a new water supply reservoir can vary significantly. The Texas Water Development Board has developed Regional Water Plans along with a list of proposed projects throughout the state, including an estimated capital cost for each (TWDB 2020). This list includes 45 projects categorized solely as new major reservoirs, with capital costs ranging from $3.3 million to $4.5 billion, as reported in 2020. Normalizing the capital cost to the raw water supply provided by each, the price per 1,000 gallons of raw water supplied is on the order of $1.50 to $3.00 during debt service and reduces to approximately $0.25 to $1.00 after debt service, in 2020 dollars.

Conjunctive Use

The 2021 Panhandle Regional Water Plan – Volume II estimated the cost of a 300-foot-deep, 350 gpm irrigation well and pump at just over $250,000 (Freese and Nichols, Inc 2020). Similar costs have been observed for production wells and their associated pumps and appurtenances in South Carolina (Walther, pers. comm, 2021). The cost-benefit of drilling a well and installing water conveyance will depend on the cost of obtaining water from other sources, such as a distant surface water source, or purchase of water from a nearby utility.

Conveyance

Conveyance costs can vary significantly, and depend on the size of pipe, the topography, the type of soils, the price of materials, the density of existing utilities and infrastructure along the pipeline route, and other factors. Evaluating the cost-benefit of conveyance requires specific assumptions appropriate for each project.

Desalination

Large-scale desalination plants which use reverse osmosis typically produce water for $1.90 to $7.60 per 1,000 gallons depending on energy sources, location, feed water quality, and other expenses (Herber, 2024). Comparatively, conventional freshwater treatment plants produce water for a $0.50 per 1,000 gallons. Operation costs can vary significantly depending on the cost of energy, feed water salinity, materials, and equipment lifecycle (e.g. membranes), size of the plant, and location.

6.3 Groundwater Management Strategies

Under the Framework, a groundwater water management strategy is any water management strategy proposed to address a Groundwater Area of Concern or groundwater shortage. Strategies may include demand-side management strategies that reduce supply gaps by reducing demands, and supply-side strategies that increase or augment supply. Examples of demand-side strategies include municipal and agriculture conservation and water use efficiency measures. Examples of supply-side strategies include ASR and relocating pumping from one aquifer to another.

6.3.1 Demand-Side Strategies

As presented in Tables 6-1 through 6-5, the Pee Dee RBC identified a portfolio of various surface water demand-side strategies consisting of agricultural, golf course, municipal, industrial, and thermoelectric water efficiency and conservation practices. These demand-side strategies also apply to groundwater withdrawers.

6.3.2 Supply-Side Strategies

The Pee Dee RBC identified and considered several potential supply-side water management strategies that could help mitigate potential groundwater supply issues. Some, like conjunctive water management and aquifer storage and recovery have already been used in the Pee Dee River basin to help mitigate or lessen groundwater supply challenges. Supply-side strategies discussed by the Pee Dee RBC are described in this subsection.

Drilling Wells into Lesser-Used Aquifer Formations

The Pee Dee River basin is underlain by the Coastal Plain aquifer system, which consists of multiple layers of permeable sands or limestone separated by clay confining units. Groundwater wells in the Pee Dee River basin primarily use groundwater from the surficial aquifer, the Crouch Branch aquifer, and the underlying McQueen Branch aquifer. For locations where wells are drilled into and are stressing groundwater supplies in a certain aquifer formation, the Pee Dee RBC discussed encouraging that new wells be drilled into lesser-used aquifer formations to avoid adding more groundwater demand to aquifer formations that are already stressed. The Pee Dee RBC also asserted that water users should take a thoughtful approach to this strategy to avoid over development in lesser-used aquifer formations or inducing seawater intrusion into aquifers near the coast.

Desalination

Desalination was described in Section 6.1.2 in the context of supply-side strategies for surface water (see that section for more information). In coastal communities with groundwater supply challenges, desalination of seawater or brackish groundwater could provide additional supply to supplement groundwater.

Conjunctive Use

Conjunctive water use was described as a supply-side surface water management strategy in Section 6.1.2, but it is also a supply-side strategy for groundwater management. In the context of groundwater management, surface water supplies can be developed and used to reduce the need to pump

groundwater in areas where aquifer levels have declined. The City of Florence case study described in Section 6.1.2 is an excellent example of conjunctive surface and groundwater management.

Water Reclamation

Water reclamation was described in Section 6.1.2 in the context of supply-side strategies for surface water (see that section for more information). The Pee Dee RBC identified several types of water reclamation that could be beneficial for reducing groundwater supply risk. Reclamation strategies discussed include reuse of wastewater for both potable and non-potable use, using reclaimed supplies as a source for aquifer storage and recovery, and capturing/treating stormwater for either potable or non-potable uses.

Aquifer Storage and Recovery

Section 6.1.2 describes ASR under the "New or Increased Storage" supply-side strategy for surface water. While ASR is a way to develop surface water supplies by storing it underground, it also replenishes groundwater supplies in the process. In this context, ASR is a supply-side strategy for groundwater as well as surface water. See Section 6.1.2 for more detail on ASR and an example of where it has been used in the Pee Dee River basin.

6.3.3 Technical Evaluation of Strategies

Groundwater management strategies for the Pee Dee River basin were developed and evaluated using observed groundwater data, including SC Groundwater Monitoring Network well hydrographs, potentiometric surface maps, and groundwater use data. This approach was used in lieu of the USGS Atlantic Coastal Plain Groundwater Model, which is still in development for the Pee Dee River basin and may be incorporated into future iterations of the plan upon completion. Please refer to Section 3.4.1 for more information regarding the groundwater model.

SC Groundwater Monitoring Network Hydrographs

Hydrographs produced from wells in the Pee Dee River basin offer continuous data on groundwater levels, helping to identify trends such as increasing, declining, or stabilization of water levels in response to withdrawals and management strategies both long-term and at specific points in time.

Potentiometric Surface Maps

Potentiometric maps provide insight into groundwater levels and flow paths, and how they have changed over time. By comparing historical and recent potentiometric surface maps, it is possible to assess the impacts of groundwater withdrawals and the effectiveness of management strategies.

Reported Groundwater Withdrawal Data

Groundwater withdrawal data is critical for evaluating how changes in usage have affected the Coastal Plain aquifer system. This data allows for the quantification of groundwater usage trends and their correlation with observed aquifer conditions.

This combined approach allows for a clearer understanding of the direct relationship between groundwater pumping and aquifer stress, helping to identify where management strategies may need to be modified.

It is important to note that groundwater withdrawal data is self-reported to SCDES by permitted and registered groundwater users and the data is manually entered into the database by the user or program staff, which may result in inconsistencies. Water use data from private domestic wells, facilities that do not meet the reporting threshold, and data from facilities failing to report their annual water use are not included.

Conjunctive Water Use: Effective Groundwater Management in Florence County

A notable example of effective groundwater management in the Pee Dee River basin is the recovery and stabilization of the pumping cone that formed in the McQueen Branch aquifer below Florence, SC during the 1980s and 1990s.

Following the implementation of a conjunctive water use strategy in the late-1990s during which the City of Florence supplemented its groundwater supplies with surface water to meet the increasing water needs of a growing population. Figure 6-2 shows the relative amounts of surface and groundwater use in Florence County since the mid-1990s. Groundwater monitoring well FLO-0128 has exhibited a multidecadal recovery and recent stabilization of the pumping cone in Florence County (Figure 6-3).

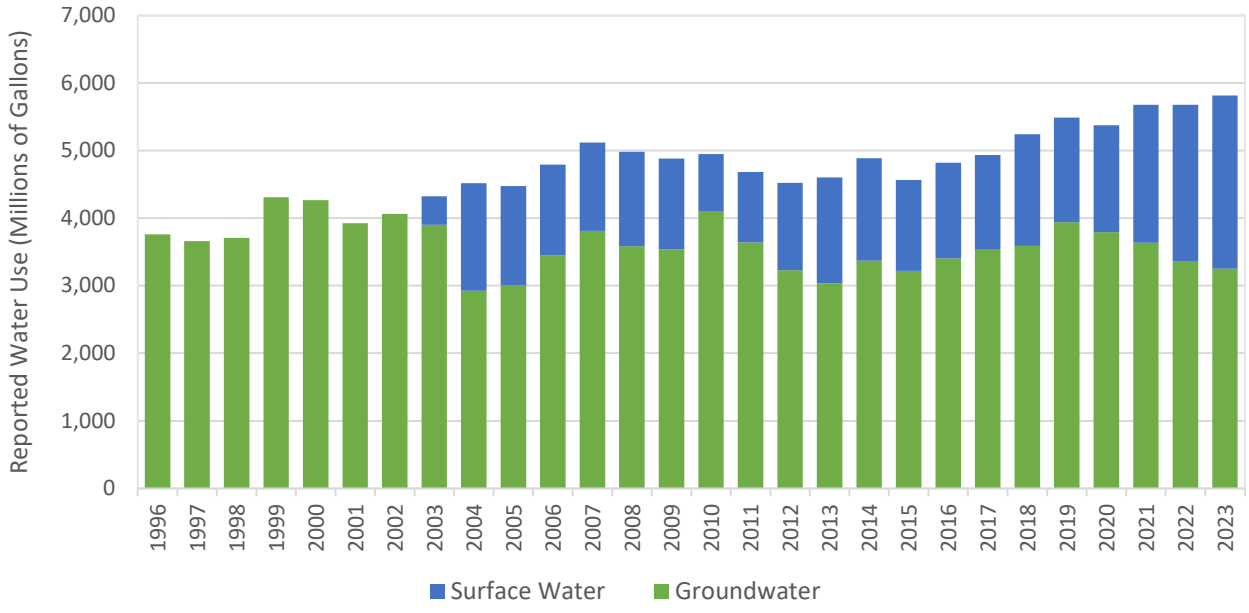


Figure 6-2. Total water use by type of supply in Florence County.

As of 2024, the cone of depression centered in northern Florence County has recovered by approximately 60 feet since reaching a record low of 92.07 feet relative to NAVD88 in the late 1990s (Czwartacki & Wachob, 2022). Observations from monitoring well FLO-0128 show the initial drawdown

period throughout the 1980s and 1990s, subsequent recovery at a rate of approximately 2.4 feet per year through 2019, and recent stabilization of water levels (Figure 6-3).

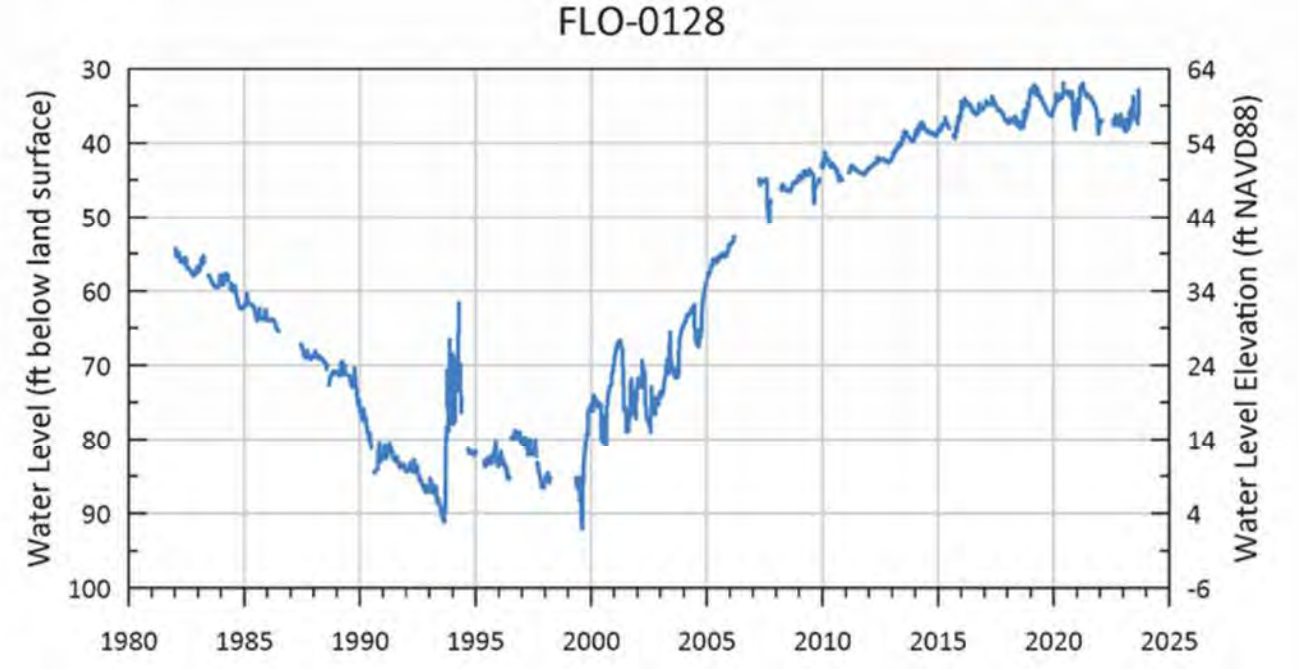


Figure 6-3. Groundwater levels in the McQueen Branch aquifer in northern Florence County.

Potentiometric surface maps, overlain with groundwater withdrawal data, further illustrate the continued effectiveness of the conjunctive water use strategy implemented by the City of Florence (see Figure 6-4). The cone of depression centered in northern Florence County marks the historical area of significant groundwater drawdown from the 1980s and 1990s. The steepness of the contours surrounding the Florence cone indicates that the effects of the persisting drawdown remain localized rather than regional, as seen in the cone of depression in Georgetown County. Furthermore, the 2022 groundwater use data illustrated in Figure 6-4 shows a lesser degree of pumping intensity at the center of the Florence cone, aligning with the observed recovery in monitoring well FLO-0128.

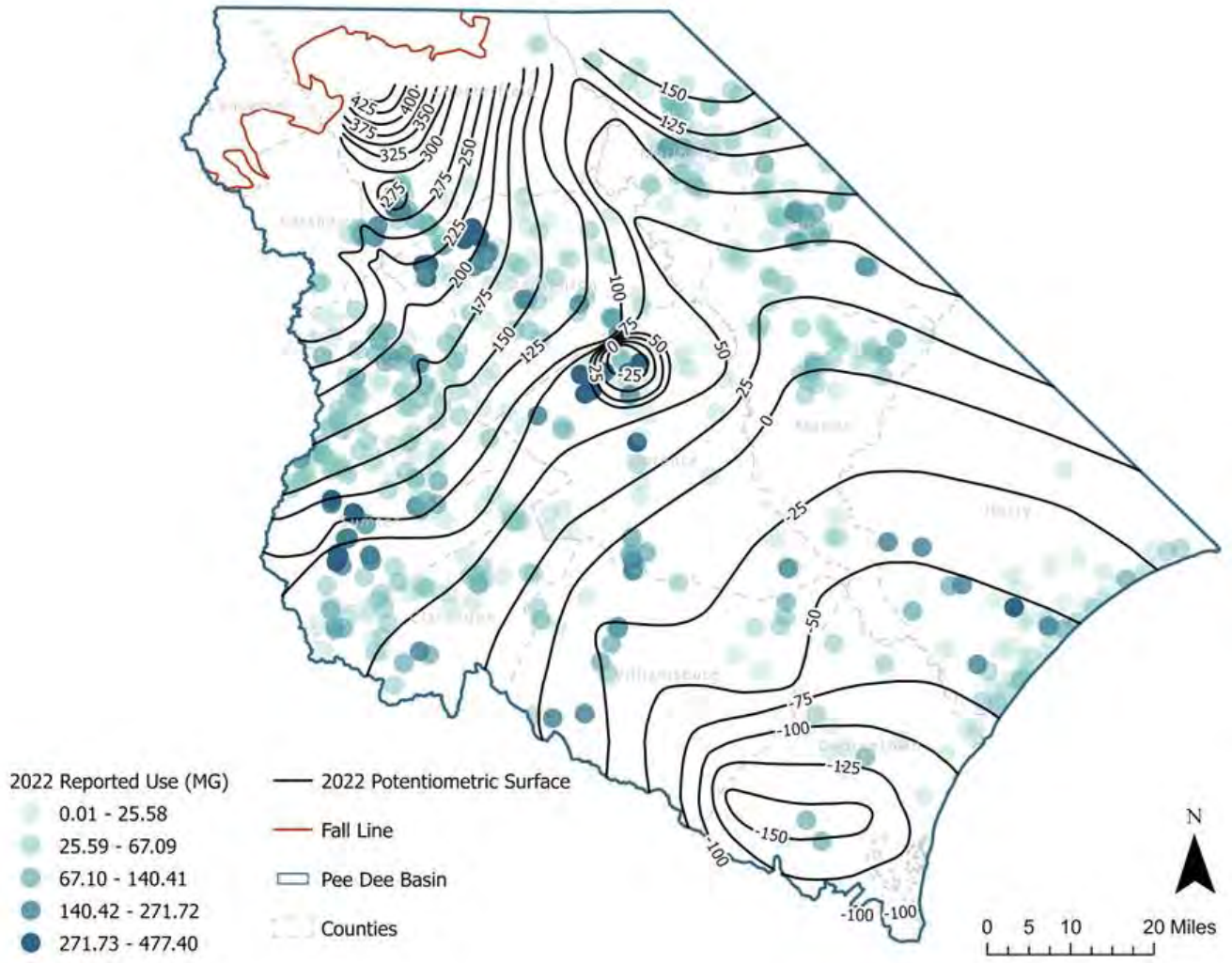


Figure 6-4. 2022 potentiometric surface of the McQueen Branch and Charleston aquifers (Czwartacki & Wachob, 2022) overlain with 2022 reported groundwater use (MG) from the McQueen Branch and Charleston aquifers in the Pee Dee River basin.
Contour lines are shown in feet relative to NAVD88.

The conjunctive use strategy was implemented by the City of Florence in the late 1990s, where increased reliance on surface water helped stabilize the demand on groundwater resources. The potentiometric surface maps and groundwater level hydrographs provide confirmation of the recovery trends and stabilization achieved through this conjunctive water management approach in the Pee Dee River basin. The recovery holds significant implications for groundwater management efforts across the state, underscoring the importance of continued monitoring and taking proactive measures to ensure the sustainable use of the state's groundwater resources.

6.3.4 Feasibility of Groundwater Management Strategies

The Pee Dee RBC assessed the feasibility of the water management strategies and practices described above with regard to consistency with regulations, reliability of water source, environmental impacts, socioeconomic impacts, and water quality impacts. This assessment is presented in Table 6-12 for supply-side groundwater strategies. Many of the supply-side strategies in Table 6-12 were assessed in the context of surface water in Table 6-11, but they are evaluated from a groundwater perspective in Table 6-12. Note that demand-side strategies for groundwater were the same as those for surface water, and the feasibility of demand-side strategies are assessed in Table 6-10.

Color coding is used to identify an expected effect of the strategy, ranging from moderate to high adverse effects to moderate to high positive effects. The selection of effects, whether it be adverse, neutral, or positive, was largely subjective and based on professional judgement and feedback from the RBC. The color coding is shown below for convenience, and it is the same coding used in Tables 6-10 and 6-11.

Color Coding for Assigning Expected Effects in Tables 6-12

Potential Moderate/High Adverse Effect	Potential Low Adverse Effect	Likely Neutral Effect (either no effect, or offsetting effects)	Potential Low Positive Effect	Potential Moderate/High Positive Effect

Table 6-12. Supply-side water management strategy feasibility assessment.

Water Management Strategy	Consistency with Regulations	Reliability of Water Source	Environmental Impacts and Benefits[1]	Socioeconomic Effects	Potential Interstate or Interbasin Effects	Other Water Quality Considerations
Drilling Wells into Lesser-used Aquifer Formations	Consistent – Wells that withdraw more than 3 MGD on average are required to apply for a permit under CUA requirements	Lesser-used aquifers should be reliable, though well yields may be lower depending on local conditions and reliability may lessen if strategy is over-used.	**Impacts:** None anticipated **Benefits**: Moderate environmental impacts – Transferring pumping to an aquifer with greater availability will reduce negative impacts in over-allocated aquifers, such as land subsidence, loss of storage capacity, and reduced well yields.	Moderate to high impacts – The cost of drilling to deeper aquifers will present a financial burden to withdrawers and may be infeasible for others	No anticipated effects	Water quality in the McQueen Branch aquifer would need to be evaluated. There is the potential for elevated hardness that could reduce the lifespan of irrigation equipment.
Desalination	Consistent	Source reliability (seawater) is considered high	**Impacts:** Moderate to high anticipated impacts due to discharge of brine, which can be toxic, and alteration of seabed during pipeline construction. **Benefits:** Reduces demand on (fresh) surface and groundwater sources	Moderate to high – The cost of desalination can be a factor of 10 higher than treatment of freshwater sources.	No anticipated effects	Brine effluent will impact quality of the receiving seawater
Conjunctive Use	Consistent – Wells that withdraw more than 3 MGD on average are required to apply for a permit under CUA requirements	Moderate to high reliability - depends on surface water supply which varies by location and can diminish during drought. The Pee Dee River basin is not projected to have significant surface water shortages.	**Impacts:** Low anticipated impacts – Surface water diversions will lessen flows, and construction of intake and treatment facilities can temporarily impact the environment. **Benefits:** Aquifer levels may recover	Moderate to high – The cost of new intake structures, treatment, and conveyance for surface water supplies and blending/switching supplies can be substantial depending on capacity.	No anticipated effects	Low to moderate anticipated impacts – Extent of impact depends on quality of local surface water, which can vary based on flow conditions.

Table 6-12 (continued). Supply-side water management strategy feasibility assessment.

Water Management Strategy	Consistency with Regulations	Reliability of Water Source	Environmental Impacts and Benefits[1]	Socioeconomic Effects	Potential Interstate or Interbasin Effects	Other Water Quality Considerations
Aquifer Storage and Recovery	Consistent	Moderate to high reliability – Reliability depends on availability of supplies for storage, and degree to which stored groundwater supplies are recoverable	**Impacts:** Low to moderate anticipated impacts: Groundwater quality impacts should be considered. **Benefits:** Depending on the extent of reclaim demand, reduced discharge from wastewater treatment facilities may result in improved receiving water quality. Can reduce risks of saltwater intrusion.	Moderate anticipated effects – Costs of well design, construction, permitting, treatment, operations, and maintenance can be significant based on the size of the system.	No anticipated effects	Moderate anticipated impacts – The geochemical impacts of mixing surface water with groundwater should be considered.
Reclaimed Water Programs/ Water Reuse and Recycling (a demand- and supply-side strategy)	SCDES regulates reclaimed wastewater systems for irrigation use with public contact; there are no laws or regulations pertaining to indirect potable reuse or direct potable reuse	Strategy reduces demand and extends supply, increasing water source reliability for other demands	**Impacts:** Low to moderate anticipated impacts: Depending on the extent of reclaim demand, reduced discharge from wastewater treatment facilities may reduce low flow levels **Benefits:** Depending on the extent of reclaim demand, reduced discharge from wastewater treatment facilities may result in improved receiving water quality	Moderate anticipated effects – Higher initial water bills to finance a reclaimed water program may be offset by long-term savings from postponing the need for new supplies and raw water treatment facilities. The need to hire operations staff could contribute to rate increase	No anticipated effects	See Environmental Benefits - Need to match end use with quality of reclaimed water. Consider emerging contaminants of concern (e.g., PFAS and microplastics)



6.3.5 Cost-Benefit Analysis of Groundwater Management Strategies

Available information related to costs and benefits in terms of potential savings of water or dollars for each supply-side groundwater strategy are summarized below. These are generalized values from literature or other locations and should be considered for planning-level assessment only, to help screen and understand the alternatives. Implementation planning would require more specific analysis. The information is presented for relative comparison purposes, so that the potential benefits, risks, and impacts of the alternatives can be understood more completely, and decision-makers can make more informed decisions about priorities. Note that the demand-side strategies for groundwater are the same as for surface water, and Section 6.2.2 describes the cost-benefit analysis for those strategies.

Drilling Wells into Lesser-Used Aquifer Formations

The 2021 Panhandle Regional Water Plan – Volume II estimated the cost of a 300-foot-deep, 350 gpm irrigation well and pump at just over $250,000 (Freese and Nichols, Inc 2020). Similar costs have been observed for production wells and their associated pumps and appurtenances in South Carolina (Walther, pers. comm, 2021). The cost-benefit of drilling a well and installing water conveyance will depend on the depth of the well, cost of obtaining water from other sources, such as a distant surface water source, or purchase of water from a nearby utility.

Desalination

The costs and benefits of desalination are described in Section 6.2.2.4.

Conjunctive Use

The costs and benefits for conjunctive water use strategies, from a groundwater management perspective, are very dependent on the scale and needed components of surface water development projects implemented to supplement or offset groundwater use. The conjunctive use approach pursued by the City of Florence provides an example of a 10 MGD surface water supply and treatment project that has been very beneficial in reversing long term declines in groundwater levels and reducing water supply risk for the city (see Chapter 5 for more information on the benefits of the project). Costs for the City of Florence's surface water supply and treatment project were unavailable.

Costs for a new intake structure and pumping facilities to deliver water to the Cherokee County Board of Public Works were estimated for the Broad River Basin Plan using the Colorado Statewide Water Supply Initiative Update, Water Project Cost Estimating Tool (CDM Smith, 2019). The new intake and pumping facilities were sized for 15 MGD capacity using a 30-inch, 2.2-mile pipeline to convey flows to an existing water treatment plant. Costs for engineering, surveying, permitting, and construction were estimated at $12 million (in 2022 dollars), which equates to $0.80 per gallon. Annual costs for debt service, operations and maintenance, and power costs total approximately $1.3 million (or $0.09 per gallon). Note that these costs do not include new surface water treatment facilities. Capital costs in the Water Project Cost Estimating Tool (2017 dollars) for various types of water treatment range from $40 million to $70 million depending on the type of treatment (assuming a 15 MGD plant). Annual operation and maintenance costs could range from $1.3 million to $2 million (again, depending on the type of treatment associated with a 15 MGD plant)

Water Reclamation

The costs and benefits of various water reclamation programs are described in Section 6.2.2.3.

Aquifer Storage and Recovery

Aquifer storage and recovery projects result in a wide variety of benefits. They provide a means for storing available supplies that is not subject to evaporative losses and has minimal impacts on the environment. They can lessen risks of saltwater intrusion into coastal aquifers. They can also help lessen the need to invest in expansion of surface water treatment facilities.

A cost/benefit evaluation of Grand Strand Water and Sewer Authority's (GSWSA) ASR project in Horry County for the City of Myrtle Beach was conducted in 1997 by Joffre Castro (Castro 1997). The ASR project implemented by GSWSA used available treatment capacity during off-peak periods to treat and then inject supplies into the aquifer. During peak use periods, the injected water was recovered and distributed to meet demands. The strategy allowed GSWSA to postpone expansion of their treatment plant and distribution lines. The evaluation conducted by Castro compared the costs of constructing and operating an ASR well to expanding the water treatment plant. The study found that the costs for expanding the treatment plant were more than twice the cost of the ASR well. Note that the unit costs are relatively dated. Since initiation, GSWSA has expanded the ASR program, and it includes 17 ASR wells either in operation or under development. Costs and benefits for ASR projects should be evaluated on a case-by-case basis, but in this instance, the ASR approach was a cost-effective alternative.

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Chapter 7
Water Management Strategy Recommendations

The Pee Dee RBC considered a wide variety of demand-side and supply-side water management strategies (described in Chapter 6) that could be recommended for implementation in the Pee Dee River basin. As water management strategies were discussed, the Pee Dee RBC was cognizant of several core considerations with respect to future water supplies that were identified in the surface water modeling and groundwater data assessment conducted for this Plan. The challenges are briefly summarized below:

- **Surface water:** Significant surface water shortages or ecological risk due to low surface water flows are not projected to occur in the foreseeable future. While surface water management strategies are not needed to reduce projected shortages, they are beneficial in reducing water costs for municipal, industrial, and agricultural water users; mitigating potential localized shortages that are difficult to capture in the modeling; and sustaining surface water supplies if unforeseen future conditions occur (e.g., changed hydrology or unanticipated population growth).
- **Groundwater:** Groundwater levels near recharge zones away from the coast have remained relatively stable over time. However, cones of depression have developed due to groundwater pumping in Florence County and along the coast in Georgetown and Horry counties. Conjunctive water management strategies (i.e. using surface water supplies to supplement groundwater) in these areas have been beneficial in reducing demands and water supply risks to groundwater. Efficient use of groundwater supplies and conjunctive water management strategies will help sustain groundwater supplies into the future. The Coastal Plain Aquifer groundwater model, which is currently being updated, should be used to further evaluate potential groundwater supply risks and water management strategies to minimize risk.

The recommended water management strategies described in this chapter reflect the Pee Dee RBC's collaborative prioritization process as well as the overall River Basin Plan vision developed by the RBC at the beginning of this planning process. The vision of the Pee Dee RBC is "To make sure water is available for all in the Pee Dee River basin." Implementing the recommended water management strategies will help foster the realization of this vision.

7.1 Selection, Prioritization, and Justification for Recommended Water Management Strategies

The RBC used a multi-step scoring process to select and prioritize the water management strategies in this Plan. The process, described in detail herein, follows these steps:

(1) First, the technical team scored the strategies from Chapter 6 using a series of criteria to identify the most impactful strategies and provide guidance on focus areas for the RBC.

(2) Second, the RBC participated in a multi-voting prioritization process and ranked the strategies according to their preference.

(3) The results of the RBC ranking were evaluated using a Forced Ranking approach, which combines multiple analytical techniques to compare the strategy rankings.

7.1.1 Preliminary Strategy Scoring

The strategies were first preliminarily scored by the consultant team (JD Solomon and Brown and Caldwell) based on their benefits, costs, implementability, and timeframe for implementation. Table 7-1 describes the scoring criteria for these four categories.

Table 7-1. Preliminary scoring rubric.

Score	Description
Benefits	
1	Localized or marginal
2	Tens of millions of gallons per day
3	Hundreds of thousands or millions of gallons per day
Costs	
1	Limited capital costs ($1M or less) (for municipalities, industry and thermoelectric); least expensive for agriculture and golf courses
2	$10M order-of-magnitude (for municipalities, industry, and thermoelectric); significant expense for agriculture and golf courses
3	$100M order-of-magnitude (for municipalities, industry, and thermoelectric); most expensive for agriculture and golf courses
Implementability	
1	Easy, common, minimal new concepts and practices
2	May have been done locally but not at statewide scale; will take formal planning and permitting time
3	Not common or does not have a precedent in South Carolina; new regulatory or permitting considerations
Time	
1	Short timeframe; common practice; could be implemented within a couple of years
2	Medium timeframe; 10-year planning and implementation order-of-magnitude
3	Long timeframe; more than 10 years

The scoring process identified the strategies with the highest impact, which tended to be those scored with high benefits and low cost. The preliminary scoring results are summarized in Table 7-2 through

Table 7-4. Water management strategies in these tables are categorized into demand side strategies for both surface water and groundwater, supply side strategies for surface water, and supply side strategies for groundwater. Note that the number of symbols (i.e. water drops, dollar signs, check marks, and hour glasses) correspond to the scoring described in Table 7-1. The strategies in Table 7-12 are first sorted by benefit and then by cost.

Table 7-2. Demand-side strategies for both surface water and groundwater.

Sector	Strategy	Benefit	Cost	Implement-ability	Time
Municipal	Update of Drought Management Plans	💧💧💧	$	✓	⌛
Municipal	Public education on water conservation	💧💧💧	$	✓	⌛
Municipal	Water efficiency standards for new construction	💧💧💧	$	✓	⌛
Municipal	Pricing structures (ex. increasing block rates)	💧💧💧	$	✓	⌛
Municipal	Leak detection and water loss control programs	💧💧💧	$$	✓	⌛
Golf Courses	Water loss control and regular maintenance	💧💧💧	$$	✓	⌛
Industrial	Water loss control and routine maintenance	💧💧💧	$$	✓	⌛
Thermoelectric	Reclaimed water	💧💧💧	$$	✓	⌛⌛
Municipal	Incentives for low flow indoor fixtures	💧💧	$	✓	⌛
Municipal	Landscape irrigation programs and codes	💧💧	$	✓✓	⌛
Municipal	Time-of-day watering limits	💧💧	$	✓	⌛
Ag/Irrigation	Water audits and center pivot sprinkler retrofits	💧💧	$	✓	⌛
Golf Courses	Time-of-day watering practices	💧💧	$	✓	⌛
Ag/Irrigation	Cover cropping, conservation tillage, mulch	💧💧	$$	✓	⌛⌛
Ag/Irrigation	Irrigation scheduling	💧💧	$$	✓✓	⌛⌛
Ag/Irrigation	Drip/Trickle irrigation (for select crops)	💧💧	$$	✓✓	⌛⌛⌛
Golf Courses	Soil moisture monitoring	💧💧	$$	✓✓	⌛
Industrial	Water reuse and recycling	💧💧	$$	✓	⌛
Industrial	Water efficient processes	💧💧	$$	✓✓	⌛⌛
Industrial	Drought management best practice collaboration	💧💧	$$	✓	⌛

Sector	Strategy	Benefit	Cost	Implement-ability	Time
Municipal	Reclaimed water programs	💧💧	$$$	✓✓✓	⌛⌛
Golf Courses	Low-water use landscaping	💧💧	$$$	✓✓	⌛
Thermoelectric	Switch to combined-cycle natural gas	💧💧	$$$	✓✓✓	⌛⌛⌛
***Demand-side strategies not ranked by the RBC**					
Municipal	Residential water audits	💧	$	✓✓	⌛⌛
Municipal	Car wash recycling programs	💧	$	✓	⌛
Ag/Irrigation	Soil moisture sensors/smart irrigation	💧	$	✓✓	⌛⌛
Industrial	Low flow fixtures, toilets, and appliances	💧	$	✓	⌛
Thermoelectric	Energy saving appliances*	💧	$	✓✓	⌛⌛
Municipal	Xeriscaping	💧	$$	✓✓✓	⌛⌛
Ag/Irrigation	Grass buffers to prevent runoff	💧	$$	✓✓	⌛
Golf Courses	Wetting agents to reduce water use	💧	$$	✓	⌛⌛
Ag/Irrigation	Crop selection	💧	$$$	✓✓✓	⌛⌛⌛

**Due to the large number of demand side strategies, only those that received a benefit score of two or three were considered by the RBC in the ranking process described in Section 7.1.2. However, these strategies are often beneficial in other contexts and should not be dismissed or ignored.*

Table 7-3. Supply-side strategies for surface water.

Sector	Strategy	Benefit	Cost	Implement-ability	Time
New or Increased Storage	New impoundments, ponds, reservoirs, tanks	💧💧💧	$$$	✓✓	⌛⌛⌛
New or Increased Storage	Dredging (pond deepening)	💧💧	$$	✓	⌛⌛
New or Increased Storage	Reservoir expansion (raising dam height)	💧💧💧	$$$	✓	⌛⌛⌛
New or Increased Storage	Aquifer storage and recovery	💧💧	$	✓✓	⌛⌛
Water Reclamation	Water reuse systems (non-potable)	💧💧	$$$	✓✓	⌛⌛
Water Reclamation	Direct potable reuse	💧💧	$$$	✓✓	⌛⌛⌛
Water Reclamation	Stormwater capture and treatment	💧💧	$$	✓	⌛⌛
Conjunctive Use	Using groundwater to augment surface water	💧💧💧	$$$	✓✓	⌛⌛⌛

Table 7-4. Supply-side strategies for groundwater.

Sector	Strategy	Benefit	Cost	Implement-ability	Time
New Supply	Drill new or supplemental wells into lesser-used aquifer formations	💧💧💧	$$	✓✓	⏳
New Supply	Desalination	💧💧	$$$	✓✓✓	⏳⏳⏳
Water Reclamation	Water reuse systems (non-potable)	💧💧	$$$	✓✓	⏳
Water Reclamation	Direct potable reuse	💧💧	$$$	✓✓	⏳⏳⏳
Water Reclamation	Reuse for aquifer storage and recovery	💧💧	$$$	✓✓✓	⏳⏳⏳
Conjunctive Use	Use surface water to supplement groundwater	💧💧	$$	✓✓	⏳⏳⏳
Conjunctive Use	Aquifer storage and recovery	💧💧	$$	✓✓	⏳
Conjunctive Use	Stormwater capture and use - potable	💧	$$	✓✓✓	⏳⏳⏳
Conjunctive Use	Stormwater capture and use - non-potable	💧	$$	✓✓	⏳⏳⏳

The initial scoring shown in Table 7-2 through Table 7-4 was used by the RBC to focus on high-impact strategies. Specifically, strategies that had the highest benefits (i.e., received a benefits score greater than or equal to two) and low costs were prioritized by the RBC using a Forced Ranking approach.

7.1.2 Preference Polling Using Forced Ranking

Forced ranking approaches can take various forms. The approach used for prioritization by the Pee Dee RBC is based on preferential voting methods by ballots (a ballot is simply a record of how a voter, in this case a workshop participant, voted). A preference ballot is utilized to provide a complete ranking of the river basin strategies, from most important to least important. The preference ballots are then converted into a preference schedule, which summarizes the results of all individual preferences.

A group of analytical methods are used to analyze and rank the data summarized in the preference schedule. Plurality, Borda Count and Pairwise Comparison are the three consensus methodologies used in the strategies prioritization. These methods are summarized below.

7.1.2.1 Plurality

Plurality involves prioritization based on the number of first-place rankings. The strategy with the most first-place votes is the highest priority. Plurality is the most intuitive but overly simplistic of the preferential voting methodologies. However, it is a useful starting point for developing consensus.

7.1.2.2 Borda Count

The Borda Count method provides points based on where strategies appear in a ranking. Each strategy gets one point for each last-place vote received, two points for each next-to-last-point vote, etc., up to N

points for each first-place vote (where N is the number of strategies). The strategy with the largest point total wins the election, or in this case, is considered the highest priority.

In the Plurality method, only the information related to first place is used (which contrasts with the Borda Count method, which uses all the information from the ballots). The Borda Count approach gives greater importance to the voter's lower preferences and favors strategies with broad consensus. The tradeoff, however, is that the highest-ranked strategy may not be any single voter's highest priority.

7.1.2.3 Pairwise Comparison

In the method of Pairwise Comparisons, each strategy is matched one-on-one with each of the other strategies. Each strategy gets one point for a one-on-one win and half a point for a tie. The results of the one-on-one competitions are transferred to a preference table, and the strategy with the most total points is the highest priority.

The method of Pairwise Comparisons was explicitly designed to satisfy the "fairness criterion" in preference voting. Any strategy that wins all possible head-to-head matchups always has a higher point total than any other strategy and thus is declared the winner. Copeland's Method is utilized for the method of Pairwise Comparison performed in this prioritization effort.

7.1.3 Aggregation of Rankings

The results of the three preferential voting methods were summarized as shown in Figure 7-1 through Figure 7-3. The results for Borda Count and Pairwise Comparison are described as a "ranking," with a rank of "1" most preferred and higher rank numbers less preferred. Conversely, the Plurality process counts the number of top votes, so a higher value is seen as more preferred. The figures below illustrate general consistency among the most preferred strategies across all three methods.

Figures 7-1, 7-2, and 7-3 focus on the highest priority water management strategies identified by the Pee Dee RBC. While some strategies were not highly prioritized, they are still viable and valuable in meeting local challenges or in specific situations.

Surface water and groundwater demand-side strategy rankings are shown in Figure 7-1. Below are observations on the data shown in Figure 7-1:

General

- Figure 7-1 focuses on the top eleven priority strategies.
- Leak detection and water loss control programs were ranked by the RBC as the highest priority demand-side water management strategies.
    - Other highly ranked strategies included updating water provider Drought Management Plans, establishing water efficiency standards for new construction, and developing landscape irrigation efficiency programs and codes.
- Public education on water conservation received several first-place rankings but it was not the highest priority strategy (though it is an important strategy and has a high priority relative to the full list of potential strategies).

Municipal

- Eight of the eleven highest priority demand-side water management strategies are in the municipal water sector.
- Many of the municipal water management strategies focus on the efficient use of water supplies. For example, water loss control, water efficiency standards, and time-of-day watering limits strive to minimize the amount of water sent to customers that does not meet its intended purpose.
- Reducing water use is another theme in the prioritized municipal water management strategies. Landscape codes and drought management strategies strive to reduce water uses that are not as beneficial as others.
- While public education on water conservation is a priority strategy and is generally focused on municipal water uses, it applies to other water sectors as well.

Industrial

- Three of the eleven highest priority demand-side water management strategies focus on industrial water uses.
- Like the municipal sector, industrial water management strategies focus on efficient use of water and reducing water demands during drought conditions.

