SECTION 2
METHODOLOGIES

The analysis methodologies used in the Technical Update are summarized in this section. The technical memoranda describing these methodologies can be found in Volume 2. See Appendix A for a comprehensive list of technical memoranda.

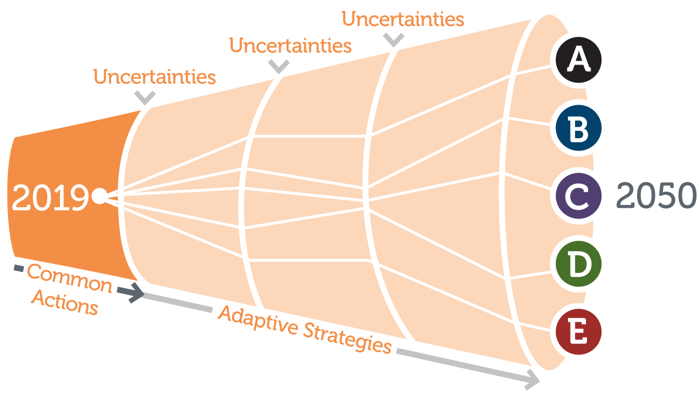
2.1 SCENARIO PLANNING

2.1.1 Description of Scenario Planning

Scenario planning is a strategic foresight planning process that acknowledges the future is uncertain. Colorado's Water Plan enlists 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 (e.g., energy, agricultural, and municipal needs).

Scenario planning and adaptive management allow decision makers and water users the flexibility to track environmental and social changes over time that provide insights into which future conditions might become more likely as time passes (see Figure 2.1.1). The scenario planning method varies from a more simplistic application of high, medium, and low stress conditions (used in SWSI 2010) by acknowledging that the future holds a degree of uncertainty, depending on a variety of environmental and social drivers.

Figure 2.1.1 Illustration of Scenario Planning Concepts



The scenario planning method includes the following six general steps.

Previous steps conducted by IBCC and described in the Colorado Water Plan	*Steps that are part of this Technical Update*	*Future steps that are to be completed by basin roundtables in BIP updates*
1 Develop expansive list of drivers that can influence future water planning conditions	**4** Quantify future supply and demand conditions for each scenario per identified drivers	**6** Develop projects and strategies that can be used to address gaps for each planning future
2 Identify most uncertain and most important key drivers	**5** Calculate baseline supply versus demand gaps for each scenario without considering future projects or strategies that may address the calculated gap	
3 Develop scenario narratives that define different plausible futures that warrant planning		

2.1.2 Development of the Planning Scenarios

Before developing the Colorado Water Plan, the CWCB initiated a multi-year stakeholder process in conjunction with the nine basin roundtables and the IBCC. Each roundtable developed one or more statewide water supply portfolios to respond to the projected low, medium, or high future water needs of communities. The IBCC subsequently synthesized and reduced the basin roundtable-generated portfolios into a smaller set of 10 representative portfolios to address projected low-, mid-, and high-range M&I water demands. The IBCC then developed a list of the following nine high-impact drivers that could greatly influence the direction of Colorado's water future. Using these drivers, 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.

1. Population/Economic Growth
2. Social/Environmental Values
3. Climate Change/Water Supply Availability
4. Urban Land Use/Urban Growth Patterns
5. Energy Economics/Water Demand
6. Level of Regulatory Oversight/Constraint
7. Agricultural Economics/Water Demand
8. Municipal and Industrial Water Demands
9. Availability of Water-Efficient Technologies

Signpost Indicators

The adaptive management framework recognizes that the future hinges on how much the drivers (scenario variables) change over time. Major changes in the drivers could tip the still-evolving future toward one scenario or another. The tipping points serve as water management decision points, (i.e., "signposts") that can lead toward the need to implement an alternative portfolio of solutions. Signposts were defined in the Water Plan as decision points that reveal whether past uncertainties now have more clarity. Signposts are a key part of scenario planning, but signpost development was not part of the Technical Update scope. Like project lists, signposts may be unique to regions or specific industries. Signposts could be developed in collaboration with basin planning efforts to identify specific indicators and criteria that signal a need for a new suite of projects or strategies. Alternatively, signposts may be seen as the frequency by which the state and/or basin roundtables evaluate and review key indicators. Section 5 of the Technical Update describes recommendations for the future establishment of signposts.

2.1.3 Description of the Planning Scenarios

The five planning scenarios are summarized in the Water Plan with names portraying each scenario's respective depiction of the future.[1] A summary graphic (see Figure 2.1.2) shows the relative increase and decrease for five main drivers compared to current levels. A full description of each planning scenario follows.

A. Business as Usual. Recent trends continue into the future. Few unanticipated events occur. The economy goes through regular economic cycles but grows over time. By 2050, Colorado's population is close to 9 million people. Single family homes dominate, but there is a slow increase of denser developments in large urban areas. Social values and regulations remain the same, but streamflow and water supplies show increased stress. Regulations are not well coordinated and create increasing uncertainty for local planners and water managers. Willingness to pay for social and environmental mitigation of new water development slowly increases. Municipal water conservation efforts slowly increase. Oil-shale development continues to be researched as an option. Large portions of agricultural land around cities are developed by 2050. Transfer of water from agriculture to urban uses continues. Efforts to mitigate the effects of the transfers slowly increase. Agricultural economics continue to be viable, but agricultural water use continues to decline. The climate is similar to the observed conditions of the 20th century.

B. Weak Economy. The world's economy struggles, and the state's economy is slow to improve. Population growth is lower than currently projected, which is slowing the conversion of agricultural land to housing. The maintenance of infrastructure, including water facilities, becomes difficult to fund. Many sectors of the State's economy, including most water users and water-dependent businesses, begin to struggle financially. There is little change in social values, levels of water conservation, urban land use patterns, and environmental regulations. Regulations are not well coordinated and create increasing uncertainty for local planners and water managers. Willingness to pay for social and environmental mitigation decreases due to economic concerns. Greenhouse gas emissions do not grow as much as projected, and the climate is similar to the observed conditions of the 20th century.

C. Cooperative Growth. Environmental stewardship becomes the norm. Broad alliances form to provide for more integrated and efficient planning and development. Population growth is consistent with current forecasts. Mass transportation planning concentrates more development in urban centers and mountain resort communities, thereby slowing the loss of agricultural land and reducing the strain on natural resources compared to traditional development. Coloradans embrace water and energy conservation. New water-saving technologies emerge. Ecotourism thrives. Water-development controls are more restrictive and require both high water-use efficiency and environmental and recreation benefits. Environmental regulations are more protective and include efforts to reoperate water supply projects to reduce effects. Demand for more water-efficient foods reduces water use. There is a moderate warming of the climate, which results in increased water use in all sectors and in turn, affects streamflow and supplies. This dynamic reinforces the social value of widespread water efficiency and increased environmental protection.

D. Adaptive Innovation. A much warmer climate causes major environmental problems globally and locally. Social attitudes shift to a shared responsibility to address problems. Technological innovation becomes the dominant solution. Strong investments in research lead to breakthrough efficiencies in the use of natural resources, including water. Renewable and clean energy become dominant. Colorado is a research hub and has a strong economy. The relatively cooler weather in Colorado (due to its higher elevation) and the high-tech job market cause population to grow faster than currently projected. The warmer climate increases demand for irrigation water in agriculture and municipal uses, but innovative technology mitigates the increased demand. The warmer climate reduces global food production, which increases the market for local agriculture and food imports to Colorado. More food is bought locally, which increases local food prices and reduces the loss of agricultural land to urban development. Higher water efficiency helps maintain streamflow, even as water supplies decline. The regulations are well defined, and permitting outcomes are predictable and expedited. The environment declines and shifts to becoming habitat for warmer-weather species. Droughts and floods become more extreme. More compact urban development occurs through innovations in mass transit.

E. Hot Growth. A vibrant economy fuels population growth and development throughout the state. Regulations are relaxed in favor of flexibility to promote and pursue business development. A much warmer global climate brings more people to Colorado with its relatively cooler climate. Families prefer low-density housing, and many seek rural properties, ranchettes, and mountain living. Agricultural and other open lands are rapidly developed. A hotter climate decreases global food production. Worldwide demand for agricultural products rises, which increases food prices. Hot and dry conditions lead to a decline in streamflow and water supplies. The environment degrades and shifts to becoming habitat for species adapted to warmer waters and climate. Droughts and floods become more extreme. Communities struggle to provide services needed to accommodate rapid business and population growth. Fossil fuel, the dominant energy source, is supplemented by production of oil shale, coal, natural gas, and oil in the state.

2.1.4 Quantification of High-Impact Drivers in the Scenarios

Quantifying future demands, supplies, gaps, and available water under each of the five scenarios is a foundational task of the Technical Update. While the preceding narrative descriptions provide a qualitative summary, more significant interpretation was needed to determine how technical analyses could quantify the future conditions described in each based on available data and scientific best practices. Figure 2.1.2 summarizes and compares how the drivers varied across the scenarios. A more detailed explanation of how the various drivers were quantified and how the drivers relate to one another and across scenarios is shown in Tables 4 through 8 of Appendix B. The methodology sections and appendices provide more information on specific, quantitative adjustments to the drivers for each scenario and how the adjustments were implemented in various analyses.

