# DIVERSIFYING COLORADO'S WATER PORTFOLIO:

## The Potential for Stormwater Capture and Use to Contribute to a Water Resilient Future




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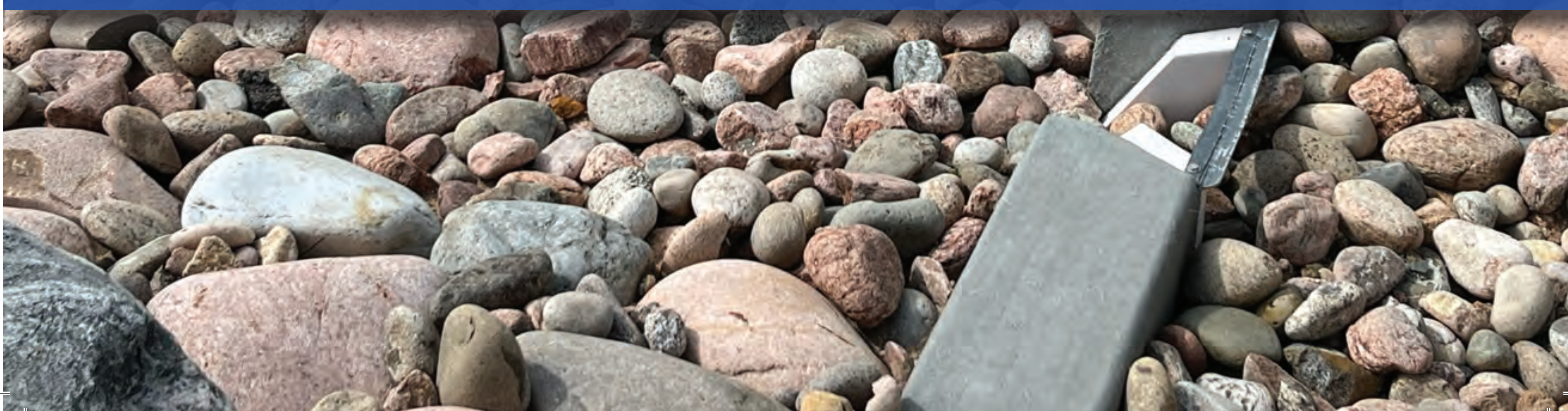

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## About the Pacific Institute

Founded in 1987, the Pacific Institute is a global water think tank that combines science-based thought leadership with active outreach to influence local, national, and international efforts in developing sustainable water policies. From working with Fortune 500 companies to frontline communities, our mission is to create and advance solutions to the world's most pressing water challenges. Since 2009, the Pacific Institute has also acted as co-secretariat for the CEO Water Mandate, a global commitment platform that mobilizes a critical mass of business leaders to address global water challenges through corporate water stewardship. For more information, visit pacinst.org.

## About Wright Water Engineers, Inc.

Founded in 1961, Wright Water Engineers is an employee-owned and operated, full-service water resources, environmental, and civil engineering firm based in Denver, Colorado, with outlying offices in Glenwood Springs and Durango. WWE's staff of approximately 50 people including professional engineers, hydrologists, scientists, biologists, chemists, geologists, and hydrogeologists. Areas of service include stormwater and drainage engineering, water rights, water conservation, watershed management, wildfire hydrology, water and wastewater system planning and design, wetlands, and water supply.

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One Water Econ is a small woman-owned consulting firm known for innovation and leadership within the water sector. We bring economic and policy expertise to help solve complex water sector challenges. One Water Econ's clients include water utilities, government agencies, research foundations, and nonprofit organizations. We routinely partner with engineers, scientists, and other multidisciplinary team members to provide a holistic approach to water resource management. Our primary services include benefit cost, triple bottom line, and economic impact analysis; ecosystem service valuation; market-based solutions for water resource management; affordability assessments; and analysis of water use and demand across sectors.