Agricultural

- While agricultural water management strategies did not rank in the top eleven, they are important.
- The overall results of the prioritization process showed that conservation tillage/cover cropping, water audits and center pivot sprinkler retrofits, and irrigation scheduling programs were the top three agricultural water management strategies identified by the RBC. The prioritized agricultural strategies are beneficial regardless of water supply challenges (i.e., periodic low stream flows for surface water users, declining aquifer levels for groundwater users) because they can increase crop yields while reducing water use and cost.

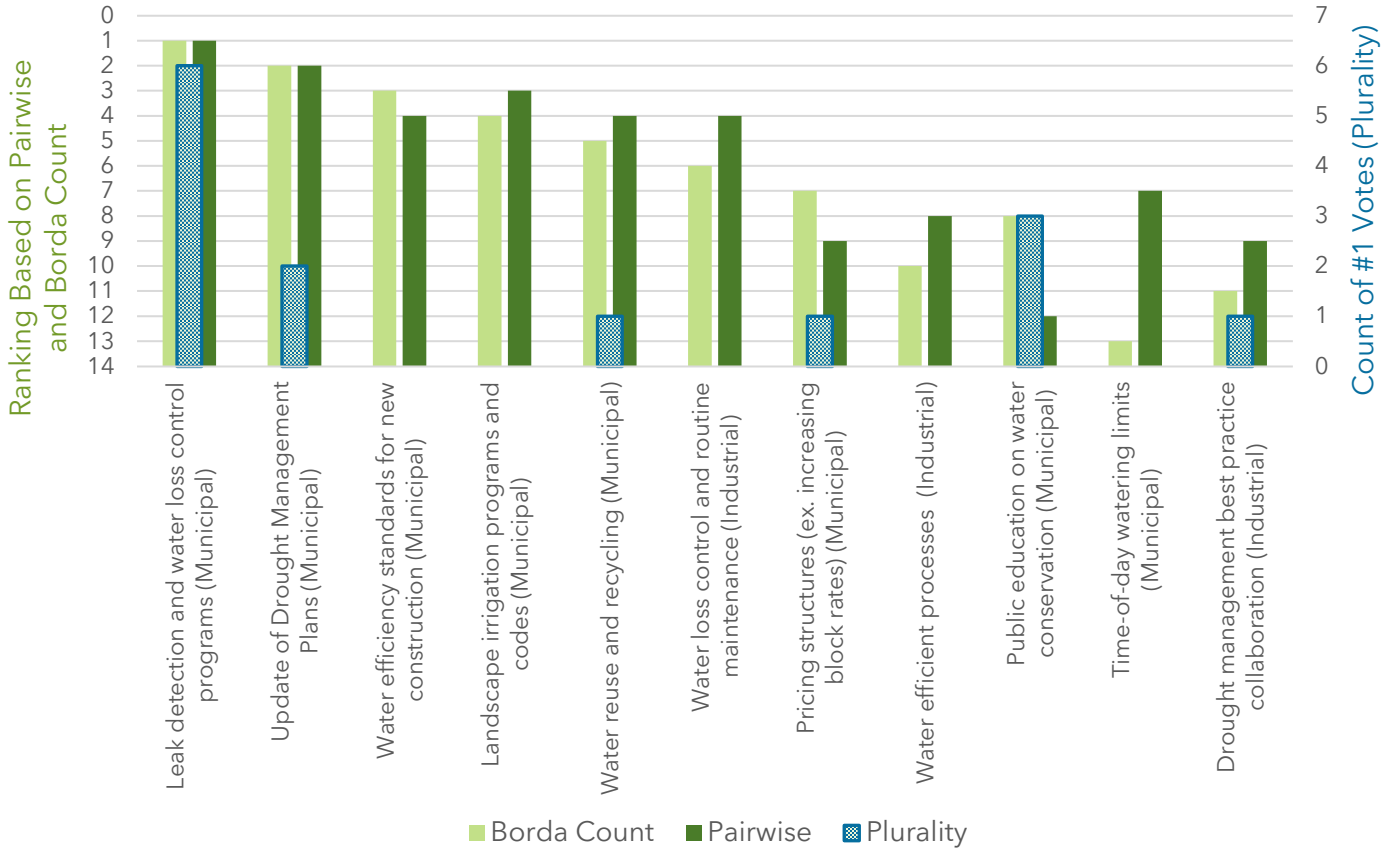


Figure 7-1. Demand-side surface water and groundwater strategy ranking comparison.

Surface water supply-side strategies and their prioritization by the RBC are shown in Figure 7-2. Below are observations on the results of the prioritization conducted by the RBC:

- Six of the eight supply-side surface water strategies were prioritized in a significant way through the RBC process.
- Using groundwater to supplement surface water supplies was the RBC's highest ranked

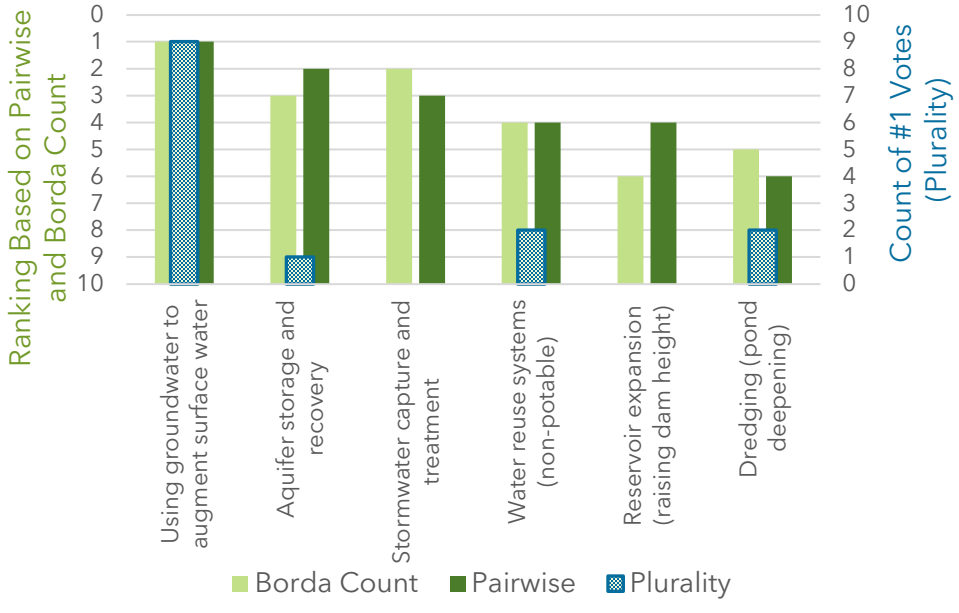


Figure 7-2. Supply-side surface water strategy ranking comparison.

priority followed by aquifer storage and recovery as well as stormwater capture and treatment.

- The three lower priority strategies in Figure 7-2 (which include water reuse, reservoir expansion, and pond deepening) were well-supported by the RBC.
- The priorities reflected a combination of strategies focused on conjunctive use of surface water and groundwater supplies, utilizing supplies that have historically not been beneficially used (i.e. wastewater and storm water), and increasing storage.
- The priorities suggest a willingness to consider innovative approaches to supply-side challenges. Conjunctive water management, utilizing stormwater, managed storage in aquifers, and reusing wastewater are strategies that have been developed and implemented in more recent time periods and offer opportunities to think in new ways about using all of the water supplies in a "one water" approach.

Groundwater supply-side strategies and their prioritization by the RBC are shown in Figure 7-3. Below are observations on the results of the prioritization conducted by the RBC:

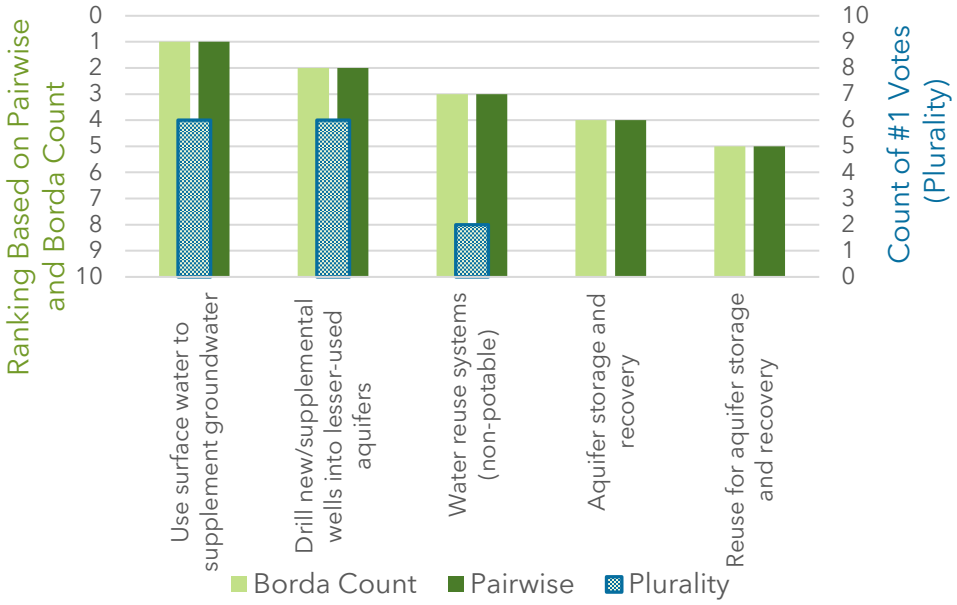


Figure 7-3. Supply-side groundwater strategy ranking comparison.

- Five of the nine supply-side groundwater strategies were prioritized in a significant way through the RBC process.
- Three supply-side groundwater strategies – using surface water to supplement groundwater supplies, drilling new wells, and reusing supplies to meet non-potable needs - were clearly prioritized by the RBC.
- Two prioritized strategies are focused on aquifer storage and recovery and are closely related. One of the strategies contemplates surface water supplies as the source of water for treatment and injection into groundwater aquifers and the other is focused on injecting treated reusable supplies (i.e. wastewater discharge) into aquifers.
- Water providers in the Pee Dee River basin have successfully implemented supply-side strategies focused on using surface water supplies to supplement groundwater and aquifer storage and recovery. The Pee Dee RBC anticipates that these strategies will be beneficial into the future but should be approached thoughtfully to prevent overuse of surface water supplies.

Additional Considerations on Water Management Strategies

The RBC noted that some strategies may not be useful or appropriate in certain geographic areas, and their feasibility may be driven by factors such as regulations and water quality.

- **Regulations:** Developing additional groundwater supplies in deeper, less-used aquifers or to supplement surface water may not be allowed depending on Capacity Use Area regulations.
- **Water Quality:** Water quality affects the feasibility of strategies focused on enhancing the conjunctive use of surface and groundwater supplies. A strategy that utilizes new sources of surface or groundwater supplies is only feasible if the quality of the surface or groundwater supply is adequate or could be sufficiently treated for its intended use.

7.2 Remaining Shortages

The surface water analyses described in Chapter 5 did not indicate any significant shortages that will need to be addressed using demand-side or supply-side surface water management strategies. The Current Use, Moderate, and High Demand planning scenarios all demonstrated no significant shortages and no ecological risk driven by future stream flow reductions. Additional details on the technical evaluation of the strategies and impacts on shortages are described in Chapter 6 in Section 6.2.

7.3 Remaining Issues Regarding Designated Reaches of Interest or Groundwater Areas of Concern

The Planning Framework defines Reaches of Interest as "specific stream reaches that may have no identified Surface Water Shortage but experience undesired impacts, environmental or otherwise, determined from current or future water-demand scenarios or proposed water management strategies" (SCDNR 2019). The Pee Dee RBC did not identify any Reaches of Interest.

The Planning Framework defines a Groundwater Area of Concern as "an area in the Coastal Plain, designated by a River Basin Council, where groundwater withdrawals from a specified aquifer are causing or are expected to cause unacceptable impacts to the resource or to the public health and well-being" (SCDNR 2019). The Pee Dee RBC identified areas around Florence County and along the coast in Georgetown and Horry counties as preliminary areas of concern due to observed cones of depression and potential groundwater risk. The Pee Dee RBC also recognizes that water providers in these areas have implemented water management strategies that have reduced groundwater supply risks. The Pee Dee RBC anticipated using the Coastal Plain Aquifer groundwater model to evaluate Groundwater Areas of Concern and explore potential water management strategies that could reduce future groundwater supply risks in these areas. Due to delays in updating the groundwater model, these analyses will be postponed until the model update is complete.

Chapter 8
Drought Response

8.1 Existing Drought Management Plans and Drought Management Advisory Groups

8.1.1 State Drought Response

Utilities in South Carolina are required to respond to drought conditions based on the requirements in the South Carolina Drought Response Act (Code of Laws of South Carolina, 1976, Section 49-23-10, et seq., as amended) (SCDNR 2009). The Act provided the state with a mechanism to respond to drought and stated that SCDNR will "formulate, coordinate, and execute a statewide drought mitigation plan." The Act also created the South Carolina Drought Response Committee (DRC), which is the committee "to be convened to address drought related problems and responses."

SCDNR developed four drought management areas (DMAs) within the state to both enable geographically specific drought mitigation measures and to prevent overly broad drought responses that ignore local conditions and challenges. The four DMAs are illustrated in Figure 8-1. The Pee Dee River basin spans the Northeast DMA and extends into part of the Central DMA.

The Governor appoints members from various sectors to represent each DMA within the DRC. The organizational entities involved in drought response in South Carolina are illustrated in Figure 8-2.



Figure 8-1. South Carolina Drought Management Areas.

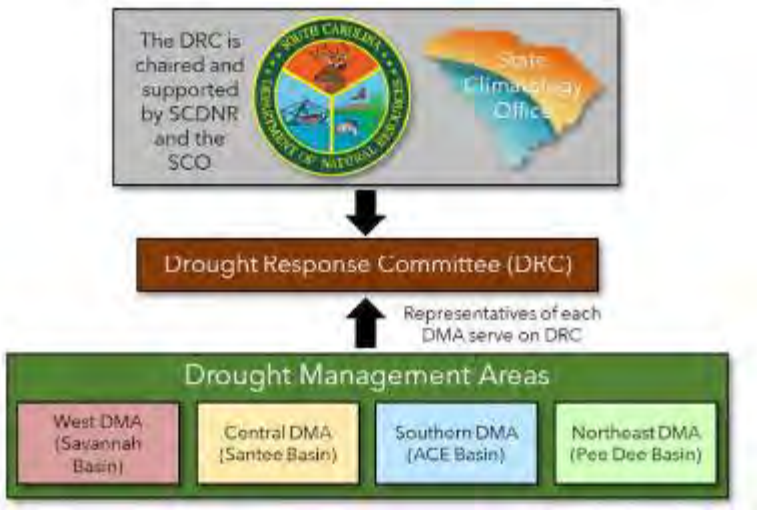


Figure 8-2. Drought Act organizational chart.

South Carolina has four drought alert phases: incipient, moderate, severe, and extreme. SCDNR and the DRC monitor a variety of drought indicators to determine when drought phases are beginning or ending. Examples of drought indicators include stream flows, groundwater levels, the Palmer Drought Severity Index, the Crop Moisture Index, the Standardized Precipitation Index, and the United States Drought Monitor. The South Carolina Drought Regulations establish thresholds for these drought indicators corresponding to the four drought alert phases. Declaration of a drought alert phase is typically not made based only on one indicator, rather a convergence of evidence approach is used. The need for the declaration of a drought alert phase is also informed by additional information including water supply and demand, rainfall records, agricultural and forestry conditions, and climatological data. SCDNR and the DRC coordinate the appropriate response with the affected DMAs or counties. Local drought response is discussed in more detail in the following section.

Details on South Carolina's drought management program are available at:

http://www.scdrought.com/

8.1.2 Local Drought Response by Public Water Utilities

Water utilities in South Carolina are required to have Drought Management Plans that meet the requirements of South Carolina drought regulations. The regulations require that drought response ordinances and plans include a minimum of the following information:

South Carolina drought regulations are available at:

http://www.scdrought.com/pdf/SCDroughtRegulations.pdf

1. A description of alternate supply sources, including time, costs, and problems associated with putting alternate sources on-line
2. A water use reduction plan and schedule for moderate, severe, and extreme drought for each category, as appropriate
3. An implementation plan and ordinance, as appropriate

The South Carolina Department of Natural Resources, per the requirements of the South Carolina Drought Management Act of 2000, developed a model Drought Management Plan and Response Ordinance to assist utilities in developing their own plans. The plans and ordinances reviewed in the Pee Dee River basin are consistent with the model plan and ordinance.

The elements of Drought Management Plans include the following:

- **Water system overview:** The water system layout and sources, system capacities, connections, and yields are described as well as the responsible representative for implementing the drought management plan.
- **Drought indicators for various phases:** Drought indicators are described for each of major drought phases – incipient, moderate, severe, and extreme drought phases. Note that most plans only cover the moderate, severe, and extreme phases, which are drought levels that result in mitigation measures.

- **Drought mitigation measures for each phase:** Plans summarize methods for mitigating drought impacts at each phase. Cooperative agreements and alternative water supply sources are described, along with pre-drought planning efforts, capital planning, and demand forecasting.
- **Drought Response Ordinance:** The actions that can be taken in each drought phase are included in the Drought Response Ordinance at the end of the Plan.

While each of the plans follow this same structure, the definitions for each drought phase and response actions can vary among the different plans.

A variety of plans in the Pee Dee River basin were reviewed to provide perspectives on the scope, triggers, and actions in the plans. Table 8-1 provides a list of the plans reviewed. Three water providers in the Pee Dee River basin use surface water, are in the SWAM model, and have drought management plans. These plans were reviewed along with a broad variety of other plans for water providers that do not use surface water. Detailed notes on the plans that were reviewed are provided in Appendix B.

Table 8-1. Water utility Drought Management Plans reviewed.

Entities Included in the Pee Dee SWAM Model	
City of Bennettsville	City of Florence
Town of Cheraw	
Sampling of Entities Not Included in the Pee Dee SWAM Model	
Marco Rural Water Company (Marion)	Marlboro Water Company
Cassatt Water Company	Town of Patrick
Chesterfield County Rural Water Company – Wolf Pond	Rural Community Water District of Georgetown County (RCWDGC)
City of Darlington	Georgetown County Water and Sewer District
City of Georgetown	Grand Strand Water and Sewer Authority
Lancaster County Water and Sewer District	City of Myrtle Beach
City of Sumter	Town of Kershaw
Trico Water Company	

Several additional water providers in the Pee Dee River basin have drought management plans, but they were not included in the sample of plans reviewed. Table 8-2 lists the water providers with plans that were not reviewed.

In total, 42 drought management plans were identified for water providers in the Pee Dee River basin. Table 8-1 identifies 18 plans that were summarized and are included in Appendix B, and Table 8-2 identifies an additional 24 plans that were not summarized.

Table 8-2. Additional Pee Dee River basin water providers with drought management plans.

Utility Names	
City of Bishopville	Town of Lamar
Town of Andrews	City of Lake City
Bethune Rural Water Company	Coward Water System
City of Conway	City of Manning
Bucksport Water System	Barrineau Public Utilities
High Hills Rural Water Company	City of North Myrtle Beach
City of Hartsville	Town of Olanta
Town of Heath Springs	Town of Pageland
Town of Hemingway	Town of Pamplico
Town of Jefferson	Darlington County Water and Sewer District
City of Johnsonville	Town of Turbeville
Town of Kingstree	Wallace Water Company

Additional information on drought management plans can be found at the link below:

http://www.scdrought.com/planning.html

While a total of 42 drought management plans are identified between Table 8-1 and Table 8-2, there are multiple communities that historically had drought management plans and have since transitioned to be served by other water providers. These communities include the Town of Timmonsville (which is now supplied by the City of Florence) as well as Latta, Mullins, Marion, and Little River Water and Sewage (which are now all supplied by GSWSA). Drought plans for these communities are now captured under the City of Florence and GSWSA.

8.1.2.1 Drought Phase Triggers

As stated above, the three commonly identified drought phases are moderate, severe, and extreme. The triggers for the three phases vary across the drought management plans reviewed and were determined by individual utilities based on their specific circumstances and water sources. Typical triggers are summarized below.

- **Committee based:** Droughts and drought phases are determined by the Drought Response Committee or the South Carolina Department of Natural Resources.
- **Demand based:** Phases are determined by specific increases in demand or specific water use levels for a specific period of time.
- **Streamflow based:** Phases are determined when streamflow falls below specific thresholds for specific periods of time. This method typically identifies prescriptive of flow rates for different months. Utilities serving coastal communities may include water quality criteria (i.e., conductivity).

- **Water level based:** Phases are determined when water in storage facilities or aquifers drop to specific levels for a specific period of time.
- **Storage index based:** Phases are determined based on the ratio of the Storage Index to the Target Storage Index.

8.1.2.2 Drought Phase Responses

Demand reduction strategies at various drought phases are largely consistent among utilities across the Pee Dee River basin. Most utilities implement a tiered, voluntary use reduction framework for moderate and severe droughts with a mandatory use reduction at the extreme drought phase. The most frequently used demand reduction strategy is summarized in Table 8-3.

Table 8-3. Typical demand reduction responses.

Drought Phase	Response
Incipient	None specified.
Moderate	Voluntary 20% reduction in residential use and 15% reduction in all other uses.
Severe	Voluntary 25% reduction in residential use and 20% reduction in all other uses. Note also mandatory restrictions for non-essential uses.
Extreme	Mandatory reduction of 30% for residential and 25% for all other uses.

Of the plans listed in Table 8-1 that were reviewed, only two in the Pee Dee River basin have a different reduction strategy (Lancaster County Water and Sewer District and the City of Myrtle Beach). While they use a tiered structure for water use reductions like other utilities, these two have different approaches to what is mandatory and voluntary and different reduction percentages.

8.1.2.3 Alternative Water Supply Agreements

Of the 18 Drought Management Plans reviewed, 12 utilities have alternative water supply agreements with other entities. The agreements identify other providers from which the utility may receive water, and in what scenarios and what quantities. This, in addition to the demand reduction strategies, represents another method of drought planning and resilience for the utilities in the Pee Dee River basin.

8.1.3 Local Drought Response in Other Sectors

Responding to droughts is important for public water supply utilities but also water uses in other sectors. Agriculture, industry, and energy producers pursue different response strategies when droughts occur, as described in this section.

8.1.3.1 Agricultural Response

Drought impacts agriculture in a variety of ways. For agricultural producers that do not irrigate, drought can cause lower crop yields, decreases in pasture productivity, and challenges to feeding livestock. Where feasible and affordable, irrigation provides a buffer for drought conditions and allows agricultural producers to maintain productivity during dry conditions, but if a drought is severe enough, water supplies for irrigation may be threatened.

Agricultural producers may respond to drought in several ways. Producers that lack irrigation systems may invest in them. As described in Chapter 2, during the severe 2002 drought, agricultural producers dug new wells to access groundwater supplies for irrigation. In some cases, producers may grow crops that require less water (if markets for those crops exist). For producers with irrigation systems, drought response oftentimes requires a greater use of irrigation supplies to maintain crop production and economic stability for farmers. If water supplies for irrigation become scarce, for example due to declining groundwater levels, irrigators may invest in higher efficiency systems, such as center pivots with low pressure nozzles or drip irrigation. Higher efficiency systems help minimize losses and provide water to crops when and where it is needed.

8.1.3.2 Industry Response

Industries use water for a variety of different purposes, and drought response may vary across industries based on production processes and available water supplies. In general, industry responds to drought in a way that helps minimize the financial impacts of decreased supply or increased costs of water. Also, while the Drought Management Act does not apply to industrial water users, SCDES regulates both water supply and discharge from industrial sources and requires best management practices (including drought management plans as necessary) to minimize impacts during droughts. Some industries may invest in water reuse technologies to reduce their water needs and long-term water costs while decreasing their vulnerability to drought conditions. In severe cases, some industries may need to cut production due to lack of supply needed for manufacturing processes or to maintain minimum supplies for critical needs like fire protection. Industries that produce their own energy to support their processes may need to reduce energy production and/or purchase energy from other providers. Finally, industries are regularly investing in water efficiency and conservation technologies as a way to reduce costs and risks, and these investments help them build resilience to the impacts of drought.

8.1.3.3 Energy Response

Hydropower production is an important industry that has a significant influence on flows in the Pee Dee River. As described in Chapter 3, Duke Energy Progress and Cube Yadkin Generation underwent FERC hydro relicensing processes culminating in issuance of new licenses in 2015 and 2016, respectively, that involved a wide variety of stakeholders and resource interests. An important outcome of those processes was the development of a Low Inflow Protocol (LIP). The LIP is a unified drought response mechanism for the hydropower facilities that takes staged actions and reductions in water use during periods of low inflow to avoid a condition in which usable water storage in the reservoirs is fully depleted. The LIP alone is not a cure for drought; however, it seeks to maintain downstream flows and provide time for drought conditions to subside and for precipitation to restore inflows and water levels in reservoirs.

The LIP has five stages of drought, and specific water management actions are implemented at each stage. Drought stages are determined using three indicators: the amount of water in the largest of the six involved lakes, High Rock Lake (in North Carolina); the water flowing into the river basin; and information from the U.S. Drought Monitor. Evaluations of these indicators are conducted monthly by North Carolina Department of Water Resources to determine drought conditions and if those conditions would trigger the LIP.

Monthly LIP Updates can be obtained at the following website:

https://www.duke-energy.com/community/lakes/drought-management-advisory/yadkin-pee-dee-dmag

The Yadkin-Pee Dee Drought Management Advisory Group (YPD-DMAG) assists in the implementation of the LIP. The YPD-DMAG consists of representatives from Duke Energy, Cube Yadkin Generation (formerly Alcoa Power Generating Inc.), several State agencies in South Carolina and North Carolina, the USFWS, homeowners' associations on the lakes, environmental advocacy groups, and public water supply systems.

Lake Robinson, located on Black Creek, is a 2,250-acre cooling reservoir for Duke Energy's Robinson Nuclear Plant, a 710-MW base-loaded facility. The plant has a drought management operating plan to manage lake levels during drought conditions while protecting the generating capabilities of the nuclear plant in compliance with the operating license issued by the Nuclear Regulatory Commission. The management plan outlines in a stepwise fashion, certain actions that are taken by the plant to manage lake levels depending upon drought severity and the resultant lake levels.

8.2 RBC Drought Response

8.2.1 Roles and Responsibilities

Under the Planning Framework, the RBC will support drought response, collect drought information, and coordinate drought response activities. With support of SCDNR and SCDES, the RBC will:

- Collect and evaluate local hydrologic information for drought assessment
- Provide local drought information and recommendations to the DRC regarding drought declarations
- Communicate drought conditions and declarations to the rest of the RBC, stakeholders, and the public
- Advocate for a coordinated, basin wide response by entities with drought management responsibilities (e.g., water utilities, reservoir operators, large water users)
- Coordinate with other drought management groups in the basin as needed

8.2.2 Communication Plan

The Pee Dee RBC will communicate drought conditions and responses within the basin through the RBC's elected Chair (or Vice Chair, if the need arises). If any part of the basin is in a declared drought as determined by the DRC, the RBC Chair will solicit input from RBC members and other water managers and users regarding drought conditions and responses in their respective locations or interests. The Chair is then responsible for communicating updates on drought conditions and responses within the basin to the Northeast or Central DMA representatives (as applicable) on the DRC or the State Climatology Office (SCO). The DRC has existing mechanisms to communicate and coordinate drought response with stakeholders and the public. Under Section 49-23-70 of the Drought Response Act, SCDNR is responsible for disseminating public information concerning all aspects of the drought.

Further communication channels may exist if a member of the Pee Dee RBC also serves on the DRC as a Northeast or Central DMA representative. This member may work with the RBC Chair (or Vice Chair) to directly communicate between the Pee Dee RBC and the DRC. At the time of this Plan's development, Lindsay Privette of the Pee Dee Regional Council of Governments serves as a Northeast DMA representative on the DRC.

The Pee Dee RBC will communicate and/or coordinate with water management groups that include a focus on the North Carolina portion of basin (i.e., the YPD-DMAG and the Yadkin-Pee Dee Water Management Group). In particular, communication and/or coordination could occur with the electric utilities (i.e. Duke Energy and Cube Hydro Carolinas) and with the LIP coordinated drought response by the Yadkin-Pee Dee DMAG, which includes SCDNR and SCDES in implementing the LIP.

8.2.3 Recommendations

Through consideration and discussion, the Pee Dee RBC developed the following five recommendations related to drought planning and response. Some of these recommendations are more policy-focused and some describe actions that the Pee Dee RBC can directly implement before and during droughts. The steps to implement these recommendations are detailed in the five-year and long-range implementation plans in Chapter 10.

8.2.3.1 Policy-level Recommendations:

1. The RBC recommends that water utilities review and update their drought management plan and response ordinance every 5 years, or more frequently if conditions change. Once updated, the plans should be submitted to the SCO for review. Changing conditions that could merit an update include:

- A change in the source(s) of water
- A significant increase in water demand (such as the addition of a new, large wholesale customer)
- A significant change in the proportion of water used by one sector compared to another (e.g., residential versus commercial use)
- The addition (or loss) of another user relying on the same source of water
- A new water supply agreement with a neighboring utility

2. When droughts occur, the RBC encourages water users and those with water interests to submit their drought impact observations through the Condition Monitoring Observer Reports (CMOR). The CMOR system, maintained by the National Drought Mitigation Center (NDMC), provides supporting evidence in the form of on-the-ground information to help the authors of the U.S. Drought Monitor better understand local conditions. The U.S. Department of Agriculture (USDA) uses the Drought Monitor to trigger disaster declarations and determine eligibility for low-interest loans and some assistance programs. The SCO also reviews and uses CMOR reports in a variety of ways.

CMOR reports can be submitted by clicking the "Submit a Report" button at the NDMC's Drought Impacts Toolkit website:

https://droughtimpacts.unl.edu/Tools/ConditionMonitoringObservations.aspx

3. The RBC recommends that industries continue and enhance information sharing on best practices for drought management. Industries tend to use water efficiently, because they strive to minimize costs associated with obtaining and utilizing water supplies. The RBC encourages industries to consider the best practices they use during droughts to save water and share that information with other industries. The intent of this collaboration is for industries to learn from one another and potentially implement additional or improve existing water saving practices.

8.2.3.2 RBC-level Recommendations:

4. The RBC recommends that a Drought Management Advisory function be created within the RBC. The RBC can directly participate in drought management, coordination, and mitigation by creating a subcommittee or other functional group or process to implement the recommendations listed in this subsection. The committee or group could also serve as an information source for communicating with industry during drought conditions and for connecting smaller communities with resources and information to help them update or develop drought management plans.

5. The RBC recommends that water utilities, when updating their drought management plan and response ordinance, look for opportunities to develop response actions that are consistent with those of neighboring utilities and improve resilience. While triggers are likely to be unique to each water utility based on their source(s) of water, coordination of response actions identified in their ordinance, to the extent practical, supports consistent messaging through the basin, and helps avoid confusion between customers. Also, utilities should reflect on the effectiveness of existing response actions and consider ways to improve responses (if needed) and increase drought resilience.

6. The RBC recommends that water utilities coordinate, to the extent practical, their drought response messaging. Drought messaging refers to both the content and the method or mechanism to deliver the message. Since that time, more targeted means to reach water customers have emerged, including e-mails, text messages, automated phone calls and social media. While the RBC recommends that coordinated messaging continue, the need to coordinate how the message is delivered has largely been eliminated because of the more effective outreach mechanisms. Coordination on the content of the messaging should continue through the standing, monthly meetings, and other means as appropriate.

7. The RBC recommends that value-added collaboration be conducted among members and stakeholders to investigate additional ways to mitigate drought-related risks. The RBC can conduct additional investigations and collaborative discussions with stakeholders to identify new strategies that could be implemented in the near term or be recommended during the next update to the River Basin Plan. Examples of value-added collaboration are described below:

- **Drought surcharges:** The RBC encourages water utilities in the basin to consider drought surcharges on water use during severe and/or extreme drought phases. Drought surcharges, when used, are typically only implemented if voluntary reductions are not successful in achieving the desired reduction in water use. In the Pee Dee River basin, several water utilities have already built into their response ordinance, the ability to implement drought surcharges during the severe and/or extreme drought phases. An example is described below:

The City of Bennetsville encourages all residential water customers to voluntarily reduce overall monthly water usage to 70 percent of the customer's monthly average. If voluntary reduction of usage is not successful, the City of Bennettsville may, at its option, implement the following excessive use rate schedule for water:

- Tier I 0 – 7,500 gallons/household/month regular rate
- Tier II 7,500 – 13,000 gallons/household/month 2 times regular rate
- Tier III Over 13,000 gallons/household/month 3 times regular rate

The City of Bennetsville may impose a drought surcharge per thousand gallons of water that increases with higher usage. The general principle behind the drought surcharge is that the fee is imposed on water use in excess of 7,500 gallon of normal monthly use. The drought surcharge is a temporary fee imposed during the current water supply shortage and is not a cost-based rate. The drought surcharge is temporary and will be terminated at such time as the City of Bennettsville determines the water supply is above the trigger levels.

- **Drought plan commonalities and vulnerabilities:** The RBC could initiate a review of drought management plans in the Pee Dee River basin to identify common drought mitigation strategies or vulnerabilities. Plans could be evaluated by the size of their water system or source(s) of supply to further categorize and evaluate vulnerabilities among similar systems. Observations on commonalities and vulnerabilities could be shared with water utilities and discussions could be initiated to explore ways to mitigate similar vulnerabilities using coordinated approaches.

Chapter 9
Policy, Legislative, Regulatory, Technical, and Planning Process Recommendations

During the fourth and final phase of the planning process, the Pee Dee RBC identified and discussed recommendations related to the river basin planning process, technical, and program considerations as well as policy, legislative, or regulatory considerations. Various recommendations were proposed by RBC members and discussed over the span of several meetings. The RBC considered the recommendations and prioritized them as described later in this chapter. The prioritization process and assessment of RBC input on water management strategies described in Chapter 7 was used to recommend policy, regulatory, technical, and planning process recommendations in this chapter.

The planning process recommendations are summarized in Section 9.1, technical and program recommendations are summarized in Section 9.2, and policy, legislative, and regulatory recommendations are summarized in Section 9.3. While all the recommendations in Chapter 9 are important, Section 9.4 highlights the technical and policy recommendations prioritized by the RBC.

9.1 River Basin Planning Process Recommendations

The following planning process recommendations should be taken into consideration for future planning process phases.

- The RBC (in conjunction with SCDES) should develop guidance and guidelines for processes to replace RBC members if current members resign, and to adjust member terms if necessary. They should develop best practices for recruiting new members.
- SCDES should organize an annual state-wide meeting of RBCs and State agencies.
- Public relations and communication strategies should be developed to educate the public on who the RBC is, what it does, and the benefits of participation. Strategies should focus on both the role of the RBC in planning and in implementation.
- Diversify meeting locations and include more field trips, if possible.
- The South Carolina Legislature should continue to fund state water planning activities, including river basin planning. Currently, nearly all the funding for the river basin planning process has come from the legislature.
- The RBC should establish a social media presence and use this to describe the river basin planning process to customers and/or the public during ongoing outreach, education, or training programs.

- RBC members should be encouraged to present observations and outcomes of the river basin planning process at conferences that focus on water resources, sustainability, environmental stewardship, smart growth, and other related topics.

9.2 Technical and Program Recommendations

Technical and program recommendations aim to address information or data gaps identified during the planning process. The following technical recommendations were identified by the Pee Dee RBC. To implement these recommendations, the Pee Dee RBC will need support from SCDNR, SCDES, and technical experts.

Members of the RBC proposed the following recommendations related to model improvements:

- **Surface water modeling should extend to coastal areas**: Current surface water models are limited to areas that are upstream of reaches influenced by tidal impacts. The RBC would like modeling and analysis tools that include these areas to provide information on potential water supply and water quality risks. This is especially important due to high projected population growth along the coast, the need for additional supplies to meet future demands in these communities, and declining local groundwater levels.
- **Improved calibration efforts**: Additional surface water gaging stations should be installed in headwater areas to better understand flow conditions and improve future model calibration. Similarly, additional groundwater monitoring should be installed in areas that may see development pressure in the future.
- **Groundwater modeling should be completed**: A groundwater model for the Pee Dee River basin was being developed by the USGS during creation of the River Basin Plan, but it was not completed by the time the Plan was published. The groundwater model will be a valuable tool for evaluating current and potential future groundwater supply risks.

Members of the RBC developed the following recommendations related to technical studies to improve knowledge of specific issues:

- **Data improvement**: RBC members discussed the need for more and/or higher quality data to inform better decision making. Potential areas for new or improved data include more rainfall and meteorological monitoring throughout the basin, more metering data to better understand per capita water use and water losses, more stream flow and groundwater monitoring locations. The RBC recommends conducting an assessment of data types, sources, and quality needed for better decision making, identifying data gaps, developing a strategy for implementing and funding data collection efforts, and distributing data to stakeholders.
- **Land protection**: Improve the understanding of land use and land protection by studying and developing a strategy for additional land protection. The RBC recommends studying the water quantity and quality impacts of land use changes.
- **Climate change and variability**: Climate variability may impact future water demands, water supplies, and hydrology and create water resource conditions that are unprecedented in historical

observations. The RBC recommends incorporating potential climate variability impacts to demand projections and hydrologic conditions in scenario planning.

- **Storm prediction**: More Doppler radar capabilities should be created to help with storm prediction and data collection.
- **Drivers of groundwater issues**: The drivers of unsustainable groundwater withdrawals (i.e. cones of depression), such as water demands, local aquifer conditions, and groundwater well spacing and pumping rates should be more thoroughly understood to better inform groundwater management strategies.
- **Reuse potential**: Water reuse and recycling is a recommended water management strategy in the Pee Dee River Basin Plan. To assess the potential for water reuse and recycling, the quantity of effluent from basin dischargers (both municipal and industrial) should be evaluated.
- **Water quality**: Surface water and groundwater quality is an existing and growing concern in the Pee Dee River basin. Future Pee Dee RBC planning efforts should consider water quality. Water quality in the Pee Dee River basin has been studied and modeled in the past, and future considerations of water quality in planning efforts should leverage prior work as appropriate. Also, existing water quality monitoring data (and data gaps) should be evaluated as water quality considerations are incorporated.
- **Flooding**: RBC members observed that flooding poses an important water-related risk that not only threatens life and property, but it also can impact the ability to provide reliable water supplies when and after a flood occurs. Future Pee Dee RBC planning efforts should consider flooding. The Pee Dee RBC should also consider communication with the Yadkin-Pee Dee Water Management Group to share information on flooding risk and management of upstream dams.

9.3 Policy, Legislative, or Regulatory Recommendations

The Pee Dee RBC engaged in discussion about issues and concerns with the existing policies, laws, and regulations governing water withdrawals and water use. Current regulations regarding surface water and groundwater withdrawals are summarized in Table 9-1 located at the end of this section. The Pee Dee RBC developed the following recommendations for modifications to existing state or local laws, regulations, or ordinances:

- The South Carolina Surface Water Withdrawal, Permitting, Use, and Reporting Act should allow for reasonable use criteria to be applied to all surface water withdrawals, like those that currently exist for groundwater withdrawal. For surface water withdrawals, reasonable use criteria vary depending on the water use category and the time of permit application (pre- or post-2011, when SCDES's regulation, 61-119 Surface Water Withdrawal, Permitting, Use and Reporting, came into effect).
- Surface water withdrawal registrations should be limited to actual need.
    - Existing (pre-2011) non-agricultural surface water withdrawers do not need to meet reasonable use criteria. The permitted withdrawal is based on the largest volume as determined by previously documented use, current treatment capacity, or designed capacity of the intake structure.



  - New (post-2011) or expanding non-agricultural surface water withdrawers must demonstrate that the requested water withdrawal amount meets the criteria for reasonable use.
  - Agricultural surface water withdrawals, all of which do not require a permit where there is remaining safe yield in a basin, do not need to satisfy reasonableness criteria for the requested withdrawal amount.

  Comparatively, under SCDES's regulation 61-113 Groundwater Use and Reporting, permittees of any use category seeking to withdraw greater than 3 million gallons in any month from groundwater must demonstrate to SCDES's satisfaction that groundwater withdrawal is reasonable and necessary and there are no unreasonable adverse effects on other water users.