Figure 2.1.2 Illustration of High-Impact Drivers Associated with Five Planning Scenarios

Drivers	A Business as Usual	B Weak Economy	C Cooperative Growth	D Adaptive Innovation	E Hot Growth
A. Economy/Population					
B. Urban Land use	No change in density	No change in density	Higher density	Higher density	Lower density
C. Climate Status/Water Supply	Same as 20th century observed	Same as 20th century observed	Between hot and dry and 20th century observed	Hot and dry	Hot and dry
D. Energy Water Needs	Low (no oil shale)	Moderate (no oil shale)	Low (no oil shale)	Low (no oil shale)	High (oil shale)
E. Agricultural Conditions	Total ag water demands decrease • Decrease in irrigated acres due to urbanization • Ag exports and demands lower • Ag is less able to compete with urban areas for water	Total ag water demands slightly decrease • Slight decrease in irrigated acres due to urbanization • Ag exports and demands constant • Ag is less able to compete with urban areas for water	Total ag water demands slightly higher • Slight decrease in irrigated acres due to urbanization • Ag exports down and local demands up • Ag is better able to compete with urban areas for water • Increased ET due to climate change	Total ag water demands slightly higher • Slight decrease in irrigated acres due to urbanization • Ag exports down and local demands up • Ag is better able to compete with urban areas for water • Increased ET due to climate change	Total ag water demands higher • Significant decrease in irrigated acres due to urbanization • Ag exports and demands high • Ag is better able to compete with urban areas for water • Increased ET due to climate change
F. Availability of New Water Efficiency Technology	• M&I Moderate • Ag: Efficiencies are increased	• M&I Moderate • Ag: Efficiencies are increased	• M&I High • Ag: Efficiencies are increased	• M&I High • Ag: Much higher efficiencies are implimented	• M&I Moderate • Ag: Efficiencies are increased
G. Social/Environmental Values	No change	No change	• Increased awareness • Increased willingness to protect environment and stream recreation	• Increased awareness • Increased willingness to protect environment and stream recreation	• Full use of resources • Low willingness to protect environment and stream recreation
H. Regulatory Constraints	Regulation / Deregulation No change	Regulation / Deregulation No change	Regulation / Deregulation Increased	Regulation / Deregulation Increased but expedited	Regulation / Deregulation Reduced
I. M&I Water Demands	Middle of the five scenarios	Lowest of the five scenarios	Second lowest of the five scenarios	Second highest of the five scenairos	Highest of the five scnarios

2.2 ANALYSIS METHODOLOGIES

TheTechnical Update offers a more scientifically rigorous and robust analysis compared to previous SWSI efforts, which did not include scenario planning, climate change considerations, water rights, or surface water modeling. The Technical Update leverages the state's 25-year investment in CDSS, including StateMod models that connect major waterways and tributaries in Colorado.

Hydrologic modeling allows for detailed temporal (hydrology over time) and spatial (geographic and node-specific) analyses. It incorporates inputs that reflect water availability drivers under a variety of future conditions throughout the state. Additionally, hydrologic modeling provides increased consistency in the representation of municipal and agricultural demand gaps in ways that could not be as equitably modeled in earlier methodologies (i.e., SWSI 2010). The models produce a wealth of time series data and quantifications of "hydrologic gaps" at representative locations under each planning scenario.

2.2.1 Incorporating Climate Change into Scenario Planning

Through an iterative effort with the CWCB, basin roundtables, and the IBCC, three composite climate projections were incorporated into the planning scenarios.[2] Of the five planning scenarios, three include some level of stressed future climate change (*Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*). The other two planning scenarios (*Business as Usual* and *Weak Economy)* assume similar climate conditions and variability to the observed conditions of the 20th century compared to historical natural flows for the period 1950–2013).

High stress conditions occur when runoff is low and consumptive use is high, whereas low stress conditions occur when runoff is high and consumptive use is low. The consumptive use, in this case, refers to the irrigation need (increased or decreased) for watering crops or other outdoor watering. This is expressed as the irrigation water requirement (IWR), which is synonymous with the term Crop Irrigation Requirement (CIR).

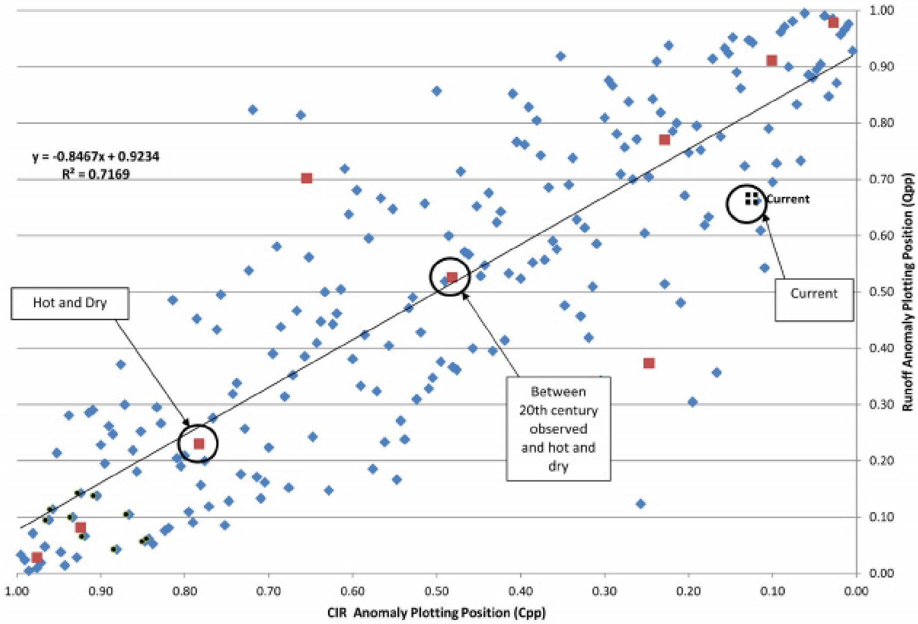
Table 2.2.1 and Figure 2.2.1 map this integration of future climate stress into the Technical Update planning scenarios. More detailed explanations of climate impacts follow and can be found in several documents such as the Colorado Climate Plan, Colorado Water Plan, and the foundational work of the multiphase Colorado River Water Availability Study (CRWAS).

Table 2.2.1 Incorporation of Climate Change into Scenario Planning

CWP Planning Scenario Name	CRWAS Climate Projection Name	Climate Stress Impact on 2050 Future Condition			
		CIR*	Runoff*	Average Annual Temperature[3]	Precipitation Change[3]
Business as Usual	Current	None	None	None	None
Weak Economy	Current	None	None	None	None
Cooperative Growth	In-Between	Moderate (50th percentile)	Moderate (50th percentile)	+ 3.78 °F (+2.0 °C)	5% increase in annual precipitation
Adaptive Innovation	Hot and Dry	High (75th percentile)	Low (25th percentile)	4.15 °F (+2.3 °C)	1% decrease in annual precipitation
Hot Growth	Hot and Dry	High (75th percentile)	(Low (25th percentile)	+ 4.15 °F (+2.3 °C)	1% decrease in annual precipitation

**See Figure 2.3 Plot of Runoff vs. Crop Irrigation Requirement (CIR)*

Figure 2.2.1 Runoff vs CIR Plotting Position



This plot of Runoff vs. CIR uses the Bureau of Reclamation's 200 composite climate scenarios. "Hot and dry" is defined as the 75th percentile of climate projections for crop irrigation requirements (water use), and the 25th percentile for natural flows. In other words, only 25 percent of projections have lower natural flows and 25 percent of projections have higher crop irrigation requirements. "Between 20th century-observed and hot and dry" is defined as the 50th percentile for both natural flows and crop irrigation requirements. This scenario represents the middle of the range in terms of severity. Baseline, or "Current" conditions, which represents no change in runoff or in crop irrigation requirements, fall at roughly the 9th and 67th percentiles; this means that 91 percent of model runs show increases in crop irrigation requirements and about two-thirds show reductions in runoff.

Turning Narrative into Numbers

Understanding how climate change could affect Colorado is key to understanding how to translate climate themes in scenario narratives into quantitative model inputs. In the Technical Update, climate stress is modeled from two dominant perspectives:

1) Supply Perspective: Output from the CRWAS-II project[4] included an extended time series of "natural flow" data developed for numerous locations throughout the state's basins (more than 300 streamflow gage locations statewide). "Natural flow" is the amount of water in the river absent the effect of humans, and serves as the foundational water supply data in the StateMod water allocation models. Although the impacts of climate projections vary across the state, natural flows under the climate projections generally show overall declines and temporal shifts to reflect earlier runoff periods. CRWAS-II project output also included a time series of climate-adjusted hydrology for both the moderate and high climate stress projections (respectively, "In-Between" and "Hot and Dry"). These datasets, also unique at more than 300 gage locations, reflect the relative change streamflow under each climate projection.

2) Demand Perspective: The runoff and IWR factors (jointly "climate factors") from both the "In-Between" and "Hot and Dry" projections reflect increased outdoor evapotranspiration (ET) rates and, therefore, increased IWR. In the Agricultural Diversion Demand methodology (Section 2.2.3) this is represented by IWR numbers that vary monthly, for every model year, for every water district. In the M&I Demand methodology (Section 2.2.4), IWR factors were applied at the county level to represent the average annual change in outdoor municipal demands. It was assumed that indoor demands and non-revenue water are not affected by climate factors.