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## ABBREVIATIONS & ACRONYMS

| | |
|---|---|
| Acre-Feet | AF |
| Acre-Feet per Year | AF/YR |
| Basin Implementation Plan | BIP |
| Best Management Practices | BMPs |
| Business as Usual | BAU |
| Colorado Department of Public Health and Environment | CDPHE |
| Colorado Division of Water Resources | CDWR |
| Colorado State University | CSU |
| Colorado Water Conservation Board | CWCB |
| Evapotranspiration | ET |
| Expert Review Panel | ERP |
| Gallons | gal |
| Green Infrastructure | GI |
| Greenhouse Gasses | GHGs |
| Green Stormwater Infrastructure | GSI |
| Historic Natural Depletions | HNDs |
| Impervious Area | IA |
| International Fire Code | IFC |
| Low Impact Development | LID |
| Million Gallons | MG |
| Millions of Gallons per Year | MG/YR |
| Municipal and Industrial | M&I |
| Municipal Separate Storm Sewer System | MS4 |
| Natural Resources Conservation Service | NRCS |
| Rainwater Harvesting | RWH |
| Stormwater Management Model | SWMM |
| Stormwater Control Measures | SCM |
| Substitute Water Supply Plan | SWSP |
| Total Maximum Daily Load | TMDL |
| US Dollars | USD |
| Water Quality Capture Volume | WQCV |
| Water Reuse Action Plan | WRAP |
| The Water Research Foundation | WRF |

## Executive Summary

The 2023 Colorado Water Plan estimates that by 2050 there will be a municipal and industrial water supply gap of between 250,000 and 750,000 acre-feet per year (CWCB 2023). *Diversifying Colorado's Water Portfolio: The Potential for Stormwater Capture and Use to Contribute to a Water Resilient Future* seeks to advance understanding of the extent to which rainwater harvesting and stormwater capture in urban areas can fill this gap.

This project achieves this goal by 1) synthesizing Colorado water law as they relate to rainwater harvesting and stormwater capture and use, 2) quantifying the volumetric potential of rainwater harvesting and stormwater capture in urban areas across each of Colorado's eight river basins and the Denver metropolitan area, 3) identifying benefits associated with stormwater capture and use, 4) highlighting examples of urban stormwater capture and use projects in Colorado, 5) engaging and facilitating input from a diverse Expert Review Panel, and 6) preparing recommendations and suggesting next steps.

## Key Findings

The project clarifies perennial questions about the role and potential of rainwater harvesting and stormwater capture and use to meet Colorado's water supply gap. For the first time, there is a baseline estimate of the volumetric and economic value for urban rainwater harvesting and stormwater capture and use in Colorado. This project answers questions about the scenarios in which rainwater harvesting and stormwater capture and use is currently allowed as well as the scales at which it may be most beneficial.

These findings are the result of extensive research, analysis, and collaboration with experts from Colorado and throughout the United States who served on the project's Expert Review Panel. The methodology used to calculate the volumetric potential of urban rainwater harvesting and stormwater capture and use was rigorously vetted and factors such as seasonality, elevation, and storm sequencing events informed these estimates.

As noted below in the findings, urban rainwater harvesting and stormwater capture and use are limited within Colorado's current legal (water rights) and regulatory frameworks. To highlight examples of how stormwater capture and use can be implemented within the existing water rights framework, the full report includes several case studies from Colorado, including the CSU Spur Campus where rainwater and stormwater runoff are captured and used on-site (ES Photo 1).

ES Photo 1 Cistern at the CSU Spur Campus.
*Source*: Jane Clary

The key findings from this project include:

**Colorado Water Law Surrounding Rainwater Harvesting and Stormwater Capture and Use**

- Residential-scale rainwater harvesting (e.g., 110-gallon storage capacity) is allowed without a decreed water right. This regulation is consistent with Colorado water law that is based on the Prior Appropriation Doctrine and protects downstream water users from injury to their decreed water rights.

- Obtaining a water right for rainwater harvesting or stormwater capture and use beyond 110 gallons at a residential household in Colorado requires significant upfront legal and engineering costs on a project-specific basis, typically requiring an augmentation plan, purchase of replacement water for augmentation from a willing water provider, and ongoing engineering and legal costs for water rights accounting and filings with the State Engineer's Office.

- Only one rainwater harvesting pilot project has been applied for and approved in Colorado since legislation was passed in 2009. Deterrents for applying for pilot projects may include significant engineering and legal costs, intensive hydrologic monitoring requirements, dual infrastructure cost (to meet stormwater management requirements separately), and uncertainty about the likelihood of long-term success of a project as a reliable water supply.