- A cost share program should be developed to drill deeper wells into aquifer units with less development pressure.
- A joint compact or water management group should be established and funded that would focus on segments of the Yadkin-Pee Dee River basin that span North Carolina and South Carolina.
- Coastal community and tidal issues should be analyzed and considered in river basin planning.
- Policies should require water utilities to review and update their drought management plan and response ordinance every five years, or more frequently if conditions change. Policies should also require that updated plans be submitted to the State Climatology Office. When droughts occur, drought impact observations should be submitted through the CMOR.
- The South Carolina legislature should provide ongoing funding for plan implementation, including administration, technical evaluations, data collection and research, and providing grants to stakeholders for water projects. Funds should accommodate adequate State staff to provide dedicated, ongoing support for plan implementation.
  - A separate bureau or group within SCDES (or other department) that has staff dedicated to River Basin Plan implementation and updates should be established.
- The State should support and fund RBC-led and statewide water education programs that include all sectors of water use and promote the types of water management strategies recommended in River Basin Plans.
- SCDES should provide guidance on how RBCs should interface with other organizations.
- The State should fund an implementation organization in the future. Ideally, the implementation organization would be the RBC, but it could also be a watershed or issue-focused organization (e.g. focused on interstate water management, water conservation, or stakeholder assistance for funding acquisition and management).
- Water supply information should be considered when evaluating the feasibility of new industries.
- Larger private water utilities should create drought management plans and coordinate with public utilities that currently have a drought plan.
- Support the protection in perpetuity of habitat, particularly in the riparian corridors of the Pee Dee River basin. Priority sites contributing significantly to water quantity, quality, and or potential for enhancement of water quality should be identified and, where possible, protected by voluntary or purchased Conservation Easements or fee-title acquisition.

Table 9-1. Summary of regulations related to surface water and groundwater withdrawal.

Water Source	Use Type	User Type	Process	Applicability	Withdrawal Volume	Use Criteria	Low Flow Period Requirements	Review Period	Reporting
Surface Water	Agricultural	Existing (pre Jan 1, 2011)	Registration	Users withdrawing more than 3 MG in a month	Highest previous water usage	No criteria	No MIF obligations	No review, in perpetuity	Annual
		New (post Jan 1, 2011) or Expanding	Registration	Users withdrawing more than 3 MG in a month	Amount of water requested by the proposed withdrawer and availability of water at the point of withdrawal based on Safe Yield Calculations	Subject to safe yield assessment	No MIF obligations	No review, in perpetuity	Annual
	Hydropower	All	Exempt (non-consumptive use)						Annual
	All Other Use Types	Existing (pre Jan 1, 2011)	Permit	Users withdrawing more than 3 MG in a month	Largest volume as determined by previously documented use, current treatment capacity, or designed capacity of the intake structure	No criteria	Must address "appropriate industry standards for water conservation." Not subject to enforcement for MIF.	30 to 50 years[1]	Annual
		New (post Jan 1, 2011) or Expanding	Permit	Users withdrawing more than 3 MG in a month	Based on reasonableness, availability of water at point of withdrawal based on Safe Yield calculations.	Reasonable use criteria	Development of Contingency Plan for low flow periods, enforceable. Public water suppliers not subject to MIF[2]	20 to 50 years[1]	Annual

Table 9-2 (continued). Summary of regulations related to surface water and groundwater withdrawal.

Water Source	Use Type	User Type	Process	Applicability	Withdrawal Volume	Use Criteria	Low Flow Period Requirements	Review Period	Reporting
Ground-water	All Other Use Types	Withdrawals in Capacity Use Areas	Permit	Users withdrawing more than 3 MG in a month	Permit withdrawals based on reasonable use guidelines, which vary by water use sector.	Reasonable use criteria	Requires development of Best Management Plan that identifies water conservation measures, alternate sources of water, justification of water use, and description of beneficial use	Every 5 years	Annual
	All Other Use Types	Withdrawals Outside of Capacity Use Areas	Registration	Users withdrawing more than 3 MG in a month	Registrations do not have limits but require reporting.	No criteria	No MIF obligations	No review, in perpetuity	Annual

[1] New surface water permitees may receive permits of 20 years or up to 40 years as determined by department review
Existing surface water permittees may receive permits of 30 years or up to 40 years as determined by department review
Municipal or governmental bodies may receive permits of up to 50 years to retire a bond it issues to finance the construction of waterworks (SECTION 49-4-100)
[2] Public water suppliers not subject to MIF but are required to implement their contingency plan in accordance with drought declarations 49-4-150 6

9.4 Selection, Prioritization, and Justification for Technical and Policy Recommendations

The RBC used a multi-step scoring process to select and prioritize the technical and policy recommendations described in Sections 9.2 and 9.3 above. The scoring and prioritization process used by the RBC was the same as that used for water management strategies and described in Section 7.1 (see that section for more detail on the process and scoring). The RBC scored and prioritized technical and policy recommendations separately.

9.4.1 Prioritization of Technical Recommendations

Like the process for water management strategies, a preliminary scoring process was used to identify the technical recommendations with the highest impact, which tended to be those scored with high benefits and low cost. A set of preliminary scores was developed by the consulting team and was considered by the RBC during the scoring process. The preliminary scoring results are summarized in Table 9-2. Note that the number of symbols (i.e. water drops, dollar signs, check marks, and hour glasses) correspond to the scoring rubric described in Table 7-1 (See Chapter 7).

Table 9-2. Preliminary scoring of technical recommendations.

Strategy	Benefit	Cost	Implement-ability	Time
Future Pee Dee RBC planning efforts should consider water quality	💧💧	$$	✓✓	⌛⌛
Extend surface water modeling to coastal areas	💧💧💧	$	✓	⌛⌛
Install additional surface water gaging stations in headwater areas	💧	$$$	✓	⌛⌛
Install additional groundwater monitoring in future growth areas	💧	$$$	✓	⌛⌛
Study the water quantity and quality impacts of land use changes	💧💧	$$	✓	⌛⌛
Incorporate future climate change projections or hydrologic conditions in future scenarios	💧💧💧	$$	✓	⌛⌛⌛
Create more Doppler radar capabilities to help with storm prediction and data collection	💧💧	$$$	✓	⌛⌛
Future Pee Dee RBC planning efforts should consider flooding	💧💧💧	$$	✓✓	⌛⌛
Better understand the drivers of unsustainable groundwater withdrawals	💧	$	✓	⌛
Evaluate the quantity of effluent from dischargers to assess reuse potential	💧	$	✓✓	⌛⌛⌛

After the preliminary scoring process, the RBC further prioritized these recommendations using a forced ranking approach. More details on this approach are provided in Section 7.1.2.

The results of three preferential voting methods derived from the forced ranking were summarized for the top five of the ten technical recommendations as shown in Figure 9-1. The results for Borda Count and Pairwise Comparison are described as a "ranking," with a rank of "1" most preferred and higher rank numbers less preferred. Conversely, the Plurality process counts the number of top votes, so a higher value is seen as more preferred. Figure 9-1 illustrates general consistency among the preferred strategies across all three methods.

Figure 9-1 focuses on the highest priority technical recommendations identified by the Pee Dee RBC. While some recommendations were not highly prioritized, they are still viable and valuable for consideration by the State and stakeholders in the basin.

Below are observations on the voting results shown in Figure 9-1:

- Additional studies and extending technical analysis tools to consider coastal areas are highly supported by the RBC.
- Evaluating the water quantity and quality impacts of land use changes is another high priority for the Pee Dee RBC.
- The Pee Dee RBC strongly favored considering water quality and flooding impacts in future updates to the River Basin Plan.

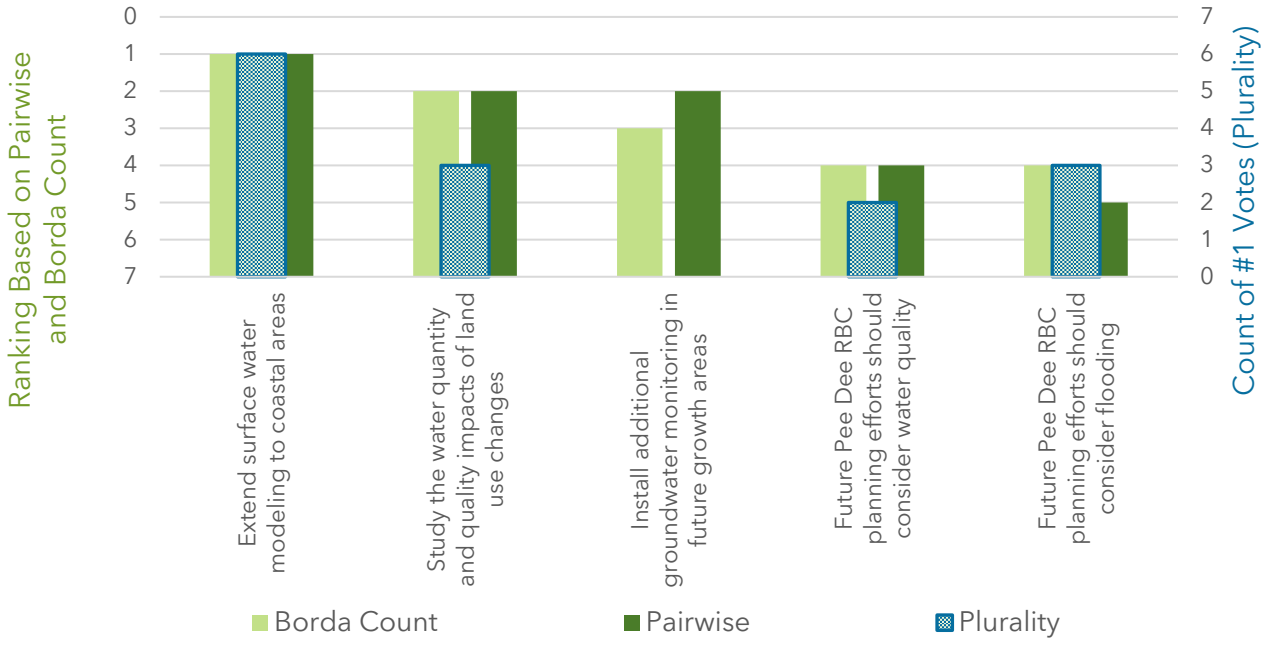


Figure 9-1. Technical recommendation ranking comparison.

Additional discussions by the Pee Dee RBC, which occurred after the prioritization process, centered on the need for good data and the importance of good data for making sound water management decisions. Several of the technical recommendations identified by the Pee Dee RBC focus on enhancing the amount and quality of data in the basin, and they include:

- Install additional surface water gaging stations in headwater areas.
- Install additional groundwater monitoring in future growth areas.
- Create more Doppler radar capabilities to help with storm prediction and data collection.
- While not a technical recommendation that was originally considered by the Pee Dee RBC, establishing a mesonet of weather stations was discussed and viewed favorably by the RBC. Specifically, the RBC discussed establishing at least one mesonet weather station in each county in the state to measure climate variables on a more consistent, comprehensive, and localized basis as a means for better drought monitoring and management as well as overall water resources management across sectors.

The Pee Dee RBC also discussed the importance of completing the groundwater model to help inform their understanding of current and potential future groundwater related risks and water management strategies to reduce risks.

9.4.2 Prioritization of Policy Recommendations

The same scoring process for technical recommendations was used for policy recommendations. The preliminary scoring process identified recommendations with the highest impact, which tended to be those scored with high benefits and low cost. A set of preliminary scores was developed by the consulting team and was considered by the RBC during the scoring process. The preliminary scoring results are summarized in Table 9-3. Note that the number of symbols (i.e. water drops, dollar signs, check marks, and hour glasses) correspond to the scoring rubric described in Table 7-1 (See Chapter 7).

Table 9-3. Preliminary scoring of policy recommendations.

Strategy	Benefit	Cost	Implement-ability	Time
Surface water withdrawal registrations should be limited to actual need	💧💧💧	$	✓✓✓	⌛⌛
Develop a cost share program to drill deeper wells into aquifer units that have less development pressure	💧	$$	✓✓	⌛⌛⌛
Fund a joint compact between SC and NC for the Yadkin-Pee Dee Basin	💧💧💧	$$$	✓✓✓	⌛⌛⌛
The State should fund an implementation organization in the future	💧💧💧	$$	✓✓	⌛⌛⌛
RBCs (where applicable) should consider coastal community (tidal) issues	💧💧💧	$	✓	⌛⌛
Water utilities should update their drought management plan and response ordinance every 5 years	💧💧	$	✓	⌛
Drought impact observations should be submitted through the Condition Monitoring Observer Reports (CMOR)	💧	$	✓	⌛
Provide ongoing funding for plan implementation (admin, tech, projects)	💧💧💧	$$$	✓✓	⌛⌛
Support and fund water education programs	💧💧	$$	✓✓	⌛⌛
Provide guidance on how RBCs should interface with other organizations	💧	$	✓	⌛
Use water supply information to evaluate the viability of new industries	💧	$	✓✓	⌛

After the preliminary scoring process, the RBC prioritized these recommendations using a forced ranking approach. More details on this approach are provided in Section 7.1.2.

The results of the three preferential voting methods derived from the forced ranking were summarized for policy recommendations as shown in Figure 9-2. The results for Borda Count and Pairwise Comparison are described as a "ranking," with a rank of "1" most preferred and higher rank numbers less preferred. Conversely, the Plurality process counts the number of top votes, so a higher value is seen as more preferred. Figure 9-2 illustrates general consistency among the most preferred strategies across all three methods.

Figure 9-2 focuses on the highest priority policy recommendations identified by the Pee Dee RBC. While some recommendations were not highly prioritized, they are still viable and valuable for consideration by the State and stakeholders in the basin.

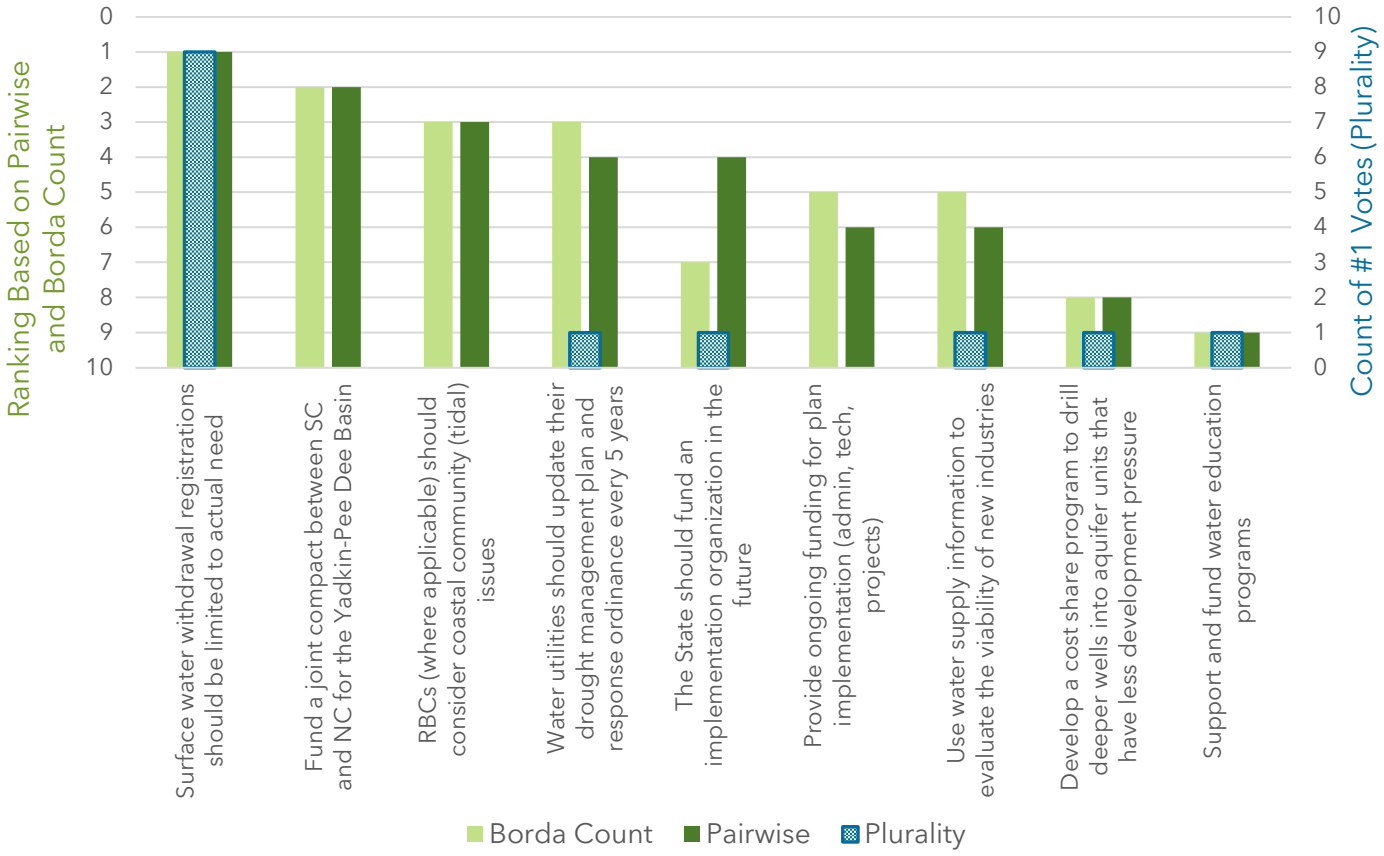


Figure 9-2. Policy recommendation ranking comparison.

Below are observations on the policy recommendations shown in Figure 9-2:

- The policy recommendation with the highest priority was that surface water withdrawal registrations should be limited to actual need. The high priority of this recommendation was very clear from the voting conducted by the RBC.
- While funding a joint compact between South Carolina / North Carolina and consideration of coastal community issues did not receive any #1 votes, they were well-supported by the RBC.



- Several policy recommendations were generally supported by the RBC and also received a #1 vote by five of the RBC members. These recommendations focus on updating drought management plans, state funding of an implementation organization, using water supply information to evaluate viability of new industry, funding for drilling wells into aquifers with less water use, and funding water education programs.
- The Pee Dee RBC prioritized and highly-supported several recommendations that focus on the continuation and implementation of the basin planning process (including funding an implementation organization, providing ongoing funding for implementation, and education programs). These recommendations will be critical for obtaining basin stakeholder buy-in and participation in the vision and implementation of the Pee Dee River Basin Plan.

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Chapter 10
River Basin Plan Implementation

10.1 Recommended Five-Year Implementation Plan

10.1.1 Implementation Objectives

The Pee Dee RBC identified five overall implementation objectives for the Pee Dee River Basin Plan, and they are listed in Table 10-1. The objectives were developed based on RBC input throughout the river basin planning process and the themes that emerged from the recommendations made in previous chapters. Objective 1, improve water use efficiency to conserve and sustain water supplies, was derived from prioritized demand-side water management strategies described in Chapter 6 and recommended in Chapter 7. Objective 2, implement one-water approaches to optimize sources of supply, recognizes the need to consider all sources of available water supply to meet current and future needs as described in Chapter 6 and recommended in Chapter 7. Objective 3, improve drought management, corresponds to drought-related recommendations in Chapter 8. Objective 4, broaden technical understanding of water resource issues, comes from recommendations in Chapter 9. Objective 5, effectively communicate RBC findings and recommendations, encompasses a variety of recommendations from Chapters 7, 8, and 9. The Planning Framework states that the RBC should prioritize the objectives. The Pee Dee RBC ranked three objectives as high priority and two objectives as medium priority. The justifications for each priority ranking are summarized in Table 10-1.

Table 10-1. Implementation objectives and prioritization.

Objective	Priority	Prioritization Justification
Objective 1: Improve water use efficiency to conserve and sustain water supplies	High	While significant shortages were not projected in the Pee Dee Basin, efficient water use helps create resilience for unforeseen challenges. Many efficiency improvements can lower costs to homeowners, industry, and agriculture; can sustain supplies; and can be pursued immediately.
Objective 2: Implement one-water approaches to optimize sources of supply	High	Where water supplies are stressed, conjunctive use of surface and groundwater can help meet demands more reliably and sustainably. Actions should be implemented proactively in areas of water stress.
Objective 3: Improve drought management	Medium	Maintaining up-to-date drought plans and effective communication are important for public water supplier response and to coordinate actions at a basin- and state-level.
Objective 4: Broaden technical understanding of water resource issues	Medium	The RBC identified a wide variety of technical issues that need additional investigation to better understand current or potential future issues and to inform strategies to mitigate water supply risks.
Objective 5: Effectively communicate RBC findings and recommendations	High	Support and participation from basin stakeholders is critical to achieve the vision of the Pee Dee River Basin Plan.

The strategies and corresponding actions to achieve each objective are presented in Table 10-2. Under each objective where applicable, strategies are listed by its priority for implementation. Table 10-2 also includes an outline of 5-year actions, responsible parties, budget, and potential funding sources to achieve each objective. The funding sources are further described in Section 10.1.2.

Implementation of strategies and actions will require funding for RBC meetings, consulting assistance, etc. The Pee Dee RBC will continually evaluate the priority of actions, specific steps for implementing actions, and timelines for implementation as funding becomes available in the future.



The Pee Dee River Basin Plan was developed collaboratively using the best available science
(Photo credit: JD Solomon)

Table 10-2. Implementation plan.

Strategy	Sector	Strategy Priority	5-Year Actions	Responsible Parties	Budget	Funding Sources
Objective 1: Improve water use efficiency to conserve and sustain water supplies						
A. Leak detection and water loss control	Muni. Ind.	1 (Muni.) 5 (Ind.)	1. Identify funding opportunities (yrs 1-5) 2. To the extent practicable, establish a baseline of residential per capita water use (recognizing that water meter and other data may not be complete) and identify ways that data could be improved (yr 1). 3. Implement an outreach and education program about recommended water management practices and funding opportunities (yrs 1-5) 4. Individual water users to implement conservation practices (yrs 2-5) 5. Develop survey of practices implemented for municipal and industrial users, funding issues, and funding sources utilized (beginning in yr 5 as part of 5-year Plan update) 6. Review and analyze per capita water usage to improve understanding of water savings of strategies (beginning in yr 5 as part of 5-year Plan update)	*RBC with support of SCDES, SCDNR, and contractors* - Identify funding opportunities and develop information to distribute. Conduct per capita water use investigation and surveys and analyze results. *Municipal and Industrial Withdrawers* – Implement appropriate strategies and seek funding as necessary.	Costs of implementation will vary by municipality according to current program capabilities and financial means. See Section 6.1.6 for discussion of cost and benefit of individual strategies. Cost of RBC support activities are included in on-going RBC meeting budgets.	Individual strategies to be funded using outside funding opportunities or by evaluating existing rate structures. Possible outside funding sources include: Fed-1, 2, 4, 5, 8, 9 and USDA-8 and 9.
B. Water efficiency standards for new construction	Muni.	2				
C. Landscape irrigation programs and codes	Muni.	3				
D. Water reuse and recycling	Muni.	4				
E. Pricing structures	Muni.	6				
F. Water efficient processes	Ind.	7				
G. Time-of-day watering limits	Muni.	8				

Note: The above strategies focus on RBC priorities as described in Chapter 7. The strategies are anticipated to have the greatest impact for the most people across the basin and center on the municipal and industrial water use sectors. The RBC also recognizes that improving water use efficiency is important across all water use sectors (including agriculture, golf courses, thermoelectric generation, etc.) both for reducing water costs and sustaining water supplies. The RBC encourages all water use sectors to implement water saving measures.

Table 10-2 (continued). Implementation plan.

Strategy	Strategy Priority	5-Year Actions	Responsible Parties	Budget	Funding Sources
Objective 2: Implement one-water approaches to optimize sources of supply					
A. Conjunctive use of surface and groundwater supplies	1	1. Identify funding opportunities (yrs 1-5) 2. Implement outreach and education program about recommended water management practices and funding opportunities (yrs 1-5) 3. Individual water users to implement new water supply practices as appropriate (yrs 3-5) 4. Develop survey of practices implemented, funding issues, and funding sources utilized (beginning in yr 5 as part of 5-year Plan update)	*RBC with support of SCDES, SCDNR, and contractors* - Identify funding opportunities and develop information to distribute. Conduct surveys and analyze results. *Water providers* - implement appropriate strategies and seek funding as necessary.	Implementation costs for individual water providers or users can vary significantly based on infrastructure needed for implementation. See Section 6.1.3 for discussion of cost/benefit. Cost of RBC support activities are included in ongoing RBC meeting budgets.	Fed-1, 2, 3, 4, 5, 8 and 9 Possible outside funding sources for agricultural water withdrawers include USDA-7
B. Drill new or supplemental well into lesser-used aquifers	2				
C. Water reuse systems (non potable)	3				
D. Aquifer storage and recovery	4				
E. Stormwater capture and treatment	5				
F. Dredging or pond deepening	6				

Table 10-2 (continued). Implementation plan.

Strategy	Strategy Priority	5-Year Actions	Responsible Parties	Budget	Funding Sources
Objective 3: Improve drought management					
A. Public water providers on RBC to update drought management plans	1	1. Public suppliers on the RBC to review, update, and improve their drought management plans, including their supporting water shortage response ordinances and send them to the SCO (yrs 1-5) 2. Public suppliers on the RBC to consider ways to incorporate RBC drought management recommendations into their drought plans and ordinances (yrs 1-5) 3. Updates to drought management plans and ordinances should be shared with the SCO (e-mailed to drought@dnr.sc.gov)	Public water suppliers in the RBC	Drought planning activities to occur within public suppliers' annual budgets.	Fed-6
B. Industry to collaborate on drought management best practices	2	1. With SCO and industry representatives on RBC, identify best practices for drought management by industries (yr 1) 2. Develop materials on best practices for drought management by industry (yr 2) 3. Develop outreach strategy to communicate with industry and distribute materials (yr 3) 4. Execute outreach strategy and update materials as necessary (yrs 3-5) 5. Develop a survey to identify practices implemented and benefits gained from outreach (yrs 3-5)	RBC with support of industry, SCO, SCDES, and contractors	No direct cost, other than ongoing contractor support, if needed. Cost of RBC activities are included in on-going RBC meeting budgets. Cost for industries may vary by organization, but are anticipated to occur within existing industry operating budgets	
C. Foster drought communications among stakeholders	3	1. Create Drought Management Advisory committee (yr 1) 2. Communicate with Yadkin-Pee Dee Water Management Group on drought issues before and when droughts occur (yrs 1-5) 3. Develop materials on benefits and implementation of RBC drought management recommendations (yr 2) 4. Develop outreach strategy to communicate with stakeholders and distribute materials (yr 3) 5. Execute outreach strategy and update materials as necessary (yrs 3-5) 6. Develop approach to track progress (yrs 3-5)	RBC with support of SCO, SCDES, and contractors	No direct cost, other than ongoing contractor support, if needed. Cost of RBC activities are included in on-going RBC meeting budgets.	Fed-6

Table 10-2 (continued). Implementation plan.

Strategy	Strategy Priority	5-Year Actions	Responsible Parties	Budget	Funding Sources
Objective 4: Broaden technical understanding of water resource issues					
A. Complete groundwater model	--	1. USGS to complete the Coastal Plain Groundwater Model, and RBC to develop a subcommittee that meets quarterly to monitor and inform the model completion process (yrs 1 and 2) 2. Use the model to identify current and potential future groundwater supply risks and water management strategies to mitigate risks (yrs 1 and 2)	USGS to complete model and conduct RBC-informed simulations	SCDES existing budget. Contractor work to support simulations may range from $15,000 to $30,000.	Funded by SCDES budget as available
B. Evaluate data gaps and needs	--	1. Research topics and geographic areas in which more data are needed make better water management decisions across all sectors of water use (yrs 1 and 2) 2. Create a data gap summary and identify strategies to fund the acquisition and distribution of new and better data (yr 2)	RBC with support of SCDES and contractors	SCDES existing budget. Contractor work on feasibility analysis may range from $25,000 to $50,000.	Funded by SCDES budget as available
C. Extend surface water modeling to coastal areas	1	1. Research potential analysis tools (yr 1) 2. Depending on the findings of the research, RBC to consider incorporating coastal analyses into future modeling as appropriate (beginning in yr 5 as part of 5-year plan update)			
D. Study the water quantity and quality impacts of land use changes	2	1. Invite RTI to educate the RBC on Catawba Wateree Water Management Group (CWWMG) land conservation modeling. (yrs 1-2) 2. Consider performing similar land conservation modeling to identify how land use changes may impact water resources (yr 3) 3. Conduct modeling (yrs 3-5)	RBC with support from SCDES, SCDNR, and contractors	SCDES existing budget. Modeling could range from $50,000 to $100,000.	Funded by SCDES budget as available

Table 10-2 (continued). Implementation plan.

Strategy	Strategy Priority	5-Year Actions	Responsible Parties	Budget	Funding Sources
Objective 4: Broaden technical understanding of water resource issues (continued)					
E. Install additional groundwater monitoring in future growth areas	3	1. Continue to monitor water levels in existing wells throughout Pee Dee River basin (yrs 1–5) 2. Identify, seek access to, and monitor water levels in existing production wells in groundwater areas of concern to confirm actual groundwater conditions (yrs 1–5) 3. Seek funding and drill new monitoring wells in current or preliminary groundwater areas of concern, as needed (yrs 1–5) 4. Conduct data analysis (analyze collected water level data) (yrs 1–5)	SCDES with potential support from USGS	Costs of monitoring existing wells are within SCDES budget. New monitoring wells and monitoring equipment may range from $10,000 to $50,000 depending on depth.	SCDES and potential USGS budgets as available
F. Consider water quality and flooding in future planning efforts	4, 5	1. RBC to first identify specific water quality and flooding issues and concerns in the basin (yrs 2-3) 2. RBC to develop approach to further address water quality and flooding issues and concerns (possibly using contractor assistance on technical aspects of approach). Water quality approach could include the need to develop a watershed plan under SCDES's Watershed Program. RBC to consider collaboration with Yadkin-Pee Dee Water Management Group regarding flood risk (yrs 4-5)	RBC with support from SCDES, SCDNR, and contractors	RBC costs are included in on-going meeting and support budgets. Contractor work could be $10,000 to $30,000 Development of watershed plans would come from SCDES's existing Watershed Program budget.	Fed-6 and 8

Note: Strategies under Objective 4 that do not have a priority were discussed by the RBC and added after the prioritization exercise described in Chapter 9.

Table 10-2 (continued). Implementation plan.

Strategy	Strategy Priority	5-Year Actions	Responsible Parties	Budget	Funding Sources
Objective 5: Effectively communicate RBC findings and recommendations					
A. Conduct Pee Dee RBC meetings to review, initiate, and support implementation actions	1	1. Pee Dee RBC to meet quarterly as needed following publication of Pee Dee River Basin Plan. Meetings will focus on implementation plan actions and identifying funding (yr 1) 2. Future RBC meetings on less frequent basis, as deemed necessary (minimum 1 per year) (yrs 2-5) 3. SCDES and/or contractors to provide new member orientation (yrs 1-5, on-going) 4. Convene existing or form new ad-hoc subcommittees to address time-sensitive matters (yrs 1-5 as needed)	RBC members to attend. SCDES and contractors to organize.	No direct cost, other than ongoing contractor support, if needed. Cost of RBC activities are included in on-going RBC meeting budgets. If contractor led, RBC meetings may range between $5,000 and $15,000 per meeting, depending on effort needed to prepare for, conduct, and document each meeting.	Funded by SC Legislature and Fed-8
B. Develop a communication plan early in the implementation process and conduct education and outreach	2	1. SCDES to provide guidance on how RBC should interface with other organizations (yr 1) 2. Develop a social media policy (yr 1) 3. Develop social media accounts for the Pee Dee RBC (yr 1) 4. Develop talking points/script to provide consistent message from RBC. Talking points will vary depending on media and whether communication is with public or elected officials/decision makers. Engage communication specialists to help with messaging (yrs 1-5) 5. Track which representatives have been spoken to and by whom from the RBC. Note any outcomes of conversation (yrs 1-5)	SCDES provides guidance on interfacing with other organizations. RBC with the support of contractors to develop talking points and track interactions. RBC to engage public via social media and meetings	No direct cost, other than ongoing contractor support, if needed. Cost of RBC activities are included in on-going RBC meeting budgets.	No direct cost

10.1.2 Funding Opportunities

Existing external funding sources may be leveraged to promote implementation of the objectives described in Section 10.1.1. For example, EPA's Water Infrastructure Finance and Information Act (WIFIA) program offers funding to support eligible water and wastewater infrastructure projects including those related to drought prevention, reduction, and mitigation. Other funding to support drought mitigation efforts may be available through the Federal Emergency Management Agency's Hazard Mitigation Grant Program (HMGP) or Building Resilient Infrastructure and Communities (BRIC) programs. Table 10-3 describes a wide variety of federal and state funding sources that could be used to implement River Basin Plan objectives. The USDA offers numerous programs for farmers and ranchers to reduce risk from drought or to restore land impacted by drought. Table 10-4 summarizes existing USDA funding sources.

In 2022 Congress passed the Inflation Reduction Act (IRA), which may provide additional funding to programs related to agricultural conservation. For example, of the $20 billion allotted to the USDA, Section 21001 of the IRA assigned $8.5 billion in addition to amounts otherwise available to an existing USDA program, the Environmental Quality Incentives Program (EQIP). EQIP pays for ecosystem restoration and emissions reduction projects on farmland and may be used for activities such as the purchase of seed for cover crops (one of the agricultural conservation strategies discussed in this plan). Annual obligations from the EQIP program through the Farm Bill have been approximately $1.1 to $1.5 billion from 2018 through 2023, with between $28 to $32 million allotted for projects in South Carolina in these years. Additionally, through the IRA, $8.45 billion was allotted to EQIP, $3.25 billon to the federal Conservation Stewardship Program, $1.4 million to the Agricultural Conservation Easement Program, and $4.95 billion to the Regional Conservation Partnership Program. The IRA indicates that activities funded by these programs must "directly improve soil carbon, reduce nitrogen losses, or reduce, capture, avoid, or sequester carbon dioxide, methane, or nitrous oxide emissions, associated with agricultural production" (Inflation Reduction Act 2022). Projects that provide water efficiency benefits in addition to these climate benefits may be eligible for funding under these programs. Section 30002 of the IRA also designated $837.5 million in funding to the Secretary of Housing and Urban Affairs for projects that improve energy or water efficiency for affordable housing (Inflation Reduction Act 2022).

In September 2022, $70 million in USDA "Partnerships for Climate-Smart Commodities" funding was invested in South Carolina's two land-grant universities, Clemson University and South Carolina State University, to promote "climate-smart" agricultural practices in South Carolina. The project will utilize a coalition of 27 entities to promote the program to farmers, with a focus on peanuts, leafy greens, beef cattle, and forestry. Most of the funding will go directly to growers to offset the costs of implementing conservation practices. There may be opportunities to leverage this new funding source to implement the agricultural conservation strategies recommended in this plan.

Table 10-3. Federal funding sources.

Funding Source Index	Program	Agency	Grant/Loan Funds Available	Description
Fed-1	U.S. Economic Development Administration (EDA) Grants	EDA	No limit (subject to federal appropriation)	EDA's Public Works Program and Economic Adjustment Assistance Program aids distressed communities by providing funding for existing physical infrastructure improvements and expansions.
Fed-2	Water Infrastructure Finance and Information Act	U.S. Environmental Protection Agency (EPA)	Up to 49 percent of eligible project costs (minimum project size is $20 million for large communities and $5 million for small communities)	A federal credit program administered by EPA for eligible water and wastewater infrastructure projects, including drought prevention, reduction, and mitigation.
Fed-3	Section 502 Direct Loan Program	USDA Rural Development	Loans based on individual county mortgage limits	Loans are available for wells and water connections in rural communities. Availability is based on community income.
Fed-4	National Rural Water Association Revolving Loan Fund	USDA Rural Utilities Service	$100,000 or 75% of the total project cost	Provides loans for predevelopment costs associated with water and wastewater projects and for existing systems in need of small-scale capital improvements.
Fed-5	Emergency Community Water Assistance Grants	UDA Rural Development	Up to $100,000 or $1,000,000 depending on the type of project	Offers grants to rural areas and towns with populations of 10,000 or less to construct waterline extensions; repair breaks or leaks; address maintenance necessary to replenish the water supply or construct a water source, intake, or treatment facility.
Fed-6	HMGP	Federal Emergency Management Agency (FEMA)	Variable	Provides funds to states, territories, tribal governments, and communities for hazard mitigation planning and implementation of mitigation projects following a presidentially declared disaster event.
Fed-7	Building Resilient Infrastructure and Communities	FEMA	Variable	Building Resilient Infrastructure and Communities will support states, local communities, tribes, and territories as they undertake hazard mitigation projects, reducing the risks they face from disasters and natural hazards.

Table 10-3 (continued). Federal funding sources.

Funding Source Index	Program	Agency	Grant/Loan Funds Available	Description
Fed-8	Planning Assistance to States	USACE	Variable – funding is 50% federal and 50% nonfederal	USACE can provide states, local governments, and other nonfederal entities assistance in the development of comprehensive plans for the development, use, and conservation of water resources.
Fed-9	Drinking Water State Revolving Fund	SCDES and SC Rural Infrastructure Authority	Congress appropriates funding for the Drinking Water State Revolving Fund that is then awarded to states by EPA based on results of the most recent Drinking Water Infrastructure Needs Survey and Assessment.	This program is a federal-state partnership aimed at ensuring that communities have safe drinking water by providing low-interest loans and grants to eligible recipients for drinking water infrastructure projects.

Table 10-4. USDA disaster assistance programs.

Funding Source Index	Program	Agency	Description
USDA-1	Crop Insurance	Risk Management Agency	Provides indemnity payments to growers who purchased crop insurance for production and quality losses related to drought, including losses from an inability to plant caused by an insured cause of loss.
USDA-2	Conservation Reserve Program Haying and Grazing	Farm Service Agency (FSA)	Provides for emergency haying and grazing on certain Conservation Reserve Program practices in a county designated as D2 or higher on the United States Drought Monitor, or in a county where there is at least 40% loss in forage production.
USDA-3	Emergency Assistance for Livestock, Honeybees, and Farm-Raised Fish Program	FSA	Provides assistance to eligible owners of livestock and producers of honeybees and farm-raised fish for losses.
USDA-4	Emergency Conservation Program	FSA	Provides funding and technical assistance for farmers and ranchers to restore farmland damaged by natural disasters and for emergency water conservation measures in severe droughts.
USDA-5	Emergency Forest Restoration Program	FSA	Provides funding to restore privately owned forests damaged by natural disasters. Assistance helps landowners carry out emergency measures to restore forest health on land damaged by drought disasters.
USDA-6	Farm Loans	FSA	Provides emergency and operating loss loans to help producers recover from production and physical losses due to natural disasters and can pay for farm operating and family living expenses.
USDA-7	Environmental Quality Incentives Program	FSA	Provides agricultural producers with financial resources and assistance to plan and implement improvements on the land in support of disaster recovery and repair and can help mitigate loss from future natural disasters. Assistance may also be available for emergency animal morality disposal from natural disasters.
USDA-8	Emergency Watershed Program (Recover)	Natural Resources Conservation Service	Offers vital recovery options for local communities to help people reduce hazards to life and property caused by droughts.
USDA-9	Emergency Community Water Assistance Grants	Rural Development	Offers grants to rural areas and towns with populations of 10,000 or less to construct waterline extensions; repair breaks or leaks; address maintenance necessary to replenish the water supply; or construct a water source, intake, or treatment facility.

10.1.3 Implementation Considerations

The Pee Dee RBC may encounter challenges with respect to implementation of the identified strategies. Potential challenges are listed and described below:

- **Funding**: Procuring sufficient and stable funding sources to implement strategies was identified by the RBC as a significant challenge. Water withdrawers may not have the financial capacity to pursue recommended strategies to achieve implementation of Objectives 1 and 2, either due to limited ability to increase water rates or limitations in external funding source availability. Agricultural and industrial water withdrawers similarly may have limited financial resources to implement expensive conservation or augmentation strategies. Identifying and pursuing new funding opportunities are time consuming endeavors that may lead to delays in implementation. Therefore, it is critical to identify immediately available funding opportunities, support funding applications, and investigate new funding sources to facilitate the implementation of strategies recommended under Objectives 1 and 2. Identifying stable funding sources is also important so that stakeholders are assured that funding will be available at predictable amounts into the future.
- **Stakeholder Acceptance**: The RBC has no authority to enforce recommendations in the basin, and implementation of many of the recommended strategies therefore require cooperation and acceptance from stakeholders. To address this, the RBC will develop and execute an outreach plan, including data to justify recommendations and strategies. The RBC will develop content relevant to various water sectors in the basin, including municipal, agricultural, industrial, energy, and golf course water users.
- **Support for the River Basin Planning Process:** Success of the River Basin Plan is dependent upon continued support for the South Carolina river basin planning process. Knowing this, the RBC developed and prioritized policy recommendations (see Chapter 9) that focus on the need for the State to fund an implementation organization in the future and to fund implementation of the River Basin Plan. The implementation organization would ideally be the Pee Dee RBC, though it could also take on other forms, such as a watershed stakeholder group or interstate water management advisory council.
- **Staff and Resource Capacity:** Implementation will need to be supported by South Carolina, but the Pee Dee RBC anticipates that the State will need additional staff capacity and resources focused and dedicated to implementation of River Basin Plans across the basins.
- **External Communications**: Guidance is needed to help direct how communications with outside groups should be conducted, what should be said, and who should be involved. Also, social media has been identified as an effective tool for communicating with the public; however, there is uncertainty surrounding who would be responsible for maintaining accounts. Running a social media account involves developing and vetting content, posting, engaging with other accounts, and providing oversite on account engagement. If a member of the RBC were to run the accounts, procedures would be required to vet and ensure content represents a broad perspective, and not only that of the account manager.
- **Continued RBC Meetings:** The Plan's success hinges on continued activity from the RBC to foster implementation of the strategies developed in this Plan. Rather than seeing the RBC as a stagnant planning body, the Planning Framework describes it as "actively engaged in promoting the implementation of the recommendations proposed" and "will continue to meet on a periodic basis

to pursue River Basin Plan implementation activities as needed" (SCDNR 2019, p. 90). The Pee Dee RBC has identified quarterly meetings as desirable in the first year after publication of the River Basin Plan to pursue funding and implementation. After the first year, meetings may be held less frequently as needed.