2.2.2 CDSS Tools

The technical analyses make extensive use of CDSS modeling tools. CDSS is a water management system developed by the CWCB and the Colorado Division of Water Resources. The primary CDSS components used for the Technical Update are as follows:

- **HydroBase:** HydroBase contains historical and current water resources data, including streamflow records, historical climate data, diversion records, and water rights.
- **Geographic information system data:** Spatial data includes geographic information system (GIS) layers of diversion locations, irrigated acreage by ditch and crop type, streamflow measurement points, rivers, climate station locations, and ditch locations.
- **Surface water allocation models:** StateMod, the state's water allocation simulation program, analyzes water supplies and water demands and allocates available supply based on water rights, locations of demands, operational protocols, etc. Shortages (gaps) are calculated if supplies cannot fully meet demands. StateMod model datasets are available in most, but not all, of the river basins in the state.

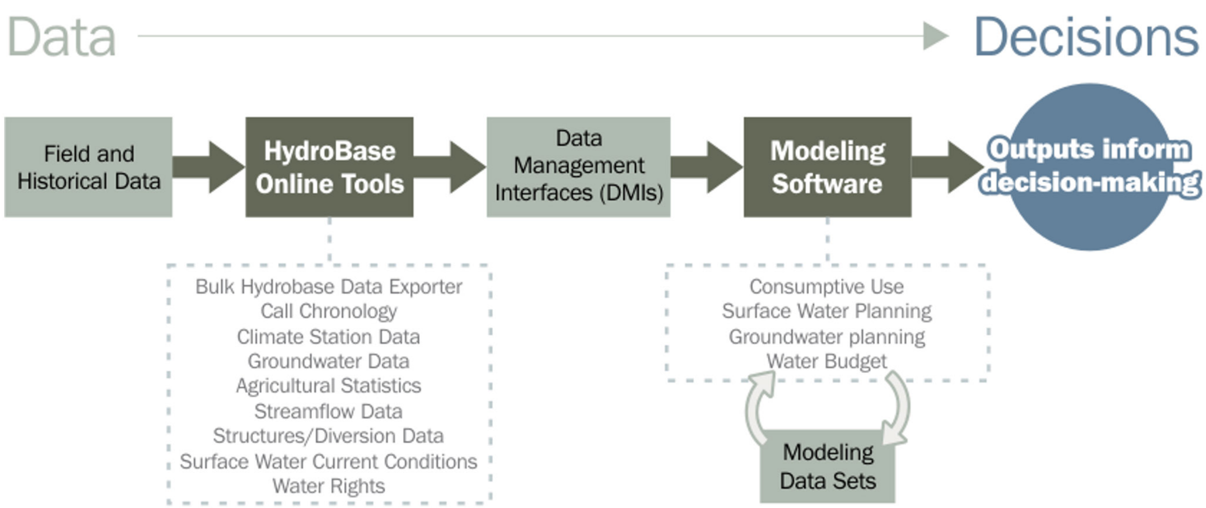
BASIN MODELING TOOLS

Many of the CDSS tools described here were not available for use when SWSI 2010 was being developed. The Technical Update has leveraged Colorado's investment in the CDSS to create a more comprehensive picture of supplies, demands, and gaps under each of the scenarios and under variable hydrologic conditions. The resulting analyses and tools are available for basin roundtables to use in updating their BIPs.

- **Consumptive use models:** StateCU, the state's crop consumptive use model, estimates the amount of water consumed by agriculture. It uses climate data (primarily temperature and precipitation), information on crop types and acreages, and water supply data to generate estimates of irrigation water requirements, consumptive use, irrigation system efficiencies, and agricultural diversion demand. StateCU model datasets are available in most, but not all, of the river basins in the state.

CDSS is foundational for statewide and basinwide water supply planning and establishes a common and accepted framework of information and tools to facilitate informed decision making. CDSS datasets and tools have been developed for use in the West Slope (Colorado; Yampa/White; Gunnison; San Juan/Dolores), North Platte, Rio Grande (consumptive use datasets only), and South Platte basins, and are being developed for the Arkansas Basin. State agencies, water users, and managers in these basins increasingly rely on CDSS as a common and efficient means for organizing, accessing, and evaluating a wide range of information and alternative water management strategies and decisions. Figure 2.2.2 illustrates the types of data and models available in CDSS and how data are incorporated and flow through the tools to facilitate informed decision making.

Figure 2.2.2 How Data and CDSS Tools Foster Informed Decision Making



2.2.3 Agricultural Diversion Demands

Agricultural demands in SWSI 2010 primarily reflected the consumptive use for crop irrigation at the field level. SWSI 2010 agricultural demands did not consider irrigation inefficiencies and ditch losses that occur as surface water diversions and/or pumped groundwater supplies are conveyed and applied to the crop. The Technical Update methodology, by accounting for crop consumptive needs plus irrigation inefficiencies, reflects the total amount of water needed to meet agricultural demands and allows for direct comparison between agricultural and municipal demands in the modeling. The updated methodology also provides information and tools for basin roundtables to use in evaluating the effectiveness of future agriculture projects. The Technical Update methodology described below was used to estimate diversion demands to meet the full irrigation needs of crops.

The Technical Update defines the current agricultural diversion demand as the amount of water that needs to be diverted or pumped to meet the full crop irrigation water requirements associated with the current levels of irrigated acreage, assuming historical climate conditions continue. In other words, the methodology assumes that irrigators will, regardless of a given delivery method's efficiency level, seek to divert enough water to meet their crops' full ET need (noting that under a range of climate patterns in water-short systems, the amount of water irrigators seek to divert is not always available). Current demand serves as the "baseline" for the Technical Update analysis and can be used to estimate the change from current to future conditions. To estimate potential future diversion demands, irrigated acreage, climate conditions, and efficiencies associated with the current agricultural diversion demand were adjusted by various factors to estimate the demands associated with the five planning scenarios that serve as the basis for the Technical Update analyses.

The results of the analyses are projected agricultural diversions and pumping required to meet the full crop requirement for each planning scenario (referred to as agricultural diversion demand). Agricultural diversion demands were incorporated into the water allocation models, which were used to determine how much water is available to meet the demands. Shortages to the agricultural diversion demands in the model are defined as an "agricultural gap".

Current Agricultural Diversion Demand

The approach used to develop the current agricultural diversion demand for the Technical Update varied based on the available data and the type of supplies (groundwater or surface water) used to meet the demand in each basin. The CWCB has developed crop consumptive use datasets using CDSS's StateCU modeling platform for most basins in the state. Two consumptive use datasets have been created for basins with full CDSS development:

> **ONGOING AGRICULTURAL SHORTAGES**
>
> Irrigators in many basins have historically operated under shortage conditions and currently experience a water supply gap in many or most years.

- **Historical Dataset.** This dataset reflects historical conditions and considers historical irrigated acreage, cropping, and climate variability. It also includes estimates of IWR associated with historical agricultural diversion demand using average system efficiency.
- **Baseline Dataset.** This dataset reflects current conditions assuming that variability in climate and hydrologic drivers will be similar to what has occurred in the past. This dataset considers current irrigated acreage and historical climate variability, and includes estimates of IWR associated with current agricultural diversion demand using average system efficiency.

For basins with both historical and baseline datasets, the following approach was used to develop the irrigated acreage, IWR, system efficiencies, and current agricultural demand:

Step	Calculation
1	Extract IWR, reflecting current acreage and crop types, from the most recent Baseline StateCU datasets
2	Develop a representative set of monthly system efficiency values for wet, dry, and average year types for each structure using information from the Historical StateCU datasets
3	Divide the monthly Baseline IWR by either the wet, dry, or average monthly system efficiency values depending on the indicator gage year type to develop the current agricultural diversion demand

The above approach was used for all basins with full CDSS datasets, though some required developing the necessary historical and/or baseline datasets, as summarized below. An additional complication pertained to the use of both surface water and groundwater supplies for irrigation in some basins. In these basins, it was necessary to partition the total agricultural diversion demand into surface diversion demand and groundwater demand. Historical groundwater demands were used to estimate current and future groundwater diversion demand patterns, assuming that the current level of groundwater pumping would likely remain the same or decrease in the future.

The basins for which full CDSS datasets are available include the West Slope basins (Colorado; Yampa/White; Gunnison; San Juan/Dolores) and the North Platte Basin (see Figure 2.2.4). In other basins, the approach was modified, or a different approach was needed based on available datasets and modeling tools. Methodologies are described in detail in Volume 2 of the Technical Update. Methodologies used in basins without full CDSS datasets are briefly summarized below:

- **South Platte and Rio Grande Basins:** Only the historical consumptive use datasets were available from CDSS. Baseline datasets were developed prior to modeling.
- **Republican Basin:** Historical and baseline StateCU models have not been developed in this basin; however, agricultural diversion demand information reflecting groundwater pumping, the source of irrigation in the Republican Basin, was available from the most recent Republican River Compact Administration (RRCA) accounting and model.
- **Arkansas Basin:** Neither historical or baseline StateCU models were available in the Arkansas Basin when the technical analysis began; however, the models are being created as a part of the Arkansas River DSS development project. Historical and baseline StateCU models were developed concurrently with the Technical Update effort and used to estimate agricultural diversion demands.

Projected Agricultural Diversion Demands in the Planning Scenarios

The Technical Update focused on several factors that can be consistently and quantitatively applied to adjust the agricultural diversion demand in each planning scenario. While there are many different factors that can impact the future of agriculture in Colorado (changing climatic conditions, new irrigation technologies, innovative crop hybrids, market fluctuations), the impact of these factors is difficult to quantify or predict with reasonable certainty. The agricultural factors that were quantified in the Technical Update are described as follows.