- The concepts of Historic Natural Depletions and Regional Factors accepted for Colorado Water Conservation Board pilot projects open the door to broader rainwater harvesting and stormwater capture and use projects for new developments in Colorado. Nonetheless, the current legal, scientific, and engineering burden, along with uncertainty regarding success in water court, likely deter new developments from pursuing rainwater harvesting or stormwater capture and use beyond two 55-gallon rain barrels, unless no other water source is available, or a research/conservation objective motivates a pilot project. From a policy and water court process perspective, increased clarity on the likelihood of success in water court and minimum data requirements for success would be a helpful next step if broader implementation of stormwater capture and use projects is desired in Colorado.

- Stormwater management is allowed (and required) in Colorado for both flood control and stormwater quality purposes. This "stormwater management" is allowed outside of the concepts of rainwater harvesting and stormwater capture and use because the stormwater that is detained or infiltrated is not allowed to be put to a beneficial use

**Volumetric Potential of Rainwater Harvesting and Stormwater Capture and Use in Colorado**

Based on analysis of several rainwater harvesting and stormwater capture and use scenarios, we find:

- For rainwater harvesting implemented at currently allowed 1–4-unit residential households in two 55-gallon rain barrels, and for a hypothetical rainwater harvesting scenario in 500-gallon cisterns at the same households, the potentially captured stormwater volumes by basin represent a small source of water for closing basin demand gaps. The volume of water from these two scenarios is generally on the order of less than 1% of residential outdoor water demand from 2015. This proportion may change, and improve, as outdoor landscapes become more sustainable and irrigation demand is reduced. Nonetheless, there are other potential benefits of rainwater harvesting at this scale that could make pursuing this strategy a beneficial endeavor.

- Stormwater runoff from existing impervious surfaces (e.g., rooftops, roads, parking lots) in Colorado's urban areas represents a substantial water source. However, this water that returns to streams through surface runoff or alluvial groundwater is not considered a "new water" source in over-appropriated basins because this water has essentially already been claimed for use under existing water rights filed in water court. Although there are some exceptions to this general statement, claiming the right to use this runoff would require site-specific water rights analysis, a plan for augmentation of out-of-priority depletions, and water court processes, or changes to existing water law. Nonetheless, these estimates suggest that larger scale stormwater capture could provide runoff volumes that could be used to meet a meaningful portion of outdoor residential water demand. Legal, economic, environmental, public health, and other site-specific constraints would need to be evaluated before pursuing stormwater capture and use at specific locations across the state.

- Based on hydrologic analysis completed as part of the Sterling Ranch pilot project, the concepts of Historic Natural Depletions and Regional Factors (Gilliom 2019) provide a framework for larger scale implementation of stormwater capture and use for new greenfield developments (e.g., neighborhood-scale). If these methods are adopted beyond the pilot project framework, there is potential for a new development to claim the right to capture and use a portion of the runoff from new impervious surfaces. For example, in the South Platte Basin, applying Regional Factors to hypothetical 10% and 25% increases in impervious area and using 10% to 25% capture rates for impervious area, the volumetric potential for urban stormwater runoff to serve as a "new water" source would be on the order of 3,100 to 19,600 AFY. More refined land development projections and Regional Factors in other river basins would be needed to improve this estimate or broaden it for use in other basins.

**Valuing Rainwater Harvesting and Stormwater Capture and Use in Colorado**

This assessment of the economic value of rainwater harvesting and stormwater capture and use in Colorado focused on the avoided costs of providing potable water for outdoor landscape uses, the value of the water quality improvements associated with rainwater and stormwater capture, and the value of other associated benefits, such as reduced risk of property loss due to wildfire. Overall, the value of these benefits is constrained by the limited capture volumes permitted under current Colorado law that effectively restricts rainwater harvesting to residential properties with two 55-gallon rain barrels. Larger scale applications of stormwater would be required for economic viability along with water rights. Specific findings in the preceding section can be summarized as follows:

- In several regions of the United States (and internationally) rainwater harvesting and stormwater capture and use practices have demonstrated their ability to provide sufficient water to meet residential outdoor water demands, offsetting the need for water providers to provide potable water for this purpose. In some studies, these potable water offsets are significant.