- **Consensus Framework:** As the RBC makes decisions related to implementation, the RBC should build consensus where possible and document alternative points of view when consensus is not possible. Full consensus on every issue is an unrealistic goal, but the RBC should have a process to discuss, revisit, and document issues from this and later planning phases that are marked by alternative or opposing points of view.
- **Clarity of Responsibilities:** The implementation plan identifies responsible entities for each short-term action, but as implementation is carried out, clear responsibilities should be established and communicated to minimize confusion and foster efficient work.

10.2 Long-Term Planning Objectives

The Pee Dee RBC's objectives described in Section 10.1 represent both short-term and long-term objectives. For each objective, short-term strategies are discussed in Section 10.1 and long-term strategies are presented below in Table 10-5.

Table 10-5. Long-term planning objectives.

Objective and Strategy	Long-Term Strategy
Objective 1: Improve water use efficiency to conserve and sustain water supplies	
All strategies	Continue short term goals. Adjust recommended actions based on water savings realized. Seek additional funding sources. Explore new technologies and incorporate into recommendations as appropriate. Continue to monitor and assess drivers of future water demand (e.g., climate change, population increases, new industries) and identify potential disruptors that could create supply shortages and the need for more aggressive water management.
Objective 2: Implement one-water approaches to optimize sources of supply	
A. Conjunctive use of surface and groundwater supplies	Continue short term goals. Continue to monitor sources of supply to assess potential for overuse. Understand the upper limit of demands that could be met with supplies in various regions of the basin.
B. Drill new or supplemental well into lesser-used aquifers	
C. Water reuse systems (non potable)	Continue short term goals.
D. Aquifer storage and recovery	Continue short term goals. Monitor implementation of strategies and incorporate lessons learned into recommendations as appropriate.
E. Stormwater capture and treatment	
F. Dredging or pond deepening	Continue short term goals.

Table 10-5 (continued). Long-term planning objectives.

Objective and Strategy	Long-Term Strategy
Objective 3: Improve drought management	
A. Public water providers on RBC to update drought management plans	Continue short-term goals. Monitor progress towards increasing the number of up-to-date or new (within last 5 years) drought management plans and implemented best practices in the basin.
B. Industry to collaborate on drought management best practices	
C. Foster drought communications among stakeholders	Continue short-term goals.
Objective 4: Broaden technical understanding of water resource issues	
A. Complete groundwater model	Update groundwater model as needed and use it to identify potential groundwater issues and inform management strategies
B. Evaluate data gaps and needs	Use new/improved data to make more informed water management decisions across all water use sectors
C. Extend surface water modeling to coastal areas	Incorporate modeling and findings into next 5-yr Plan update
D. Study the water quantity and quality impacts of land use changes	Incorporate land use projections and recharge impacts into future modeling efforts. Revise future strategy recommendations based on study results and modeling.
E. Install additional groundwater monitoring in future growth areas	Continue short-term goals. Monitor number of active monitoring locations in the basin and the results of monitoring.
F. Consider water quality in future planning efforts	Adopt approach recommended through short-term activities into the next 5-yr Plan update.
G. Consider flooding in future planning efforts	
Objective 5: Effectively communicate RBC findings and recommendations	
A. Conduct Pee Dee RBC meetings to review, initiate, and support implementation actions	Maintain regular meeting schedule to encourage continuity between various iterations of RBC membership.
B. Develop a communication plan early in the implementation process and conduct education and outreach	Continue regular communication to emphasize the ongoing work and impacts of the RBC.

10.3 Progress of River Basin Plan Implementation

The Framework proposes the development of progress metrics to assess the degree to which River Basin Plan recommendations and strategies are successfully being adopted and implemented across the Pee Dee River basin. A progress metric is a "benchmark used to monitor the success or failure of an action taken by an RBC" (SCDNR 2009). Noting that the ultimate value and impact of the river basin planning process is the dissemination of its findings and implementation of its recommendations, the Pee Dee RBC developed progress metrics around each of the five implementation objectives defined at the beginning of this chapter. The progress metrics are:

1. Improve water use efficiency to conserve water resources

   Metric 1a: Municipal and agricultural water conservation and efficiency strategies are considered, evaluated, and implemented. On the municipal side, a 5-year reduction in residential per capita demand is realized and water utility financial strength is maintained.

   Metric 1b: Funding opportunities are identified and used to implement strategies.

2. Implement one-water approaches to optimize sources of supply

   Metric 2a: Supply-side, one-water approaches are considered in long-range planning by water users and are proactively implemented (as opposed to reactive implementation in response to a crisis).

   Metric 2b: Funding opportunities are identified and successfully used to implement supply-side strategies.

3. Improve drought management

   Metric 3a: One hundred percent of public water suppliers' drought management plans are updated within the last 5 years and submitted to the SCO for review.

   Metric 3b: Drought-related best practices for industry are identified and shared with industry.

4. Broaden technical understanding of water resource management issues

   Metric 5a: A process is developed for extending surface water modeling and/or analyses to consider coastal areas.

   Metric 5b: The RBC has become familiar with the study in the Catawba River basin that assessed the relative impacts of climate and land use change on water supply resiliency and considered the value of a similar study in the Pee Dee River basin.

   Metric 5c: Water quality issues and concerns in the basin are identified and a strategy to study approaches to address them is developed.

   Metric 5c: Flood-related issues and concerns in the basin are identified and a strategy to study approaches to address them is developed.

5. Effectively communicate RBC findings and recommendations

   Metric 4a: Within 2 years, the RBC has presented the Pee Dee River Basin Plan to all County Councils that are within the basin and requested their feedback and ideas for future study.

   Metric 4b: Within 2 years, the RBC has communicated with all of the basin's legislative representatives at the state level regarding basin challenges and relevant policy recommendations.

This 2025 plan is the first for the Pee Dee River basin. Future 5-year updates will evaluate the Pee Dee RBC's performance relative to the progress metrics.

As noted throughout this plan, communication and the development of stakeholder buy-in is key to successful plan implementation. To develop stakeholder acceptance, RBC members, who are the ambassadors of the River Basin Plan, must have confidence in the planning process and outcomes. A key responsibility of RBC members, as defined in the Framework, is to regularly communicate with stakeholders to maintain a current understanding of RBC activities, the River Basin Plan, and emerging issues.

To assess each RBC member's confidence in the plan, the plan approval process dictates that there will first be a test for consensus on the Draft Pee Dee River Basin Plan. For the test of consensus, each member rates their concurrence with the plan using a five-point scale, as shown below:

1. Full Endorsement (i.e., member likes it).
2. Endorsement but with minor points of contention (i.e., basically member likes it).
3. Endorsement but with major points of contention (i.e., member can live with it).
4. Stand aside with major reservations (i.e., member cannot live with it in its current state and can only support it if changes are made).
5. Withdraw – Member will not support the draft river basin plan. The Planning Framework indicates that if a member votes 5 they will not continue working within the RBC's process and will leave the RBC. In practice, if a member votes 5 but wishes to remain engaged in future work of the RBC, the RBC has the discretion to vote on whether the member may remain on the RBC.

For the Final River Basin Plan, each RBC member votes simply to support or not support the plan. By indicating support, the member would be acknowledging his/her concurrence with the Final River Basin Plan and their commitment to support implementation of the plan. The results of the test for consensus of the Draft River Basin Plan and the RBC's votes on the Final River Basin Plan are shown in Table 10-6. The full results are included in Appendix C.

Table 10-6. Test of consensus results.

Test of Consensus Result	Number of RBC Members
Draft River Basin Plan	
1. Full Endorsement (i.e., member likes it).	11
2. Endorsement but with minor points of contention (i.e., basically member likes it).	8
3. Endorsement but with major points of contention (i.e., member can live with it).	0
4. Stand aside with major reservations (i.e., member cannot live with it in its current state and can only support it if changes are made).	0
5. Withdraw – Member will not support the draft river basin plan.	0
Final River Basin Plan	
Support	19
Does Not Support	0

Chapter 11
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Appendix A: Demand Projections

Table A-1. Current Water Demands, Consumptive Use, and Returns

Source	User	Use Category	Withdrawl (MGD)	Consumptive Use (%)	Consumptive Use (MGD)	Return (MGD)
Coastal Surface Water	Combined User Data	Agriculture	0.47	100.0%	0.47	0.00
Coastal Surface Water	Combined User Data	Golf	3.94	100.0%	3.94	0.00
Coastal Surface Water	Combined User Data	Industry	7.68	100.0%	7.68	0.00
Coastal Surface Water	Combined User Data	Water Supply	58.70	100.0%	58.70	0.00
Groundwater	Combined User Data	Agriculture	34.30	100.0%	34.30	0.00
Groundwater	Combined User Data	Aquaculture	0.00	100.0%	0.00	0.00
Groundwater	Combined User Data	Golf	1.50	100.0%	1.50	0.00
Groundwater	Combined User Data	Industry	9.40	100.0%	9.40	0.00
Groundwater	Combined User Data	Nuclear Power	1.00	100.0%	1.00	0.00
Groundwater	Combined User Data	Water Supply	65.70	100.0%	65.70	0.00
Groundwater (SWAM)	Bishopville	Water Supply	1.30	19.2%	0.25	1.05
Groundwater (SWAM)	Hartsville	Water Supply	1.23	5.1%	0.06	1.17
Groundwater (SWAM)	Lynchburg	Water Supply	1.38	94.8%	1.31	0.07
Groundwater (SWAM)	Manning	Water Supply	1.04	9.5%	0.10	0.95
Groundwater (SWAM)	Martek	Industry	1.07	73.1%	0.78	0.29
Groundwater (SWAM)	McCall Farms	Industry	0.65	5.8%	0.04	0.61
Groundwater (SWAM)	McColl	Water Supply	0.29	41.8%	0.12	0.17
Groundwater (SWAM)	Pilgrims Pride	Industry	0.50	43.9%	0.22	0.28
Groundwater (SWAM)	Sumter	Water Supply	11.25	19.4%	2.19	9.07
Surface Water (SWAM)	Atkinson	Agriculture	0.01	100.0%	0.01	0.00
Surface Water (SWAM)	Belger	Agriculture	0.00	0.0%	0.00	0.00
Surface Water (SWAM)	Bennettsville	Water Supply	2.17	19.9%	0.43	1.74
Surface Water (SWAM)	Black Crest	Agriculture	0.59	100.0%	0.59	0.00
Surface Water (SWAM)	Carolina Plantation	Agriculture	0.27	100.0%	0.27	0.00
Surface Water (SWAM)	Chapman	Agriculture	0.02	100.0%	0.02	0.00
Surface Water (SWAM)	Cheraw	Golf	0.13	100.0%	0.13	0.00
Surface Water (SWAM)	Cheraw	Water Supply	2.47	14.1%	0.35	2.13
Surface Water (SWAM)	Dargan	Agriculture	0.07	100.0%	0.07	0.00
Surface Water (SWAM)	Domtar	Industry	16.36	2.5%	0.41	15.95
Surface Water (SWAM)	Florence	Golf	0.06	100.0%	0.06	0.00
Surface Water (SWAM)	Florence	Water Supply	14.20	21.5%	3.06	11.14
Surface Water (SWAM)	Hanson (Brewer)	Mining	0.11	100.0%	0.11	0.00
Surface Water (SWAM)	Hanson (Jefferson)	Mining	0.04	85.0%	0.03	0.01
Surface Water (SWAM)	Hanson (Marlboro)	Mining	0.03	100.0%	0.03	0.00
Surface Water (SWAM)	HB Robinson	Nuclear Power	745.28	0.3%	2.02	743.26
Surface Water (SWAM)	Hinson	Agriculture	0.00	100.0%	0.00	0.00
Surface Water (SWAM)	Hinson2	Agriculture	0.00	0.0%	0.00	0.00
Surface Water (SWAM)	Hinson3	Agriculture	0.00	0.0%	0.00	0.00
Surface Water (SWAM)	Hinson4	Agriculture	0.00	0.0%	0.00	0.00
Surface Water (SWAM)	Hinson5	Agriculture	0.00	0.0%	0.00	0.00
Surface Water (SWAM)	IP (Georgetown)	Industry	30.77	30.9%	9.51	21.27
Surface Water (SWAM)	Irwin	Agriculture	0.02	100.0%	0.02	0.00
Surface Water (SWAM)	Lawson Turf	Agriculture	0.22	100.0%	0.22	0.00
Surface Water (SWAM)	Martin Marietta	Mining	0.04	85.0%	0.03	0.01
Surface Water (SWAM)	McDonald	Agriculture	0.01	100.0%	0.01	0.00
Surface Water (SWAM)	Nucor	Industry	3.21	92.2%	2.96	0.25
Surface Water (SWAM)	Oaklyn Plantation	Agriculture	0.00	0.0%	0.00	0.00
Surface Water (SWAM)	O'Tuel	Agriculture	0.22	100.0%	0.22	0.00
Surface Water (SWAM)	Richard Rogers	Agriculture	0.22	100.0%	0.22	0.00
Surface Water (SWAM)	Rogers	Agriculture	0.23	100.0%	0.23	0.00
Surface Water (SWAM)	Sonoco	Industry	12.63	34.0%	4.30	8.34
Surface Water (SWAM)	Sugar Hill	Agriculture	0.01	100.0%	0.01	0.00
Surface Water (SWAM)	Tolson	Agriculture	0.05	100.0%	0.05	0.00
Surface Water (SWAM)	Turf Connections	Agriculture	0.13	100.0%	0.13	0.00
Surface Water (SWAM)	WestRock	Industry	16.51	22.7%	3.74	12.77
Surface Water (SWAM)	White Plains	Golf	0.06	100.0%	0.06	0.00

Table A-2. Permitted and Registered Amounts for Current Water Users

Source	Owner	Permit or Registration	Use Category	Aquifer	Permit or Registration Amount (MGD)	Permit or Registration Amount (MGM)	Permit or Registration Amount (MGY)
Groundwater	3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.77	23.42	281.00
Groundwater	527	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.58	17.63	211.50
Groundwater	1001	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.11	3.33	40.00
Groundwater	#1 200 Pump Station	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.63	19.17	230.00
Groundwater	#1 WELL PUMP STATION	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch-Mcqueen Branch	2.52	76.58	919.00
Groundwater	#1WELL151TOP OF HILL	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch-Mcqueen Branch	2.52	76.58	919.00
Groundwater	#2 200 Pump Station	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.63	19.17	230.00
Groundwater	#2 WELL BY WOODS	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch-Mcqueen Branch	2.52	76.58	919.00
Groundwater	#3 BY TANK	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	2.52	76.58	919.00
Groundwater	#4WELL BY JEFFERSONS	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch-Mcqueen Branch	2.52	76.58	919.00
Groundwater	#5 WELL 145 BY TRANS	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	2.52	76.58	919.00
Groundwater	10 Mile Bay Farm Well #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.87	26.54	318.50
Groundwater	10 Mile Bay Farm Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.87	26.54	318.50
Groundwater	10 Mile Bay Farm Well #3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.87	26.54	318.50
Groundwater	10 Mile Bay Farm Well #4	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.87	26.54	318.50
Groundwater	2012 Cypress Rd	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.42	43.33	520.00
Groundwater	2052 Billie Dr/Wise Farm	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.70	21.42	257.00
Groundwater	30/29TH AV NORTH	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch-Mcqueen Branch	0.27	8.33	100.00
Groundwater	301 Firestation	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.34	40.91	490.90
Groundwater	31-113635 Well #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.77	23.42	281.00
Groundwater	31-113699 Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.77	23.42	281.00
Groundwater	313 Field	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.63	19.17	230.00
Groundwater	3892 Black River Rd		Agriculture	Crouch Branch	0.00	0.00	0.00
Groundwater	4"" Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.45	13.74	164.90
Groundwater	4"" Well 3HP	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.15	4.67	56.00
Groundwater	4""WELL 2HP	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.15	4.67	56.00
Groundwater	4""WELL 5HP	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.15	4.67	56.00
Groundwater	4009 Well #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.08	2.42	29.00
Groundwater	527 Big House	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.34	40.91	490.90
Groundwater	6 Inch Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.06	1.88	22.60
Groundwater	6""WELL 3HP	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.15	4.67	56.00
Groundwater	6""WELL 5HP	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.15	4.67	56.00
Groundwater	79 Cypress Rd	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.42	43.33	520.00
Groundwater	95 Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.45	13.74	164.90
Groundwater	Airport		Agriculture	McQueen Branch	0.00	0.00	0.00
Groundwater	Akins Farm Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.29	8.83	106.00
Groundwater	Ald 7th Cut	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	2.11	64.08	769.00
Groundwater	Alex's Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.13	4.08	49.00
Groundwater	Allen Road	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.10	3.00	36.00

Table A-2. Permitted and Registered Amounts for Current Water Users

Source	Owner	Permit or Registration	Use Category	Aquifer	Permit or Registration Amount (MGD)	Permit or Registration Amount (MGM)	Permit or Registration Amount (MGY)
Groundwater	Aluminum Gate #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.45	13.58	163.00
Groundwater	Aluminum Gate #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.45	13.58	163.00
Groundwater	Ammons #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.46	44.38	532.50
Groundwater	Ammons #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.46	44.38	532.50
Groundwater	Ammons #3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.46	44.38	532.50
Groundwater	Arcadian Shores	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.02	0.71	8.50
Groundwater	Ashland Cross Roads Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.14	4.17	50.00
Groundwater	Ashwood 1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.46	13.98	167.79
Groundwater	Ashwood/Green Lane	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.19	5.78	69.40
Groundwater	Ashwood/Lake Ashwood Rd	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.19	5.78	69.40
Groundwater	Atlantic Center	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.10	3.00	36.00
Groundwater	Austin Farm	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.19	5.92	71.00
Groundwater	Avery Lane	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.11	3.33	40.00
Groundwater	Bacon Hill Rd Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.32	9.75	117.00
Groundwater	Bad bump	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	3.70	112.67	1,352.00
Groundwater	Baker Farm #1 Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.28	8.44	101.30
Groundwater	Baker Farm #2 Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.28	8.44	101.30
Groundwater	Barn Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.34	40.91	490.90
Groundwater	Barnett Tract - 310	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.63	19.17	230.00
Groundwater	Batson Farm #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Surficial	0.75	22.92	275.00
Groundwater	Batson Farm #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.75	22.92	275.00
Groundwater	Bay Road Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.68	20.58	247.00
Groundwater	Bear Branch	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.07	2.17	26.00
Groundwater	Beatson Farm-Old Georgetown Rd	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.70	21.42	257.00
Groundwater	BELK #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.34	40.83	490.00
Groundwater	BELK #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.34	40.83	490.00
Groundwater	Bell	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.41	42.92	515.00
Groundwater	Berry 1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.28	39.00	468.00
Groundwater	Berry 2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.28	39.00	468.00
Groundwater	Beverly Creek Well No. 1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.18	5.34	64.12
Groundwater	Beverly Creek Well No. 3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.18	5.34	64.12
Groundwater	Biddle	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	3.70	112.67	1,352.00
Groundwater	Big Stuckey	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.20	36.58	439.00
Groundwater	Big Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.68	20.58	247.00
Groundwater	Bill Dingle	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	2.04	62.15	745.80
Groundwater	Billys	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.41	42.92	515.00
Groundwater	Blackswamp Rd	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.31	9.46	113.50
Groundwater	BLENHEIM WELL #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.38	11.68	140.16

Table A-2. Permitted and Registered Amounts for Current Water Users

Source	Owner	Permit or Registration	Use Category	Aquifer	Permit or Registration Amount (MGD)	Permit or Registration Amount (MGM)	Permit or Registration Amount (MGY)
Groundwater	BLENHEIM WELL #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.38	11.68	140.16
Groundwater	BLENHEIM WELL #3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.38	11.68	140.16
Groundwater	Bob Flemming	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.12	3.80	45.60
Groundwater	Bobo Newsome Rd Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.14	4.17	50.00
Groundwater	Bonanza Crossing @ Bloomville Rd		Agriculture	Crouch Branch	0.00	0.00	0.00
Groundwater	Boos House Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.68	20.58	247.00
Groundwater	Boots Branch Road	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.16	35.42	425.00
Groundwater	Boston Wells Road Well		Agriculture	McQueen Branch	0.00	0.00	0.00
Groundwater	Bottom Farm #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.07	2.00	24.00
Groundwater	Bottom Farm #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.07	2.00	24.00
Groundwater	Boxwood well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.25	7.50	90.00
Groundwater	Bradbury	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.36	10.83	130.00
Groundwater	Brick Church Well #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.33	10.17	122.00
Groundwater	Brick Church Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.33	10.17	122.00
Groundwater	Brick Church Well #3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.33	10.17	122.00
Groundwater	Bristow	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.04	1.29	15.48
Groundwater	Broadway Farm	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.75	22.92	275.00
Groundwater	Brunson	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	2.04	62.15	745.80
Groundwater	BULK'S BARN		Agriculture		0.00	0.00	0.00
Groundwater	Bunker Hill Road Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.14	4.14	49.70
Groundwater	Burgess Crossing Rd. Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.04	1.25	15.00
Groundwater	Burndown Well (JD Heriot Rd)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	3.70	112.67	1,352.00
Groundwater	Butler Scurry Rd.	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch-Mcqueen Branch	0.38	11.70	140.40
Groundwater	Canal Rd.	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.63	19.17	230.00
Groundwater	Cane Branch Circle	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.11	3.33	40.00
Groundwater	CARTER WELL #1 (Carter Melon)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.96	29.17	350.00
Groundwater	CARTER WELL #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.96	29.17	350.00
Groundwater	Carterville Highway-Chandler Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.16	5.00	60.00
Groundwater	CC #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.48	14.48	173.78
Groundwater	CC #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.48	14.48	173.78
Groundwater	CC Rd. Well		Agriculture	McQueen Branch	0.00	0.00	0.00
Groundwater	Cemetery Rd Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.34	40.91	490.90
Groundwater	Center Road	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.16	5.00	60.00
Groundwater	Center Road Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.11	3.33	40.00
Groundwater	CF #2 WELL PUMPSTAT	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	2.52	76.58	919.00
Groundwater	Chapman Home Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.26	7.83	94.00
Groundwater	Chavis Place	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch - Mcqueen Branch	0.06	1.78	21.36
Groundwater	Church Field	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.75	22.92	275.00
Groundwater	Clarendon Well #3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.24	7.33	88.00

Table A-2. Permitted and Registered Amounts for Current Water Users

Source	Owner	Permit or Registration	Use Category	Aquifer	Permit or Registration Amount (MGD)	Permit or Registration Amount (MGM)	Permit or Registration Amount (MGY)
Groundwater	Clubhouse Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.34	40.91	490.90
Groundwater	Clyde Black Well-Keels Road Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch-Mcqueen Branch	0.20	6.17	74.00
Groundwater	Cooper	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.28	39.00	468.00
Groundwater	Cousar well #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.45	13.58	163.00
Groundwater	Covington Field	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.15	4.67	56.00
Groundwater	Cow Pond Tract	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.82	25.00	300.00
Groundwater	Cribb #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.52	15.83	190.00
Groundwater	Cribb #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.52	15.83	190.00
Groundwater	Cribbs Well #2		Agriculture		0.00	0.00	0.00
Groundwater	Crosland #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.15	4.67	56.00
Groundwater	Curtis Mill Pond Rd. Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.19	36.33	436.00
Groundwater	D #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.34	40.83	490.00
Groundwater	D #3 well 2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.34	40.83	490.00
Groundwater	DABBS WELL		Agriculture		0.00	0.00	0.00
Groundwater	Dairy Pivot	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.52	15.88	190.50
Groundwater	Dalzell Cel	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	1.40	42.67	512.00
Groundwater	Dalzell Center	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.40	42.67	512.00
Groundwater	Deep Gravel Well 8""	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.03	1.00	12.00
Groundwater	Dells	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	2.11	64.08	769.00
Groundwater	Deschamps	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.58	17.63	211.50
Groundwater	Donaldson Rd Well #3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.08	2.40	28.80
Groundwater	Donna	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	3.70	112.67	1,352.00
Groundwater	DRIVEWAY		Agriculture		0.00	0.00	0.00
Groundwater	Dubose Field	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.17	5.25	63.00
Groundwater	Duck Pond	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.70	21.42	257.00
Groundwater	Eastern School Rd	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.28	8.42	101.00
Groundwater	Eastern School Rd/Hwy 527	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch-Mcqueen Branch	0.40	12.16	145.88
Groundwater	Eckley & Dickenson	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.95	28.83	346.00
Groundwater	Edwards	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.91	27.60	331.20
Groundwater	Egg & I Farm		Agriculture	McQueen Branch	0.15	4.56	54.70
Groundwater	Egg Plant		Agriculture	McQueen Branch	0.00	0.00	0.00
Groundwater	Eliason Road	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.20	6.17	74.00
Groundwater	Elliot/Hwy 527	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.52	46.08	553.00
Groundwater	Elmore 1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.49	15.03	180.30
Groundwater	Elmore 2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.49	15.03	180.30
Groundwater	Elmore 3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.49	15.03	180.30
Groundwater	Farm 1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	2.11	64.08	769.00
Groundwater	Farm 2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	2.11	64.08	769.00
Groundwater	Fats Well (Heriot Rd)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	3.70	112.67	1,352.00
Groundwater	Field 20 Pivot	WTR-Groundwater Withdrawal Registration	Agriculture	Mcqueen Branch	0.33	9.93	119.20
Groundwater	Fields Bridge Rd.	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.52	46.08	553.00

Table A-2. Permitted and Registered Amounts for Current Water Users

Source	Owner	Permit or Registration	Use Category	Aquifer	Permit or Registration Amount (MGD)	Permit or Registration Amount (MGM)	Permit or Registration Amount (MGY)
Groundwater	Flinns Rd Pivot	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.52	15.88	190.50
Groundwater	Forrest 6 Tower	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.85	25.83	310.00
Groundwater	Forrest Pond	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.85	25.83	310.00
Groundwater	Fox Mill	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.41	42.92	515.00
Groundwater	Frank Evans	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	2.11	64.08	769.00
Groundwater	FreeStates Road Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.14	4.30	51.60
Groundwater	Gamble New	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	2.04	62.15	745.80
Groundwater	Garland Dirt Rd.	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.34	40.91	490.90
Groundwater	Gass	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	3.70	112.67	1,352.00
Groundwater	Goodland Farms	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch-Mcqueen Branch	0.54	16.43	197.20
Groundwater	Goodson	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	3.70	112.67	1,352.00
Groundwater	Grain Bins	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.41	42.92	515.00
Groundwater	Grain Bins Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.29	8.83	106.00
Groundwater	Green Barn Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.11	3.20	38.40
Groundwater	Grice Buster Field	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.21	6.25	75.00
Groundwater	Hamer Farm Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.07	2.26	27.15
Groundwater	Hay Field	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.63	19.17	230.00
Groundwater	Hebron Church Farm Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.07	2.26	27.15
Groundwater	Herbert Lee Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.54	16.33	196.00
Groundwater	Herndon 1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.25	7.48	89.70
Groundwater	Hickory Grove Well #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.07	2.15	25.80
Groundwater	Hickory Grove Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.07	2.15	25.80
Groundwater	HIGHWAY 151 CF#4	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	2.52	76.58	919.00
Groundwater	HL	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.82	25.00	300.00
Groundwater	Hodge	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.45	13.74	164.90
Groundwater	Hodge Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.18	5.58	67.00
Groundwater	Hodges Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.36	10.83	130.00
Groundwater	Hog Barn	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	3.70	112.67	1,352.00
Groundwater	Home Farm Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.12	3.75	45.00
Groundwater	Home Place Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.66	20.00	240.00
Groundwater	Howzer	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	2.03	61.73	740.80
Groundwater	HP #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch-Mcqueen Branch	0.29	8.75	105.00
Groundwater	HP #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch-Mcqueen Branch	0.29	8.75	105.00
Groundwater	Hudson Back	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.91	27.60	331.20
Groundwater	Hudson Front	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.91	27.60	331.20
Groundwater	Huggins Place	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.17	5.20	62.40
Groundwater	Hunter Farm Well No. 1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.07	2.10	25.25
Groundwater	HWY 145 #8 WELL	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	2.52	76.58	919.00

Table A-2. Permitted and Registered Amounts for Current Water Users

Source	Owner	Permit or Registration	Use Category	Aquifer	Permit or Registration Amount (MGD)	Permit or Registration Amount (MGM)	Permit or Registration Amount (MGY)
Groundwater	Hwy 15	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	2.03	61.73	740.80
Groundwater	HWY 151 CF #3 WELL	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	2.52	76.58	919.00
Groundwater	HWY 151 Market well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	2.52	76.58	919.00
Groundwater	Hwy 38 #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.34	10.42	125.00
Groundwater	Hwy 38 #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.34	10.42	125.00
Groundwater	Hwy 401 & Nancy Branch	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.14	4.17	50.00
Groundwater	Hwy 401/Swimming Pen	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.52	46.08	553.00
Groundwater	HWY 441	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.22	6.61	79.30
Groundwater	HWY 527	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.24	37.67	452.00
Groundwater	HWY 527	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.77	23.42	281.00
Groundwater	Hwy 527 Sardinia	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.20	6.17	74.00
Groundwater	Hwy 9 Field Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.38	11.67	140.00
Groundwater	HWY145 #7 WELL	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	2.52	76.58	919.00
Groundwater	Indian Branch	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.39	11.92	143.00
Groundwater	Indian Branch Rd Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.14	4.20	50.40
Groundwater	IP-STN #3 WELL	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.32	9.58	115.00
Groundwater	IRR #1	WTR-Groundwater Withdrawal Registration	Agriculture		0.00	0.00	0.00
Groundwater	IRR #2	WTR-Groundwater Withdrawal Registration	Agriculture		0.00	0.00	0.00
Groundwater	IRR #3	WTR-Groundwater Withdrawal Registration	Agriculture		0.00	0.00	0.00
Groundwater	Irrigation #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Surficial	0.14	4.17	50.00
Groundwater	IRRIGATION #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Surficial	0.14	4.17	50.00
Groundwater	IRRIGATION #3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Surficial	0.14	4.17	50.00
Groundwater	IRRIGATION #4	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Surficial	0.14	4.17	50.00
Groundwater	Irrigation Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.10	3.00	36.00
Groundwater	Irrigation Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.07	2.00	24.00
Groundwater	J Ben Rodgers Rd Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.16	4.77	57.30
Groundwater	J W Rhames Rd Left	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.27	8.33	100.00
Groundwater	Jack's Irrigation		Agriculture	Crouch Branch	0.00	0.00	0.00
Groundwater	Jackson Farm	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch-Mcqueen Branch	0.73	22.15	265.80
Groundwater	James Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.18	5.58	67.00
Groundwater	Jefferies Creek Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.08	2.50	30.00
Groundwater	Jerry's	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	2.04	62.15	745.80
Groundwater	Jessamyn	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.41	42.92	515.00
Groundwater	Jessamyn Rd Well #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch-Mcqueen Branch	0.15	4.55	54.60
Groundwater	Jimmys	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	2.03	61.73	740.80
Groundwater	Jimmys #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch-Mcqueen Branch	2.03	61.73	740.80
Groundwater	Joe Johnson Rd.	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.09	2.67	32.00
Groundwater	John's House #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.05	1.42	17.00
Groundwater	Josey Farm	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.73	22.15	265.80

Table A-2. Permitted and Registered Amounts for Current Water Users

Source	Owner	Permit or Registration	Use Category	Aquifer	Permit or Registration Amount (MGD)	Permit or Registration Amount (MGM)	Permit or Registration Amount (MGY)
Groundwater	Keel's Pivot	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.54	16.33	196.00
Groundwater	Kelly Farm	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.29	8.75	105.00
Groundwater	Kilgo	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.28	39.00	468.00
Groundwater	Kirby Field	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.17	5.25	63.00
Groundwater	Kirven	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.28	39.00	468.00
Groundwater	Kissiah	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.25	7.50	90.00
Groundwater	Lamar	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.12	3.67	44.00
Groundwater	Lamar Cantey & Bradham	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.27	8.33	100.00
Groundwater	Latitude Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.40	42.67	512.00
Groundwater	Lee Field Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.22	6.61	79.30
Groundwater	Les Tindal Rd #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.24	7.42	89.00
Groundwater	Levi	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	2.04	62.15	745.80
Groundwater	Levy Road	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture		0.53	16.17	194.00
Groundwater	Lewis Field Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch-Mcqueen Branch	0.35	10.50	126.00
Groundwater	LFW1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.09	2.81	33.70
Groundwater	LFW2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.09	2.81	33.70
Groundwater	Lins	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	2.03	61.73	740.80
Groundwater	Linwood Farms - Willard	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.66	20.00	240.00
Groundwater	Little Sister P1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.75	22.68	272.10
Groundwater	Little Sister P2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.75	22.68	272.10
Groundwater	Little Stuckey	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch-Mcqueen Branch	1.20	36.58	439.00
Groundwater	Long Field Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.70	21.42	257.00
Groundwater	Lottie	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.85	25.83	310.00
Groundwater	Luckey Road 1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.12	3.67	44.00
Groundwater	Lynchburg Hwy Well (Cribbs Well #3)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.51	15.63	187.60
Groundwater	Maidendown Bay Well #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.34	10.42	125.00
Groundwater	Maidendown Bay Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.34	10.42	125.00
Groundwater	Maidendown Bay Well #3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.34	10.42	125.00
Groundwater	Mason Lane Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.08	2.50	30.00
Groundwater	Mayes Well #2		Agriculture		0.00	0.00	0.00
Groundwater	Mayesville Farm Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.29	8.83	106.00
Groundwater	Mayesville Swamp	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.52	46.08	553.00
Groundwater	Maysville Flats	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.52	46.08	553.00
Groundwater	Mcabe	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	2.04	62.15	745.80
Groundwater	McCall Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.52	15.83	190.00
Groundwater	McCoy Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.51	15.63	187.60
Groundwater	McElveen Rd. #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.20	6.17	74.00
Groundwater	Mcgee Town	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.09	2.67	32.00
Groundwater	McIntosh Pond Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.82	25.00	300.00

Table A-2. Permitted and Registered Amounts for Current Water Users

Source	Owner	Permit or Registration	Use Category	Aquifer	Permit or Registration Amount (MGD)	Permit or Registration Amount (MGM)	Permit or Registration Amount (MGY)
Groundwater	McKnight Road	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	1.24	37.67	452.00
Groundwater	McPhaul Field Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.38	11.67	140.00
Groundwater	McQueen Lane Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.07	2.00	24.00
Groundwater	MILK BARN	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.27	8.33	100.00
Groundwater	Mims	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.85	25.83	310.00
Groundwater	Mims Tract Well #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.89	27.15	325.80
Groundwater	Mims Tract Well #1		Agriculture	McQueen Branch	0.00	0.00	0.00
Groundwater	Mims Tract Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.89	27.15	325.80
Groundwater	Mims Tract Well #2		Agriculture	McQueen Branch	0.00	0.00	0.00
Groundwater	Minturn School Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.12	3.75	45.00
Groundwater	Moccasin & Sandy Grove	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.42	43.33	520.00
Groundwater	Moore Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.51	15.63	187.60
Groundwater	Mother's House Pivot	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.52	15.88	190.50
Groundwater	Motor Pool Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch-Charleston	0.02	0.71	8.50
Groundwater	Mt Sinai/St. Charles Rd	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.52	46.08	553.00
Groundwater	Mulberry Church #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.16	35.42	425.00
Groundwater	Nebo	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	2.11	64.08	769.00
Groundwater	NEW D #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.34	40.83	490.00
Groundwater	Nitrogen Tank	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	2.04	62.15	745.80
Groundwater	No # Puddin Swamp Rd		Agriculture	Crouch Branch	0.00	0.00	0.00
Groundwater	Norwood Pivot #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.14	4.27	51.30
Groundwater	Old Camden #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.26	7.83	94.00
Groundwater	Old Camden #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.26	7.83	94.00
Groundwater	Old Creek Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.13	4.08	49.00
Groundwater	Old Manning Road		Agriculture		0.00	0.00	0.00
Groundwater	OLD SHED	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	2.11	64.08	769.00
Groundwater	OLD SHED		Agriculture		0.00	0.00	0.00
Groundwater	Park Rd.	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.38	11.70	140.40
Groundwater	Parnell Farm		Agriculture	McQueen Branch	0.15	4.56	54.70
Groundwater	Pate Well-Queen Chapel Rd	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.96	29.17	350.00
Groundwater	Pauls Shop	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.73	22.15	265.80
Groundwater	Paxville Bay Valley	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.17	5.07	60.90
Groundwater	Paxville Big Pivot	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.17	5.07	60.90
Groundwater	Paxville Hwy Well (HWY 261 Well)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.27	8.33	100.00
Groundwater	Philadelphia #1 (Little)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.48	14.50	174.00
Groundwater	Philadelphia #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.48	14.50	174.00
Groundwater	Phillips Farm Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.54	16.33	196.00
Groundwater	Phillips Well-Queen Chapel Rd	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.96	29.17	350.00
Groundwater	Pigeon Barn	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.22	6.58	79.00
Groundwater	Pigeon Barn 2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.22	6.58	79.00
Groundwater	Pinchum Sly	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.28	39.00	468.00

Table A-2. Permitted and Registered Amounts for Current Water Users

Source	Owner	Permit or Registration	Use Category	Aquifer	Permit or Registration Amount (MGD)	Permit or Registration Amount (MGM)	Permit or Registration Amount (MGY)
Groundwater	Pinewood Dr.	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.37	11.17	134.00
Groundwater	Pond Well		Agriculture		0.00	0.00	0.00
Groundwater	Pondville	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.34	10.42	125.00
Groundwater	Pork Chops	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	2.03	61.73	740.80
Groundwater	Pork Chops #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch-Mcqueen Branch	0.73	22.15	265.80
Groundwater	POULTRY		Agriculture		0.00	0.00	0.00
Groundwater	Pump Station 1	WTR-Groundwater Withdrawal Registration	Agriculture	Mcqueen Branch	0.33	9.93	119.20
Groundwater	Pump Station 2	WTR-Groundwater Withdrawal Registration	Agriculture	Mcqueen Branch	0.33	9.93	119.20
Groundwater	Queen Chapel Rd	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	2.03	61.73	740.80
Groundwater	Quiet Brook Pivot Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.52	15.88	190.50
Groundwater	Rabb #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.32	9.67	116.00
Groundwater	Raccoon Rd	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.19	5.93	71.16
Groundwater	Raccoon Rd		Agriculture		0.00	0.00	0.00
Groundwater	Ralph Jackson	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.70	21.42	257.00
Groundwater	Ray Williams (Jamestown Rd)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.08	2.58	31.00
Groundwater	Reames Back	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.28	39.00	468.00
Groundwater	Reames Front	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.28	39.00	468.00
Groundwater	Red Hill Rd Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.16	4.77	57.30
Groundwater	Reg 1827	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch-Mcqueen Branch	0.04	1.08	13.00
Groundwater	Reynolds Farm	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.73	22.15	265.80
Groundwater	River Pump Station	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.63	19.17	230.00
Groundwater	Rivers	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	3.70	112.67	1,352.00
Groundwater	Roberts	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.46	13.98	167.79
Groundwater	Rodgers Farm Well #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.16	4.92	59.00
Groundwater	Rogers Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	2.11	64.08	769.00
Groundwater	ROOSTER COOP #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.27	8.33	100.00
Groundwater	ROOSTER COOP #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.27	8.33	100.00
Groundwater	Roper Woods	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch-Charleston	0.12	3.50	42.00
Groundwater	Ross	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	3.70	112.67	1,352.00
Groundwater	S Curve Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.60	18.17	218.10
Groundwater	Sandy Grove & State Park	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.42	43.33	520.00
Groundwater	Sandy Grove Chapel Rd	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.42	43.33	520.00
Groundwater	Sandy Grove Church Rd @ Hwy 15	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.36	10.83	130.00
Groundwater	Savanah 1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.24	7.38	88.60
Groundwater	Savanah 2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.24	7.38	88.60
Groundwater	Scarborough Rd		Agriculture	McQueen Branch	0.00	0.00	0.00
Groundwater	SEGARS #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.34	40.83	490.00
Groundwater	SEGARS #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.34	40.83	490.00
Groundwater	SEGARS #3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.34	40.83	490.00
Groundwater	Segars (Rembert Church Rd)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	3.70	112.67	1,352.00