- **Urbanization.** Urbanization of irrigated agricultural lands will reduce agricultural demands. The approach to evaluating the impact of urbanization relied on mapping current irrigated lands, current municipal boundaries, and basinwide population projections to determine the amount of irrigated acreage that would likely be dried up and urbanized within each basin by 2050. The analysis assumed if mapped irrigated lands fall within or are directly adjacent to mapped municipal boundaries, the irrigated lands will be urbanized by 2050; however, if population projections suggested that no local increase in population will occur in a scenario, then it was assumed that irrigated lands would not be urbanized in those locations in that basin for that scenario.
- **Planned Agricultural Development Projects.** The BIPs developed by each of the basin roundtables described their current agricultural needs as well as each basin's future agricultural goals and approaches to meeting those goals. The North Platte and Yampa basins included a goal to increase agriculture in their basins by putting new lands under production. Irrigated acreage in these basins was projected to increase based on their planned agricultural projects.
- **Groundwater Acreage Sustainability.** A large portion of irrigated acreage in Colorado relies on groundwater supplies, primarily in the South Platte, Republican, Arkansas, and Rio Grande basins. Sustaining these groundwater supplies, both in terms of physical and legal availability, is necessary for preserving groundwater-irrigated acreage. If groundwater levels or augmentation supplies cannot be sustained, irrigated acreage served by groundwater in these basins will likely decrease in the future.
- **Climate.** Factors reflecting increases in IWR due to a potentially warmer and drier future climate were applied in *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*. Background on climate adjustments are provided in Section 2.2.1.

■ POTENTIAL FOR BUY & DRY

In addition to urbanization, irrigated acreage in the South Platte and Arkansas basins is anticipated to decline resulting from permanent agricultural-to-urban water right transfers (widely known as "Buy and Dry"). Meetings were held with stakeholders to estimate these future declines in the five planning scenarios.

- **Emerging Technologies.** Emerging agricultural technologies will play a significant role in future water use. Instrumentation, automation, and telemetry have improved irrigation efficiency and scheduling in many areas of Colorado and will likely continue to improve. Efficiency improvements in delivery and application of water through drip irrigation, more efficient sprinklers, ditch lining, or enclosing open ditches (or additional adoption of these technologies) may reduce water supply shortages and/or reduce the amount of water diverted or pumped. Innovations in crop hybrids have resulted in more drought tolerance while preserving or increasing yields. Two adjustments were made to provide perspective on the potential effect of these emerging technologies in the five planning scenarios:

  » *Sprinkler Development.* The South Platte and Arkansas basins have experienced significant conversion of flood irrigation (less water efficient) practices to center-pivot sprinklers and drip irrigation systems (more water efficient) for the past several decades. Discussions with stakeholders in the basin indicated a continued likelihood of this development to varying degrees in the five planning scenarios.

  » *Technological Innovations.* The *Adaptive Innovation* planning scenario narrative contemplates future technological innovations that mitigate potential climate-change-related increases in irrigation demand and decreases in supply. To implement this narrative in the agricultural diversion demand methodology, the impact of contemplated technological innovations was translated as reductions to IWR and improved water delivery efficiencies.

Agricultural Diversion Demand Calculation Process

In general, the adjustment factors discussed in the previous section impact either the acreage, IWR, or efficiency components of the agricultural diversion demand analyses. The following general approach was used to integrate the planning scenario factors and develop the planning scenario agricultural demand.

STEP	ADJUSTMENT	DETAILS
1	Adjust acreage by the urbanization, planned agricultural projects, and groundwater acreage sustainability factors	Using the current irrigated acreage as a starting point, irrigated acreage was increased or decreased in each basin using the acreage values associated with each factor.
2	Calculate adjusted IWR	Revise the consumptive use datasets developed for the current agricultural diversion demand effort with the adjusted acreage and simulate the models to calculate the adjusted IWR for each planning scenario in each basin.
3	Adjust the IWR by the Climate factor	Multiply the adjusted IWR from Step 2 by the adjustment factors associated with the climate change projection pertaining to each planning scenario.
4	Adjust the system efficiency by the Emerging Technologies factor	Using the historical wet, dry, and average monthly system efficiencies as a starting point, increase the system efficiency of each irrigation ditch by 10 percent. This occurs only in the *Adaptive Innovation* scenario.
5	Develop the agricultural diversion demand for the five planning scenarios	Divide the climate-adjusted IWR from Step 3 by system efficiency values to develop the agricultural diversion demand for each planning scenario.

Assumptions and Limitations

The following assumptions and limitations should be considered when reviewing the agricultural diversion demand methodologies and results:

- **Comparison to Historical Diversions.** The current agricultural diversion demands are not directly comparable to historical diversions, because historical diversions reflect changing irrigation practices, crop types, and acreage, as well as physical and legal water availability shortages.
- **Irrigated Acreage Assessments.** The current agricultural diversion demand analysis relies on the irrigated acreage assessments developed by the CWCB and DWR, generally performed every five years. While the assessments are being continually improved, some acreage delineation inconsistencies and incorrect assignment of water supplies remain.

CROP TYPE CONSIDERATIONS

Note that future crop types were not adjusted in the planning scenarios but could be during the BIP update process if roundtables would like to evaluate changes in diversion demand from different cropping patterns.

- **Recharge Demands.** A small number of irrigation systems in the Rio Grande Basin have decrees allowing preferential use of groundwater supplies while diverting surface water for on-farm aquifer recharge. Although the structures are legally allowed to use either surface or groundwater supplies on their acreage, designating their agricultural diversion demand as a groundwater demand for the Technical Update efforts is consistent with their current irrigation practices.
- **Shoulder Season Irrigation Practices.** The agricultural diversion demand approach relies on IWR and historical system efficiencies from wet, dry, and average year types to capture the variability of irrigation practices across changing hydrologic conditions. Although this approach allows for estimating demands that can vary based on IWR, it may not fully capture the agricultural diversion demand associated with irrigation practices during months when the IWR is very low or zero (e.g., early-season diversions associated with "wetting up" a ditch).
- **Agricultural Diversion Demands.** The agricultural diversion demand is defined as the amount of water that would need to be diverted or pumped to meet the full crop irrigation demand but does not reflect nor consider the common practice of re-diverting irrigation return flows many times within a river basin. As such, it is not appropriate to assume the total demand reflects the amount of native streamflow that would need to be diverted to meet the full crop irrigation demand.
- **Pumping Estimates.** Groundwater withdrawals have been metered and recorded in recent years, but records are generally not available over a long historical period. As a result, it was necessary to estimate groundwater-only and supplemental irrigation (co-mingled) supplies. In basins with CDSS models, pumping was initially estimated based on IWR in the StateCU datasets and then adjusted to account for historical restrictions to pumping. This approach holds supplemental/co-mingled pumping to current levels, which leaves any change of agricultural diversion demand (positive or negative) in the five planning scenarios a change in surface water agricultural diversion demand.
- **Planning Scenario Adjustments.** The five planning scenarios describe plausible futures with characteristics that require several adjustments to agricultural diversion demands; however, some of the agricultural drivers in the scenario narratives were not explicitly represented in the analyses as they could not be defensibly quantified (examples include narrative commentary on food security, crop type, and future agricultural economies). It is difficult to isolate the impact of a specific adjustment because the adjustments tend to compound and overlap within a planning scenario. If water resources planners are interested in the impact of an individual adjustment, they are encouraged to obtain the consumptive use datasets and implement the adjustments in a stepwise fashion, analyzing the results after each adjustment is implemented.

2.2.4 M&I Demands

The M&I demands were prepared on a spatial and temporal scale in ways that could be incorporated into the hydrologic modeling of future demand and supply scenarios. As with SWSI 2010, the methods used in this approach are for general statewide and basinwide planning and are not intended to replace demand projections prepared by local entities or for project-specific purposes.

Where the Technical Update uses M&I demands across five scenarios and a much more robust calculation, SWSI 2010 used a more simplistic approach that is worth explaining for context. In SWSI 2010, municipal/industrial demands were defined as water uses typical of municipal systems (including residential, commercial, light industrial, non-agricultural irrigation, non-revenue water, and firefighting) and a baseline was developed by multiplying the Colorado State Demography Office (SDO) population projections by per-capita rate of use.

Like SWSI 2010, the Technical Update uses population multiplied by per-capita rate of use (in terms of gallons per capita per day or "gpcd") in preparing a range of possibilities that reflect the uncertainties in future municipal demands.

Municipal Demand = (population) x (gallons per capita per day)

Unlike SWSI 2010, the Technical Update provides projected demands in the year 2050 for five future scenarios that each include a different level of conservation and water management that is characteristic of the scenario as defined in the Water Plan. The potential impact from drivers of climate, urban land use, technology, regulations, and social values are incorporated into the municipal demand projections through adjustments to the current gpcd rate of use.

2050 PROJECTIONS

Projected M&I demands reflect anticipated conditions in the year 2050. Demands for time periods between now and 2050 were not estimated. See Section 3 for more explanation.

The Water Plan provides relative rankings of M&I water use in the planning scenario narratives (see Figure 1.1.1 in Section 1.1.2). These rankings influenced the municipal demand projections. The rankings provide direction for how the combinations of M&I drivers affect the future volumetric demands under each scenario. They were interpreted to apply to average annual statewide volumetric demands rather than per capita demands. The rankings heavily influenced, and in some cases constrained, the combinations of drivers and population used in each scenario.