- Although rainwater harvesting and stormwater capture and use have the potential to provide alternative or complementary sources of water supply in Colorado's urbanized areas, the 110-gallon residential capture volume currently allowed without water rights is insufficient to meaningfully contribute to overall water system resilience.

- When implemented at scale, rainwater harvesting has the potential to make more meaningful contributions to the overall water supply portfolio and conservation targets in some basins. This is particularly true for scenarios envisioning the possible offsets created by widespread adoption of 500-gallon or larger cisterns, which would require water rights under current water law.

- Captured rainwater can offset costs to residential water customers as well as retail water providers. Water providers can avoid energy, treatment, and infrastructure costs associated with delivering potable water for residential landscape irrigation. Legal limitations on stormwater capture and use in Colorado create unfavorable conditions for realizing these avoided cost benefits.

- As exemplified for the scenario examining the capture of runoff from 10% of impervious surfaces, neighborhood-, community-, or regional-scale stormwater capture can contribute to water supply reliability by creating additive or marginal sources of supply, creating flexibility and redundancy within the supply system. The analysis shows that allowing for greater capture volumes could meaningfully reduce the water supply gaps projected by several of the Basin Plans and associated economic impacts. However, larger scale infrastructure and storage would be needed to realize this potential.

- The rainwater harvesting practices reviewed in this report (i.e., the 110- and 500-gallon storage volumes) may have limited practical potential to reduce water quality impairments in Colorado's urbanized areas. Implementation challenges (e.g., reliance on homeowners to maintain practices) and relatively low capture volumes may prevent this benefit from being fully realized.

- Available evidence suggests that larger scale stormwater capture and use adoption will have greater benefits (relative to costs). As demonstrated by Sterling Ranch and other projects, capture in larger volume systems either at the site- or neighborhood-scale can provide sufficient volumes to meaningfully offset potable water demand, reduce water quality impacts, and potentially provide additional, high-value benefits.

## Key Recommendations

To optimize the opportunity for urban rainwater harvesting and stormwater capture and use to contribute to the diversifying of Colorado's water portfolio, we offer a suite of 16 recommendations which fall into the following thematic areas:

- Build on existing legal pathways to allow stormwater and rainwater to meaningfully contribute to and diversify water portfolios.
- Provide guidance to land use planners and housing developers on how to include stormwater and rainwater as alternative water supplies to offset potable water use.
- Create the enabling conditions to advance stormwater capture and use and rainwater harvesting as strategies to contribute to more water-resilient communities.
- Conduct a more detailed assessment of the co-benefits of stormwater capture and use to identify targeted areas for implementation and potential co-funding partnerships.

Recommendations seek to advance the enabling conditions under which urban rainwater harvesting and stormwater capture and use will be able to meaningfully address Colorado's estimated municipal and industrial water gap, ultimately contributing to a more water resilient future for all those that live, work, and recreate in the Centennial State.

# 1 Introduction

The Colorado Water Conservation Board (CWCB) developed the Colorado Water Plan to guide state policy regarding optimal conservation and development of Colorado's water resources. The plan recognizes challenges such as climate change, increasing water demands, and the need for water conservation and increased storage, and encourages forward-thinking, sustainable, and resilient solutions to these challenges (CWCB 2023). The plan also recognizes the importance of a "One Water" ethic, defined by The Water Research Foundation (WRF) as "an integrated planning and implementation approach to managing finite water resources for long-term resilience and reliability, meeting both community and ecosystem needs."

Across the United States, One Water management approaches are used to stretch and optimize limited water supplies. These can include conservation, efficiency, and different forms of reuse, such as recycling wastewater or industrial process water, using graywater, or harvesting rainwater. In Colorado, rainwater harvesting and stormwater capture and use have not been a focus for a variety of reasons, including uncertainties related to water rights, the extent to which harvested rainwater represents a "new'' water supply, and the volumetric potential and economic viability of rainwater harvesting. To address some of these questions, the CWCB funded this project, *Diversifying Colorado's Water Portfolio: The Potential for Stormwater Capture and Use to Contribute to a Water Resilient Future*. Project objectives include:

1. Quantifying the volumetric potential of urban stormwater capture and use in each of Colorado's eight river basins and the Denver metropolitan area. This volumetric potential is explored in the context of Colorado water rights law, including statutes, rules, and court decrees (hereinafter, referred to as water rights), including currently allowable residential rainwater harvesting and other, larger-scale projects that require water rights.