Table A-2. Permitted and Registered Amounts for Current Water Users

Source	Owner	Permit or Registration	Use Category	Aquifer	Permit or Registration Amount (MGD)	Permit or Registration Amount (MGM)	Permit or Registration Amount (MGY)
Groundwater	Selby	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch-Mcqueen Branch	0.29	8.75	105.00
Groundwater	Severance Farm		Agriculture	McQueen Branch	0.15	4.56	54.70
Groundwater	Shaw 1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.28	39.00	468.00
Groundwater	Shaw 2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.28	39.00	468.00
Groundwater	Sherwood Well No. 2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.14	4.17	50.00
Groundwater	Shop	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	2.03	61.73	740.80
Groundwater	Shop	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	2.04	62.15	745.80
Groundwater	Shop Big	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.20	36.58	439.00
Groundwater	Shop Little	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.20	36.58	439.00
Groundwater	Shop Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.34	40.91	490.90
Groundwater	Siding	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	3.70	112.67	1,352.00
Groundwater	Silo #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.52	15.83	190.00
Groundwater	Silo #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.52	15.83	190.00
Groundwater	Silo #3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.52	15.83	190.00
Groundwater	Sinclair Farm	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.36	10.86	130.30
Groundwater	Smith	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	2.04	62.15	745.80
Groundwater	Snead Field	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.73	22.15	265.80
Groundwater	St. Charles #1, HWY 401	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.28	8.67	104.00
Groundwater	St. Charles #2, HWY 401	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.28	8.67	104.00
Groundwater	St. Charles FC	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.28	8.67	104.00
Groundwater	Stafford	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.91	27.60	331.20
Groundwater	State Park #6	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.42	43.33	520.00
Groundwater	State Park #7Q	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.42	43.33	520.00
Groundwater	Stateline Well #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.25	7.57	90.80
Groundwater	Stateline Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.25	7.57	90.80
Groundwater	Stokes	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.20	36.58	439.00
Groundwater	Store	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.29	8.75	105.00
Groundwater	Suggs Field	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.14	4.17	50.00
Groundwater	Sumter County Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.10	2.92	35.00
Groundwater	Swimming Pen Rd	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.19	5.93	71.16
Groundwater	SYSTEM A	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.12	3.53	42.40
Groundwater	SYSTEM B	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.12	3.53	42.40
Groundwater	SYSTEM C	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.12	3.53	42.40
Groundwater	T Barn	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	2.11	64.08	769.00
Groundwater	Tailback South	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.16	35.42	425.00
Groundwater	Tarleton Rd Well #1.	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.19	36.33	436.00
Groundwater	Tarleton Rd. Well #2.	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.19	36.33	436.00
Groundwater	Tarleton Rd. Well #3.	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.19	36.33	436.00
Groundwater	Taylor	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.25	7.50	90.00

Table A-2. Permitted and Registered Amounts for Current Water Users

Source	Owner	Permit or Registration	Use Category	Aquifer	Permit or Registration Amount (MGD)	Permit or Registration Amount (MGM)	Permit or Registration Amount (MGY)
Groundwater	Tees	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	3.70	112.67	1,352.00
Groundwater	Tims	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.05	1.67	20.00
Groundwater	Tindal Tract		Agriculture		0.00	0.00	0.00
Groundwater	Tindal, Swimming Pen Rd		Agriculture	Crouch Branch	0.00	0.00	0.00
Groundwater	Toby Well (Woodrow Rd)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.11	3.33	40.00
Groundwater	Toeys	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	2.04	62.15	745.80
Groundwater	Toh Barn	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	2.04	62.15	745.80
Groundwater	Toms Creek	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.82	25.00	300.00
Groundwater	Tower	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.82	25.00	300.00
Groundwater	TRCT 3350 Field 7	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.03	0.77	9.20
Groundwater	Turf well	WTR-Groundwater Withdrawal Registration	Agriculture	Crouch Branch	0.33	9.93	119.20
Groundwater	Turkey House	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	2.03	61.73	740.80
Groundwater	Turkey House Well (Levy Rd)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.08	2.58	31.00
Groundwater	UNA Rd	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.01	0.42	5.00
Groundwater	Unruh #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.22	6.67	80.00
Groundwater	Warners Bay #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.16	4.82	57.80
Groundwater	Warr Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.16	5.00	60.00
Groundwater	Welch Place Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.89	27.15	325.80
Groundwater	WELL #1	WTR-Groundwater Withdrawal Registration	Agriculture		0.00	0.00	0.00
Groundwater	WELL #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.19	5.83	70.00
Groundwater	WELL #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.15	4.71	56.50
Groundwater	WELL #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.24	7.20	86.40
Groundwater	WELL #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.75	22.92	275.00
Groundwater	WELL #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.26	38.29	459.50
Groundwater	WELL #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.69	21.00	252.00
Groundwater	WELL #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Charleston	0.46	14.04	168.50
Groundwater	WELL #1	WTR-Groundwater Withdrawal Registration	Agriculture		0.00	0.00	0.00
Groundwater	WELL #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.03	1.00	12.00
Groundwater	WELL #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.12	3.67	44.00
Groundwater	WELL #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.08	2.34	28.08
Groundwater	WELL #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.38	11.45	137.40
Groundwater	WELL #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.95	29.00	348.00
Groundwater	WELL #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.45	13.74	164.90
Groundwater	Well #1		Agriculture	McQueen Branch	0.00	0.00	0.00
Groundwater	WELL #1 - Stoney Run	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.45	13.70	164.40
Groundwater	Well #1 (Half Circle Pivot)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.98	29.67	356.00
Groundwater	WELL #1 (Old Manning Rd)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.42	12.67	152.00
Groundwater	Well #1 Bethel Church Rd	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.49	15.00	180.00
Groundwater	WELL #1 DUBOSE SIDE	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.88	26.81	321.70

Table A-2. Permitted and Registered Amounts for Current Water Users

Source	Owner	Permit or Registration	Use Category	Aquifer	Permit or Registration Amount (MGD)	Permit or Registration Amount (MGM)	Permit or Registration Amount (MGY)
Groundwater	WELL #1 Waters	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.72	22.00	264.00
Groundwater	Well #1, Eden Rd. Turkey House	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.81	24.67	296.00
Groundwater	WELL #1/BAY	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.55	16.75	201.00
Groundwater	Well #10	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.34	40.83	490.00
Groundwater	Well #10		Agriculture		0.00	0.00	0.00
Groundwater	Well #11	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch-Mcqueen Branch	1.34	40.83	490.00
Groundwater	Well #11		Agriculture		0.00	0.00	0.00
Groundwater	Well #12		Agriculture		0.00	0.00	0.00
Groundwater	Well #2	WTR-Groundwater Withdrawal Registration	Agriculture		0.00	0.00	0.00
Groundwater	Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.75	22.92	275.00
Groundwater	Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.26	38.29	459.50
Groundwater	Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.69	21.00	252.00
Groundwater	Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Charleston	0.46	14.04	168.50
Groundwater	Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.66	20.00	240.00
Groundwater	Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.49	15.00	180.00
Groundwater	Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.95	29.00	348.00
Groundwater	Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.45	13.74	164.90
Groundwater	Well #2		Agriculture		0.00	0.00	0.00
Groundwater	Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.19	5.83	70.00
Groundwater	WELL #2 Holy Lane		Agriculture		0.00	0.00	0.00
Groundwater	Well #2 - Grain Bins	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.45	13.70	164.40
Groundwater	Well #2 (Big Full Circle)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.98	29.67	356.00
Groundwater	WELL #2 Stokes	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.72	22.00	264.00
Groundwater	Well #2, EDENS WELL	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.81	24.67	296.00
Groundwater	WELL #2/HOG HOUSE	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.55	16.75	201.00
Groundwater	Well #3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.75	22.92	275.00
Groundwater	Well #3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.26	38.29	459.50
Groundwater	Well #3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.69	21.00	252.00
Groundwater	Well #3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Charleston	0.46	14.04	168.50
Groundwater	Well #3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.49	15.00	180.00
Groundwater	Well #3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.45	13.74	164.90
Groundwater	Well #3		Agriculture		0.00	0.00	0.00
Groundwater	Well #3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.19	5.83	70.00
Groundwater	Well #3 - Hebron	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.00	0.00	0.00
Groundwater	Well #3 - Jack's	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.45	13.70	164.40
Groundwater	WELL #3 Scott		Agriculture		0.00	0.00	0.00
Groundwater	Well #3 (Small Field Circle)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.98	29.67	356.00
Groundwater	WELL #3 Heriot	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.72	22.00	264.00
Groundwater	WELL #3 R MCDANIEL	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.88	26.81	321.70
Groundwater	Well #3, Black River Rd.	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.81	24.67	296.00
Groundwater	WELL #3/SHOP	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.55	16.75	201.00
Groundwater	Well #4	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.75	22.92	275.00

Table A-2. Permitted and Registered Amounts for Current Water Users

Source	Owner	Permit or Registration	Use Category	Aquifer	Permit or Registration Amount (MGD)	Permit or Registration Amount (MGM)	Permit or Registration Amount (MGY)
Groundwater	Well #4	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.69	21.00	252.00
Groundwater	Well #4	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Charleston	0.46	14.04	168.50
Groundwater	Well #4		Agriculture	McQueen Branch	0.00	0.00	0.00
Groundwater	WELL #4 COLOUGH	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.88	26.81	321.70
Groundwater	Well #4 Rabon	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.72	22.00	264.00
Groundwater	Well #5	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.75	22.92	275.00
Groundwater	Well #5	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.69	21.00	252.00
Groundwater	Well #5		Agriculture		0.00	0.00	0.00
Groundwater	WELL #5 DR BRADFORD	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.88	26.81	321.70
Groundwater	Well #6	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.75	22.92	275.00
Groundwater	Well #6	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.69	21.00	252.00
Groundwater	Well #6		Agriculture		0.00	0.00	0.00
Groundwater	Well #6 Green	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.72	22.00	264.00
Groundwater	WELL #6 HANNAH	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.88	26.81	321.70
Groundwater	Well #7	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.75	22.92	275.00
Groundwater	Well #7	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.69	21.00	252.00
Groundwater	Well #7		Agriculture		0.00	0.00	0.00
Groundwater	Well #8		Agriculture		0.00	0.00	0.00
Groundwater	Well #9		Agriculture		0.00	0.00	0.00
Groundwater	Well 1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.95	28.83	346.00
Groundwater	Well 1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.49	14.93	179.19
Groundwater	Well 1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.22	6.67	80.00
Groundwater	Well 1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	1.96	59.60	715.20
Groundwater	Well 1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.09	2.67	32.00
Groundwater	Well 1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.75	22.92	275.00
Groundwater	WELL 10	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch-Mcqueen Branch	0.58	17.57	210.80
Groundwater	Well 11	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch-Mcqueen Branch	1.96	59.60	715.20
Groundwater	Well 12	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch-Mcqueen Branch	1.96	59.60	715.20
Groundwater	Well 2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.95	28.83	346.00
Groundwater	Well 2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.49	14.93	179.19
Groundwater	Well 2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.22	6.67	80.00
Groundwater	Well 2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch-Mcqueen Branch	1.96	59.60	715.20
Groundwater	Well 2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.75	22.92	275.00
Groundwater	Well 3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.95	28.83	346.00
Groundwater	Well 3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.49	14.93	179.19
Groundwater	Well 3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.22	6.67	80.00
Groundwater	Well 3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch-Mcqueen Branch	1.96	59.60	715.20
Groundwater	Beverly Creek Well No. 2		Agriculture	McQueen Branch	0.00	0.00	0
Groundwater	Northbridge Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	1.40	42.67	512
Groundwater	Well 3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.75	22.92	275.00
Groundwater	Well 4	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.49	14.93	179.19

Table A-2. Permitted and Registered Amounts for Current Water Users

Source	Owner	Permit or Registration	Use Category	Aquifer	Permit or Registration Amount (MGD)	Permit or Registration Amount (MGM)	Permit or Registration Amount (MGY)
Groundwater	Well 4	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch-Mcqueen Branch	1.96	59.60	715.20
Groundwater	Well 5	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch-Mcqueen Branch	1.96	59.60	715.20
Groundwater	Well 6	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch-Mcqueen Branch	1.96	59.60	715.20
Groundwater	Well 7	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch-Mcqueen Branch	1.96	59.60	715.20
Groundwater	Well 8	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch-Mcqueen Branch	1.96	59.60	715.20
Groundwater	Well 9	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch-Mcqueen Branch	0.58	17.57	210.80
Groundwater	Well Field 1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.31	9.40	112.80
Groundwater	Well Field 2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.31	9.40	112.80
Groundwater	WELL#1 Windham		Agriculture		0.00	0.00	0.00
Groundwater	Well#5 Segars	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.72	22.00	264.00
Groundwater	Westly Chapel	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.39	11.92	143.00
Groundwater	Wilkes #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.08	2.33	28.00
Groundwater	William's Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.13	4.08	49.00
Groundwater	Willie (Chaney Grove)		Agriculture	McQueen Branch	0.00	0.00	0.00
Groundwater	Winters Hill Road Left	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.27	8.33	100.00
Groundwater	Witt	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Crouch Branch	0.14	4.20	50.40
Groundwater	Woodham Farm Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.14	4.17	50.00
Groundwater	Zeigler	WTR-Groundwater Withdrawal Capacity Use Area Permit	Agriculture	Mcqueen Branch	0.29	8.75	105.00
Groundwater	WELL #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Aquaculture	Crouch Branch	0.08	2.58	31.00
Groundwater	Deep Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Mcqueen Branch	0.20	6.00	72.00
Groundwater	G1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Surficial	0.01	0.22	2.60
Groundwater	International Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Crouch Branch-Mcqueen Branch	0.15	4.54	54.50
Groundwater	IRR. WELL	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Crouch Branch	0.19	5.83	70.00
Groundwater	IRR. WELL 1		Golf	Surficial	0.07	2.08	25.00
Groundwater	IRR. WELL 2		Golf	Surficial	0.07	2.08	25.00
Groundwater	IRR. WELL 3		Golf	Surficial	0.07	2.08	25.00
Groundwater	IRR. WELL 4		Golf	Surficial	0.07	2.08	25.00
Groundwater	IRRIGATION WELL #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Crouch Branch	0.18	5.42	65.00
Groundwater	IRRIGATION WELL #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Crouch Branch	0.18	5.42	65.00
Groundwater	Irrigation Well #3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Crouch Branch	0.18	5.42	65.00
Groundwater	IRRIGATION WELL 1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Crouch Branch	0.05	1.67	20.00
Groundwater	LOST CREEK AQUIFER	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Mcqueen Branch	0.09	2.82	33.90
Groundwater	MAIN IRRIGATION WELL		Golf	Crouch Branch	0.07	2.08	25.00
Groundwater	Main Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Crouch Branch-Mcqueen Branch	0.11	3.33	40.00
Groundwater	Main Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Crouch Branch-Mcqueen Branch	0.15	4.54	54.50
Groundwater	Maintenance	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Surficial	0.18	5.42	65.00
Groundwater	MBN-WELL #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Mcqueen Branch	0.15	4.58	55.00
Groundwater	Restroom Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Surficial	0.18	5.42	65.00
Groundwater	RESTROOMWELL		Golf	Crouch Branch	0.07	2.08	25.00
Groundwater	South Beach Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Crouch Branch-Mcqueen Branch	0.07	2.08	25.00
Groundwater	Well	WTR-Groundwater Withdrawal Registration	Golf		0.00	0.00	0.00
Groundwater	WELL ""G2""	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Surficial	0.01	0.22	2.60

Table A-2. Permitted and Registered Amounts for Current Water Users

Source	Owner	Permit or Registration	Use Category	Aquifer	Permit or Registration Amount (MGD)	Permit or Registration Amount (MGM)	Permit or Registration Amount (MGY)
Groundwater	WELL ""G3""	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Surficial	0.01	0.22	2.60
Groundwater	WELL ""G4""	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Surficial	0.01	0.22	2.60
Groundwater	WELL ""G5""	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Surficial	0.01	0.22	2.60
Groundwater	WELL # 2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Crouch Branch	0.21	6.25	75.00
Groundwater	WELL #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Crouch Branch	0.10	3.00	36.00
Groundwater	WELL #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Crouch Branch	0.07	2.08	25.00
Groundwater	WELL #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Crouch Branch	0.04	1.30	15.60
Groundwater	WELL #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Surficial	0.10	3.00	36.00
Groundwater	WELL #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Surficial	0.27	8.25	99.00
Groundwater	WELL #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Surficial	0.15	4.58	55.00
Groundwater	WELL #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Crouch Branch	0.14	4.17	50.00
Groundwater	WELL #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Crouch Branch	0.08	2.50	30.00
Groundwater	WELL #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Surficial	0.19	5.83	70.00
Groundwater	WELL #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Crouch Branch	0.13	4.04	48.50
Groundwater	WELL #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Crouch Branch-Mcqueen Branch	0.09	2.67	32.00
Groundwater	Well #10	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Surficial	0.15	4.58	55.00
Groundwater	Well #11	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Surficial	0.15	4.58	55.00
Groundwater	Well #12	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Surficial	0.15	4.58	55.00
Groundwater	WELL #13	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Surficial	0.15	4.58	55.00
Groundwater	Well #14	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Surficial	0.15	4.58	55.00
Groundwater	Well #15	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Surficial	0.15	4.58	55.00
Groundwater	Well #16	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Surficial	0.15	4.58	55.00
Groundwater	Well #17	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Surficial	0.15	4.58	55.00
Groundwater	Well #18	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Surficial	0.15	4.58	55.00
Groundwater	Well #19	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Surficial	0.15	4.58	55.00
Groundwater	WELL #1A	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Crouch Branch	0.21	6.25	75.00
Groundwater	Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Crouch Branch	0.10	3.00	36.00
Groundwater	Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Crouch Branch	0.04	1.30	15.60
Groundwater	Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Crouch Branch	0.10	3.00	36.00
Groundwater	Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Crouch Branch	0.27	8.25	99.00
Groundwater	Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Surficial	0.15	4.58	55.00
Groundwater	Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Crouch Branch	0.08	2.50	30.00
Groundwater	Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Surficial	0.19	5.83	70.00
Groundwater	Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Crouch Branch	0.13	4.04	48.50
Groundwater	Well #20	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Surficial	0.15	4.58	55.00
Groundwater	WELL #21	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Surficial	0.15	4.58	55.00
Groundwater	Well #22	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Surficial	0.15	4.58	55.00
Groundwater	Well #23	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Surficial	0.15	4.58	55.00

Table A-2. Permitted and Registered Amounts for Current Water Users

Source	Owner	Permit or Registration	Use Category	Aquifer	Permit or Registration Amount (MGD)	Permit or Registration Amount (MGM)	Permit or Registration Amount (MGY)
Groundwater	Well #3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Crouch Branch	0.10	3.00	36.00
Groundwater	Well #3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Surficial	0.07	2.08	25.00
Groundwater	Well #3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Crouch Branch	0.04	1.30	15.60
Groundwater	Well #3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Crouch Branch	0.27	8.25	99.00
Groundwater	Well #3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Surficial	0.15	4.58	55.00
Groundwater	Well #3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Surficial	0.19	5.83	70.00
Groundwater	Well #3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Crouch Branch	0.13	4.04	48.50
Groundwater	Well #4	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Crouch Branch	0.07	2.08	25.00
Groundwater	Well #4	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Crouch Branch	0.04	1.30	15.60
Groundwater	Well #4	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Surficial	0.15	4.58	55.00
Groundwater	Well #4	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Surficial	0.19	5.83	70.00
Groundwater	Well #4	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Crouch Branch	0.14	4.13	49.50
Groundwater	Well #5	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Crouch Branch	0.07	2.08	25.00
Groundwater	Well #5	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Surficial	0.15	4.58	55.00
Groundwater	Well #5	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Surficial	0.19	5.83	70.00
Groundwater	Well #5	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Crouch Branch	0.14	4.13	49.50
Groundwater	Well #6	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Surficial	0.15	4.58	55.00
Groundwater	Well #6	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Surficial	0.19	5.83	70.00
Groundwater	Well #6	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Crouch Branch	0.14	4.13	49.50
Groundwater	Well #7	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Surficial	0.19	5.83	70.00
Groundwater	Well #7	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Crouch Branch	0.14	4.13	49.50
Groundwater	Well #8	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Surficial	0.15	4.58	55.00
Groundwater	Well #8	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Surficial	0.19	5.83	70.00
Groundwater	Well #9	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Surficial	0.15	4.58	55.00
Groundwater	Well #9	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Crouch Branch-Mcqueen Branch	0.19	5.83	70.00
Groundwater	WELL @ 11TH	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Crouch Branch	0.07	2.07	24.84
Groundwater	WELL @ 13TH	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Surficial	0.07	2.07	24.84
Groundwater	WELL @ 16TH	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Surficial	0.07	2.07	24.84
Groundwater	WELL A	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Crouch Branch	0.07	2.00	24.00
Groundwater	Well at Hole 14	WTR-Groundwater Withdrawal Capacity Use Area Permit	Golf	Crouch Branch	0.22	6.58	79.00
Groundwater	#3 Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Mcqueen Branch	0.48	14.58	175.00
Groundwater	#4 Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Mcqueen Branch	0.48	14.58	175.00
Groundwater	#5 Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Mcqueen Branch	0.48	14.58	175.00
Groundwater	001 (HWY. 15)		Industry		0.00	0.00	0.00
Groundwater	002 (LEWIS RD.)		Industry		0.00	0.00	0.00
Groundwater	East Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Mcqueen Branch	0.86	26.25	315.00
Groundwater	Facility Water Supply Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Charleston	0.21	6.33	76.00
Groundwater	NO. 11 WELL	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Mcqueen Branch	4.82	146.50	1,758.00
Groundwater	NO. 9 WELL	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Mcqueen Branch	4.82	146.50	1,758.00

Table A-2. Permitted and Registered Amounts for Current Water Users

Source	Owner	Permit or Registration	Use Category	Aquifer	Permit or Registration Amount (MGD)	Permit or Registration Amount (MGM)	Permit or Registration Amount (MGY)
Groundwater	NO.1 WELL	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Mcqueen Branch	4.82	146.50	1,758.00
Groundwater	NO.2 WELL	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Mcqueen Branch	4.82	146.50	1,758.00
Groundwater	NO.5 WELL	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Mcqueen Branch	4.82	146.50	1,758.00
Groundwater	NO.6 WELL	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Mcqueen Branch	4.82	146.50	1,758.00
Groundwater	NO.7 WELL	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Mcqueen Branch	4.82	146.50	1,758.00
Groundwater	North Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Mcqueen Branch	0.86	26.25	315.00
Groundwater	PW #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Mcqueen Branch	1.37	41.67	500.00
Groundwater	PW #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Mcqueen Branch	1.37	41.67	500.00
Groundwater	PW #3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Mcqueen Branch	1.37	41.67	500.00
Groundwater	PW #3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Crouch Branch-Mcqueen Branch	1.78	54.17	650.00
Groundwater	PW #4	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Mcqueen Branch	1.37	41.67	500.00
Groundwater	PW #4	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Crouch Branch	1.78	54.17	650.00
Groundwater	PW #5	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Charleston	1.78	54.17	650.00
Groundwater	PW #6	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Charleston	1.78	54.17	650.00
Groundwater	PW #7	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Charleston	1.78	54.17	650.00
Groundwater	RW-1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Surficial	0.38	11.50	138.00
Groundwater	RW-10	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Surficial	0.38	11.50	138.00
Groundwater	RW-11	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Surficial	0.38	11.50	138.00
Groundwater	RW-12	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Surficial	0.38	11.50	138.00
Groundwater	RW-13	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Surficial	0.38	11.50	138.00
Groundwater	RW-14	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Surficial	0.38	11.50	138.00
Groundwater	RW-15	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Surficial	0.38	11.50	138.00
Groundwater	RW-2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Surficial	0.38	11.50	138.00
Groundwater	RW-3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Surficial	0.38	11.50	138.00
Groundwater	RW-4	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Surficial	0.38	11.50	138.00
Groundwater	RW-5	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Surficial	0.38	11.50	138.00
Groundwater	RW-6	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Surficial	0.38	11.50	138.00
Groundwater	RW-7	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Surficial	0.38	11.50	138.00
Groundwater	RW-8	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Surficial	0.38	11.50	138.00
Groundwater	RW-9	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Surficial	0.38	11.50	138.00
Groundwater	SOUTH WELL	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Crouch Branch	0.01	0.42	5.00
Groundwater	Tower Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Mcqueen Branch	0.86	26.25	315.00
Groundwater	WELL #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Mcqueen Branch	0.01	0.42	5.00
Groundwater	WELL #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Mcqueen Branch	2.35	71.33	856.00
Groundwater	WELL #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Crouch Branch	0.10	3.00	36.00
Groundwater	WELL #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Gordon	0.16	5.00	60.00
Groundwater	WELL #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Crouch Branch	1.64	50.00	600.00
Groundwater	WELL #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Mcqueen Branch	1.64	50.00	600.00

Table A-2. Permitted and Registered Amounts for Current Water Users

Source	Owner	Permit or Registration	Use Category	Aquifer	Permit or Registration Amount (MGD)	Permit or Registration Amount (MGM)	Permit or Registration Amount (MGY)
Groundwater	Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Mcqueen Branch	0.35	10.50	126.00
Groundwater	Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Mcqueen Branch	1.75	53.25	639.00
Groundwater	Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Crouch Branch	0.10	3.00	36.00
Groundwater	Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Gordon	0.16	5.00	60.00
Groundwater	Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Crouch Branch	1.64	50.00	600.00
Groundwater	Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Mcqueen Branch	1.64	50.00	600.00
Groundwater	Well #3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Mcqueen Branch	2.35	71.33	856.00
Groundwater	Well #3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Gordon	0.16	5.00	60.00
Groundwater	Well #3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Crouch Branch-Mcqueen Branch	1.64	50.00	600.00
Groundwater	Well #3R	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Mcqueen Branch	1.64	50.00	600.00
Groundwater	Well #4	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Mcqueen Branch	2.35	71.33	856.00
Groundwater	Well #4	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Charleston	1.75	53.25	639.00
Groundwater	Well #4	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Gordon	0.16	5.00	60.00
Groundwater	Well #4	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Mcqueen Branch	1.64	50.00	600.00
Groundwater	Well #5	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Charleston	1.75	53.25	639.00
Groundwater	Well #5	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Crouch Branch	1.64	50.00	600.00
Groundwater	Well #6	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Mcqueen Branch	2.35	71.33	856.00
Groundwater	Well #7	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Mcqueen Branch	2.35	71.33	856.00
Groundwater	Well #8	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Mcqueen Branch	2.35	71.33	856.00
Groundwater	Well #9	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Mcqueen Branch	2.35	71.33	856.00
Groundwater	Williamsburg Co. Dev.	WTR-Groundwater Withdrawal Capacity Use Area Permit	Industry	Crouch Branch-Mcqueen Branch	0.12	3.60	43.20
Groundwater	AB-1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Nuclear Power	Mcqueen Branch	1.82	55.30	663.60
Groundwater	AB-2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Nuclear Power	Mcqueen Branch	1.82	55.30	663.60
Groundwater	Well # 10	WTR-Groundwater Withdrawal Capacity Use Area Permit	Nuclear Power	Mcqueen Branch	1.82	55.30	663.60
Groundwater	Well # 9	WTR-Groundwater Withdrawal Capacity Use Area Permit	Nuclear Power	Mcqueen Branch	1.82	55.30	663.60
Groundwater	WELL #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Nuclear Power	Mcqueen Branch	1.82	55.30	663.60
Groundwater	Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Nuclear Power	Mcqueen Branch	1.82	55.30	663.60
Groundwater	Well #6	WTR-Groundwater Withdrawal Capacity Use Area Permit	Nuclear Power	Crouch Branch	1.82	55.30	663.60
Groundwater	Well #8	WTR-Groundwater Withdrawal Capacity Use Area Permit	Nuclear Power	Crouch Branch	1.82	55.30	663.60
Groundwater	Well #A	WTR-Groundwater Withdrawal Capacity Use Area Permit	Nuclear Power	Mcqueen Branch	1.82	55.30	663.60
Groundwater	Well #B	WTR-Groundwater Withdrawal Capacity Use Area Permit	Nuclear Power	Mcqueen Branch	1.82	55.30	663.60
Groundwater	Well #C	WTR-Groundwater Withdrawal Capacity Use Area Permit	Nuclear Power	Mcqueen Branch	1.82	55.30	663.60
Groundwater	Well #D	WTR-Groundwater Withdrawal Capacity Use Area Permit	Nuclear Power	Mcqueen Branch	1.82	55.30	663.60
Groundwater	Well E	WTR-Groundwater Withdrawal Capacity Use Area Permit	Nuclear Power	Mcqueen Branch	1.82	55.30	663.60
Groundwater	#1 Ruby Rd.	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	4.93	150.00	1,800.00
Groundwater	#10 Center Rd.	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	4.93	150.00	1,800.00
Groundwater	#11 Center Rd.	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	4.93	150.00	1,800.00
Groundwater	#12 Clyde School	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	4.93	150.00	1,800.00

Table A-2. Permitted and Registered Amounts for Current Water Users

Source	Owner	Permit or Registration	Use Category	Aquifer	Permit or Registration Amount (MGD)	Permit or Registration Amount (MGM)	Permit or Registration Amount (MGY)
Groundwater	#2 Airport Rd.	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	4.93	150.00	1,800.00
Groundwater	#3 Camden Rd.	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	4.93	150.00	1,800.00
Groundwater	#4 Ruby Rd.	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	4.93	150.00	1,800.00
Groundwater	#5 Ashland Plant	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	4.93	150.00	1,800.00
Groundwater	#6 Stucky Bottom	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	4.93	150.00	1,800.00
Groundwater	#7 McKenzie Rd.	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	4.93	150.00	1,800.00
Groundwater	#8 Ruby Rd,	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	4.93	150.00	1,800.00
Groundwater	111 Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.33	10.00	120.00
Groundwater	12th and Madison	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.26	38.42	461.00
Groundwater	1st and Jackson	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.26	38.42	461.00
Groundwater	20th and Hudson	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.26	38.42	461.00
Groundwater	21ST AVENUE NORTH	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch-Charleston	0.02	0.71	8.50
Groundwater	341 Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Bedrock	0.33	10.00	120.00
Groundwater	38TH AVE NORTH	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	0.02	0.71	8.50
Groundwater	3RD AVENUE SOUTH	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch-Charleston	0.02	0.71	8.50
Groundwater	79TH AVENUE NORTH	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	0.02	0.71	8.50
Groundwater	903 Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Bedrock	0.33	10.00	120.00
Groundwater	Abrams Well (#43)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	5.12	155.68	1,868.20
Groundwater	AIRPORT	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	1.81	55.08	661.00
Groundwater	ARCADIA WELL	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	2.26	68.61	823.30
Groundwater	Aynor Park Well (#2 ASR)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	5.12	155.68	1,868.20
Groundwater	Aynor Tank Well (#1)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	5.12	155.68	1,868.20
Groundwater	Baker lot Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	3.47	105.67	1,268.00
Groundwater	Bay Road Well (#21)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	5.12	155.68	1,868.20
Groundwater	Beauty Spot Rd/Wallace St	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.96	59.75	717.00
Groundwater	Beauty Spot/International	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.96	59.75	717.00
Groundwater	Best Rd Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.33	10.00	120.00
Groundwater	BH-1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.49	14.85	178.16
Groundwater	BH-2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.49	14.85	178.16
Groundwater	BH-3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.49	14.85	178.16
Groundwater	BH-4	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.49	14.85	178.16
Groundwater	BH-5	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.49	14.85	178.16
Groundwater	BILLY MAC WELL	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.82	25.00	300.00
Groundwater	Black River WTP Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	2.26	68.61	823.30
Groundwater	Bluff Rd.	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.50	45.67	548.00
Groundwater	Braves Village (#103 ASR)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch-Charleston	5.12	155.68	1,868.20
Groundwater	Brockington Street	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	0.80	24.31	291.75
Groundwater	Bucksport WWTP	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	5.12	155.68	1,868.20

Table A-2. Permitted and Registered Amounts for Current Water Users

Source	Owner	Permit or Registration	Use Category	Aquifer	Permit or Registration Amount (MGD)	Permit or Registration Amount (MGM)	Permit or Registration Amount (MGY)
Groundwater	Burning Ridge Well (#28 ASR)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch-Charleston	5.12	155.68	1,868.20
Groundwater	BURT BEATSON WELL #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	15.22	462.80	5,553.60
Groundwater	By-Pass	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	0.93	28.25	339.00
Groundwater	Carolina Forest Well (#71 ASR)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	5.12	155.68	1,868.20
Groundwater	Carolina Pines (ASR # 105)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch-Charleston	5.12	155.68	1,868.20
Groundwater	Caropines Well (#36 ASR)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	5.12	155.68	1,868.20
Groundwater	Caropines Well (#39)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	5.12	155.68	1,868.20
Groundwater	Cedar Creek Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	3.47	105.67	1,268.00
Groundwater	Cemetery Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.81	54.92	659.00
Groundwater	CENTER WELL 9	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	4.93	150.00	1,800.00
Groundwater	Central WWTP	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	5.12	155.68	1,868.20
Groundwater	Checkerboard	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	1.81	55.08	661.00
Groundwater	Chestnut Cross Road Well (#23 ASR)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	5.12	155.68	1,868.20
Groundwater	CLA 24	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.03	0.92	11.00
Groundwater	CLA 28	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.03	0.92	11.00
Groundwater	CLA-146	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.47	44.68	536.20
Groundwater	CLA-27	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.47	44.68	536.20
Groundwater	CLA-29	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.47	44.68	536.20
Groundwater	CLA-64	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.47	44.68	536.20
Groundwater	Clemson Rd.	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.50	45.67	548.00
Groundwater	Cleveland Street	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	1.02	31.08	373.00
Groundwater	Conway Reservoir Well (#91)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	5.12	155.68	1,868.20
Groundwater	Council Street	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.73	52.75	633.00
Groundwater	County Camp	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch-Charleston	0.80	24.31	291.75
Groundwater	Coxe Rd (Well #11)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.96	59.75	717.00
Groundwater	Cox's Ferry Well (#18)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	5.12	155.68	1,868.20
Groundwater	CRESENT BEACH	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	2.30	70.02	840.30
Groundwater	Crystal Lakes Well (#24 ASR)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	5.12	155.68	1,868.20
Groundwater	Daisy Well (#9 ASR)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	5.12	155.68	1,868.20
Groundwater	Deep Creek Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	2.26	68.61	823.30
Groundwater	Deerfield Well (#104 ASR)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Charleston	5.12	155.68	1,868.20
Groundwater	Deerfield Well (#32)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	5.12	155.68	1,868.20
Groundwater	Dingle Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.71	21.50	258.00
Groundwater	DRINKING WATER	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	2.35	71.33	856.00
Groundwater	E. Main St. Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.96	59.75	717.00
Groundwater	ECA Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Charleston	0.52	15.92	191.00
Groundwater	ECA Well - New	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	0.52	15.92	191.00
Groundwater	EMERGENCY WELL #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.05	1.67	20.00

Table A-2. Permitted and Registered Amounts for Current Water Users

Source	Owner	Permit or Registration	Use Category	Aquifer	Permit or Registration Amount (MGD)	Permit or Registration Amount (MGM)	Permit or Registration Amount (MGY)
Groundwater	Eutaw St. Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch-Charleston	1.50	45.67	548.00
Groundwater	EVERGREEN WELL	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.47	44.86	538.34
Groundwater	Fennel Field	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	0.80	24.31	291.75
Groundwater	Fire Pond Well # 03	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.19	5.75	69.00
Groundwater	Forestbrook Well (#41)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	5.12	155.68	1,868.20
Groundwater	Francis Marion Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.24	7.25	87.00
Groundwater	Front Street	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.02	31.08	373.00
Groundwater	Garden City Well (#27)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	5.12	155.68	1,868.20
Groundwater	Gibson Ave.	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	0.33	10.00	120.00
Groundwater	Gibson Hwy #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.96	59.75	717.00
Groundwater	Gibson Hwy #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.96	59.75	717.00
Groundwater	Greenwood Park	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.50	45.67	548.00
Groundwater	GSF High School Well (#15)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	5.12	155.68	1,868.20
Groundwater	Guest House Well # 05	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.19	5.75	69.00
Groundwater	HAGLEY WELL	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	2.26	68.61	823.30
Groundwater	Hampton	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	0.93	28.25	339.00
Groundwater	Hanes Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.81	54.92	659.00
Groundwater	Hettie Ricket Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	3.47	105.67	1,268.00
Groundwater	HIGHTANK MURRELLS IN	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	2.26	68.61	823.30
Groundwater	Highway #34	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.26	38.42	461.00
Groundwater	Highway #9	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.26	38.42	461.00
Groundwater	Highway 377	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.80	24.31	291.75
Groundwater	Highway Department Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.73	52.75	633.00
Groundwater	HORSEPEN WELL	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.82	25.00	300.00
Groundwater	HWY 179 WELL	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Charleston	0.21	6.39	76.70
Groundwater	HWY 260	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.30	9.00	108.00
Groundwater	HWY 341 Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	0.14	4.17	50.00
Groundwater	Hwy 403 WTP	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	13.46	409.42	4,913.00
Groundwater	HWY 458	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Charleston	0.21	6.39	76.70
Groundwater	Hwy 501 Well (#22 ASR)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	5.12	155.68	1,868.20
Groundwater	Hydropillar Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch-Charleston	1.18	36.00	432.00
Groundwater	Hyman Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	0.24	7.25	87.00
Groundwater	I-20 Industrial Park	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.73	52.75	633.00
Groundwater	Industrial Park	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	1.02	31.08	373.00
Groundwater	Industrial Park Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Charleston	0.52	15.92	191.00
Groundwater	INLET OAKS WELL	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	2.26	68.61	823.30
Groundwater	INTERCHANGE WELL	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	2.30	70.02	840.30
Groundwater	Irrigation Well # 04	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.19	5.75	69.00

Table A-2. Permitted and Registered Amounts for Current Water Users

Source	Owner	Permit or Registration	Use Category	Aquifer	Permit or Registration Amount (MGD)	Permit or Registration Amount (MGM)	Permit or Registration Amount (MGY)
Groundwater	James Industrial Park	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.73	52.75	633.00
Groundwater	Jamestown Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	3.47	105.67	1,268.00
Groundwater	Jamestown Well (#11 ASR)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	5.12	155.68	1,868.20
Groundwater	Jamestown Well (#38)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	5.12	155.68	1,868.20
Groundwater	JORDANVILLE/WELL #6	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch-Charleston	1.47	44.86	538.34
Groundwater	Joyner Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	3.47	105.67	1,268.00
Groundwater	Keeler Rd Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch-Charleston	0.29	8.92	107.00
Groundwater	KING WELL	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.54	16.33	195.95
Groundwater	Kingsburg Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Charleston	0.63	19.08	229.00
Groundwater	KRISPY KREME WELL	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	2.30	70.02	840.30
Groundwater	Lee Well		Water Supply	McQueen Branch	0.00	0.00	0.00
Groundwater	LITCHFIELD HIGH TANK	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	2.26	68.61	823.30
Groundwater	Long Bay Well (#14)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	5.12	155.68	1,868.20
Groundwater	Longs Well (#29)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	5.12	155.68	1,868.20
Groundwater	Longs WWTP	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	5.12	155.68	1,868.20
Groundwater	Lucknow Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	3.47	105.67	1,268.00
Groundwater	Main Well #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	0.14	4.17	50.00
Groundwater	Main Well #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	0.05	1.67	20.00
Groundwater	MAIN WELL RED HILL	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Charleston	2.26	68.61	823.30
Groundwater	MAINWELL PLANTERSV 1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	2.26	68.61	823.30
Groundwater	MARYVILLE #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.54	16.33	195.95
Groundwater	Matthews Road	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	1.81	55.08	661.00
Groundwater	McColl Apt.	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	0.33	10.00	120.00
Groundwater	McQueen Well #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.32	40.00	480.00
Groundwater	McQueen Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.32	40.00	480.00
Groundwater	McQueen Well #3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.32	40.00	480.00
Groundwater	Morris Street	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	1.81	55.08	661.00
Groundwater	Mouzon Water System		Water Supply	Gramling	0.00	0.00	0.00
Groundwater	Myrtle Beach WTP Well #1 (#89)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	5.12	155.68	1,868.20
Groundwater	Myrtle Beach WTP Well #2 (#95)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch-Charleston	5.12	155.68	1,868.20
Groundwater	Near R/R-West Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.18	5.42	65.00
Groundwater	Near Water Plt/East	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.18	5.42	65.00
Groundwater	Nesmith Rd Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch-Charleston	0.29	8.92	107.00
Groundwater	New Hope Well #3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	0.21	6.33	76.00
Groundwater	New Hwy 38	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.32	40.00	480.00
Groundwater	New Well #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	0.48	14.58	175.00
Groundwater	New Well #1 Avondale	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	0.14	4.17	50.00
Groundwater	New Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	0.48	14.58	175.00
Groundwater	New Well #3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.18	5.42	65.00