Description of Municipal Demand Methodology

Municipal diversion demands were calculated based on the factors described below.

Population

A unique population and growth pattern projection for the year 2050 was prepared for each planning scenario, as further described in the *Updated Population Projections for Water Plan Scenarios* (see Volume 2) and summarized in Table 2.2.2. The population projections were informed by the planning scenario narratives in the Water Plan.

The SDO forecast was adopted as the "medium" projection in Table 2.2.2. The variances around the SDO forecast assumed for other scenarios were estimated from the historical population growth experience of the state and each of its basins. Three sets of initial projections, with some modifications to the distribution of growth within the state, were then used to develop population forecasts consistent with the five planning scenarios.

Table 2.2.2 2050 Population Projections used for Five Planning Scenarios

	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Population Projection	Medium	Low	Medium, Adjusted	High, Adjusted	High

Only three pieces of information were required to develop probabilistic estimates of the potential range surrounding the "median" population projections produced by the SDO. The information requirements were:

- The compound average annual growth rate implied by the SDO forecast
- The historical standard deviation in population growth rates by decade
- The historical compound average annual growth rate for the area being projected

The following sequence of steps was used to implement the analysis:

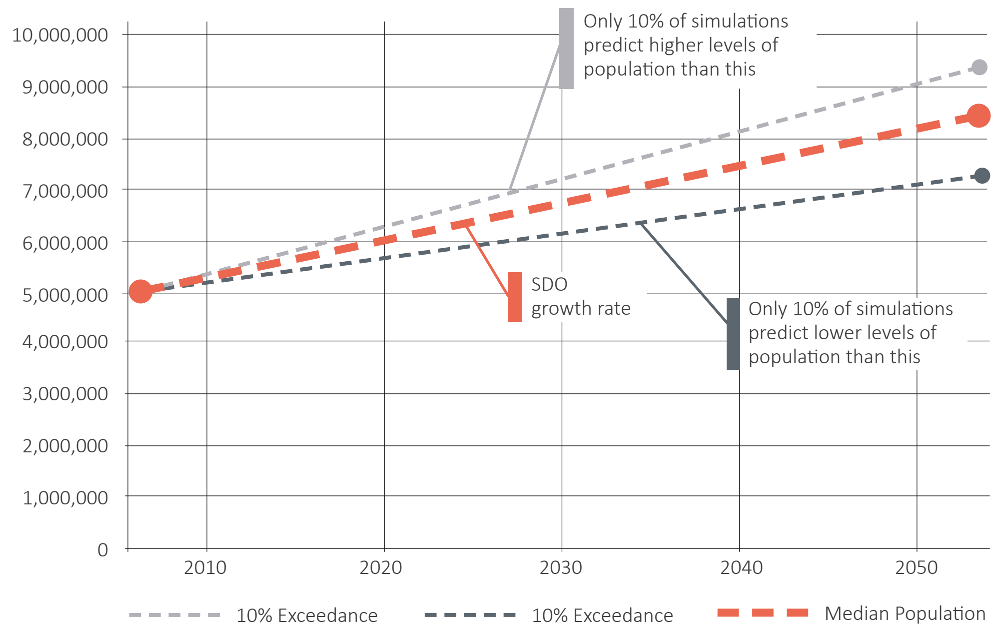
STEP	CALCULATION	DETAILS
1	Calculate median compound average annual growth rate	Calculated for the state and each basin based on the 2017 SDO projections through 2050.
2	Estimate the standard deviation in future growth rates	Based on historical standard deviation and historical and projected compound growth rates.
3	Use Monte Carlo techniques to simulate alternative future populations for each area based on baseline compound average annual growth rate and estimated standard deviation in growth rates by decade	Simulations result in thousands of alternative future populations derived from above for the state and each basin in 2050.
4	Select "High Growth" and "Low Growth" projections	CWCB selected the 10 percent exceedance probability for the "high growth" projections and the 90 percent exceedance probability for the "low growth" projections (see Figure 2.2.3).

Baseline Water Demands

Baseline municipal water demands were prepared by county, on a per-capita and volumetric basis. One of the key objectives for the Technical Update was to maximize the use of new data that were not available for SWSI 2010. The baseline (circa 2015) demands were prepared for each county using the following four data sources:

1. Data reported to the CWCB by water providers pursuant to House Bill 2010-1051[5]
2. Municipal water efficiency plans (WEP)
3. Targeted water provider outreach
4. Basin Implementation Plans

Figure 2.2.3 Projected Population Growth Through 2050



Per Capita Water Demand Projections. 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, regulations, and social values. The potential future impact of these drivers on each of the five water demand categories was evaluated and values were developed that considered the planning scenario descriptions in the Water Plan and with input from the M&I TAG.

The residential indoor demand category was adjusted for each planning scenario to a fixed gpcd value, while percentage adjustments were applied to the other demand categories (positive values created an increase in gpcd and negative values a decrease in gpcd). The adjustment values are shown in Table 2.2.3. The adjusted future indoor and outdoor gpcd rates[6] were used to represent all new population (associated with new construction) and a portion of the existing population reflected by the adoption rates shown in Table 2.2.4 (associated with retrofits); the remainder of the existing population continues at the baseline gpcd rate. The resulting future gpcd rates used in demand modeling, therefore, include the combined effects of active and passive conservation.

Table 2.2.3 Municipal Per Capita Rate Adjustments for Planning Scenarios

Demand Category	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Residential Indoor (gpcd)	42.4	42.4	36.4	33.3	42.4
Non-Residential Indoor	0%	-5%	-10%	-10%	+5%
Outdoor	0%	-5%	-15%	-20%	+5%
Non-Revenue Water	0%	+5%	0%	-5%	0%

Table 2.2.4 Municipal Adoption Rates Applied to Indoor and Outdoor Demand Categories for Planning Scenarios

	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Adoption Rate	50%	40%	60%	70%	60%

Climate

Changes in climate primarily influence outdoor aspects of municipal demands due to impacts on landscape vegetation irrigation water needs. These impacts are typically associated with warmer temperatures that increase evapotranspiration (ET) rates and lengths of growing seasons, which increase the landscape irrigation water demand and consumptive use. For the Technical Update, it was assumed that indoor demands and non-revenue water are not affected by climate changes. ET change factors developed under the CRWAS Phase II (See Section 2.2.1) were used to estimate the impacts of changing climate on future outdoor demands for the Technical Update. These factors were applied to outdoor demands at a county level to represent the average annual change in outdoor demand in the year 2050 due to the climate status.

Municipal Demand Calculation Process

The calculation process for developing current and future municipal demands for the five planning scenarios is summarized below:

STEP	CALCULATION
1	Using water provider population, distributed water and customer water use data, prepare one population-weighted average current gpcd for each county
2	Disaggregate the representative current gpcd value into the appropriate sectoral uses
3	Adjust the current disaggregated gpcd values using the methodologies described in the sections above to prepare future gpcd values for each county under each of the five planning scenarios
4	Apply climate change factors to the 2050 outdoor municipal demand projections in *Cooperative Growth*, *Adaptive Innovation* and *Hot Growth*

Description of Industrial Demand Methodology

The Water Plan provides some narrative guidance regarding effects on self-supplied industrial (industrial) demands under the five planning scenarios, although less specific than for the municipal demands. New and updated information related to current and projected industrial demands is limited. Based on published references and data collected through outreach with the M&I TAG, SWSI 2010 values were updated where possible and appropriate as follows:

- Large Industry: Baseline large-industry demands for facilities represented in SWSI 2010 were updated using either BIP data, recent data from existing hydrologic models, or interpolated values between 2008 and 2035 in SWSI 2010. Technical Update values vary by scenario as shown in Table 2.2.5. Large industry demands in Jefferson County were not varied by scenario.

CLIMATE SHIFTS

Climate change could impact SSI water needs like thermoelectric generation, snow making, etc. Analyzing the potential impacts of climate change on the various sectors of SSI water demands would require a more complex evaluation than could be conducted in this round of Technical Update work but could be considered in future iterations or BIP updates.

- Snowmaking: Baseline demands were updated based on current snowmaking acres for each resort[7] and water use factors from SWSI 2010 and are in line with the linear increase from 2008 through 2050 reported in SWSI 2010. SWSI 2010 projections represent the best available information for *Business as Usual* demands in 2050. As with SWSI 2010, snowmaking demands are not varied by scenario for the Technical Update, in part, due to uncertainty regarding the effects of climate change.
- Thermoelectric: Baseline and *Business as Usual* thermoelectric demands for 10 of the thirteen facilities included were updated using data provided by M&I TAG participants. Baseline and *Business as Usual* demands for one facility were based on information from the Yampa-White-Green BIP. SWSI 2010 values were used to define Baseline and *Business as Usual* demands for the remaining two facilities where no updated information was available. Thermoelectric demands for all facilities were varied by scenario according to the factors in Table 2.2.5.
- Energy Development: Baseline energy development demands were updated using either BIP data or interpolating between 2008 and 2035 values used in SWSI 2010. Demand projections in the Rio Grande Basin were based on information from the BIP and did not vary by scenario. Demands in all other basins were based on low, medium, and high projections from SWSI 2010.