2. Identifying and monetizing benefits associated with stormwater capture and use.

3. Highlighting examples of where urban stormwater capture and use projects have been implemented in Colorado with lessons learned from these projects.

4. Engaging a diverse Expert Review Panel (ERP) (Appendix A) to support an informed and relevant project, including practitioners from academia, agriculture, Colorado water law, economics, public office, utilities, scientists, engineers, and water supply planners.

5. Preparing recommendations and suggesting next steps.

This report summarizes findings from tasks completed to achieve these objectives, organized as follows:

- **Section 2** introduces basic rainwater harvesting and stormwater capture in the broader national context. Diverse approaches for rainwater harvesting and stormwater capture and use currently used across the country are summarized here with particular attention to those most relevant to Colorado. The goal is to provide an overview of the range of possible approaches used, including end-uses, project scales, and methods for harvesting rainwater and stormwater.

- **Section 3** focuses the discussion on the context of current Colorado water rights. We introduce water rights concepts, rainwater harvesting legislation in Colorado, evolving engineering concepts related to stormwater capture and use for new developments such as Historic Natural Depletions (HNDs) and Regional Factors, and stormwater management.

- **Section 4** highlights existing rainwater harvesting and stormwater capture and use case studies in Colorado to provide a more comprehensive view of project development and implementation within the legal and policy context of Colorado.

- **Section 5** quantifies the volumetric potential of rainwater harvesting and stormwater capture and use in Colorado's urban areas. In the context of residential rainwater harvesting, we explore a currently allowable 110-gallon scenario and a hypothetical 500-gallon scenario, with varying adoption rates and water rights implications. To support larger scale stormwater capture estimates, we provide estimates of urban stormwater runoff at various capture rates for existing impervious areas and an example scenario with these estimates applied to future urban development within the South Platte River basin. These scenarios are then compared to residential outdoor water demand estimates from the Colorado Water Plan.

- **Section 6** provides a high-level overview of the multiple benefits related to stormwater capture and use practices considered in this report. We provide an overview of relevant literature, describing benefits provided by the level of capture currently allowable under Colorado water law without a water right (i.e., two 55-gallon rain barrels), as well as additional levels (and types) of capture that would require water rights. Where feasible, we provide quantitative and monetized estimates of the value of the benefits of stormwater capture and use.

- **Section 7** summarizes the findings of this research and provides recommendations and next steps based on the literature, data, and analysis provided throughout the report.

# 2 Rainwater Harvesting, Stormwater Capture and Use Concepts, and the National Context

This section defines basic terminology related to rainwater harvesting and stormwater capture used throughout this report, discusses different scales of stormwater capture and use, and provides national context as a backdrop for Colorado-specific discussions. Water rights-related terms are discussed in Section 3.

## 2.1 Common Definitions of Rainwater Harvesting and Stormwater Capture and Use

Commonly used definitions of terminology used in this report include:

- **Precipitation –** Precipitation occurs in various forms (e.g., rain, snow, hail) and the amount varies seasonally, annually, and by location (CSU n.d.). In the context of this report, the primary form of precipitation considered for rainwater harvesting and stormwater capture and use projects is rainfall.

- **Stormwater –** Stormwater is rainwater or melted snow that runs off streets, buildings, lawns, and other surfaces. When stormwater is absorbed into soil, it is filtered and ultimately evaporates, transpires, replenishes aquifers, or flows into streams and rivers (EPA 2015a). The Colorado Department of Public Health and Environment (CDPHE) definition of stormwater includes stormwater runoff, snow melt runoff, and surface runoff and drainage.[1] In this report, the term stormwater is inclusive of runoff from all surfaces within an urban area, whereas stormwater collected from residential rooftops is distinguished as rainwater harvesting.