Table A-2. Permitted and Registered Amounts for Current Water Users

Source	Owner	Permit or Registration	Use Category	Aquifer	Permit or Registration Amount (MGD)	Permit or Registration Amount (MGM)	Permit or Registration Amount (MGY)
Groundwater	North 5th St. Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.81	54.92	659.00
Groundwater	North ASR Well (#63 ASR)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	5.12	155.68	1,868.20
Groundwater	North Booster Well (#97 ASR)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	5.12	155.68	1,868.20
Groundwater	North Main	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	0.93	28.25	339.00
Groundwater	North Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	0.35	10.67	128.00
Groundwater	North Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	0.21	6.33	76.00
Groundwater	Oak Hill Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.63	19.08	229.00
Groundwater	OCEAN DRIVE	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	2.30	70.02	840.30
Groundwater	OCR-BH_2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.35	10.60	127.20
Groundwater	OCR-BH_2		Water Supply	Crouch Branch	0.00	0.00	0.00
Groundwater	OCR-BH-1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.35	10.60	127.20
Groundwater	OCR-BH-1		Water Supply	Crouch Branch	0.00	0.00	0.00
Groundwater	Odom Rd (Well #10)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.96	59.75	717.00
Groundwater	Old Beauty Spot #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.96	59.75	717.00
Groundwater	Old Beauty Spot #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.96	59.75	717.00
Groundwater	Old Hwy 403 Timmonsville (former G21423)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	13.46	409.42	4,913.00
Groundwater	Old Stagecoach Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	3.47	105.67	1,268.00
Groundwater	PAWLEYS PLANTATION	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	2.26	68.61	823.30
Groundwater	PAWLEYS SHOP WELL	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	2.26	68.61	823.30
Groundwater	Pawly's Swamp	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch-Charleston	1.47	44.86	538.34
Groundwater	Pender Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.71	21.50	258.00
Groundwater	PENNY ROYAL #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	2.26	68.61	823.30
Groundwater	PENNY ROYAL WELL	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	2.26	68.61	823.30
Groundwater	Perry Road Well (#84)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch-Charleston	5.12	155.68	1,868.20
Groundwater	Piedmont Road	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.73	52.75	633.00
Groundwater	Pine Street	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	0.93	28.25	339.00
Groundwater	Pirate Cove Well (#13)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	5.12	155.68	1,868.20
Groundwater	Pirateland Well (#17 ASR)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	5.12	155.68	1,868.20
Groundwater	Plantersville Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	2.26	68.61	823.30
Groundwater	Prestwick Well (#45 ASR)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	5.12	155.68	1,868.20
Groundwater	Prevatte Street	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	1.02	31.08	373.00
Groundwater	Process Well # 01A	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	0.19	5.75	69.00
Groundwater	Prosses Well # 01B	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.19	5.75	69.00
Groundwater	Racetrack Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch-Charleston	1.18	36.00	432.00
Groundwater	Rae Street	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	1.81	55.08	661.00
Groundwater	Railroad Ave. Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.50	45.67	548.00
Groundwater	Replacement Well #11	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	3.88	117.92	1,415.00
Groundwater	River Rd. Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.24	7.25	87.00

Table A-2. Permitted and Registered Amounts for Current Water Users

Source	Owner	Permit or Registration	Use Category	Aquifer	Permit or Registration Amount (MGD)	Permit or Registration Amount (MGM)	Permit or Registration Amount (MGY)
Groundwater	ROGER SHERRILL WELL #3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	15.22	462.80	5,553.60
Groundwater	Rogers Rd. Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch-Charleston	1.50	45.67	548.00
Groundwater	ROSE HILL WELL	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	2.26	68.61	823.30
Groundwater	RV BRIARCLIFF	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	0.02	0.71	8.50
Groundwater	SAMPIT WELL	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	2.26	68.61	823.30
Groundwater	Sandy Grove Ch Rd	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.96	59.75	717.00
Groundwater	Seaside Elementary (#34 ASR)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	5.12	155.68	1,868.20
Groundwater	Shed Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.63	19.08	229.00
Groundwater	Shop Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	0.35	10.67	128.00
Groundwater	Sloan Rd. Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch-Charleston	1.50	45.67	548.00
Groundwater	Smith St. Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch-Charleston	1.50	45.67	548.00
Groundwater	Smith St. Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.81	54.92	659.00
Groundwater	Sollie Circle	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	2.26	68.61	823.30
Groundwater	South 5th St. Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.81	54.92	659.00
Groundwater	SOUTH WELL	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.35	10.67	128.00
Groundwater	South Well #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	0.21	6.33	76.00
Groundwater	Springs Mill	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.02	31.08	373.00
Groundwater	St. Anne Street	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	1.02	31.08	373.00
Groundwater	Studio City Well (#16 ASR)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	5.12	155.68	1,868.20
Groundwater	Surfside 10th Ave Well (#10)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	5.12	155.68	1,868.20
Groundwater	Surfside 3rd Ave Well (#3 ASR)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	5.12	155.68	1,868.20
Groundwater	SYDNOR#1 DEBORDIEU 3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	2.26	68.61	823.30
Groundwater	SYDNOR#2 DEBORDIEU 2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	2.26	68.61	823.30
Groundwater	Tamarack Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.82	25.00	300.00
Groundwater	Tatum Well #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.32	40.00	480.00
Groundwater	Tatum Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.32	40.00	480.00
Groundwater	Tern Hall Well (#25)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	5.12	155.68	1,868.20
Groundwater	test Well #2/Cypress St Replacement	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.41	12.34	148.12
Groundwater	Tilly Swamp Well (#19 ASR)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	5.12	155.68	1,868.20
Groundwater	TPI Tank Well (#69 ASR)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Charleston	5.12	155.68	1,868.20
Groundwater	Trade St. & First Ave.	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.24	7.25	87.00
Groundwater	Tupperware Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Charleston	0.52	15.92	191.00
Groundwater	Tyson Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.71	21.50	258.00
Groundwater	Vereen WWTP	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	5.12	155.68	1,868.20
Groundwater	Vox Hwy Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.63	19.08	229.00
Groundwater	WACCHESAW PLANTATION	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	2.26	68.61	823.30
Groundwater	Wallace Road	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.81	55.08	661.00
Groundwater	WALT BEARD WELL #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	15.22	462.80	5,553.60

Table A-2. Permitted and Registered Amounts for Current Water Users

Source	Owner	Permit or Registration	Use Category	Aquifer	Permit or Registration Amount (MGD)	Permit or Registration Amount (MGM)	Permit or Registration Amount (MGY)
Groundwater	Wampee Well (#46)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	5.12	155.68	1,868.20
Groundwater	Water Supply # 02	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.19	5.75	69.00
Groundwater	Water Well #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	1.03	31.25	375.00
Groundwater	Watson's Riverside Well (#44 ASR)	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	5.12	155.68	1,868.20
Groundwater	Wedgefield Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	2.26	68.61	823.30
Groundwater	WELDON DRIVE	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	15.22	462.80	5,553.60
Groundwater	WELL # 10 HWY 151	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	3.76	114.30	1,371.60
Groundwater	WELL #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.21	6.25	75.00
Groundwater	WELL #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.08	2.33	28.00
Groundwater	WELL #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	2.47	75.00	900.00
Groundwater	WELL #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.15	4.67	56.00
Groundwater	WELL #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.85	56.25	675.00
Groundwater	WELL #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.43	13.00	156.00
Groundwater	WELL #1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	0.27	8.33	100.00
Groundwater	WELL #1	WTR-Groundwater Withdrawal Registration	Water Supply	Mcqueen Branch	0.11	3.33	40.00
Groundwater	WELL #1 - Road 92	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	3.76	114.30	1,371.60
Groundwater	Well #1 Cassatt Rd.	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	3.47	105.67	1,268.00
Groundwater	WELL #1 E TRTMNT PLT	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	0.28	8.42	101.00
Groundwater	Well #1 Hwy 52	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.14	4.17	50.00
Groundwater	Well #1 Main	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	0.04	1.10	13.20
Groundwater	Well #1 Old Stage Coach Rd.	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	3.47	105.67	1,268.00
Groundwater	WELL #1 PLANT 2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	15.22	462.80	5,553.60
Groundwater	WELL #1 PLANT 3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	15.22	462.80	5,553.60
Groundwater	WELL #1 PLANT 4	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	15.22	462.80	5,553.60
Groundwater	WELL #1 PLANT 5	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	15.22	462.80	5,553.60
Groundwater	WELL #1 TRMNT PLANT	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.15	4.50	54.00
Groundwater	Well #1/Fire Dept.	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.41	12.34	148.12
Groundwater	Well #10	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	1.85	56.25	675.00
Groundwater	Well #10	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	3.88	117.92	1,415.00
Groundwater	Well #11 - Old Creek Road	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	3.76	114.30	1,371.60
Groundwater	Well #12	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	3.76	114.30	1,371.60
Groundwater	Well #12	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	3.88	117.92	1,415.00
Groundwater	Well #14	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	3.88	117.92	1,415.00
Groundwater	Well #15	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	3.88	117.92	1,415.00
Groundwater	Well #16	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	3.88	117.92	1,415.00
Groundwater	Well #16 Pine Street	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	13.46	409.42	4,913.00
Groundwater	Well #17	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	3.88	117.92	1,415.00
Groundwater	Well #17 Dexter Drive	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	13.46	409.42	4,913.00

Table A-2. Permitted and Registered Amounts for Current Water Users

Source	Owner	Permit or Registration	Use Category	Aquifer	Permit or Registration Amount (MGD)	Permit or Registration Amount (MGM)	Permit or Registration Amount (MGY)
Groundwater	Well #18	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	3.88	117.92	1,415.00
Groundwater	Well #18 Gully Br. Deep	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	13.46	409.42	4,913.00
Groundwater	Well #19	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	3.88	117.92	1,415.00
Groundwater	Well #19 Edisto Shallow	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	13.46	409.42	4,913.00
Groundwater	Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.21	6.25	75.00
Groundwater	Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	2.35	71.33	856.00
Groundwater	Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	2.47	75.00	900.00
Groundwater	Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.15	4.67	56.00
Groundwater	Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.85	56.25	675.00
Groundwater	Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.15	4.50	54.00
Groundwater	Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.43	13.00	156.00
Groundwater	Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.15	4.50	54.00
Groundwater	Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	0.27	8.33	100.00
Groundwater	Well #2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.28	8.42	101.00
Groundwater	WELL #2		Water Supply	Crouch Branch	0.00	0.00	0.00
Groundwater	Well #2	WTR-Groundwater Withdrawal Registration	Water Supply	Crouch Branch	0.11	3.33	40.00
Groundwater	WELL #2 - Road 346	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	3.76	114.30	1,371.60
Groundwater	Well #2 Church St.	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.14	4.17	50.00
Groundwater	Well #2 Main St	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.14	4.17	50.00
Groundwater	Well #2 New	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	0.15	4.52	54.20
Groundwater	Well #2 New	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	0.04	1.10	13.20
Groundwater	Well #2 Old Stage Coach Rd.	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	3.47	105.67	1,268.00
Groundwater	WELL #2 PLANT 2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	15.22	462.80	5,553.60
Groundwater	WELL #2 PLANT 3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	15.22	462.80	5,553.60
Groundwater	WELL #2 PLANT 4	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	15.22	462.80	5,553.60
Groundwater	WELL #2 PLANT 5	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	15.22	462.80	5,553.60
Groundwater	WELL #2 TRTMNT PLNT	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	0.07	2.25	27.00
Groundwater	WELL #2 W TRTMNT PLT	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	0.28	8.42	101.00
Groundwater	WELL #2/Cypress St	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.41	12.34	148.12
Groundwater	Well #20	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	3.88	117.92	1,415.00
Groundwater	Well #21 Darlington Street	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	13.46	409.42	4,913.00
Groundwater	Well #22	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	3.88	117.92	1,415.00
Groundwater	Well #22 McCown Shallow	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	13.46	409.42	4,913.00
Groundwater	Well #23	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	3.88	117.92	1,415.00
Groundwater	Well #24 Lucas Street	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	13.46	409.42	4,913.00
Groundwater	Well #25		Water Supply	McQueen Branch	0.00	0.00	0.00
Groundwater	Well #25 Oakdale	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	13.46	409.42	4,913.00
Groundwater	Well #26 G.E. Deep	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	13.46	409.42	4,913.00
Groundwater	Well #27 Harmony Street	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	13.46	409.42	4,913.00

Table A-2. Permitted and Registered Amounts for Current Water Users

Source	Owner	Permit or Registration	Use Category	Aquifer	Permit or Registration Amount (MGD)	Permit or Registration Amount (MGM)	Permit or Registration Amount (MGY)
Groundwater	Well #28 Santiago Drive	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	13.46	409.42	4,913.00
Groundwater	WELL #2R	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	0.13	3.92	47.04
Groundwater	Well #3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	3.76	114.30	1,371.60
Groundwater	Well #3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	0.19	5.83	70.00
Groundwater	Well #3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	2.47	75.00	900.00
Groundwater	Well #3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	0.13	3.92	47.04
Groundwater	Well #3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.85	56.25	675.00
Groundwater	Well #3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.43	13.00	156.00
Groundwater	Well #3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	3.88	117.92	1,415.00
Groundwater	Well #3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	0.27	8.33	100.00
Groundwater	Well #3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.28	8.42	101.00
Groundwater	WELL #3 BHND TRTMNT	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	0.07	2.25	27.00
Groundwater	WELL #3 BLD 2233	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	1.03	31.25	375.00
Groundwater	WELL #3 PLANT 1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	15.22	462.80	5,553.60
Groundwater	WELL #3 PLANT 2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	15.22	462.80	5,553.60
Groundwater	WELL #3 PLANT 3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	15.22	462.80	5,553.60
Groundwater	WELL #3 PLANT 4	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	15.22	462.80	5,553.60
Groundwater	WELL #3 PLANT 5	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	15.22	462.80	5,553.60
Groundwater	WELL #3/Prison	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.41	12.34	148.12
Groundwater	Well #30 Wallace-Gregg	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	13.46	409.42	4,913.00
Groundwater	Well #31 Mt. Zion	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	13.46	409.42	4,913.00
Groundwater	Well #32 Ebenezer Deep	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	13.46	409.42	4,913.00
Groundwater	Well #33 South Park	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	13.46	409.42	4,913.00
Groundwater	Well #34 South Florence	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	13.46	409.42	4,913.00
Groundwater	Well #35 Roberta Drive	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	13.46	409.42	4,913.00
Groundwater	Well #36 Green Acres Deep	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	13.46	409.42	4,913.00
Groundwater	Well #37 Ebenezer Shallow	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	13.46	409.42	4,913.00
Groundwater	Well #38 McCown Shallow	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	13.46	409.42	4,913.00
Groundwater	Well #39 Gully Br. Shallow	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	13.46	409.42	4,913.00
Groundwater	Well #4	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	0.19	5.83	70.00
Groundwater	Well #4	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	2.47	75.00	900.00
Groundwater	Well #4	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	1.85	56.25	675.00
Groundwater	Well #4	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	0.27	8.33	100.00
Groundwater	WELL #4 - Sowell Road	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	3.76	114.30	1,371.60
Groundwater	WELL #4 BLD 2004	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	1.03	31.25	375.00
Groundwater	WELL #4 PLANT 1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	15.22	462.80	5,553.60
Groundwater	WELL #4 PLANT 2	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	15.22	462.80	5,553.60
Groundwater	Well #40 Green Acres Shallow	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	13.46	409.42	4,913.00

Table A-2. Permitted and Registered Amounts for Current Water Users

Source	Owner	Permit or Registration	Use Category	Aquifer	Permit or Registration Amount (MGD)	Permit or Registration Amount (MGM)	Permit or Registration Amount (MGY)
Groundwater	Well #41 Eureka Road	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	13.46	409.42	4,913.00
Groundwater	Well #42 Range Way	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	13.46	409.42	4,913.00
Groundwater	Well #43 McCurdy Road	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	13.46	409.42	4,913.00
Groundwater	Well #45 Alligator Deep	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	13.46	409.42	4,913.00
Groundwater	Well #46 Alligator Shallow	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	13.46	409.42	4,913.00
Groundwater	Well #47 Twin Church	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	13.46	409.42	4,913.00
Groundwater	Well #48 River Road	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	13.46	409.42	4,913.00
Groundwater	Well #4A	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	3.88	117.92	1,415.00
Groundwater	Well #5	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.47	44.86	538.34
Groundwater	Well #5	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	2.47	75.00	900.00
Groundwater	Well #5	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	1.85	56.25	675.00
Groundwater	WELL #5 - Hwy 1 South	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	3.76	114.30	1,371.60
Groundwater	WELL #5 BLD 1415	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	1.03	31.25	375.00
Groundwater	WELL #5 PLANT 3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	15.22	462.80	5,553.60
Groundwater	WELL #5 Treatment Plant	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.15	4.50	54.00
Groundwater	Well #6	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch-Charleston	1.85	56.25	675.00
Groundwater	Well #6	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	3.88	117.92	1,415.00
Groundwater	WELL #6 - Hwy 145	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	3.76	114.30	1,371.60
Groundwater	WELL #6 BLD 3656	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.03	31.25	375.00
Groundwater	WELL #6 PLANT 1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	15.22	462.80	5,553.60
Groundwater	WELL #6 PLANT 3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	15.22	462.80	5,553.60
Groundwater	Well #7	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	1.85	56.25	675.00
Groundwater	Well #7	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	3.88	117.92	1,415.00
Groundwater	WELL #7 - Hwy 1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	3.76	114.30	1,371.60
Groundwater	WELL #7 BLD 5640	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.03	31.25	375.00
Groundwater	WELL #7 PLANT 1	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	15.22	462.80	5,553.60
Groundwater	Well #7 Water Plant 3	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	15.22	462.80	5,553.60
Groundwater	Well #8	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	1.85	56.25	675.00
Groundwater	Well #8	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	3.88	117.92	1,415.00
Groundwater	WELL #8 - Hwy 151 South	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	3.76	114.30	1,371.60
Groundwater	Well #9	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	3.76	114.30	1,371.60
Groundwater	Well #9	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.85	56.25	675.00
Groundwater	Well #9	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	3.88	117.92	1,415.00
Groundwater	WELL 1-A	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Charleston	0.21	6.39	76.70
Groundwater	Well 24	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	3.88	117.92	1,415.00
Groundwater	WELL ONE-A	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	0.13	3.92	47.04
Groundwater	West Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.63	19.08	229.00
Groundwater	WHITE POINT WELL	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	2.30	70.02	840.30

Table A-2. Permitted and Registered Amounts for Current Water Users

Source	Owner	Permit or Registration	Use Category	Aquifer	Permit or Registration Amount (MGD)	Permit or Registration Amount (MGM)	Permit or Registration Amount (MGY)
Groundwater	WINDY HILL	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	2.30	70.02	840.30
Groundwater	LAKE ARROWHEAD	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch-Charleston	0.02	0.71	8.5
Groundwater	AVX	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	0.02	0.71	8.5
Groundwater	WIRE MILL WELL	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	0.82	25.00	300.00
Groundwater	WITHALACOOCHE	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch-Charleston	1.50	45.67	548.00
Groundwater	WWTP Deep	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch-Mcqueen Branch	2.26	68.61	823.30
Groundwater	WWTP Shallow	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Surficial	2.26	68.61	823.30
Groundwater	X-ROADS WELL	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch	1.47	44.86	538.34
Groundwater	YAUHANNAH WELL	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Crouch Branch	2.26	68.61	823.30
Groundwater	Zion Well	WTR-Groundwater Withdrawal Capacity Use Area Permit	Water Supply	Mcqueen Branch-Charleston	1.50	45.67	548.00
Surface Water	Pond	WTR-Surface Water Withdrawal Agricultural Registration	Agriculture		0.00	0.00	0
Surface Water	Pond 2	WTR-Surface Water Withdrawal Agricultural Registration	Agriculture		0.00	0.00	0
Surface Water	Griggs Farm	WTR-Surface Water Withdrawal Agricultural Registration	Agriculture		0.05	1.63	19.548
Surface Water	Tolson Pond	WTR-Surface Water Withdrawal Agricultural Registration	Agriculture		0.00	0.00	0
Surface Water	#6 Newton	WTR-Surface Water Withdrawal Agricultural Registration	Agriculture		0.38	11.48	137.81
Surface Water	Atkinson Farm	WTR-Surface Water Withdrawal Agricultural Registration	Agriculture		0.27	8.00	96.00
Surface Water	Back Swamp Creek	WTR-Surface Water Withdrawal Agricultural Registration	Agriculture		0.18	5.50	66.00
Surface Water	Black Creek (S01)	WTR-Surface Water Withdrawal Agricultural Registration	Agriculture		180.00	5,400.00	64,800.00
Surface Water	Black River intake	WTR-Surface Water Withdrawal Agricultural Registration	Agriculture		1.00	30.00	360.00
Surface Water	Chappell Creek	WTR-Surface Water Withdrawal Agricultural Registration	Agriculture		0.39	11.57	138.78
Surface Water	Frank's Creek	WTR-Surface Water Withdrawal Agricultural Registration	Agriculture		0.32	9.72	116.64
Surface Water	Griggs Stream	WTR-Surface Water Withdrawal Agricultural Registration	Agriculture		0.11	3.26	39.10
Surface Water	Griggs Stream	WTR-Surface Water Withdrawal Agricultural Registration	Agriculture		0.08	2.40	28.80
Surface Water	Hawkins Canal #3	WTR-Surface Water Withdrawal Agricultural Registration	Agriculture		0.27	8.00	96.00
Surface Water	Louthers Lake	WTR-Surface Water Withdrawal Agricultural Registration	Agriculture		0.17	5.00	60.00
Surface Water	McCalls Mill Pond	WTR-Surface Water Withdrawal Agricultural Registration	Agriculture		1.90	57.02	684.28
Surface Water	McDonald Canal	WTR-Surface Water Withdrawal Agricultural Registration	Agriculture		0.31	9.22	110.59
Surface Water	Mcintosh pond	WTR-Surface Water Withdrawal Agricultural Registration	Agriculture		0.19	5.81	69.72
Surface Water	McLeod #2, Field 3	WTR-Surface Water Withdrawal Agricultural Registration	Agriculture		1.13	33.94	407.30
Surface Water	McLeod #3, Field 5	WTR-Surface Water Withdrawal Agricultural Registration	Agriculture		1.17	35.10	421.20
Surface Water	McLeod Pond #1	WTR-Surface Water Withdrawal Agricultural Registration	Agriculture		1.12	33.67	404.04
Surface Water	Naked Creek Intake	WTR-Surface Water Withdrawal Agricultural Registration	Agriculture		3.43	103.00	1,236.00
Surface Water	PEE DEE RIVER	WTR-Surface Water Withdrawal Agricultural Registration	Agriculture		0.55	16.52	198.24
Surface Water	Pump #1	WTR-Surface Water Withdrawal Agricultural Registration	Agriculture		0.86	25.80	309.60
Surface Water	Pump #2	WTR-Surface Water Withdrawal Agricultural Registration	Agriculture		0.32	9.52	114.24
Surface Water	Pump #3	WTR-Surface Water Withdrawal Agricultural Registration	Agriculture		0.25	7.62	91.44
Surface Water	Pump #4	WTR-Surface Water Withdrawal Agricultural Registration	Agriculture		0.09	2.77	33.24
Surface Water	Pump for John's and Bess	WTR-Surface Water Withdrawal Agricultural Registration	Agriculture		3.01	90.40	1,084.80

Table A-2. Permitted and Registered Amounts for Current Water Users

Source	Owner	Permit or Registration	Use Category	Aquifer	Permit or Registration Amount (MGD)	Permit or Registration Amount (MGM)	Permit or Registration Amount (MGY)
Surface Water	Red Oak Camp Creek	WTR-Surface Water Withdrawal Agricultural Registration	Agriculture		3.04	91.30	1,095.60
Surface Water	River Intake Holy Lane	WTR-Surface Water Withdrawal Agricultural Registration	Agriculture		0.23	7.00	84.00
Surface Water	River Intake Mills Rd	WTR-Surface Water Withdrawal Agricultural Registration	Agriculture		1.00	30.00	360.00
Surface Water	T.C Coxe	WTR-Surface Water Withdrawal Agricultural Registration	Agriculture		2.00	60.00	720.00
Surface Water	Tom's Creek Pond	WTR-Surface Water Withdrawal Agricultural Registration	Agriculture		0.10	3.00	36.00
Surface Water	Westfield Creek	WTR-Surface Water Withdrawal Agricultural Registration	Agriculture		0.20	6.00	72.00
Surface Water	#1 Intake	WTR-Surface Water Withdrawal Existing Permit	Golf		0.89	26.78	321.36
Surface Water	Irrigation Lake	WTR-Surface Water Withdrawal Permit	Golf		0.60	18.00	216
Surface Water	Waterway Pump	WTR-Surface Water Withdrawal Existing Permit	Golf		0.83	25.00	300
Surface Water	Arcadian Shores GC - 26GC017S01	WTR-Surface Water Withdrawal Existing Permit	Golf		0.74	22.30	267.60
Surface Water	Buck Creek Intake	WTR-Surface Water Withdrawal Existing Permit	Golf		0.26	7.75	93.00
Surface Water	Golf Course Intake	WTR-Surface Water Withdrawal Permit	Golf		0.13	4.00	48.00
Surface Water	Golf Course Irrigation Pump House	WTR-Surface Water Withdrawal Existing Permit	Golf		1.56	46.80	561.64
Surface Water	Grande Dunes Transfer Station South	WTR-Surface Water Withdrawal Existing Permit	Golf		2.83	84.82	1,017.84
Surface Water	ICW Intake		Golf		0.60	18.00	216.00
Surface Water	ICW Intake	WTR-Surface Water Withdrawal Existing Permit	Golf		1.12	33.48	401.76
Surface Water	ICWW Intake	WTR-Surface Water Withdrawal Existing Permit	Golf		4.76	142.85	1,714.20
Surface Water	ICWW Under Bridge - North Pump	WTR-Surface Water Withdrawal Existing Permit	Golf		2.83	84.82	1,017.84
Surface Water	Intracoastal Waterway	WTR-Surface Water Withdrawal Existing Permit	Golf		0.36	10.80	129.60
Surface Water	Intracoastal Waterway	WTR-Surface Water Withdrawal Existing Permit	Golf		1.19	35.71	428.52
Surface Water	Irrigation Lake	WTR-Surface Water Withdrawal Existing Permit	Golf		1.63	49.00	588.00
Surface Water	Irrigation Lake #12	WTR-Surface Water Withdrawal Existing Permit	Golf		2.38	71.42	857.04
Surface Water	Main Pump House	WTR-Surface Water Withdrawal Existing Permit	Golf		2.31	69.19	830.28
Surface Water	Marina Basin	WTR-Surface Water Withdrawal Existing Permit	Golf		0.97	29.02	348.24
Surface Water	Oatland Lake Intake	WTR-Surface Water Withdrawal Existing Permit	Golf		3.33	100.00	1,200.00
Surface Water	Palmetto Transfer Pump	WTR-Surface Water Withdrawal Existing Permit	Golf		1.49	44.60	535.20
Surface Water	Pinehills transfer pump	WTR-Surface Water Withdrawal Existing Permit	Golf		1.49	44.60	535.20
Surface Water	Prince Creek Intake	WTR-Surface Water Withdrawal Existing Permit	Golf		0.74	22.32	267.84
Surface Water	Pump house	WTR-Surface Water Withdrawal Existing Permit	Golf		2.01	60.26	723.12
Surface Water	Pump House - Midway Lake	WTR-Surface Water Withdrawal Existing Permit	Golf		0.24	7.10	85.20
Surface Water	Pump House (Lake)	WTR-Surface Water Withdrawal Existing Permit	Golf		1.49	44.64	535.68
Surface Water	Pump House-Cane Patch Lake	WTR-Surface Water Withdrawal Existing Permit	Golf		0.20	5.99	71.88
Surface Water	Pump Station	WTR-Surface Water Withdrawal Existing Permit	Golf		0.67	20.00	240.00
Surface Water	Pumphouse	WTR-Surface Water Withdrawal Existing Permit	Golf		1.51	45.30	543.60
Surface Water	Pumphouse Intake	WTR-Surface Water Withdrawal Existing Permit	Golf		1.64	49.10	589.20
Surface Water	Reserve Pump House - 22GC018S01	WTR-Surface Water Withdrawal Existing Permit	Golf		2.23	66.96	803.52
Surface Water	River Hills Golf & CC Pumphouse	WTR-Surface Water Withdrawal Existing Permit	Golf		1.22	36.60	439.20
Surface Water	Singleton Lake Intake	WTR-Surface Water Withdrawal Existing Permit	Golf		4.32	129.58	1,554.96
Surface Water	TB Main Intake	WTR-Surface Water Withdrawal Existing Permit	Golf		2.38	71.42	857.04

Table A-2. Permitted and Registered Amounts for Current Water Users

Source	Owner	Permit or Registration	Use Category	Aquifer	Permit or Registration Amount (MGD)	Permit or Registration Amount (MGM)	Permit or Registration Amount (MGY)
Surface Water	Tradition Maintenance Facility Intake	WTR-Surface Water Withdrawal Existing Permit	Golf		1.34	40.20	482.40
Surface Water	Transfer Pump	WTR-Surface Water Withdrawal Existing Permit	Golf		0.54	16.07	192.84
Surface Water	Unnamed Trib To Waverly Creek	WTR-Surface Water Withdrawal Existing Permit	Golf		1.57	47.00	564.00
Surface Water	Waccamaw River Intake-26GC032S01	WTR-Surface Water Withdrawal Existing Permit	Golf		0.35	10.36	124.32
Surface Water	Black Creek	WTR-Surface Water Withdrawal Existing Permit	Industry		1.03	31.00	372.00
Surface Water	Mill Supply	WTR-Surface Water Withdrawal - Special Authorization	Industry		0.00	0.00	0.00
Surface Water	North Pond-North PH - 22IN008S01	WTR-Surface Water Withdrawal Existing Permit	Industry		4.23	127.00	1,524.00
Surface Water	North Pond-South PH - 22IN008S02	WTR-Surface Water Withdrawal Existing Permit	Industry		3.97	119.00	1,428.00
Surface Water	Pee Dee River - 34IN005S01	WTR-Surface Water Withdrawal Existing Permit	Industry		31.23	937.00	11,244.00
Surface Water	Pond House (NO1)	WTR-Surface Water Withdrawal Existing Permit	Industry		11.16	334.80	4,017.60
Surface Water	Power Intake	WTR-Surface Water Withdrawal Existing Permit	Industry		29.13	873.89	10,486.68
Surface Water	River Fresh Water Intake	WTR-Surface Water Withdrawal Existing Permit	Industry		41.66	1,249.90	14,998.80
Surface Water	Sampit Intake 1	WTR-Surface Water Withdrawal Existing Permit	Industry		3.12	93.70	1,124.40
Surface Water	Sampit Intake 2	WTR-Surface Water Withdrawal Existing Permit	Industry		3.12	93.70	1,124.40
Surface Water	Brewer Intake	WTR-Surface Water Withdrawal Existing Permit	Mining		6.84	205.30	2,463.60
Surface Water	Jefferson Intake	WTR-Surface Water Withdrawal Existing Permit	Mining		0.89	26.80	321.60
Surface Water	Marlboro Intake	WTR-Surface Water Withdrawal Existing Permit	Mining		4.46	133.90	1,606.80
Surface Water	Raley Millpond	WTR-Surface Water Withdrawal Existing Permit	Mining		3.27	98.21	1,178.52
Surface Water	Robinson Fossil Plant Intake	WTR-Surface Water Withdrawal Existing Permit	Nuclear Power		129.47	3,884.00	46,608.00
Surface Water	Robinson Nuclear Plant Intake	WTR-Surface Water Withdrawal Existing Permit	Nuclear Power		746.20	22,386.00	268,632.00
Surface Water	22WS001S01	WTR-Surface Water Withdrawal Existing Permit	Water Supply		12.40	372.00	4,464.00
Surface Water	22WS002S01	WTR-Surface Water Withdrawal Existing Permit	Water Supply		12.20	366.00	4,392.00
Surface Water	Bull Creek	WTR-Surface Water Withdrawal Existing Permit	Water Supply		62.00	1,860.00	22,320.00
Surface Water	Lake Wallace	WTR-Surface Water Withdrawal Existing Permit	Water Supply		4.00	120.00	1,440.00
Surface Water	Myrtle Beach SWTP - 26WS009S01	WTR-Surface Water Withdrawal Existing Permit	Water Supply		62.00	1,860.00	22,320.00
Surface Water	Pee Dee Intake	WTR-Surface Water Withdrawal Existing Permit	Water Supply		31.00	930.00	11,160.00
Surface Water	Pee Dee River - 13WS001S01	WTR-Surface Water Withdrawal Existing Permit	Water Supply		11.90	357.00	4,284.00

Table A-3. Projected Water Demands

Source	User	Use Category	Year	Moderate Demand (MGD)	High Demand (MGD)
Coastal Surface Water	Combined User Data	Agriculture	2025	0.00	0.53
Coastal Surface Water	Combined User Data	Agriculture	2030	0.00	0.53
Coastal Surface Water	Combined User Data	Agriculture	2035	0.00	0.53
Coastal Surface Water	Combined User Data	Agriculture	2040	0.00	0.53
Coastal Surface Water	Combined User Data	Agriculture	2050	0.00	0.53
Coastal Surface Water	Combined User Data	Agriculture	2060	0.00	0.53
Coastal Surface Water	Combined User Data	Agriculture	2070	0.00	0.53
Coastal Surface Water	Combined User Data	Golf	2025	3.78	9.23
Coastal Surface Water	Combined User Data	Golf	2030	3.79	9.26
Coastal Surface Water	Combined User Data	Golf	2035	3.81	9.29
Coastal Surface Water	Combined User Data	Golf	2040	3.82	9.32
Coastal Surface Water	Combined User Data	Golf	2050	3.85	9.41
Coastal Surface Water	Combined User Data	Golf	2060	3.87	9.52
Coastal Surface Water	Combined User Data	Golf	2070	3.90	9.66
Coastal Surface Water	Combined User Data	Industry	2025	6.56	11.55
Coastal Surface Water	Combined User Data	Industry	2030	7.09	12.82
Coastal Surface Water	Combined User Data	Industry	2035	7.59	14.22
Coastal Surface Water	Combined User Data	Industry	2040	8.04	15.78
Coastal Surface Water	Combined User Data	Industry	2050	8.98	19.43
Coastal Surface Water	Combined User Data	Industry	2060	9.83	23.91
Coastal Surface Water	Combined User Data	Industry	2070	10.77	29.44
Coastal Surface Water	Combined User Data	Water Supply	2025	61.49	67.96
Coastal Surface Water	Combined User Data	Water Supply	2030	68.41	76.33
Coastal Surface Water	Combined User Data	Water Supply	2035	75.35	85.80
Coastal Surface Water	Combined User Data	Water Supply	2040	82.32	96.73
Coastal Surface Water	Combined User Data	Water Supply	2050	95.76	122.38
Coastal Surface Water	Combined User Data	Water Supply	2060	109.66	155.92
Coastal Surface Water	Combined User Data	Water Supply	2070	123.04	198.20
Groundwater	Combined User Data	Agriculture	2025	27.30	70.90
Groundwater	Combined User Data	Agriculture	2030	28.20	73.50
Groundwater	Combined User Data	Agriculture	2035	29.10	76.30
Groundwater	Combined User Data	Agriculture	2040	30.00	79.10
Groundwater	Combined User Data	Agriculture	2050	32.00	85.00
Groundwater	Combined User Data	Agriculture	2060	34.20	91.40
Groundwater	Combined User Data	Agriculture	2070	36.50	98.30
Groundwater	Combined User Data	Golf	2025	1.20	4.20
Groundwater	Combined User Data	Golf	2030	1.20	4.20
Groundwater	Combined User Data	Golf	2035	1.20	4.20
Groundwater	Combined User Data	Golf	2040	1.20	4.20
Groundwater	Combined User Data	Golf	2050	1.20	4.20
Groundwater	Combined User Data	Golf	2060	1.20	4.20
Groundwater	Combined User Data	Golf	2070	1.20	4.20
Groundwater	Combined User Data	Industry	2025	11.30	18.50
Groundwater	Combined User Data	Industry	2030	12.30	20.50
Groundwater	Combined User Data	Industry	2035	13.40	22.80
Groundwater	Combined User Data	Industry	2040	14.30	25.20
Groundwater	Combined User Data	Industry	2050	16.50	31.10
Groundwater	Combined User Data	Industry	2060	18.90	38.30
Groundwater	Combined User Data	Industry	2070	21.60	47.10
Groundwater	Combined User Data	Nuclear Power	2025	1.10	1.30
Groundwater	Combined User Data	Nuclear Power	2030	1.10	1.30
Groundwater	Combined User Data	Nuclear Power	2035	1.10	1.30
Groundwater	Combined User Data	Nuclear Power	2040	1.10	1.30
Groundwater	Combined User Data	Nuclear Power	2050	1.10	1.30
Groundwater	Combined User Data	Nuclear Power	2060	1.10	1.30
Groundwater	Combined User Data	Nuclear Power	2070	1.10	1.30
Groundwater	Combined User Data	Water Supply	2025	61.20	82.60
Groundwater	Combined User Data	Water Supply	2030	60.40	87.60
Groundwater	Combined User Data	Water Supply	2035	59.60	92.90
Groundwater	Combined User Data	Water Supply	2040	59.70	98.90
Groundwater	Combined User Data	Water Supply	2050	62.40	111.50
Groundwater	Combined User Data	Water Supply	2060	65.50	127.00
Groundwater	Combined User Data	Water Supply	2070	68.20	144.50
Groundwater	Combined User Data	Aquaculture	2025	0.00	0.10
Groundwater	Combined User Data	Aquaculture	2030	0.00	0.10
Groundwater	Combined User Data	Aquaculture	2035	0.00	0.10
Groundwater	Combined User Data	Aquaculture	2040	0.00	0.10
Groundwater	Combined User Data	Aquaculture	2050	0.00	0.10
Groundwater	Combined User Data	Aquaculture	2060	0.00	0.10
Groundwater	Combined User Data	Aquaculture	2070	0.00	0.10
Groundwater (SWAM)	Bishopville	Water Supply	2025	1.21	1.47
Groundwater (SWAM)	Bishopville	Water Supply	2030	1.11	1.54
Groundwater (SWAM)	Bishopville	Water Supply	2035	1.01	1.61
Groundwater (SWAM)	Bishopville	Water Supply	2040	0.95	1.68
Groundwater (SWAM)	Bishopville	Water Supply	2050	0.95	1.84