Table 2.2.5 Adjustments to SSI Demands for Each Planning Scenario

SSI Category	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Large Industry	-	-10%	0%	0%	10%
Snowmaking	-	0%	0%	0%	0%
Thermoelectric	-	-5%	10%	-5%	10%
Energy Development	SWSI 2010- Medium	SWSI 2010- Medium	SWSI 2010- Low	SWSI 2010- Low	SWSI 2010- High

Assumptions and Limitations

- The projected demands represent potential demands under conditions described for each scenario; however, they do not necessarily represent the full potential for water management strategies under each scenario (e.g., more aggressive active conservation programs). Basins may continue to develop water conservation efforts as part of existing and future projects that reduce consumption.
- Erroneous or suspect reported non-revenue water loss values were adjusted, using stakeholder input where possible, to provide a reasonable range of planning values for several water providers. An emphasis should continue to be placed on improving this data and understanding the associated real and apparent losses.
- Aside from the climate driver described above, per capita drivers were not modified by basin or county. Drivers were applied using the same values and methodology for each county and are intended to prepare a scenario planning approach that can be further customized at the basin level.
- Planning scenarios do not include acute drought response efforts like imposing restrictions, so comparing to other areas of the country (e.g., Southern California) is not appropriate if their current demands reflect not only aggressive active conservation, but also imposed restrictions.
- Demand projections were prepared using the same adoption rate for indoor and outdoor demands and for residential and non-residential demands. The adoption rate should be further investigated at a local level because it is highly influenced by new construction and active water conservation programs. The adoption rate also encompasses effects from the persistence of demand reductions associated with indoor and outdoor uses.
- The per capita gpcd metric is being used as a projection tool for this statewide planning project, even in areas with a significant influence from non-permanent residents, such as mountain resort communities, and is not applicable as a comparison tool between communities. It is not appropriate to compare a gpcd value from areas that have a significant influence from tourism and non-permanent residents to areas that have a primarily year-round, residential type of population. Specific characteristics about each community need to be understood when interpreting per-capita demand data.
- Urban land use changes have the potential to significantly affect future municipal (primarily outdoor) and agricultural demands. The range of impacts may not be fully reflected in the Technical Update municipal and agricultural demand projections, primarily due to a lack of information available for use in statewide planning projections. Future demand projections may be improved by collecting service area delineations and density information regarding developed and irrigated, landscaped areas under current conditions and anticipated for the future planning year (i.e., 2050).

- The climate factor adjustments described above represent the average annual change in 2050 for the climate represented in each scenario. Outdoor demands will vary annually and monthly, and this type of annual variability is not included in the hydrologic modeling for the Technical Update. This could be incorporated into future technical updates.
- The adjustments assume that amount and type of vegetative cover and irrigation methods and management remain the same in the future as today.
- The methodology assumes that the percentage reduction of current to future outdoor use found from existing programs (20 to 30 percent) remains possible and representative of the potential percentage reductions under scenarios that include climate change; however, some communities are already struggling to support healthy landscapes in response to utility rate increases. Active management will likely be required to maintain healthy landscapes in a hotter and drier future or landscapes may need to change.

2.2.5 Hydrologic Modeling and Analysis

The water supply modeling focused on physical streamflow, water available to meet projected or new demands, and the agricultural and M&I gap under a variety of hydrological conditions. While surface water availability in SWSI 2010[8] represented the amount of unappropriated streamflow that may be developed in the future in basins with available streamflow, it also found that the groundwater supplies were generally declining, and the discussion regarding these supplies focused on sustainability (as opposed to supplies that may be developed in the future). The Technical Update provides more in-depth analyses of current and climate-adjusted hydrology and analyses of water availability to meet future projected agricultural and municipal diversion demands. The analyses, discussed in more detail below, relies primarily on water allocation models to simulate how climate-adjusted hydrology will impact the existing demands, supplies and gaps, and what unappropriated supplies may be available to meet the future projected demands.

Modeling Period

The hydrologic models use 1975 to current-year (models vary in the most recent year of data depending on the basin) as the reference modeling time period, because existing transbasin diversion projects were, in general, fully operational by the mid-1970s. In addition, record keeping and data describing diversions (of all kinds) in years prior to the 1970s are of relatively low quality in some basins. Models simulating the planning scenarios use 1975 to current-year water supplies (in some scenarios, adjusted for climate change impacts), current administrative practices and infrastructure, and projected demands. The 1975 to current-year period of record provides a robust variety of hydrological conditions (i.e., high flow years and extended droughts) over which the planning scenarios can be analyzed.

Methodology to Develop Current Water Supply

Current water supply information consists of physical streamflow and water availability at key locations throughout the modeled basin. The bulk of the analysis of current water supplies relies on models and data developed under the CDSS program. In basins where the CDSS program has not been fully implemented, the methodology for those basins was modified to use available water supply information. The sections below discuss the specific methodologies that were used to evaluate current water supplies for each basin.

CDSS Basin Water Supply

StateMod water allocation models are available for several of the basins through the CDSS program (see Figure 2.2.4). For basins with full CDSS model development, two water allocation datasets were developed:

- Historical Dataset. Historical model datasets allocate water to meet historical agricultural and municipal diversion demands in each basin. They contain historical diversions and pumping that reflect administrative and operational constraints on water supply as they occurred over time. The historical models were calibrated by comparing historical measured diversions, reservoir contents, and streamflow to simulated results. Model adjustments were made until there was adequate correlation between the measured and simulated data. They are an appropriate dataset to assess historical conditions in basins over an extended period of time.
- Baseline Dataset. Baseline model datasets allocate water to meet current agricultural and municipal diversion demands assuming recent historical climatic and hydrologic conditions will continue into the future. Baseline models reflect current administrative, infrastructure, and operational conditions overlaid on the hydrology of the entire study period. For example, the model could include the operation of an existing reservoir constructed in 1985, but it would be simulated using hydrology reflective of 1975 to 2013 conditions. Baseline datasets and models are appropriate to use for "what if" planning scenarios.

For basins with both historical and baseline datasets, the following approach was used to develop the current water supply information:

Step	Procedure
1	Incorporate current agricultural diversion demands into the Baseline models.
2	Incorporate current M&I diversion demands.
3	Simulate the models.
4	Extract the monthly physical streamflow and water availability at key locations in each basin.
5	Summarize the agricultural gap and crop demand gap by Water District and by basin for on average and for critically dry years. No M&I gaps occur under current conditions.
6	Summarize total storage by water district and by basin over the modeled period.

Non-CDSS Basin Water Supply

As shown in Figure 2.2.4, StateMod water allocation models have not yet been developed for the Arkansas, Republican, Rio Grande, and Cache La Poudre/Laramie basins. As these regions are generally water supply limited, a water allocation model may not be necessary to understand future water availability in the basin. Historical data can be used to estimate current water supplies in the basin at a level sufficient for the Technical Update planning effort. Current water supply information in these basins was developed primarily using historical data:

- Current physical streamflow was based on historical data from key streamflow gages.
- Current water availability was set to zero.
- Current agricultural gap was based on historical consumptive use analyses and estimated as the difference between the current agricultural diversion demand and the historical pumping (in the Republican Basin) or the historical diversions and pumping (in the Arkansas and Rio Grande basins) on average and for critically dry years.
- Current M&I gap was set to zero, assuming the M&I demands are fully satisfied under current conditions.

Although the methodologies for estimating current water supplies in each of these basins differs from the basins with CDSS models and datasets, they provide appropriate estimates of physical streamflow, water availability, and gaps for current conditions for comparison to the five planning scenario results.

Figure 2.2.4 CDSS and Basin Modeling Map

Methodology to Develop Planning Scenario Water Supply

The planning scenario water supplies were estimated using an approach similar to that used to estimate the current water supplies. For planning scenario water supplies, agricultural and municipal diversion demands reflective of 2050 conditions specific to each of the five planning scenarios were used as was, in some scenarios, climate-adjusted hydrology. Once the planning scenario datasets were developed, results were compared to the current water supply to assess the impact of the projected demands and hydrology.

CDSS Basin Methodologies

The baseline StateMod datasets developed for the current water supply analysis served as the starting point for the planning scenario datasets. The following steps were taken to develop the planning scenario StateMod datasets and ultimately the water supply information:

Step	Procedure
1	Incorporate the appropriate planning scenario agricultural diversion demands into the planning scenario models.
2	Incorporate the appropriate planning scenario M&I diversion demands into the planning scenario models.
3	Incorporate the appropriate climate-adjusted natural flow into *Cooperative Growth*, *Adaptive Innovation*, and *Hot Growth*. Note that *Business as Usual* and *Weak Economy* reflect current (or recent historical) hydrology.
4	Run the planning scenario models.
5	Extract the monthly physical streamflow and water availability at key locations in each basin.
6	Summarize the M&I gap by water district and by basin on average and for very dry years.
7	Summarize the agricultural gap and crop demand gap by water district and by basin on average and for very dry years.
8	Summarize total storage by water district and by basin over the modeled period.
9	Estimate the amount of water available from changed irrigation water rights associated with land undergoing urbanization
10	Estimate the transbasin import reductions due to changes in physical or legally available supply in the exporting basin.