- **Rainwater Harvesting –** Rainwater harvesting commonly refers to stormwater runoff collected directly from roof surfaces with an intent to use the water. Roof surfaces often have lower levels of pollutants than other stormwater runoff surfaces and collected water will generally require less treatment. Some have also referenced this water source as roof runoff (Sharvelle et al. 2017). Direct capture of rainwater is still considered stormwater collection and, depending on the use, may require treatment prior to use (MNPCA 2023). In this report, the term rainwater harvesting is used when referring specifically to water captured and stored from residential or non-residential rooftops in rain barrels or cisterns.

- **Stormwater Capture and Use –** A stormwater capture and use system is a constructed system that captures and retains stormwater for beneficial use (as defined in Section 3.1) at a different time or place than when or where the stormwater was generated. A stormwater capture and use system potentially has 1) a collection system (collection and conveyance from all impervious areas, including rooftops, downspouts, and stormwater infrastructure such as curbs, gutters, and storm sewers), 2) a storage unit (such as a barrel, cistern, or pond), 3) a treatment system to remove solids, pollutants, and microorganisms along with any necessary treatment control systems, and may

[1] CDPHE WQCC 5 CCR-1002-61

have 4) a distribution system to enable use of the water (such as pumps, pipes, and control systems).

## 2.2 National Approaches Used for Rainwater Harvesting and Stormwater Capture and Use

Rainwater harvesting (and use) and stormwater capture and use practices vary across urban areas in the United States. Factors that influence the project design and approach include, but are not limited to, the project site, goals and intended end-uses, demands, and legal requirements (e.g., water rights). Projects that seek to address multiple goals, such as enhancing water supply reliability and mitigating pollution impacts, will likely look different from those with the single goal of reducing nuisance flooding[2] or collecting water for landscape irrigation. In New York City, for example, 60-gallon rain barrels were distributed to residential properties in 2023 with multiple objectives in mind (see box, below).

**Residential Site-Scale Approaches Bring Multiple Benefits at the Community Scale**

The City of New York provided over 7,500 rain barrels free of charge to its residents in the summer of 2023. The easy-to-install 60-gallon rain barrels help to alleviate nuisance flooding, reduce the burden on the combined sewer system, protect local waterways, reduce potable water consumption, and lower customer water bills (Stormwater Solutions 2023).

There will also be differences in approaches depending on who is driving the project and who the project is seeking to serve. For example, a commercial entity may design their campus to prevent nuisance flooding by directing rainwater away from their building and parking lot runoff to a bioswale that allows fast infiltration. A regional water management agency, on the other hand, may provide incentives and educational opportunities for commercial property owners to install cisterns that can provide a slow release of captured water to the vegetation in nearby bioswales, thereby reducing potable water demand as well. Communities with long-term control plans to reduce combined sewer overflows may incentivize rain barrels to reduce flows in the combined sewer systems (Ghodsi et al. 2021). Even though Colorado does not have combined sewer system issues, the interests of various stakeholders may intersect, creating an opportunity for advancing a multitude of goals with numerous co-benefits. These collaborative efforts can be helpful for co-funding projects.

Here we provide examples of different approaches to rainwater harvesting, rainwater use, and stormwater capture and use across different scales, with a variety of stakeholders, drivers, and outcomes. The examples chosen are not meant to be comprehensive, but rather to offer readers a diversity of ways that stormwater is being captured and used across the nation.

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[2] Nuisance flooding refers to low levels of inundation that do not pose significant threats to public safety or cause major property damage, but can disrupt routine day-to-day activities, put added strain on infrastructure systems such as roadways and sewers, and cause minor property damage (Moftakhari et al. 2018).

### 2.2.1 Site-Scale

Site-scale refers to rainwater harvesting or stormwater capture at a single property, typically at a home or commercial property with a small (<1 acre) lot, including multi-family residences with up to four units. Rainwater harvesting and stormwater capture and use at these sites typically use on-site storage systems, like rain barrels or cisterns, that allow for use of the captured water for landscape irrigation on the property.

#### Residential Rainwater Harvesting

Residential rooftop rainwater harvesting, as is legal in Colorado under specific circumstances (described below in Section 3), is an example of a site-scale approach to stormwater capture. Although Colorado law currently narrows the options for the specific approach to rooftop rainwater harvesting allowed, there is still a range of designs that can be applied (Figure 1).