Table A-3. Projected Water Demands

Source	User	Use Category	Year	Moderate Demand (MGD)	High Demand (MGD)
Groundwater (SWAM)	Bishopville	Water Supply	2060	0.95	2.02
Groundwater (SWAM)	Bishopville	Water Supply	2070	0.95	2.21
Groundwater (SWAM)	Hartsville	Water Supply	2025	1.18	1.93
Groundwater (SWAM)	Hartsville	Water Supply	2030	1.08	2.02
Groundwater (SWAM)	Hartsville	Water Supply	2035	0.99	2.12
Groundwater (SWAM)	Hartsville	Water Supply	2040	0.94	2.21
Groundwater (SWAM)	Hartsville	Water Supply	2050	0.94	2.43
Groundwater (SWAM)	Hartsville	Water Supply	2060	0.94	2.66
Groundwater (SWAM)	Hartsville	Water Supply	2070	0.94	2.91
Groundwater (SWAM)	Hinson	Agriculture	2025	0.00	0.00
Groundwater (SWAM)	Hinson	Agriculture	2030	0.00	0.00
Groundwater (SWAM)	Hinson	Agriculture	2035	0.00	0.00
Groundwater (SWAM)	Hinson	Agriculture	2040	0.00	0.00
Groundwater (SWAM)	Hinson	Agriculture	2050	0.00	0.00
Groundwater (SWAM)	Hinson	Agriculture	2060	0.00	0.00
Groundwater (SWAM)	Hinson	Agriculture	2070	0.00	0.00
Groundwater (SWAM)	Lynchburg	Water Supply	2025	0.07	0.29
Groundwater (SWAM)	Lynchburg	Water Supply	2030	0.06	0.30
Groundwater (SWAM)	Lynchburg	Water Supply	2035	0.05	0.32
Groundwater (SWAM)	Lynchburg	Water Supply	2040	0.05	0.33
Groundwater (SWAM)	Lynchburg	Water Supply	2050	0.05	0.36
Groundwater (SWAM)	Lynchburg	Water Supply	2060	0.05	0.40
Groundwater (SWAM)	Lynchburg	Water Supply	2070	0.05	0.44
Groundwater (SWAM)	Manning	Water Supply	2025	0.96	1.40
Groundwater (SWAM)	Manning	Water Supply	2030	0.86	1.47
Groundwater (SWAM)	Manning	Water Supply	2035	0.76	1.54
Groundwater (SWAM)	Manning	Water Supply	2040	0.70	1.61
Groundwater (SWAM)	Manning	Water Supply	2050	0.70	1.76
Groundwater (SWAM)	Manning	Water Supply	2060	0.70	1.93
Groundwater (SWAM)	Manning	Water Supply	2070	0.70	2.12
Groundwater (SWAM)	WS: McColl	Water Supply	2025	0.29	0.45
Groundwater (SWAM)	WS: McColl	Water Supply	2030	0.28	0.48
Groundwater (SWAM)	WS: McColl	Water Supply	2035	0.27	0.50
Groundwater (SWAM)	WS: McColl	Water Supply	2040	0.26	0.52
Groundwater (SWAM)	WS: McColl	Water Supply	2050	0.26	0.57
Groundwater (SWAM)	WS: McColl	Water Supply	2060	0.26	0.62
Groundwater (SWAM)	WS: McColl	Water Supply	2070	0.26	0.68
Groundwater (SWAM)	WS: Sumter	Water Supply	2025	11.32	13.32
Groundwater (SWAM)	WS: Sumter	Water Supply	2030	11.01	13.94
Groundwater (SWAM)	WS: Sumter	Water Supply	2035	10.67	14.59
Groundwater (SWAM)	WS: Sumter	Water Supply	2040	10.45	15.27
Groundwater (SWAM)	WS: Sumter	Water Supply	2050	10.45	16.73
Groundwater (SWAM)	WS: Sumter	Water Supply	2060	10.45	18.33
Groundwater (SWAM)	WS: Sumter	Water Supply	2070	10.45	20.07
Surface Water (SWAM)	Hanson (Brewer)	Mining	2025	0.08	0.58
Surface Water (SWAM)	Hanson (Brewer)	Mining	2030	0.08	0.58
Surface Water (SWAM)	Hanson (Brewer)	Mining	2035	0.08	0.58
Surface Water (SWAM)	Hanson (Brewer)	Mining	2040	0.08	0.57
Surface Water (SWAM)	Hanson (Brewer)	Mining	2050	0.08	0.58
Surface Water (SWAM)	Hanson (Brewer)	Mining	2060	0.08	0.57
Surface Water (SWAM)	Hanson (Brewer)	Mining	2070	0.08	0.58
Surface Water (SWAM)	0304020105-Reedys Branch-Great Pee Dee River	Agriculture	2025	0.01	0.02
Surface Water (SWAM)	0304020105-Reedys Branch-Great Pee Dee River	Agriculture	2030	0.01	0.04
Surface Water (SWAM)	0304020105-Reedys Branch-Great Pee Dee River	Agriculture	2035	0.02	0.06
Surface Water (SWAM)	0304020105-Reedys Branch-Great Pee Dee River	Agriculture	2040	0.03	0.08
Surface Water (SWAM)	0304020105-Reedys Branch-Great Pee Dee River	Agriculture	2050	0.04	0.13
Surface Water (SWAM)	0304020105-Reedys Branch-Great Pee Dee River	Agriculture	2060	0.06	0.18
Surface Water (SWAM)	0304020105-Reedys Branch-Great Pee Dee River	Agriculture	2070	0.07	0.24
Surface Water (SWAM)	0304020107-Lower Black Creek	Agriculture	2025	0.01	0.03
Surface Water (SWAM)	0304020107-Lower Black Creek	Agriculture	2030	0.03	0.07
Surface Water (SWAM)	0304020107-Lower Black Creek	Agriculture	2035	0.04	0.12
Surface Water (SWAM)	0304020107-Lower Black Creek	Agriculture	2040	0.06	0.16
Surface Water (SWAM)	0304020107-Lower Black Creek	Agriculture	2050	0.10	0.26
Surface Water (SWAM)	0304020107-Lower Black Creek	Agriculture	2060	0.13	0.36
Surface Water (SWAM)	0304020107-Lower Black Creek	Agriculture	2070	0.17	0.47
Surface Water (SWAM)	0304020108-Three Creeks-Great Pee Dee River	Agriculture	2025	0.01	0.02
Surface Water (SWAM)	0304020108-Three Creeks-Great Pee Dee River	Agriculture	2030	0.02	0.05
Surface Water (SWAM)	0304020108-Three Creeks-Great Pee Dee River	Agriculture	2035	0.03	0.08
Surface Water (SWAM)	0304020108-Three Creeks-Great Pee Dee River	Agriculture	2040	0.05	0.11
Surface Water (SWAM)	0304020108-Three Creeks-Great Pee Dee River	Agriculture	2050	0.07	0.18
Surface Water (SWAM)	0304020108-Three Creeks-Great Pee Dee River	Agriculture	2060	0.10	0.25
Surface Water (SWAM)	0304020108-Three Creeks-Great Pee Dee River	Agriculture	2070	0.13	0.32
Surface Water (SWAM)	0304020203-Upper Lynches River	Agriculture	2025	0.00	0.00
Surface Water (SWAM)	0304020203-Upper Lynches River	Agriculture	2030	0.00	0.00
Surface Water (SWAM)	0304020203-Upper Lynches River	Agriculture	2035	0.00	0.00

Table A-3. Projected Water Demands

Source	User	Use Category	Year	Moderate Demand (MGD)	High Demand (MGD)
Surface Water (SWAM)	0304020203-Upper Lynches River	Agriculture	2040	0.00	0.00
Surface Water (SWAM)	0304020203-Upper Lynches River	Agriculture	2050	0.00	0.00
Surface Water (SWAM)	0304020203-Upper Lynches River	Agriculture	2060	0.00	0.00
Surface Water (SWAM)	0304020203-Upper Lynches River	Agriculture	2070	0.00	0.00
Surface Water (SWAM)	0304020205-Middle Lynches River	Agriculture	2025	0.00	0.01
Surface Water (SWAM)	0304020205-Middle Lynches River	Agriculture	2030	0.01	0.03
Surface Water (SWAM)	0304020205-Middle Lynches River	Agriculture	2035	0.01	0.04
Surface Water (SWAM)	0304020205-Middle Lynches River	Agriculture	2040	0.02	0.06
Surface Water (SWAM)	0304020205-Middle Lynches River	Agriculture	2050	0.03	0.09
Surface Water (SWAM)	0304020205-Middle Lynches River	Agriculture	2060	0.04	0.13
Surface Water (SWAM)	0304020205-Middle Lynches River	Agriculture	2070	0.05	0.17
Surface Water (SWAM)	0304020401-Upper Little Pee Dee River	Agriculture	2025	0.00	0.00
Surface Water (SWAM)	0304020401-Upper Little Pee Dee River	Agriculture	2030	0.00	0.00
Surface Water (SWAM)	0304020401-Upper Little Pee Dee River	Agriculture	2035	0.00	0.00
Surface Water (SWAM)	0304020401-Upper Little Pee Dee River	Agriculture	2040	0.00	0.00
Surface Water (SWAM)	0304020401-Upper Little Pee Dee River	Agriculture	2050	0.00	0.00
Surface Water (SWAM)	0304020401-Upper Little Pee Dee River	Agriculture	2060	0.00	0.00
Surface Water (SWAM)	0304020401-Upper Little Pee Dee River	Agriculture	2070	0.00	0.00
Surface Water (SWAM)	0304020408-Lower Little Pee Dee River	Agriculture	2025	0.00	0.00
Surface Water (SWAM)	0304020408-Lower Little Pee Dee River	Agriculture	2030	0.00	0.00
Surface Water (SWAM)	0304020408-Lower Little Pee Dee River	Agriculture	2035	0.00	0.01
Surface Water (SWAM)	0304020408-Lower Little Pee Dee River	Agriculture	2040	0.00	0.01
Surface Water (SWAM)	0304020408-Lower Little Pee Dee River	Agriculture	2050	0.00	0.01
Surface Water (SWAM)	0304020408-Lower Little Pee Dee River	Agriculture	2060	0.00	0.02
Surface Water (SWAM)	0304020408-Lower Little Pee Dee River	Agriculture	2070	0.00	0.02
Surface Water (SWAM)	0304020504-Pocotaligo River	Agriculture	2025	0.02	0.02
Surface Water (SWAM)	0304020504-Pocotaligo River	Agriculture	2030	0.03	0.06
Surface Water (SWAM)	0304020504-Pocotaligo River	Agriculture	2035	0.06	0.09
Surface Water (SWAM)	0304020504-Pocotaligo River	Agriculture	2040	0.08	0.12
Surface Water (SWAM)	0304020504-Pocotaligo River	Agriculture	2050	0.12	0.19
Surface Water (SWAM)	0304020504-Pocotaligo River	Agriculture	2060	0.17	0.27
Surface Water (SWAM)	0304020504-Pocotaligo River	Agriculture	2070	0.22	0.35
Surface Water (SWAM)	0304020505-Pudding Swamp	Agriculture	2025	0.00	0.00
Surface Water (SWAM)	0304020505-Pudding Swamp	Agriculture	2030	0.00	0.00
Surface Water (SWAM)	0304020505-Pudding Swamp	Agriculture	2035	0.00	0.01
Surface Water (SWAM)	0304020505-Pudding Swamp	Agriculture	2040	0.00	0.01
Surface Water (SWAM)	0304020505-Pudding Swamp	Agriculture	2050	0.01	0.02
Surface Water (SWAM)	0304020505-Pudding Swamp	Agriculture	2060	0.01	0.02
Surface Water (SWAM)	0304020505-Pudding Swamp	Agriculture	2070	0.01	0.03
Surface Water (SWAM)	Atkinson	Agriculture	2025	0.00	0.05
Surface Water (SWAM)	Atkinson	Agriculture	2030	0.00	0.05
Surface Water (SWAM)	Atkinson	Agriculture	2035	0.00	0.05
Surface Water (SWAM)	Atkinson	Agriculture	2040	0.00	0.05
Surface Water (SWAM)	Atkinson	Agriculture	2050	0.00	0.05
Surface Water (SWAM)	Atkinson	Agriculture	2060	0.00	0.05
Surface Water (SWAM)	Atkinson	Agriculture	2070	0.00	0.05
Surface Water (SWAM)	Belger	Agriculture	2025	0.00	0.00
Surface Water (SWAM)	Belger	Agriculture	2030	0.00	0.00
Surface Water (SWAM)	Belger	Agriculture	2035	0.00	0.00
Surface Water (SWAM)	Belger	Agriculture	2040	0.00	0.00
Surface Water (SWAM)	Belger	Agriculture	2050	0.00	0.00
Surface Water (SWAM)	Belger	Agriculture	2060	0.00	0.00
Surface Water (SWAM)	Belger	Agriculture	2070	0.00	0.00
Surface Water (SWAM)	Bennettsville	Water Supply	2025	2.22	2.62
Surface Water (SWAM)	Bennettsville	Water Supply	2030	2.12	2.75
Surface Water (SWAM)	Bennettsville	Water Supply	2035	2.01	2.87
Surface Water (SWAM)	Bennettsville	Water Supply	2040	1.95	3.01
Surface Water (SWAM)	Bennettsville	Water Supply	2050	1.95	3.30
Surface Water (SWAM)	Bennettsville	Water Supply	2060	1.95	3.61
Surface Water (SWAM)	Bennettsville	Water Supply	2070	1.95	3.95
Surface Water (SWAM)	Black Crest	Agriculture	2025	0.58	0.82
Surface Water (SWAM)	Black Crest	Agriculture	2030	0.58	0.82
Surface Water (SWAM)	Black Crest	Agriculture	2035	0.58	0.82
Surface Water (SWAM)	Black Crest	Agriculture	2040	0.58	0.82
Surface Water (SWAM)	Black Crest	Agriculture	2050	0.58	0.82
Surface Water (SWAM)	Black Crest	Agriculture	2060	0.58	0.82
Surface Water (SWAM)	Black Crest	Agriculture	2070	0.58	0.82
Surface Water (SWAM)	Carolina Plantation	Agriculture	2025	0.27	0.45
Surface Water (SWAM)	Carolina Plantation	Agriculture	2030	0.27	0.45
Surface Water (SWAM)	Carolina Plantation	Agriculture	2035	0.27	0.45
Surface Water (SWAM)	Carolina Plantation	Agriculture	2040	0.27	0.45
Surface Water (SWAM)	Carolina Plantation	Agriculture	2050	0.27	0.45
Surface Water (SWAM)	Carolina Plantation	Agriculture	2060	0.27	0.45
Surface Water (SWAM)	Carolina Plantation	Agriculture	2070	0.27	0.45
Surface Water (SWAM)	Chapman	Agriculture	2025	0.02	0.04

Table A-3. Projected Water Demands

Source	User	Use Category	Year	Moderate Demand (MGD)	High Demand (MGD)
Surface Water (SWAM)	Chapman	Agriculture	2030	0.02	0.04
Surface Water (SWAM)	Chapman	Agriculture	2035	0.02	0.04
Surface Water (SWAM)	Chapman	Agriculture	2040	0.02	0.04
Surface Water (SWAM)	Chapman	Agriculture	2050	0.02	0.04
Surface Water (SWAM)	Chapman	Agriculture	2060	0.02	0.04
Surface Water (SWAM)	Chapman	Agriculture	2070	0.02	0.04
Surface Water (SWAM)	Cheraw	Golf Course	2025	0.12	0.25
Surface Water (SWAM)	Cheraw	Water Supply	2025	2.29	2.83
Surface Water (SWAM)	Cheraw	Golf Course	2030	0.12	0.25
Surface Water (SWAM)	Cheraw	Water Supply	2030	2.12	2.96
Surface Water (SWAM)	Cheraw	Golf Course	2035	0.12	0.25
Surface Water (SWAM)	Cheraw	Water Supply	2035	1.95	3.10
Surface Water (SWAM)	Cheraw	Golf Course	2040	0.12	0.25
Surface Water (SWAM)	Cheraw	Water Supply	2040	1.84	3.24
Surface Water (SWAM)	Cheraw	Golf Course	2050	0.12	0.25
Surface Water (SWAM)	Cheraw	Water Supply	2050	1.84	3.55
Surface Water (SWAM)	Cheraw	Golf Course	2060	0.12	0.25
Surface Water (SWAM)	Cheraw	Water Supply	2060	1.84	3.89
Surface Water (SWAM)	Cheraw	Golf Course	2070	0.12	0.25
Surface Water (SWAM)	Cheraw	Water Supply	2070	1.84	4.26
Surface Water (SWAM)	Dargan	Agriculture	2025	0.09	0.31
Surface Water (SWAM)	Dargan	Agriculture	2030	0.09	0.31
Surface Water (SWAM)	Dargan	Agriculture	2035	0.09	0.31
Surface Water (SWAM)	Dargan	Agriculture	2040	0.09	0.31
Surface Water (SWAM)	Dargan	Agriculture	2050	0.09	0.31
Surface Water (SWAM)	Dargan	Agriculture	2060	0.09	0.31
Surface Water (SWAM)	Dargan	Agriculture	2070	0.09	0.31
Surface Water (SWAM)	Domtar	Industry	2025	17.25	19.50
Surface Water (SWAM)	Domtar	Industry	2030	17.62	21.64
Surface Water (SWAM)	Domtar	Industry	2035	17.90	24.01
Surface Water (SWAM)	Domtar	Industry	2040	18.17	26.56
Surface Water (SWAM)	Domtar	Industry	2050	19.13	32.79
Surface Water (SWAM)	Domtar	Industry	2060	20.05	40.25
Surface Water (SWAM)	Domtar	Industry	2070	21.13	49.69
Surface Water (SWAM)	Florence	Golf Course	2025	0.04	0.10
Surface Water (SWAM)	Florence	Water Supply	2025	13.54	16.54
Surface Water (SWAM)	Florence	Golf Course	2030	0.04	0.10
Surface Water (SWAM)	Florence	Water Supply	2030	13.21	17.31
Surface Water (SWAM)	Florence	Golf Course	2035	0.04	0.10
Surface Water (SWAM)	Florence	Water Supply	2035	12.81	18.12
Surface Water (SWAM)	Florence	Golf Course	2040	0.04	0.10
Surface Water (SWAM)	Florence	Water Supply	2040	12.55	18.97
Surface Water (SWAM)	Florence	Golf Course	2050	0.04	0.10
Surface Water (SWAM)	Florence	Water Supply	2050	12.55	20.77
Surface Water (SWAM)	Florence	Golf Course	2060	0.04	0.10
Surface Water (SWAM)	Florence	Water Supply	2060	12.55	22.75
Surface Water (SWAM)	Florence	Golf Course	2070	0.04	0.10
Surface Water (SWAM)	Florence	Water Supply	2070	12.55	24.92
Surface Water (SWAM)	Hanson (Jefferson)	Mining	2025	0.03	0.04
Surface Water (SWAM)	Hanson (Jefferson)	Mining	2030	0.03	0.04
Surface Water (SWAM)	Hanson (Jefferson)	Mining	2035	0.03	0.04
Surface Water (SWAM)	Hanson (Jefferson)	Mining	2040	0.03	0.04
Surface Water (SWAM)	Hanson (Jefferson)	Mining	2050	0.03	0.04
Surface Water (SWAM)	Hanson (Jefferson)	Mining	2060	0.03	0.04
Surface Water (SWAM)	Hanson (Jefferson)	Mining	2070	0.03	0.04
Surface Water (SWAM)	Hanson (Marlboro)	Mining	2025	0.00	0.00
Surface Water (SWAM)	Hanson (Marlboro)	Mining	2030	0.00	0.00
Surface Water (SWAM)	Hanson (Marlboro)	Mining	2035	0.00	0.00
Surface Water (SWAM)	Hanson (Marlboro)	Mining	2040	0.00	0.00
Surface Water (SWAM)	Hanson (Marlboro)	Mining	2050	0.00	0.00
Surface Water (SWAM)	Hanson (Marlboro)	Mining	2060	0.00	0.00
Surface Water (SWAM)	Hanson (Marlboro)	Mining	2070	0.00	0.00
Surface Water (SWAM)	HB Robinson	Nuclear Power	2025	722.54	825.44
Surface Water (SWAM)	HB Robinson	Nuclear Power	2030	722.54	825.44
Surface Water (SWAM)	HB Robinson	Nuclear Power	2035	722.54	825.44
Surface Water (SWAM)	HB Robinson	Nuclear Power	2040	720.53	823.22
Surface Water (SWAM)	HB Robinson	Nuclear Power	2050	722.54	825.44
Surface Water (SWAM)	HB Robinson	Nuclear Power	2060	720.53	823.22
Surface Water (SWAM)	HB Robinson	Nuclear Power	2070	722.54	825.44
Surface Water (SWAM)	IP (Georgetown)	Industry	2025	32.88	37.21
Surface Water (SWAM)	IP (Georgetown)	Industry	2030	33.58	41.28
Surface Water (SWAM)	IP (Georgetown)	Industry	2035	34.12	45.80
Surface Water (SWAM)	IP (Georgetown)	Industry	2040	34.63	50.67
Surface Water (SWAM)	IP (Georgetown)	Industry	2050	36.45	62.56
Surface Water (SWAM)	IP (Georgetown)	Industry	2060	38.21	76.78

Table A-3. Projected Water Demands

Source	User	Use Category	Year	Moderate Demand (MGD)	High Demand (MGD)
Surface Water (SWAM)	IP (Georgetown)	Industry	2070	40.28	94.80
Surface Water (SWAM)	Irwin	Agriculture	2025	0.03	0.07
Surface Water (SWAM)	Irwin	Agriculture	2030	0.03	0.07
Surface Water (SWAM)	Irwin	Agriculture	2035	0.03	0.07
Surface Water (SWAM)	Irwin	Agriculture	2040	0.03	0.07
Surface Water (SWAM)	Irwin	Agriculture	2050	0.03	0.07
Surface Water (SWAM)	Irwin	Agriculture	2060	0.03	0.07
Surface Water (SWAM)	Irwin	Agriculture	2070	0.03	0.07
Surface Water (SWAM)	Lawson Turf	Agriculture	2025	0.23	0.39
Surface Water (SWAM)	Lawson Turf	Agriculture	2030	0.23	0.39
Surface Water (SWAM)	Lawson Turf	Agriculture	2035	0.23	0.39
Surface Water (SWAM)	Lawson Turf	Agriculture	2040	0.23	0.39
Surface Water (SWAM)	Lawson Turf	Agriculture	2050	0.23	0.39
Surface Water (SWAM)	Lawson Turf	Agriculture	2060	0.23	0.39
Surface Water (SWAM)	Lawson Turf	Agriculture	2070	0.23	0.39
Surface Water (SWAM)	Martin Marietta	Mining	2025	1.18	1.38
Surface Water (SWAM)	Martin Marietta	Mining	2030	1.18	1.38
Surface Water (SWAM)	Martin Marietta	Mining	2035	1.18	1.38
Surface Water (SWAM)	Martin Marietta	Mining	2040	1.17	1.37
Surface Water (SWAM)	Martin Marietta	Mining	2050	1.18	1.38
Surface Water (SWAM)	Martin Marietta	Mining	2060	1.17	1.37
Surface Water (SWAM)	Martin Marietta	Mining	2070	1.18	1.38
Surface Water (SWAM)	McDonald	Agriculture	2025	0.00	0.00
Surface Water (SWAM)	McDonald	Agriculture	2030	0.00	0.00
Surface Water (SWAM)	McDonald	Agriculture	2035	0.00	0.00
Surface Water (SWAM)	McDonald	Agriculture	2040	0.00	0.00
Surface Water (SWAM)	McDonald	Agriculture	2050	0.00	0.00
Surface Water (SWAM)	McDonald	Agriculture	2060	0.00	0.00
Surface Water (SWAM)	McDonald	Agriculture	2070	0.00	0.00
Surface Water (SWAM)	Nucor	Industry	2025	0.50	0.62
Surface Water (SWAM)	Nucor	Industry	2030	0.50	0.69
Surface Water (SWAM)	Nucor	Industry	2035	0.50	0.76
Surface Water (SWAM)	Nucor	Industry	2040	0.51	0.84
Surface Water (SWAM)	Nucor	Industry	2050	0.50	1.04
Surface Water (SWAM)	Nucor	Industry	2060	0.50	1.27
Surface Water (SWAM)	Nucor	Industry	2070	0.51	1.57
Surface Water (SWAM)	O'Tuel	Agriculture	2025	0.14	0.64
Surface Water (SWAM)	O'Tuel	Agriculture	2030	0.14	0.64
Surface Water (SWAM)	O'Tuel	Agriculture	2035	0.14	0.64
Surface Water (SWAM)	O'Tuel	Agriculture	2040	0.14	0.64
Surface Water (SWAM)	O'Tuel	Agriculture	2050	0.14	0.64
Surface Water (SWAM)	O'Tuel	Agriculture	2060	0.14	0.64
Surface Water (SWAM)	O'Tuel	Agriculture	2070	0.14	0.64
Surface Water (SWAM)	Richard Rogers	Agriculture	2025	0.20	0.55
Surface Water (SWAM)	Richard Rogers	Agriculture	2030	0.20	0.55
Surface Water (SWAM)	Richard Rogers	Agriculture	2035	0.20	0.55
Surface Water (SWAM)	Richard Rogers	Agriculture	2040	0.20	0.55
Surface Water (SWAM)	Richard Rogers	Agriculture	2050	0.20	0.55
Surface Water (SWAM)	Richard Rogers	Agriculture	2060	0.20	0.55
Surface Water (SWAM)	Richard Rogers	Agriculture	2070	0.20	0.55
Surface Water (SWAM)	Rogers	Agriculture	2025	0.20	0.63
Surface Water (SWAM)	Rogers	Agriculture	2030	0.20	0.63
Surface Water (SWAM)	Rogers	Agriculture	2035	0.20	0.63
Surface Water (SWAM)	Rogers	Agriculture	2040	0.20	0.63
Surface Water (SWAM)	Rogers	Agriculture	2050	0.20	0.63
Surface Water (SWAM)	Rogers	Agriculture	2060	0.20	0.63
Surface Water (SWAM)	Rogers	Agriculture	2070	0.20	0.63
Surface Water (SWAM)	Sugar Hill	Agriculture	2025	0.01	0.04
Surface Water (SWAM)	Sugar Hill	Agriculture	2030	0.01	0.04
Surface Water (SWAM)	Sugar Hill	Agriculture	2035	0.01	0.04
Surface Water (SWAM)	Sugar Hill	Agriculture	2040	0.01	0.04
Surface Water (SWAM)	Sugar Hill	Agriculture	2050	0.01	0.04
Surface Water (SWAM)	Sugar Hill	Agriculture	2060	0.01	0.04
Surface Water (SWAM)	Sugar Hill	Agriculture	2070	0.01	0.04
Surface Water (SWAM)	Sunoco	Industry	2025	9.73	11.70
Surface Water (SWAM)	Sunoco	Industry	2030	10.57	12.98
Surface Water (SWAM)	Sunoco	Industry	2035	11.42	14.40
Surface Water (SWAM)	Sunoco	Industry	2040	12.40	15.93
Surface Water (SWAM)	Sunoco	Industry	2050	15.00	19.67
Surface Water (SWAM)	Sunoco	Industry	2060	17.71	24.14
Surface Water (SWAM)	Sunoco	Industry	2070	21.02	29.80
Surface Water (SWAM)	Tolson	Agriculture	2025	0.14	0.40
Surface Water (SWAM)	Tolson	Agriculture	2030	0.14	0.40
Surface Water (SWAM)	Tolson	Agriculture	2035	0.14	0.40
Surface Water (SWAM)	Tolson	Agriculture	2040	0.14	0.40

Table A-3. Projected Water Demands

Source	User	Use Category	Year	Moderate Demand (MGD)	High Demand (MGD)
Surface Water (SWAM)	Tolson	Agriculture	2050	0.14	0.40
Surface Water (SWAM)	Tolson	Agriculture	2060	0.14	0.40
Surface Water (SWAM)	Tolson	Agriculture	2070	0.14	0.40
Surface Water (SWAM)	Turf Connections	Agriculture	2025	0.00	0.00
Surface Water (SWAM)	Turf Connections	Agriculture	2030	0.00	0.00
Surface Water (SWAM)	Turf Connections	Agriculture	2035	0.00	0.00
Surface Water (SWAM)	Turf Connections	Agriculture	2040	0.00	0.00
Surface Water (SWAM)	Turf Connections	Agriculture	2050	0.00	0.00
Surface Water (SWAM)	Turf Connections	Agriculture	2060	0.00	0.00
Surface Water (SWAM)	Turf Connections	Agriculture	2070	0.00	0.00
Surface Water (SWAM)	WestRock	Industry	2025	16.60	20.17
Surface Water (SWAM)	WestRock	Industry	2030	16.96	22.38
Surface Water (SWAM)	WestRock	Industry	2035	17.23	24.83
Surface Water (SWAM)	WestRock	Industry	2040	17.49	27.47
Surface Water (SWAM)	WestRock	Industry	2050	18.41	33.92
Surface Water (SWAM)	WestRock	Industry	2060	19.30	41.63
Surface Water (SWAM)	WestRock	Industry	2070	20.34	51.40
Surface Water (SWAM)	White Plans	Golf Course	2025	0.04	0.06
Surface Water (SWAM)	White Plans	Golf Course	2030	0.04	0.06
Surface Water (SWAM)	White Plans	Golf Course	2035	0.04	0.06
Surface Water (SWAM)	White Plans	Golf Course	2040	0.04	0.06
Surface Water (SWAM)	White Plans	Golf Course	2050	0.04	0.06
Surface Water (SWAM)	White Plans	Golf Course	2060	0.04	0.06
Surface Water (SWAM)	White Plans	Golf Course	2070	0.04	0.06

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Appendix B: Drought Management Plans

Summary of Drought Management Plans in the Pee Dee River Basin

Entity	Drought Management Area	Plan Last Updated	Customers	Water Source	Drought Indicator / Trigger Types	Demand Reduction Strategies	Alternative Water Supply Agreements
Entities Included in Pee Dee SWAM Model							
City of Bennettsville	Northeast (Pee Dee)	2003	12,000 customers	Surface and groundwater sources: Surface: Crooked Creek (Lake Wallace) Groundwater: 4 groundwater wells	**Moderate**: reservoir level reaches 141.5 ft-msl **Severe**: reservoir level reaches 140.5 ft-msl **Extreme**: reservoir level reaches 139.5 ft-msl	Voluntary usage reductions for Moderate and Severe drought phases and Mandatory reduction for Extreme. Different reduction targets for different water uses. **Moderate**: Voluntary 20% reduction in residential use and 15% reduction in all other uses **Severe**: Voluntary 25% reduction in residential use and 20% reduction in all other uses. Note also mandatory restrictions for non-essential uses **Extreme**: Mandatory reduction of 30% for residential and 25% for all other uses	Agreements with the Marlboro Water Company and Wallace Water Company are in place to facilitate implementation of the plan. Water purchase contracts cover drought and water shortage conditions. Additional detail on agreements is not provided.
Town of Cheraw	Northeast (Pee Dee)	2003	6,500 customers through 2,600 taps	Pee Dee River	**Moderate**: river level is 18" at the intake for 3 consecutive days **Severe**: river level is less than 12" at the intake for 3 consecutive days **Extreme**: river level is less than 8" at the intake for 3 consecutive days	Voluntary usage reductions for Moderate and Severe drought phases and Mandatory reduction for Extreme. Different reduction targets for different water uses. **Moderate**: Voluntary 20% reduction in residential use and 15% reduction in all other uses **Severe**: Voluntary 25% reduction in residential use and 20% reduction in all other uses. Note also mandatory restrictions for non-essential uses **Extreme**: Mandatory reduction of 30% for residential and 25% for all other uses	The Town of Cheraw has an agreement with Chesterfield County Rural Water. There will be two locations where they can receive water or provide to the rural water. An agreement with the Town of Chesterfield for emergency supply is being considered or negotiated.
City of Florence	Northeast (Pee Dee)	2004 (City of Florence Drought Management Plan was adopted and incorporated in their municipal code of ordinances in 2004)	26,735 customers	Groundwater supply from 24 wells in Middendorf aquifer and 5 wells in Black Creek aquifer. Surface water supply from Pee Dee River	**Moderate**: Pumping levels from the city's groundwater system reach an average depth of 280 feet below the ground surface elevation in combination with a stream flow of the Pee Dee River at the Pee Dee gauging station of 800 cfs; or the surface water plant is disabled and the groundwater system is not disabled and pumping levels from the city's groundwater system reach an average depth of 280 feet below the ground surface elevation; or the surface water plant is not disabled and the groundwater system is partially disabled and the 2 systems in combination with each other cannot meet the SCDHEC requirement of peak system demands at 16 hours per day of treatment capacity. **Severe**: Pumping levels from the city's groundwater system reach an average depth of 300 feet below the ground surface elevation in combination with a stream flow of the Pee Dee River at the Pee Dee gauging station of 600 cubic feet per second; or the surface water plant is disabled and the groundwater system is not disabled and pumping levels from the city's groundwater system reach an average depth of 290 feet below the ground surface elevation; or the surface water plant is not disabled and the groundwater system is partially disabled and the 2 systems in combination with each other cannot meet the SCDHEC requirement of peak system demands at 18 hours per day of treatment capacity. **Extreme**: Pumping levels from the city's groundwater system reach an average depth of 320 feet below the ground surface elevation in combination with a stream flow of the Pee Dee River at the Pee Dee gauging station of 500 cubic feet per second; or the surface water plant is disabled and the groundwater system is not disabled and pumping levels from the city's groundwater system reach an average depth of 300 feet below the ground surface elevation; or the surface water plant is not disabled and the groundwater system is partially disabled and the 2 systems in combination with each other cannot meet the SCDHEC requirement of peak system demands at 20 hours per day of treatment capacity.	Voluntary usage reductions for Moderate and Severe drought phases and Mandatory reduction for Extreme. Different reduction targets for different water uses. **Moderate**: Voluntary 20% reduction in residential use and 15% reduction in all other uses **Severe**: Voluntary 25% reduction in residential use and 20% reduction in all other uses. Note also mandatory restrictions for non-essential uses **Extreme**: Mandatory reduction of 30% for residential and 25% for all other uses	Cooperative water supply agreement with Darlington County Water and Sewer Authority
Sampling of Entities Not Included in Pee Dee SWAM Model							
Cassatt Water Company	Northeast (Pee Dee)	2003	9,200 taps	16 groundwater wells	Drought phases determined by the Drought Response Committee	Voluntary usage reductions for Moderate and Severe drought phases and Mandatory reduction for Extreme. Different reduction targets for different water uses. **Moderate**: Voluntary 20% reduction in residential use and 15% reduction in all other uses **Severe**: Voluntary 25% reduction in residential use and 20% reduction in all other uses. Note also mandatory restrictions for non-essential uses **Extreme**: Mandatory reduction of 30% for residential and 25% for all other uses	None
Chesterfield County Rural Water Company - Wolf Pond	Northeast (Pee Dee)	2003	The service area includes the entire County with the exception of the Towns of Cheraw, Chesterfield, Patrick, McBee and Pageland.	Groundwater wells: Alligator Rural Water, Anson County Water, Lancaster County Water, Town of Chesterfield, Town of Pageland, and Union County Water.	Moderate, severe, and extreme drought phases are declared by SC Department of Natural Resources and the Drought Response Committee.	Voluntary usage reductions for Moderate and Severe drought phases and Mandatory reduction for Extreme. Different reduction targets for different water uses. **Moderate**: Voluntary 20% reduction in residential use and 15% reduction in all other uses **Severe**: Voluntary 25% reduction in residential use and 20% reduction in all other uses. Note also mandatory restrictions for non-essential uses **Extreme**: Mandatory reduction of 30% for residential and 25% for all other uses	None
City of Darlington	Northeast (Pee Dee)	2003	3,200 taps	4 groundwater wells	**Moderate**: when average demand increases by 15% **Severe**: when average demand increases by 25% **Extreme**: when average demand increases by 35% ***for all - OR when the DNR declares moderate/severe/extreme drought for this area***	Voluntary usage reductions for Moderate and Severe drought phases and Mandatory reduction for Extreme. Different reduction targets for different water uses. **Moderate**: Voluntary 20% reduction in residential use and 15% reduction in all other uses **Severe**: Voluntary 25% reduction in residential use and 20% reduction in all other uses. Note also mandatory restrictions for non-essential uses **Extreme**: Mandatory reduction of 30% for residential and 25% for all other uses	None

Summary of Drought Management Plans in the Pee Dee River Basin

Entity	Drought Management Area	Plan Last Updated	Customers	Water Source	Drought Indicator / Trigger Types	Demand Reduction Strategies	Alternative Water Supply Agreements
City of Georgetown	Central	2003	City of Georgetown and limited areas south of the Sampit River	surface and groundwater sources	**Moderate**: Pee Dee River water level at intake of IP canal falls below -3 feet level **Severe**: Pee Dee River water level at intake of IP canal falls below -5 ft level or supplemental pumping for over 7 consecutive days or additional pumping incurred at mouth of canal **Extreme**: Pee Dee River flow les than 900 cfs for 10 consecutive days or IP implements supplemental pumping at mouth of canal for over 14 consecutive days	Voluntary usage reductions for Moderate and Severe drought phases and Mandatory reduction for Extreme. Different reduction targets for different water uses. **Moderate**: Voluntary 20% reduction in residential use and 15% reduction in all other uses **Severe**: Voluntary 25% reduction in residential use and 20% reduction in all other uses. Note also mandatory restrictions for non-essential uses **Extreme**: Mandatory reduction of 30% for residential and 25% for all other uses	None
City of Marion	Northeast (Pee Dee)	2003	2,787 residential service connections	9 groundwater wells	**Moderate**: average daily use greater than 3.6 MGD for 30 consecutive days **Severe**: average daily use greater than 3.2 MGD for 60 consecutive days **Extreme**: average daily use greater than 3.65 MGD for 60 consecutive days	Voluntary usage reductions for Moderate and Severe drought phases and Mandatory reduction for Extreme. Different reduction targets for different water uses. **Moderate**: Voluntary 20% reduction in residential use and 15% reduction in all other uses **Severe**: Voluntary 25% reduction in residential use and 20% reduction in all other uses. Note also mandatory restrictions for non-essential uses **Extreme**: Mandatory reduction of 30% for residential and 25% for all other uses	None
City of Sumter	Central	2003	Sumter, Oswego, Mayesville, and Rembert	18 groundwater wells	**Moderate**: elevated tank level drops to 7 ft below top of tanks for 5 days **Severe**: elevated tank level drops to 8 feet below top of tank for 5 days **Extreme**: elevated tank level drops to 9 feet below top of tank for 2 days	Voluntary usage reductions for Moderate and Severe drought phases and Mandatory reduction for Extreme. Different reduction targets for different water uses. **Moderate**: Voluntary 20% reduction in residential use and 15% reduction in all other uses **Severe**: Voluntary 25% reduction in residential use and 20% reduction in all other uses. Note also mandatory restrictions for non-essential uses **Extreme**: Mandatory reduction of 30% for residential and 25% for all other uses	None
Lancaster County Water and Sewer District	Northeast (Pee Dee)	2011	16,560 active customers	Catawba River	**Watch**: On the first day of the month, Storage index is below the Target Storage Index, but greater than 90% of Target Storage Index; The U.S. Drought Monitor 3 Month Numeric Average has a value greater than or equal to 0; The sum of the actual rolling six-month average streamflows at the Monitored USGS Streamflow Gages is equal to or less than 85% of the sum of the period of record rolling average streamflows for the same six-month period. **Incipient**: On the first day of the month, the Storage Index is at or below 90% of Target Storage Index, but greater than 75% of the Target Storage Index and either of the following conditions exists; The U.S. Drought Monitor 3 Month Numeric Average has a value > 1 or the sum of the actual rolling six-month average streamflows at the Monitored USGS Streamflow Gages is equal to or less than 78% of the sum of the period of record rolling average streamflows for the same six-month period. **Moderate**: on the first day of the month, the Storage Index is at or below 75% of Target Storage Index, but greater than 57% of the Target Storage Index and either of the following conditions exists; The U.S. Drought Monitor 3 Month Numeric Average has a value > 2 or the sum of the actual rolling six-month average streamflows at the Monitored USGS Streamflow Gages is equal to or less than 65% of the sum of the period of record rolling average streamflows for the same six-month period. **Severe**: on the first day of the month, the Storage Index is at or below 57% of Target Storage Index, but greater than 42% of the Target Storage Index and either of the following conditions exists; The U.S. Drought Monitor 3 Month Numeric Average has a value > 3 or the sum of the actual rolling six-month average streamflows at the Monitored USGS Streamflow Gages is equal to or less than 55% of the sum of the period of record rolling average streamflows for the same six-month period. **Extreme**: on the first day of the month, the Storage Index is at or below 42% of Target Storage Index and either of the following conditions exists; The U.S. Drought Monitor 3 Month Numeric Average has a value > 4 or the sum of the actual rolling six-month average streamflows at the Monitored USGS Streamflow Gages is equal to or less than 40% of the sum of the period of record rolling average streamflows for the same six-month period.	Voluntary usage reductions for Incipient drought phase and Mandatory reduction for Moderate, Severe, and Extreme. Different reduction targets for different water uses. **Incipient**: Voluntary 3-5% reduction in residential use and 5% reduction in all other uses **Moderate**: Mandatory 5-10% reduction in residential use and 10% reduction in all other uses **Severe**: Mandatory 10-20% reduction in residential use and 20% reduction in all other uses **Extreme**: Mandatory 30% reduction in residential use and 25% reduction in all other uses	Springs Industries via City of Lancaster can supply a maximum of 1 million gallons per day during moderate drought conditions and 0.5 million gallons per day during severe drought conditions. Emergency connections with Charlotte Mecklenburg Utilities Department along Hwy 521 at the state line, along Harrisburg Road at Bridgehampton Subdivision, and along Harrisburg Road at the state line for approximately 1 million gallon per day during emergencies. Emergency connection with Union County, North Carolina along Shinnecock Lane at the state line for an amount as is necessary to handle any shortfall of the surrounding area as the hydraulics will permit during emergency situations
Marco Rural Water Company (Marion)	Northeast (Pee Dee)	2003	5,100 customers	7 groundwater wells	**Moderate**: storage below 75% capacity; average daily use greater than 1.6 MGD for 15 consecutive days **Severe**: storage below 50% capacity; average daily use greater than 1.8 MGD for 10 consecutive days **Extreme**: storage below 25% capacity; average daily use greater than 20 MGD for 5 consecutive days	Voluntary usage reductions for Moderate and Severe drought phases and Mandatory reduction for Extreme. Different reduction targets for different water uses. **Moderate**: Voluntary 20% reduction in residential use and 15% reduction in all other uses **Severe**: Voluntary 25% reduction in residential use and 20% reduction in all other uses. Note also mandatory restrictions for non-essential uses **Extreme**: Mandatory reduction of 30% for residential and 25% for all other uses	Water Users Agreement signed by each water user stating Marco has the right to restrict water use if necessary.
Marlboro Water Company	Northeast (Pee Dee)	2003	1,752 residential and commercial taps	3 groundwater wells	**Moderate**: storage falls below 60% of capacity; average daily use greater than 0.8 mgd for 30 consecutive days **Severe**: storage falls below 50% of capacity; average daily use greater than 1.0 mgd for 14 consecutive days **Extreme**: storage falls below 40% of capacity; average daily use greater than 1.5 mgd for 7 consecutive days	Voluntary usage reductions for Moderate and Severe drought phases and Mandatory reduction for Extreme. Different reduction targets for different water uses. **Moderate**: Voluntary 20% reduction in residential use and 15% reduction in all other uses **Severe**: Voluntary 25% reduction in residential use and 20% reduction in all other uses. Note also mandatory restrictions for non-essential uses **Extreme**: Mandatory reduction of 30% for residential and 25% for all other uses	Agreements with Trico Water Company, City of Bennettsville, Ton of Clio, and Wallace Water Company
Town of Patrick	Northeast (Pee Dee)	2003	313 active customers	Two groundwater wells	**Moderate** drought: aquifer levels less than 65% **Severe** drought: aquifer levels less than 75% **Extreme** drought: aquifer levels less than 85%	Voluntary usage reductions for Moderate and Severe drought phases and Mandatory reduction for Extreme. Different reduction targets for different water uses. **Moderate**: Voluntary 20% reduction in residential use and 15% reduction in all other uses **Severe**: Voluntary 25% reduction in residential use and 20% reduction in all other uses. Note also mandatory restrictions for non-essential uses **Extreme**: Mandatory reduction of 30% for residential and 25% for all other uses	None
Rural Community Water District of Georgetown County (RCWDGC)	Central	2003	2,110 Taps	3 groundwater wells	**Moderate**: average daily use greater than .938 MGD for 10 consecutive days, Static water level drops 10' below average, pumping level drops 10' below average. **Severe**: average daily use greater than 1.050 MGD for 10 consecutive days, static water level drops 20' below average, pumping level drops 20' below average. **Extreme**: average daily use greater than 1.200 MGD for 10 consecutive days, static water level drops 25' below average, pumping level drops 25' below average. ***for all, or determination by RCWDGC leadership***	Voluntary usage reductions for Moderate and Severe drought phases and Mandatory reduction for Extreme. Different reduction targets for different water uses. **Moderate**: Voluntary 20% reduction in residential use and 15% reduction in all other uses **Severe**: Voluntary 25% reduction in residential use and 20% reduction in all other uses. Note also mandatory restrictions for non-essential uses **Extreme**: Mandatory reduction of 30% for residential and 25% for all other uses	Browns Ferry Water - interconnect on SC Route 51 with manual valves Georgetown County Water and Sewer - interconnect at Black River on Hwy. 701 with manual valves and on Wedgefield Road with pressure sensing valves City of Georgetown - interconnect on North Frasier Street at area boundary with manual valves