The planning scenario StateMod datasets incorporate the projected hydrology and demands with the baseline representation of the basins' infrastructure and operations. Adjustments to other modeling parameters, such as order of supplies used to meet municipal diversion demands or alternative methods for conveying water, were not made in the planning scenario datasets under this effort. In addition, the models utilize existing infrastructure to the full operational potential, and no adjustments were made to limit those operations. For example, in planning scenarios that contemplate lower water supplies, simulated reservoir storage may be drawn down to lower levels and on a more frequent basis than has occurred historically. While reservoirs are being simulated within their existing operational constraints in the models, it is possible that water providers would obtain additional storage or other water rights in a drier future rather than consistently operating existing facilities at low levels.

Non-CDSS Basin Methodologies

The absence of basinwide planning models in some basins limited the options to evaluate the projected demands and hydrology. As a result, the existing analysis tools are not conducive to implementing the "what-if" planning scenario conditions; however, they do provide information on the basin operations which were used in developing the planning scenario water supply information. Various qualitative and quantitative methods were used to develop the planning scenario water supply information in these basins as described:

- **Republican Basin.** For the Republican Basin, the current level of appropriated groundwater supplies serves as the maximum available water supply in the basin into the future and assumes that no unappropriated surface or groundwater supplies will be available. Projected water supplies in the Republican Basin were estimated as follows:
  - » Current irrigation practices, in which irrigators pump less than the full amount needed by the crops, was assumed to continue into the future based on discussions with stakeholders in the basin. The current agricultural gap percentage was used to estimate the planning scenario gaps, and associated crop demand gaps, on average and for critically dry years.
  - » Planning scenario water availability was set to zero.

FREE RIVER

Some water users (primarily agriculture) have historically supplemented their water rights with additional diversions under free river conditions. The modeling assumes this will continue. As a result, available free river is first allocated to agriculture and then to other water rights. Basin roundtables could propose future projects to allocate available free river to meet M&I needs.

- Any projected planning scenario M&I demand greater than current M&I demand was assumed to be a gap due to lack of future water availability. Planning scenario M&I gaps were estimated as the difference between the planning scenario M&I demand and the current M&I demand on average and for very dry years.

- **Arkansas and Rio Grande Basins.** The *Business as Usual* and *Weak Economy* scenarios do not include climate-adjusted hydrology or demands, therefore the anticipated changes in these scenarios result from changes in M&I demands and irrigated acreage, respectively. The approach to develop water supply information in these basins included the following assumptions:
  - Water availability was set to zero.
  - Historical agricultural shortages are expected to continue into the future, exacerbated by reduced supplies under climate-adjusted hydrology.
  - Current pumping levels serve as the maximum groundwater supply available to meet projected demands.
  - Any groundwater supplies associated with the removal of irrigated acreage due to groundwater sustainability adjustments remain in the aquifers and are not available to offset gaps experienced by other demands in the basin.
  - Any projected planning scenario M&I demand greater than current M&I demand was assumed to be a gap, due to lack of future water availability.[9]

  In general, the current agricultural gap was used as the basis for the planning scenario agricultural gap, and further reductions in supplies due to climate-adjusted hydrology were applied to gaps. In each planning scenario, the average reduction in streamflow at indicator gages throughout the basin was used to increase the agricultural gap in *Cooperative Growth, Adaptive Innovation*, and *Hot Growth*. The M&I gap was based on the difference between the current M&I demand and the planning scenario M&I demand, assuming no additional supplies are available to meet the increased demand. Simulated streamflow under the planning scenarios with climate-adjusted hydrology was not available; however, the change in runoff (i.e., natural flow), both magnitude and timing, between current conditions and climate-adjusted conditions is provided to reflect the general impact of these projected hydrology adjustments.

- **Cache la Poudre and Laramie Basins.** Although these basins do not have the full suite of CDSS modeling tools available, model results from neighboring sub-basins with similar levels of irrigated acreage, M&I demands, storage, and transbasin supplies were used to inform and adjust the results in these basins. The planning scenario agricultural gaps in these basins were based on the current agricultural gap and then adjusted based on the gap results from neighboring sub-basins in each planning scenario. The planning scenario M&I gap in these basins was assumed to be similar to M&I gaps experienced in neighboring sub-basins, particularly in sub-basins where municipal supplies are generally similar and consist of sources like Colorado-Big Thompson supplies, changed water rights, and storage. The outflow from the Cache La Poudre River to the South Platte River was based on historical streamflow for *Business as Usual* and *Weak Economy* and adjusted with the hydrology factors in planning scenarios with climate-adjusted hydrology. The planning scenario water supply information from the Cache La Poudre and Laramie basins was then incorporated into the overall South Platte and North Platte Basin results, respectively.

Assumptions and Limitations

- Basinwide Planning Model: A primary objective of CDSS is to develop water allocation models that can be used to evaluate potential future planning issues or management alternatives based on Colorado water law at a regional level. The level of detail regarding representation of hydrology, operations, and demands in the model is appropriate for the Technical Update efforts. The models operate on a monthly time-step and, therefore, do not capture daily changes in streamflow, routing of reservoir releases, or daily accretions or depletions to the river system. One hundred percent of the consumptive use demands are represented in the model, and many are represented with their individual water rights and operations. Smaller streams are not individually represented in the model; rather the demands and contributing inflow from those tributaries are grouped and represented on larger tributaries in the model. Information used in the modeling datasets is based on available data collected and developed through CDSS, including information recorded by the State Engineer's Office. The model datasets and results are intended for basinwide planning purposes.
- Model Calibration: Each water allocation model undergoes calibration, in which the model developer adjusts model inputs to achieve better agreement between the simulated and measured streamflow, diversions, and reservoir contents. The model builds on historical water supply information, and if information is missing, errant, or there are data inconsistencies, the model cannot be well calibrated and cannot accurately predict future conditions. The models are only as good as the input.
- Representation of Water Supplies and Operations: The baseline models reflect one representation of waer users' operations associated with their current infrastructure. The representation in the model is intended to capture their typical operations; however, they are simplified and do not reflect the full suite of operations generally available to larger water providers. This representation may not capture operational adjustments or agreements implemented during drought conditions, or the maximum operational flexibility of using water supplies from multiple sources. In addition, the model allocates water according to prior appropriation, and non-decreed "gentlemen's agreements" are generally not represented in the models.

- Groundwater Pumping Levels/ Transbasin Diversions: The models reflect current levels of groundwater pumping and transbasin diversions. Noting that administration of groundwater pumping shifted due to the mid-2000s drought, post-drought groundwater pumping levels were used in the baseline and planning scenario models. Similarly, the historical transbasin diversions were used in the baseline and planning scenario models. Transbasin diversions are based on many factors, including water availability and storage in both the source and destination basins, demands, other water supplies available to the water provider, and other operational considerations like water quality. Projecting how these factors may change under the 2050 planning scenarios was beyond the Technical Update scope; therefore, transbasin diversions were set to historical levels.
- Interstate Compacts. The Technical Update modeling only takes into account Compact administration where a Compact is currently being actively administered. It does not account for or make assumptions relating to how potential future administration could occur where a Compact is not currently being administered.
- Solutions/Projects: The Technical Update is intended to develop water supply and gap information that can be used by basin roundtables for future planning efforts, including the development of potential solutions to mitigate gaps. The models can be used to evaluate the effectiveness of a future solution, though future projects and/or solutions are not currently included in the models.
- Urbanization: As agricultural lands are urbanized, the irrigation supplies on those lands could potentially be transferred to other uses, such as municipal or industrial; however, the transfer of these supplies is subject to a variety of unknowns such as seniority, type of water supply, location of supply relative to the demand, and willingness to change the use of water through water court. Potentially available supplies from urbanized agricultural lands were quantified after gap calculations were conducted and are not considered in the gap; however, the supply potentially available from these lands is described in each basin (see Section 4) and can be applied to gaps at the discretion of basin roundtables in their BIP updates.

2.2.6 Environment and Recreation

The methodologies described in this section informed the development of tools to help basin roundtables update their BIPs and evaluate and prioritize future environment and recreation projects.

NONCONSUMPTIVE USES

In prior SWSIs, the term "nonconsumptive" referred to "environment and recreation" data sets and analyses. For the purposes of the Technical Update these two terms can be viewed as interchangeable; however, the phrase "environment and recreation" (or E&R) will be used moving forward.

Background on E&R Database and Enhancements for Technical Update

Beginning with the original SWSI phases and continuing through and beyond the SWSI 2010 process, the basin roundtables first identified E&R needs, then developed and refined mapping and evaluation tools, and subsequently identified projects to address those needs. The evolution of addressing E&R issues in the state is described in the graphic below. The Technical Update advances the development of tools that can be utilized by the basin roundtables in identifying E&R needs and providing support for E&R projects and methods.

SWSI I & II	SWSI 2010	Post-SWSI 2010
Developed E&R mapping tools.	BRTs used E&R mapping tools to develop maps for each basin showing E&R focus areas. BRTs identified projects and methods to meet E&R needs and developed maps showing: location of projects/methods, status of projects/methods, E&R focus areas that have projects/methods completed or in progress.	Developed nonconsumptive needs assessment database (NCNAdb), which contains nonconsumptive attributes, projects and associated protections.

Technical Update Enhancements for E&R Database

The Technical Update focused on enhancing the Nonconsumptive Needs Assessment database (NCNAdb, now referred to as the E&Rdb). The E&Rdb was updated and will allow the CWCB and basin roundtables to better leverage E&R data, streamline data entry and reporting, and promote collaboration based upon common, consistent and reliable technology and processes. Building on the technical foundation of the existing NCNAdb, several improvements were implemented that serve to accomplish the goals described in Table 2.2.6.