Figure 1. Rain barrels harvesting roof runoff at residential households.
*Source*: Rebecca Olson (left), BlueBarrel (right)
*Notes:* The picture on the left shows rainwater harvesting from a second-story deck that then can provide water for nearby planters. The image on the right shows raised barrels that water a garden space through passive, gravity-fed drip lines.

#### Commercial and Institutional Rainwater Harvesting

Site-scale rainwater harvesting and stormwater capture and use can be applied at commercial buildings and by institutions with larger properties. To date in Colorado, Denver Green School and Colorado State University (CSU) Spur stormwater capture projects are local examples of this category of projects that are implemented with augmentation plans to address water rights (see Section 4 for in-depth case studies of these projects).[3] Outside of Colorado, there are a wide range of examples of commercial and institutional rainwater

[3] Augmentation plans authorize out-of-priority diversions for beneficial use to the extent that a replacement supply of water is made available to substitute for the otherwise diminished amount of water available to supply other water rights. For a more in-depth discussion of these plans, please see Section 4.

harvesting and stormwater capture and use. They can range from simple approaches, much like the rain barrels used on residential properties, to more complex systems that collect graywater, blackwater,[4] and rainwater, and apply it to uses such as toilet flushing and cooling tower make-up. For example, in New York City, the New School installed an on-site water treatment and recycling system during construction of one of their buildings in 2014 (Natural Systems Utilities 2020). According to Natural Systems Utilities, a partner in the project, the on-site water treatment system collects blackwater and rainwater, with the capacity to treat 40,000 gallons per day. After treatment, the water is reused for toilet flushing, cooling tower make-up water, irrigation, and sidewalk maintenance. When installed, it was estimated to reduce potable water use by 74% and contribute to an 89% reduction in flows to the combined sewer system. Stormwater is reclaimed after it is captured in the building's vegetated green roof.

### Wildfire-Related Damage Reduction and Other Uses

Harvested rain or stormwater may be a potential water source for reducing damages associated with wildfires. In places where wildfire is a high risk, like California, Colorado, and Texas, guidelines for property owners are available to help in the design of on-site rainwater harvesting systems to increase their property's fire resilience. For example, the Department of Energy has information on how to install a cistern to help with fire suppression (US Department of Energy 2022). Local agencies may also provide guidance that is more site-specific. The Resource Conservation District of the Santa Monica Mountains in Southern California is creating guidelines that describe how rainwater stored in cisterns can be used to create low ignition zones that extinguish embers by dampening areas directly surrounding a building during high-risk fire conditions.[5]

The Philip Merrill Environmental Center (Figure 2), headquarters for the Chesapeake Bay Foundation in Maryland, uses rainwater harvested from its rooftop in the building's indoor sprinkler system for fire suppression (US Department of Energy 2002). In addition to meeting water quality standards for the protection of human health, indoor fire suppression systems must also meet state-specific codes, such as the International Fire Code (IFC) for flow rates, volume of water needed, and length of time sprinklers must be engaged to suppress fires (IFC 2018). The treated stormwater is also used for irrigation, cleaning gear, and doing laundry, reducing on-site water usage by 80% compared to other typical office buildings (US Department of Energy 2002). It is the first building to receive a Leadership in Energy and Environmental Design (LEED) Platinum rating by the US Green Building Council for its innovation in green technology (Chesapeake Bay Foundation n.d.). One benefit of using harvested, on-site water for firefighting activities is that it can reduce demand on the public supply system that is used to keep community hydrants pressurized during emergency situations.

[4] Blackwater is water from toilets and other uses that introduce fecal matter and other pathogens. It requires additional treatment over graywater, which comes from dishwashers, clothes washers, and other fixtures with lower risk of pathogen exposure.
[5] Personal communication with Resource Conservation District of the Santa Monica Mountains (2023).

Figure 2. Rainwater is captured, treated, and used for fire suppression and other activities at the Philip Merrill Environmental Center, headquarters for the Chesapeake Bay Foundation and a LEED Version 1 Platinum certified building. Photo by DroneVideoNow.