Summary of Drought Management Plans in the Pee Dee River Basin

Entity	Drought Management Area	Plan Last Updated	Customers	Water Source	Drought Indicator / Trigger Types	Demand Reduction Strategies	Alternative Water Supply Agreements
Georgetown County Water and Sewer District	Northeast (Pee Dee)	2003	Unincorporated area of Georgetown County and the Town of Pawleys Island	11 deep aquifer wells	**Moderate**: The Pee Dee River flow as measured at Pee Dee, S.C. is less than 2,500 cubic feet per second over a twenty-four hour period, the average daily demand for the Waccamaw Neck service area is equal to 80% of the Waccamaw Neck Water Treatment Plant production capacity, the Waccamaw River conductivity measured at the Waccamaw Water Treatment Plant intake is 800 micro seimans for 12 continuous hours and rising, the available well capacity in any given subsystem is greater than 20% of the average day demand. **Severe**: The Pee Dee River flow as measured at Pee Dee, S.C. is less than 1,500 cubic feet per second, the average daily demand for the Waccamaw Neck service area is equal to 90% of the Waccamaw Neck Water Treatment Plant production capacity, the Waccamaw River conductivity measured at the Waccamaw Water Treatment Plant intake is 1,000 micro seimans for 12 continuous hours, The available well capacity in any given subsystem is greater than 10% of the average day demand. **Extreme**: The Pee Dee River flow as measured at Pee Dee, S.C. is less than 900 cubic feet per second, the average daily demand is equal to or greater than the total Waccamaw Neck available emergency and backup supplies, the Waccamaw River conductivity measured at the Waccamaw Water Treatment Plant intake is 1,200 micro seimans or greater for 6 continuous hours, the available well capacity in any given subsystem is equal to or less than the average day demand.	Voluntary usage reductions for Moderate and Severe drought phases and Mandatory reduction for Extreme. Different reduction targets for different water uses. **Moderate**: Voluntary 20% reduction in residential use and 15% reduction in all other uses **Severe**: Voluntary 25% reduction in residential use and 20% reduction in all other uses. Note also mandatory restrictions for non-essential uses **Extreme**: Mandatory reduction of 30% for residential and 25% for all other uses	Water purchase agreement with the Grand Strand Water and sewer Authority, the City of Georgetown, the Rural Community Water district, the Town of Andrews, and the Browns Ferry Water Company. Grand Strand Water and Sewer Authority Agreement provides 1.15 mgd guaranteed available capacity and 0.85 mgd emergency reserve.
Grand Strand Water and Sewer Authority	Northeast (Pee Dee)	2003	over 35,000 retail customers	Bull Creek, arm of the combined Great Pee Dee and Little Pee Dee Rivers, and 25 wells in the Black Creek Aquifer	**Moderate**: Stream-flow less than 2,000 cubic feet per second and/or Waccamaw River measured at Georgetown County Water and Sewer District intake - conductivity greater than 800 microsiemens (24 Hours). **Severe**: Stream-flow less than 1,200 cubic feet per second and/or Waccamaw River measured at Georgetown County Water and Sewer District intake – conductivity greater than 1,000 microsiemens (12 Hours). **Extreme**: Stream-flow less than 900 cubic feet per second and/or Waccamaw River measured at Georgetown County Water and Sewer District intake – conductivity greater than 1,200 microsiemens (6 Hours).	Voluntary usage reductions for Moderate and Severe drought phases and Mandatory reduction for Extreme. Different reduction targets for different water uses. **Moderate**: Voluntary 20% reduction in residential use and 15% reduction in all other uses **Severe**: Voluntary 25% reduction in residential use and 20% reduction in all other uses. Note also mandatory restrictions for non-essential uses **Extreme**: Mandatory reduction of 30% for residential and 25% for all other uses	Agreements with City of Conway, City of North Myrtle Beach, City of Loris, Georgetown County Water and Sewer District, City of Myrtle Beach, Little River Water and Sewerage Company
City of Myrtle Beach	Northeast (Pee Dee)	2003	46,175 customers	Atlantic Intra-Coastal Waterway and Bull Creek, 10 deep wells	**Moderate**: Saltwater/Freshwater interface in the Atlantic IntraCoastal Waterway located in vicinity of North Myrtle Beach Airport **Severe**: Saltwater/Freshwater interface in the Atlantic IntraCoastal Waterway located in vicinity of Briarcliffe Forest **Extreme**: Saltwater/Freshwater interface in the Atlantic IntraCoastal Waterway located in vicinity of Grande Dunes Bridge	Voluntary usage reductions for Moderate and Severe drought phases and Mandatory reduction for Extreme. Different reduction targets for different water uses. **Moderate**: Voluntary 10% reduction in all uses **Severe**: Voluntary 20% reduction in all uses **Extreme**: Mandatory reduction of 30% for all uses	Two inter-connects with Grand Strand Water and Sewer Authority. Approximately 5 Million Gallons a Day of water can be provided to either party (Bi-directional option).
Town of Kershaw	Northeast (Pee Dee)	2003	1,200 active customers	Catawba River	**Moderate**: streamflow less than 2258 cfs jan-apr, 1707 cfs may, June, dec, or 1269 cfs july-nov for 5 consecutive days, or avg daily use grater than 30 mgd for 12 consecutive days **Severe**: streamflow less than 2252 cfs jan-apr, 1701 cfs may, jun, dec, and 1263 cfs jul-nov for 5 consecutive days, or avg daily use greater than 34.5 mgd for 12 consecutive days **Extreme**: streamflow less than 2245 cfs jan-apr, 1695 may, jun, dec, and 1257 cfs jul-nov for 5 consecutive days, or avg daily use greater than 35.6 mgd for 12 consecutive days	Voluntary usage reductions for Moderate and Severe drought phases and Mandatory reduction for Extreme. Different reduction targets for different water uses. **Moderate**: Voluntary 20% reduction in residential use and 15% reduction in all other uses **Severe**: Voluntary 25% reduction in residential use and 20% reduction in all other uses. Note also mandatory restrictions for non-essential uses **Extreme**: Mandatory reduction of 30% for residential and 25% for all other uses	Lancaster County Water and Sewer District via emergency connection adjacent to intersection of Fork Hill Road and US Highway 521 (about 100,000 gpd) Agreements under negotiation include: Union County North Carolina and Charlotte Mecklenburg Utilities Dept.
Trico Water Company	Northeast (Pee Dee)	2003	5,406 customers	13 groundwater wells drawing from Black Creek and Middendorf Aquifers	**Moderate**: when average daily use is greater than 2.5 MGD for 7 consecutive days **Severe**: when average daily use is greater than 3 MGD for 14 consecutive days **Extreme**: when average daily use is greater than 3.5 MGD for 7 consecutive days	Voluntary usage reductions for Moderate and Severe drought phases and Mandatory reduction for Extreme. Different reduction targets for different water uses. **Moderate**: Voluntary 20% reduction in residential use and 15% reduction in all other uses **Severe**: Voluntary 25% reduction in residential use and 20% reduction in all other uses. Note also mandatory restrictions for non-essential uses **Extreme**: Mandatory reduction of 30% for residential and 25% for all other uses	Tie in with Marlboro Water Company (should have been complete in 2003)

Appendix C: Draft and Final Consensus Survey Results

To assess each RBC member's confidence in the plan, the plan approval process dictates that there will be a test for consensus on the Draft River Basin Plan and a vote of support or disagreement on the Final River Basin Plan. For the test of consensus on the Draft Plan, each member rates their concurrence with the plan using a five-point scale, as shown below:

1. Full Endorsement (i.e., member likes it).
2. Endorsement but with minor points of contention (i.e., basically member likes it).
3. Endorsement but with major points of contention (i.e., member can live with it).
4. Stand aside with major reservations (i.e., member cannot live with it in its current state and can only support it if changes are made).
5. Withdraw – Member will not support the draft river basin plan, will not continue working within the RBC's process, and will leave the RBC.

For the Final River Basin Plan, each RBC member votes simply to support or not support the plan. By indicating support, the member would be acknowledging his/her concurrence with the Final River Basin Plan and their commitment to support implementation of the plan. The results of the test for consensus of the Draft River Basin Plan and the RBC's votes on the Final River Basin Plan are shown in Table C-1.

Table C-1. Level of consensus for the Draft and Final River Basin Plans

Name	Draft Plan Level of Endorsement	Final Plan Support or Disagree
Everett Allen	2	Support
Michael Bankert	1	Support
Tim Brown	1	Support
Cliff Chamblee	2	Support
John Crutchfield	1	Support
Jason Gamble	2	Support
Michael Hemingway	1	Support
Megan Hyman	1	Support
Eric Krueger	1	Support
Frances McClary	1	Support
Douglas Newton	2	Support
Hughes Page	1	Support
Bob Perry	2	Support
Lindsay Privette (Vice Chair)	1	Support
Buddy Richardson II (Chair)	1	Support
John Rivers	2	Support
Debra Buffkin	2	Support
Dr. Jeff Steinmetz	2	Support
Cynthia Walters	1	Support

Appendix D: Public Comments and Responses

Public comments on the Draft Pee Dee River Basin Plan were accepted from December 13, 2024 through February 13, 2025. Comments were received from the following:

Brad Turley
Carolina Wildlands Foundation

Becky Ryon
Coastal Conservation League

Neil Stevenson

The Pee Dee RBC appreciates the comments and suggestions for improving the draft plan. Where noted, the final River Basin Plan was revised to address comments. All submitted comments are included on the following pages, and a response follows each comment.

Comments Submitted By:

Brad Turley
Carolina Wetlands Foundation
RBC responses follow each comment in blue text

Comment:

Background

My farm is on the SC/NC state line in Chesterfield county. I started a foundation, Carolina Wildlands Foundation www.CarolinaWildlands.org, to educate and bring more young people into the field biology profession at a time they are needed most. We've had over 50 interns and fellows do research from Francis Marion, Winthrop, Wingate, Newberry, Davidson, and of course, U of South Carolina and Clemson. Our website shows some of the research that we've done. A few years ago we did some e Coli testing on Thompson Creek with a certified lab and had counts as high as 4800. Since then, we've made it our mission to figure out how to get the Creek back to a healthier condition so a child can play, swim, paddle or fish in it again without fear of sickness and infection. To this end, we have become an Adopt-a-Stream site to monitor water quality in Thompson Creek. Here's a short video that we did about the Creek to help tell its story. https://vimeo.com/1002041941

Interpretation

I mentioned in the public meeting that regulations and orders are always open to interpretation. Because of that, I read Governor McMaster's Executive Order 2024-22. And after my reading, I am more convinced than ever that water quality is an important part of the Order and that the course taken by the RBC plan, as submitted, doesn't fulfill the Executive Order's intent or obligations and is missing key elements. The Governor is asking to ensure high quality clean water in sufficient quantities – not sufficient water that is unusable and unsafe. The focus on quantity in lieu of quality seems misguided and morally wrong.

Response: The RBC appreciates Mr. Turley's thoughts on the importance of water quality. The Pee Dee River Basin recommends that future iterations of the plan include water quality considerations (see Chapter 9), and it describes an implementation process for identifying and analyzing water quality concerns in the Pee Dee River

basin (see Chapter 10). While water quality is a concern of the RBC, the RBC also acknowledges that water quantity issues were to be the focus of initial River Basin Plans per the guidance provided in the South Carolina State Planning Framework. Page 15 of the framework says:

> *The River Basin Plans described in this document are intended to focus on water quantity issues; water quality concerns, however, may be highlighted when appropriate in a River Basin Plan. Water quality considerations will be more fully developed in later iterations of the River Basin Plans.*

The RBC looks forward to evaluating water quality issues more fully in later iterations of the River Basin Plan.

Comment:

Observations

1. Jurisdiction - The plan focuses on SC with little regard for NC impact on our State. Only 43% of the Pee Dee Watershed is in SC. Most of the river and many of its tributaries originate in NC and flow into SC.

    1. NC has control of much of the water flow (quantity) coming into SC. What control does SC have if NC decides to ensure its citizens have water before SC? (as Georgia has been with some of its neighboring states). Can we truly rely on the FERC licensing for NC dams on the river as the sole guarantee for SC's people and aquatic ecosystems in times of severe drought and/or overuse? How come this wasn't addressed in the Plan?

Response: The plan acknowledges that most of the river basin is in North Carolina and that flows into South Carolina are heavily regulated by North Carolina reservoirs (see Chapters 2 and 3). In Chapter 3, the plan cites the licensing process for the Yadkin-Pee Dee Hydro Project that was completed in 2015 and 2016. The resulting 40-year license reflected collaborative efforts that address a wide variety of stakeholder relicensing interests including instream flow requirements, power production, fish passage, water quality, recreation, endangered species, and cultural resources. Minimum flow requirements for downstream needs and drought-focused low inflow protocols were developed that have resulted in more stable downstream flows. Chapter 8 includes additional information on low inflow protocols that regulate downstream flows in drought conditions. The RBC included a policy recommendation in Chapter 9 that would foster closer collaboration between South Carolina and North Carolina in segments of the Yadkin-Pee Dee River basin that span both states.

Comment:

2. It was mentioned that SC coordinates and works with NC but no details of with whom or how. Why aren't the interstate agencies, groups or working committee with whom they work identified in the Plan?

Response: In Chapter 8, the plan cites SCDNR and SCDES involvement in the Yadkin-Pee Dee Drought Management Advisory Group (YPD-DMAG) and identifies both the YPD-DMAG and Yadkin-Pee Dee Water Management Group as entities to be included in the Pee Dee RBC's drought-related communication plan. In addition, Chapter 9 includes recommendations for collaborating with the Yadkin-Pee Dee Water Management Group in the future. The Pee Dee RBC saw these channels of communication as important first steps, and did not feel that an exhaustive list of groups was needed in the initial plan. As implementation proceeds, additional groups may be identified and included in collaborative efforts. The diversity of RBC members will help foster a broad array of potential groups with which to collaborate.

Comment:

3. NC has substantially more concentrated animal feeding operations (CAFO's) than SC. According to multiple sources involving legal action related to CAFO waste, NC has nearly 1 billion chickens. At approximately .2 lbs. of waste per day per bird, that is a lot of waste that as to be disposed of. We are downstream of whatever NC puts onto their land or into their waterways in the Pee Dee basin – on purpose or inadvertently – bacteria, chemicals and pharmaceuticals. We have no control, why isn't it addressed in the Plan?

Response: The Pee Dee River Basin recommends that future iterations of the plan include water quality considerations (see Chapter 9), and it describes an implementation process for identifying and analyzing water quality concerns in the Pee Dee River basin (see Chapter 10). While water quality is a concern of the RBC, the RBC also acknowledges that water quantity issues were to be the focus of initial River Basin Plans per the guidance provided in the South Carolina State Planning Framework. The RBC looks forward to evaluating water quality issues more fully in later iterations of the River Basin Plan. In addition, while Mr. Turley's comment focuses on North Carolina, the RBC notes that SCDES has programs in place to regulate CAFOs in South Carolina.

Comment:

2. Topics – Current plan topics seem to be incomplete or missing a number of key points:

    1. The Plan only addresses permitted water sources. It does not include any nonpermitted uses such as individual wells. While the data isn't readily available, shouldn't an attempt be made to quantify the number and volume of water used by these individual sources? Shouldn't the disposal of the waste after such use be discussed in the Plan?

Response: Unpermitted and unregistered uses are not reflected in the current and future demand estimates described in Chapter 4 of the plan. Unpermitted and unregistered uses were assumed to be negligible in the demand estimates – an assumption that is consistent with the approach taken in other basins. Text was added to Chapter 4 to document this assumption. The assumption could be revisited in future iterations of the plan.

Comment:

2. Existing groundwater contamination sites, such as Galey & Lord in Society Hill have been ignored by the Plan. Can that quantity of water be considered an adequate water supply for thousands of homes and for businesses? If the EPA has confirmed and is involved in a toxic site cleanup in the Pee Dee river basin that has and is affecting our water system, shouldn't it and any others water contamination sites be part of the plan?

Response: The Pee Dee River Basin recommends that future iterations of the plan include water quality considerations (see Chapter 9), and it describes an implementation process for identifying and analyzing water quality concerns in the Pee Dee River basin (see Chapter 10). While water quality is a concern of the RBC, the RBC also acknowledges that water quantity issues were to be the focus of initial River Basin Plans per the guidance provided in the South Carolina State Planning Framework. The RBC looks forward to evaluating water quality issues more fully in later iterations of the River Basin Plan. The RBC notes that SCDES's Groundwater Protection Program regulates groundwater contamination sites. The RBC also notes that the River Basin Plan is regional in nature, and local issues (such as the issue Mr. Turley cites) should be addressed in away that aligns with the plan's vision. In addition, text was added to Chapter 7 highlighting the need to consider water quality when evaluating suitable water management strategies.

Comment:

3. There are multiple graphic GIS layer maps on the SC Watershed Atlas site: Surface Water Intakes, Public Water Supply Wells, Protection Zones, Water Quality Monitoring sites, 303(d) Impaired Waters and the like. Wouldn't this help the reader better understand the efforts that the State has been taking on their behalf? Why aren't these links or maps included as part of the plan?

Response: A featurette on the South Carolina Watershed Atlas was added to Chapter 3 of the plan. The featurette describes the atlas and provides a link.

Comment:

4. Deforestation is a serious issue in our surrounding counties. Chesterfield, Lancaster and Union NC counties have lost nearly 5% of their county's forests since 2001 according to the USGS National Land Cover Database. Chesterfield County alone has lost over 25,000 acres. There is no mention in the plan of this water impacting phenomenon. Given the known effects that forest clearing has on groundwater recharge and surface runoff, shouldn't deforestation in the river basin be addressed in the Plan?

Response: Section 2.3.5 of the plan acknowledges the need to protect a variety of land use types (including forests) to help maintain water quality and quantity. In addition, Chapter 9 of the plan includes a recommendation to study the impacts of land use changes on water quality and quantity. The RBC notes that hydrologic impacts of historical deforestation should be reflected in existing surface water gaging data that were incorporated into the SWAM model, and as a result, these impacts are a part of current and future projections of stream flow regimes. The RBC also notes that the SWAM model is regionally focused (which is appropriate for a regional plan such as this), and smaller-scale, local hydrologic changes may not be fully reflected in SWAM.

Comment:

5. Surface water supplies are "adequate" through 2070. What about the long history of extensive ditching, draining, and unregulated withdrawals that have significantly altered the natural hydrology? Can the Plan at least acknowledge this reality, and strongly recommend opportunities to restore hydric soils, wetlands and riparian forest buffers to regain some of the natural water storage that has been lost over centuries?

Response: The RBC notes that hydrologic impacts of historical ditching or draining should be reflected in existing surface water gaging data that were incorporated into the SWAM model, and as a result, these impacts are a part of current and future projections of stream flow regimes and water supply adequacy. The RBC also notes that the SWAM model is regionally focused (which is appropriate for a regional plan such as this), and smaller-scale, local hydrologic changes may not be fully reflected in SWAM. Section 2.3.5 of the plan acknowledges the role of a variety of land use types (including wetlands and forests) to help maintain water quality and quantity and encourages land protection in recharge areas and along waterways. In addition, Chapter 9 of the plan includes a recommendation to study the impacts of land use changes on water quality and quantity.

Comment:

6. Groundwater supplies are "relatively stable" except for "sustainability issues" in aquifers in Georgetown, Horry, Florence, yet there is increasing dependence on groundwater wells there and throughout the river basin. Can the Plan address a key question: are current land use patterns and trends short-circuiting the natural hydrology and small water cycles of the watershed or restoring it?

Response: Section 2.3.5 of the plan acknowledges the role of a variety of land use types (including wetlands and forests) to help maintain water quality and quantity and encourages land protection in recharge areas and along waterways. The RBC notes that historical land use impacts related to groundwater recharge should be reflected in recharge estimates conducted using the USGS's Soil-Water Balance model. The Soil-Water Balance model will be used to create recharge-related inputs for the updated Coastal Plain Groundwater Model (the groundwater model update process is ongoing as of River Basin Plan publication). In addition, Chapter 9 of the plan includes a recommendation to study the impacts of land use changes on water quality and quantity.

Comment:

7. What about water quality for both surface and ground water...how do those interact with the quantity of both surface and ground water? Can the plan strongly recommend extensive biofiltration and recharge of stormwater and wastewater as development continues?

Response: The Pee Dee River Basin recommends that future iterations of the plan include water quality considerations (see Chapter 9), and it describes an implementation process for identifying and analyzing water quality concerns in the Pee Dee River basin (see Chapter 10). While water quality is a concern of the RBC, the RBC also acknowledges that water quantity issues were to be the focus of initial River Basin Plans per the guidance provided in the South Carolina State Planning Framework. Text was added to Chapter 7 highlighting the need to consider water quality when evaluating suitable water management strategies that focus on enhancing water quantity. Reclamation of stormwater and wastewater are water management strategies described in Chapter 6 of the plan and were highly prioritized by the RBC, as described in Chapter 7.

Comment:

8. Reducing use and increasing efficiency. Using both groundwater and surface water to spread demand. The recommendations focus on household water conservation. What about the biggest users of all - agriculture and industry? There were big increases in center-pivot irrigation systems across the Pee Dee over the last 10 years. Are they even necessary? What are industries located in the river basin doing to reduce their demand? Can the Plan acknowledge the need for significant agricultural and industrial water conservation, and include recommendations for how that can happen?

Response: Chapter 4 describes the relative amounts of water use across user types, and thermoelectric generation and public water supply are the largest water uses in the basin. The Pee Dee RBC agrees that water management strategies for industry and agriculture are important. Chapter 6 describes a wide variety of water conservation strategies that focus on agriculture and industry. Chapter 7 describes water conservation strategies that were prioritized by the RBC, several of which focus on industry. Chapter 7 also asserts that agricultural water conservation strategies are important and should be pursue because they can help sustain water supplies, increase crop yields, and lower costs.

Comment:

9. There are no recommendations or guidelines offered for senior DES officials on how to respond or act when the time comes. Whether a catastrophic weather event or some unusual seismic activity that changes the waterways and courses, the plan seems to be reporting the permitted "facts", at least when it comes to water quantities. There are no best case, most likely case and worst-case scenarios provided to guide the Governor or the DES Director in future events. As a former manager, I always looked to my staff to provide ideas, recommendations, solutions, and their help in trying to solve problems – current and future. Why are is there no help or guidance for senior management in terms of potential water quantity and quality problems? If water does have to be rationed or cut back – who goes first? Is keeping a golf course green a better use of water than forcing a citizen to use bottled water – maybe if the quality of the water is inadequate to drink. Can the Plan better address the process for setting water allocation priorities?

Response: South Carolina has a formalized system for drought management and implementing drought-related water management strategies (see Chapter 8 of the plan and also South Carolina's drought management website at http://www.scdrought.com/index.html). Section 9.3 of the plan includes a variety of policy, legislative, and regulatory recommendations that are meant to provide ideas to decision-makers on ways to improve state or local laws, regulations, or ordinances.

Comment:

10. Finally, if this is a 50-year plan, even if it is revised and amended over time, it seems that most of the people on the committee aren't going to be around in 2075. What is being done to bring more young people onto the board and be involved to ensure the Plan's continuity and reality?

Response: The Pee Dee RBC wants to see the plan implemented and revised over time, and the plan has recommendations for the provision of funding and State staff to support future RBC meetings and plan implementation. SCDES has processes in place to replace RBC members when they retire or otherwise step down. The role and vision of the RBC will be promoted throughout the basin as the plan's recommended communication and outreach activities are implemented. As the plan is implemented and communicated, stakeholders (both younger and older) will become more aware of and involved in sustainable water management and in the RBC.

Comment:

Summary

While I commend the initial efforts, the plan seems incomplete and is setting the Governor and senior DES officials up for more than a few headaches. It seems that the plan is good at reporting permitted water quantity issues but amiss at water quality and recommendations for catastrophic events. Will this document provide enough substance and direction to our current and future State leadership if our water future estimates are off or a catastrophic event occurs?

Thank you for your attention and support

Response: The Pee Dee RBC thanks you for your comment.

Comments Submitted By:

Becky Ryon
Coastal Conservation League
RBC responses follow each comment in blue text

Comment:

Thank you to the entire Pee Dee River Basin Council for the many months of work in drafting this plan. The care and consideration of the participants is evident and the Pee Dee River Basin will be more resilient as a result of their efforts. With that said, I would like to mention a few questions and concerns from the draft.

- While I recognize this plan is focused on water quantity versus quality, what are the next steps for discussing water quality in the river basin?

Response: The Pee Dee River Basin recommends that future iterations of the plan include water quality considerations (see Chapter 9), and it describes an implementation process for identifying and analyzing water quality concerns in the Pee Dee River basin (see Chapter 10).

Comment:

- The Little Pee Dee River experienced drought conditions this summer. How does this plan address possible summer droughts and water usage? How is saltwater intrusion affected by drought conditions? Please consider recommending additional gauges on the Great Pee Dee River especially as we need more monitoring along waterways to understand the flows, not just for floods but to monitor drought stages.

Response: The modeling used to evaluate surface water supplies considers drought conditions. Also, the High Demand scenario considers increased future water demands, and significant shortages were not estimated. Saltwater intrusion risks can occur when surface water flows during drought are inadequate to prevent migration of saltwater upstream in waterways with surface water supply intakes. The Pee Dee RBC recognized that overall data improvements are needed and included recommendations for this in the plan. Chapter 9 of the plan includes a recommendation to install more surface water gages, and Chapter 10 of the plan describes implementation steps to identify data gaps and develop strategies to fund the acquisition and distribution of new data (surface water gages could be a part of that implementation action).

Comment:

- One key difference I have noticed between this plan and the Edisto plan, as a previous example, is that the Edisto plan identified the percentage of water that is already allocated for permitted uses versus how much remains unclaimed and still available. I did not see any allocation data included in this plan. The Edisto plan, however, did not adequately project for industry growth and failed entirely to include the Canadys gas plant in the future water usage projections. The Pee Dee plan fails to include any mention of the Winyah Generating Station which falls within the Pee Dee watershed, though the outfalls overlap with the Santee. If it is not included in the Pee Dee plan, please ensure it is incorporated into the Santee River Basin Council discussions that are just beginning.

Response: The plan includes an evaluation of permitted and registered water uses and compares those to existing uses (see Section 4.2 of the plan). The Winyah Generating Station will be considered in the Santee River Basin Plan.

Comment:

- I would recommend further projecting water usage for both electric utilities and existing industries as demand grows with the growing population, as well as the potential for large usage from industrial users such as data centers in the near future.

Response: Industrial water use was projected to grow at rates indicated by the U.S. Energy Information Agency. Thermoelectric power production at the H.B. Robinson Nuclear Plant was projected to be constant into the future per recommendations from Duke Energy. The cyclical nature of river basin planning provides the opportunity to revise water demand assumptions during the next iteration of the plan if industries, stakeholders, or other sources of data suggest that industrial or thermoelectric demands in the Pee Dee River basin will significantly increase or decrease in the future.

Comment:

- Furthermore, I do not think this plan sufficiently addresses the likely high residential density for the Myrtle Beach and Conway areas projected in the coming decades. Some forecasts have Horry County surpassing Charleston County in population by 2027.

Response: Figure 4-5 and Table 4-7 show projected population increases that were considered for Horry County. Horry County is projected to have the highest population change of any county in the basin and is projected to double or triple (depending on the planning scenario) by the year 2070.

Comment:

- The SWAM model does not include the Waccamaw River/Intracoastal Waterway but it is my recommendation that it should.

Response: The Pee Dee RBC agrees, and Chapter 9 provides recommendation to extend surface water modeling to coastal areas. This was the RBC's highest priority technical recommendation (see Figure 9-1).

Comment:

- The plan notes that, under a high demand scenario, the groundwater in the Crouch Branch aquifer in Georgetown County will be at critically low levels. While some strategies are analyzed in the plan, it does not feel like this is given enough weight. I would love to see a commitment to these strategies and a coordinated effort throughout the river basin, as this is not a localized issue.

Thank you for your consideration of these questions and comments.

Response: The current and future groundwater risks for the Crouch Branch Aquifer in Georgetown County are highlighted in both the River Basin Plan (see Chapter 5) and the Executive Summary. Chapter 9 of the plan includes a recommendation to complete the groundwater model and use it to evaluate future groundwater supply risks and strategies to reduce risks. The RBC agrees with Ms. Ryon's desire for a basinwide commitment to strategies, and the plan includes a wide variety of recommended outreach and education actions for communicating and promoting the plan's vision for implementing water management strategies that foster sustainable water supplies.

Comments Submitted By:

Neil Stevenson

RBC responses follow each comment in blue text

Comment:

Please support Clean Water! South Carolina deserves it!

Response: The Pee Dee RBC agrees and appreciates your comment.


Brown AND
Caldwell

Appendix B: Drivers Matrix

Driver	Driver Description	Impact on Water Resources	Underlying Data	Apply to Scenarios	Bucket
1. Social/Environmental Values	Social/environmental values reflect the public's perception of water use, support of water and energy conservation, and allocation of water supply toward environmental uses. Social values influence drivers such as regulations and adoption of water efficiency technologies, but they also affect the types of solutions that Coloradans pursue to meet future water needs or respond to climate change. For example, social values can impact the degree to which residents voluntarily adopt water-efficient technologies that may cost them money. They can also influence the demand for local agricultural products and the desire to maintain open space. Personal experiences, education, and outreach impact the degree of public awareness of water issues, which in turn can affect the public's perception of the water supply solutions as well as recreation and environmental protections that are pursued.	If values trend toward greater water and energy conservation, new technologies may emerge that help conserve water. Also, development of new supplies may occur in ways that meet municipal and agricultural needs while preserving or enhancing the environment and providing recreational benefits.	CWCB survey regarding public opinions, attitudes, and awareness regarding water in Colorado	Not applied directly; considered in conservation assumptions	Influencer; Solution
2. Population/Economic Growth	Population growth is driven by both state and national economic trends and land use planning and development statewide (see Driver #3). Colorado's moderate climate and quality of life draw both permanent residents and tourists. Population and economic growth/decline is forecasted by the State Demography Office (SDO) using census data and economic drivers.	Population growth is a primary driver for municipal water demand and urbanization. Population change directly influences water use, while economic growth influences the types of water use (municipal, industrial, recreation, etc.). While Colorado's recent efforts to save water though efficiency and conservation have kept water demands steady in spite of growth, water demands are nevertheless projected to increase.	State Demography Office (SDO) population projections	Statistically calculated high growth and low growth Economic assumptions considered in conservation assumptions and industrial water needs	Direct Impact
3. Urban Land Use/Urban Growth	Urban land use and growth considers both density and type of development, as well as urbanization of undeveloped and agricultural lands. Zoning and other decisions affecting population density in cities and towns impacts how water is used inside and outside of single- and multi-family housing and businesses. It also impacts the degree to which urban sprawl may occur in the future. Denser redevelopment is influenced by water resource availability and social values with a preference for low water use, low energy use, and green infrastructure.	Population growth patterns can impact availability of water resources and how local governments use water (in-house use versus watering of green spaces). As urban areas grow into undeveloped areas of the watershed, both runoff into streams and water quality are affected. Finally, the urbanization of agricultural lands results in a shift of water use from the agricultural sector to the municipal sector, which can impact timing of use and return flows, wildlife habitat, and overall watershed health.	Municipal boundaries, irrigated lands	When population is projected to increase, irrigated lands were reduced when within municipal boundaries Housing density was not directly considered in municipal water use. General trends in density were considered in conservation assumptions	Influencer; Solution
4. Availability of Water Efficient Technologies	Availability and adoption of water efficiency technology drives water demands from municipal, industrial, and agricultural perspectives. Increased efficiency can be implemented in all sectors (municipal, industrial, energy, agricultural) and can offset growth through decreased demand by individual users.	Indoor municipal demands can be reduced by installing low-flow fixtures, and outdoor demands are influenced by types of landscaping and efficiency of irrigation systems. On the agricultural side, irrigation efficiency technologies can reduce water losses on-farm and in ditches that deliver water from rivers and streams to farms. In addition, crop hybrids that are drought tolerant and crops that require less water can reduce irrigation demand.	1051 data, WEPs (municipal water efficiency plan), water provider outreach	Not applied directly; considered in conservation assumptions Considered general trends in water efficiency and technologies	Influencer; Solution
5. Climate Change	Climate change is the long-term shift in temperature and regional weather patterns that results in a range of projected future conditions that include a warmer and potentially drier future for Colorado. A range of climate-adjusted conditions were developed statewide through the multi-phase Colorado River Water Availability Study and are used to adjust hydrology and the demand for water reflective of the future climatic conditions.	Climate conditions impact both water supplies and water demands. Climate change may decrease streamflows and/or shift yearly streamflow patterns, which would impact agricultural, municipal, and industrial water supplies and create or increase risks for environment and recreation attributes. Higher temperatures associated with climate change will increase irrigation water demands for agricultural crops and outdoor urban landscapes and result in reduced return flows to streams.	CRWAS-II (models by USBR simulating future hydrologic conditions) VIC model (variable infiltration capacity) CMIP model (coupled model intercomparison project, phase 5)	Calculated annual mean temperature offset (deg C), annual precip change factor, influenced streamflow and irrigation water requirement (IWR) change factors Scaling factors from VIC model used to modify historical time series of streamflows and irrigation requirements	Direct Impact
6. Level of Regulatory Oversight/Constraint	Regulatory oversight includes the legal framework in Colorado and nationwide through which water is administered, developed, and managed. This includes oversight from DWR, Colorado Department of Public Health & Environment (CDPHE), U.S. Environmental Protection Agency (EPA), and others.	Regulatory constraints are influenced by social values, and they may drive changes in demands. For example, industrial water needs for energy extraction or thermoelectric energy production may be higher or lower in the future depending on state and local regulations and policies. Regulation can also drive the types of water supply solutions that stakeholders pursue. For example, the efficiency of permitting for certain types of water projects and the associated environmental mitigation requirements could influence their feasibility and cost.		Not applied directly; considered in conservation assumptions	Influencer; Solution

Driver	Driver Description	Impact on Water Resources	Underlying Data	Apply to Scenarios	Bucket
7. Agricultural Economics/Water Demand	Agricultural conditions, such as the amount of irrigated land in production, crops grown, and climate, influence demand for irrigation supplies. Urbanization, municipal transfers of agricultural water supply, availability of surface and groundwater supplies, and in some basins, interstate compact compliance, all influence the amount of agricultural land that will be in production in the future. Demands and prices for local agricultural products also affect the economic sustainability of continued agriculture and resulting demands for water.	Changes in the economics of the agricultural sector may impact the amount and types of crops grown, as well as the amount of land under irrigation. These changes will impact water demands for agricultural purposes.	Irrigation water requirement for each ditch system based on crop type, acreage, and climate conditions. Meetings with major agricultural water providers regarding current and future agricultural operations	Irrigated acreage, climatic conditions, and efficiencies in the current agricultural diversion demand are then adjusted by various factors to estimate the agricultural diversion demand in the scenarios	Analysis Result
8. Energy Economics/Water demand	The energy sector uses water in a variety of ways, including direct use for hydropower, or indirect uses such as steam generation or cooling. Water needs for energy shift in response to population growth and current regulations, policies, and planning for the energy industry. These needs are also affected by the type of energy production that is used in the future and can be influenced by state and national energy policies.	As the sources of energy shift from nonrenewable (coal and gas) to renewable (water, wind, and solar), the demand for water will shift as well. It is anticipated that renewable sources of energy will be less water consumptive.	Outreach to industry users, "water use factors" for snowmaking, SWSI Phase I Study, Phase I & II Energy Development Water Needs Assessment Reports for energy extraction & production, BIPs, Tech Update M&I TAG members	Categories of industrial water demands were adjusted by a factor (percent) for the scenarios	Analysis Result
9. Municipal and Industrial Water Demands	The municipal and industrial sector serves the residents and businesses of Colorado with water. Municipal water demands are influenced by changes in other drivers such as population, urban land use, adoption of conservation measures, and climate.	Water in Colorado is scarce, and as the population grows, increased municipal and industrial demand for water is met through development of new supplies (if available), at the expense of water from a different sector, or through water conservation.	1051 data, WEPs (municipal water efficiency plan), water provider outreach Municipal demands were calculated for each county and then summarized by basin. Water demands for counties that are located in multiple basins were distributed between basins by using the portion of the county population located within each basin to prorate the water demands.	Projected future per capita rates of water demand in gpcd were calculated for each county by adjusting the baseline gpcd values by future demand drivers representing urban land use, technology, water rates, provider policies, state/federal regulations, social values (i.e., support for higher muni water efficiency & preference for human water use versus other concerns) Relative level of M&I demands described in planning scenarios narrative was adopted & adhered to in the projections (e.g., weak economy had the lowest demand & hot growth had the highest demand)	Analysis Result