Table 2.2.6 Enhancement Goals and Actions for the E&Rdb

Overall Goal	Action and Results
Enhanced Technical Foundation	Data loading processes are consistent and streamlined to add efficiency and improve data quality.
	Implement the Source Water Route Framework as a common spatial unit to provide statewide consistency.
Engaging and Meaningful User Experience	Develop Excel-based templates for data entry to improve uniformity of data and add efficiency.
	Develop standard reports to enhance consistency of data retrieval.
	Provide mapping data on the CDSS MapViewer to increase ease of use and enable visualization of database content.
	Develop a user manual and identify potential improvements through user feedback.
Integration into Colorado Water Planning Process	Improve database content and expand to include project identification, project descriptions, dates, etc. making it more useful and meaningful for planning purposes.

Updating the spatial unit of analysis was an important aspect of enhancing the technical foundation of the E&Rdb. The update occurred because of the retirement of the USGS stream segment-based spatial unit called the common ID (COMID), which had been used in the NCNAdb. The Source Water Route Framework (SWRF), a Colorado-specific spatial dataset, was included as a spatial unit of analysis for the updated E&Rdb. The updated E&Rdb also relies on the USGS's National Hydrography Dataset (NHD). Data in the database can be queried by hydrologic unit code (HUC) and/or stream segment.

Improvements were also made to the data in the E&Rdb. The prior NCNAdb included more than 100 E&R attributes compiled through stakeholder outreach in each basin. The original attributes were reviewed and quality checked to identify repetitive or unreliable data sources and datasets. Closely related attributes that provided repetitive or overlapping data were consolidated into a single attribute. Additionally, previous attributes that did not have public data sources or datasets available to confirm spatial data were archived and not included in the updated attribute list. Several attributes were also renamed to better reflect the dataset and simplify database development. The final 58 attributes were grouped into several "macro" categories that help increase organization of the E&Rdb and provide a foundational set of attributes for the E&R Flow Tool (described below).

Background on Flow Tool and Enhancements for Technical Update

In addition to the updated E&Rdb, the Technical Update includes an E&R Flow Tool (Flow Tool) designed to assess flow conditions and associated ecological health at selected nodes in each basin. The Flow Tool will serve as a resource to help basin roundtables refine, categorize, and prioritize their current portfolio of E&R projects and methods and to better understand risks to ecological attributes based on possible future flow conditions under each planning scenario.

Prior to the Technical Update, the CWCB funded the development and testing of a tool known as the Watershed Flow Evaluation Tool (WFET). To date, the WFET has been applied in the Colorado and Yampa-White-Green basins. The WFET offers an approach to conducting a watershed-scale, science-based assessment of flow-related ecological risk throughout a basin, particularly when site-specific studies are sparse.

Also prior to the Technical Update, the Historical Streamflow Analysis Tool (HSAT) was developed and made available for use in the first round of BIPs and emphasized the evaluation of hydrologic variability at gage locations across Colorado. The user interface includes a simple dropdown menu and the output included automatically generated tables and plots. Many of the basic flow summaries included in the HSAT were carried forward into the Flow Tool.

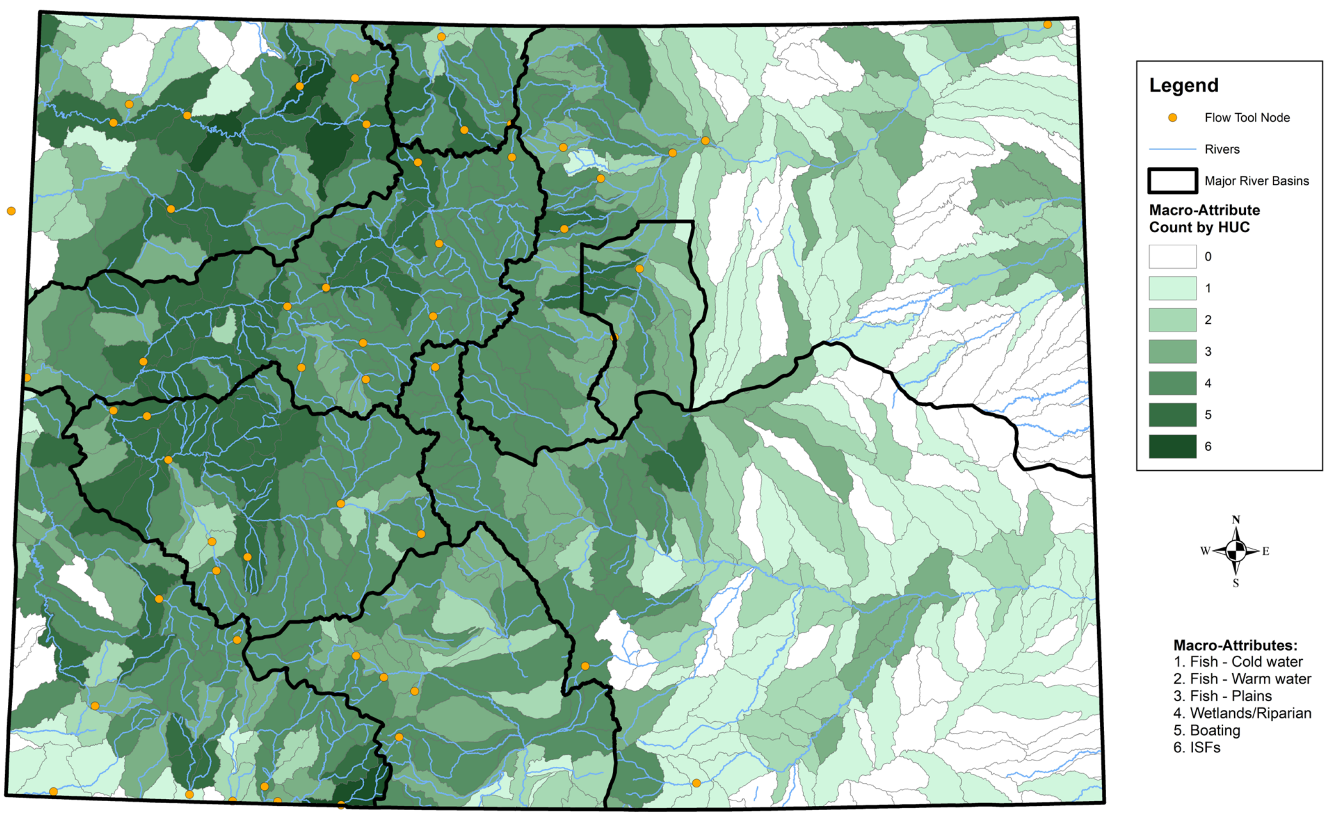
Methodology Description

The Flow Tool is built on a legacy of stakeholder involvement and was created through a methodology that was developed collaboratively with the E&R TAG and builds on the previous E&R tools described above. The Flow Tool was designed to incorporate and compare modeling output from the five planning scenarios against baseline (existing) and naturalized (unimpaired) flow condition scenarios. Key outputs include a comparison of monthly flow regimes relative to ecological-flow indicators, building off the WFET.

The Flow Tool uses monthly streamflow output from CDSS water allocation models. The Excel-based tool was designed to incorporate and compare modeling output from the five planning scenarios against historical gage data and the baseline/current conditions scenario. Key outputs include a comparison of monthly flow regimes relative to ecological-flow indicators.

The Flow Tool analyzes and produces data for 54 pre-selected model nodes corresponding to stream gages (see Figure 2.2.5). The nodes included in the Flow Tool were selected for inclusion based on a number of factors. Gages were reviewed to determine available attribute data (where key E&R attributes were located and concentrated within a basin [darker shaded HUCs in Figure 2.2.5]), to consider spatial coverage across basins, and to assess data availability.

Figure 2.2.5 Nodes in Flow Tool



The Flow Tool estimates the response of E&R attributes in rivers under various hydrologic scenarios. The flow-ecology relationships in the Flow Tool were first developed as part of the WFET and were patterned after similar relationships that have been developed across the globe to inform water management. Flow-ecology quantifies the relationship between specific flow statistics (e.g., average magnitude of peak flow, the ratio of flow in August and September to mean annual flow) and the risk status (low to very high) for E&R attributes under the flow scenario being analyzed. Data-derived relationships have been developed for riparian/wetland plants (cottonwoods), coldwater fish (trout), warmwater fish (bluehead sucker, flannelmouth sucker, and roundtail chub), and Plains fish. Other metrics were developed with basic, well-established relationships between hydrology and stream ecology. Relationships for recreational boating were developed with stakeholders during WFET development.

The Flow Tool compares historical gage records to current-conditions-modeling-output and planning-scenario-modeling-output. The comparison provides insights on where and how much monthly flow regimes are expected to change relative to ecological flow indicators related to macro-attribute categories discussed above. This comparison also highlights areas where future E&R projects and protections could be beneficial. Basin roundtables will then be able to apply their own analysis (and preferences) to determine the best way to meet these E&R needs.

Flow Tool Limitations

While the Flow Tool is intended to provide data for use in planning E&R projects and methods, it should be noted that it is not prescriptive. Tool output is currently limited to monthly timesteps, and does not designate gap values nor provide basis for any regulatory actions. The Flow Tool does not identify areas where ecological change may be associated with factors other than streamflow, nor detail results as accurately as a site-specific analysis. The tool does not evaluate potential shifts in flooding magnitude and frequency that could result from climate change.