### 2.2.2 Neighborhood- or Medium-Scale

Neighborhood- or medium-scale refers to rainwater harvesting and stormwater capture approaches that collect stormwater from multiple sites that are geographically (and hydrologically) connected. For example, one to several city blocks could be considered a neighborhood. At this scale, it is common to have more than one property owner, and therefore, more than one entity involved in the project; but it could also be a multi-acre plot of land owned by a single entity such as a sports stadium, university campus, school, or public park. Rainwater harvesting and stormwater capture and use projects at this scale can include, but are not limited to, capture and infiltration into the subsurface, large underground storage structures, and surface storage (e.g., ponds). Stormwater retention-irrigation systems[6], such as those used in Austin, Texas, combine stormwater detention requirements with irrigation systems. These systems capture stormwater in irrigation ponds to protect sensitive watersheds from pollutants that might otherwise be discharged directly into receiving streams. The captured stormwater is then used on-site for landscape irrigation. The water captured from these projects is also commonly used within the neighborhood where it was collected.

At the neighborhood scale, underground collection systems can be designed to store, treat, and distribute stormwater to irrigate parks and for other non-potable uses like toilet flushing.

[6] For more information on retention irrigation ponds visit https://www.austintexas.gov/faq/retention-irrigation-ponds.

Figure 3 shows a schematic of the underground system at the National Mall in Washington DC. This system of cisterns, drains, and perforated drainage pipes can collect up to one million gallons of stormwater in multiple storage tanks. It is then distributed to a central location for treatment before being used for irrigation. Another example in Figure 4 shows Allianz Field in Saint Paul, Minnesota, where rainwater and stormwater are captured and reused for irrigation in and around the stadium, helping to reduce use of potable water supplies (US EPA 2022). The grounds also have tree trenches and other green infrastructure features for reducing runoff and pollution from reaching the nearby Mississippi River.

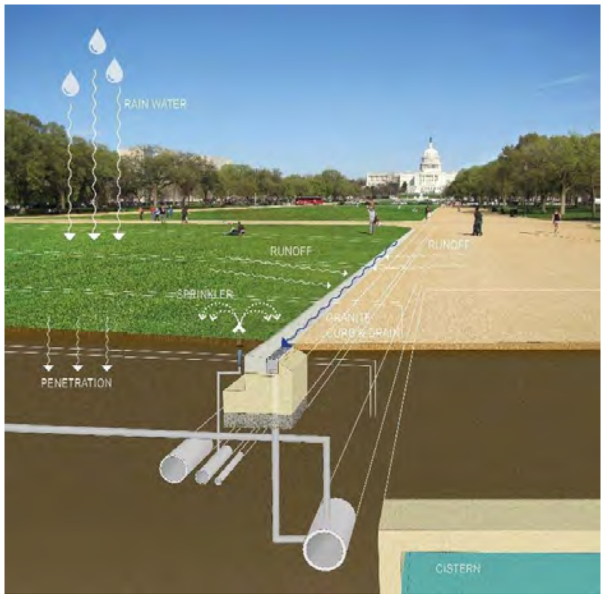


Figure 3. The National Mall in Washington DC. is irrigated with stormwater harvested in a sub-surface collection and distribution system.
*Source*: HOK Media

Figure 4. Allianz Field in Saint Paul, Minnesota, where rainwater and stormwater are captured and reused for irrigating the field.
*Source*: Chris 73/Wikimedia Commons

### 2.2.3 Community- or Large-Scale

Community-scale rainwater harvesting and stormwater capture and use can be projects or programs that can reach across an entire community. Approaches used at this scale can vary significantly; in some cases, they can entail large-scale diversion of stormwater flows to groundwater recharge areas. Here, we also consider community-scale projects that, rather than being defined by a specific area, use programmatic approaches to incentivize distributed capture and use projects across an entire community. These are typically implemented through public-private and public-public partnerships and require higher-level coordination to plan, fund, implement, and maintain.

**Utility Incentives and Debt Finance for Stormwater Capture**

Financial incentives are a tool cities and water providers can use to encourage private property owners to install distributed stormwater capture systems on their property. Because rainwater and stormwater captured via private property installations can benefit the broader water system overall, by providing a source of alternative water supplies (see Section 6, below, for more details), cities and utilities can invest in incentives to install stormwater capture practices on private property just as they do for more conventional water infrastructure. In other words, public water providers can debt finance incentive programs for stormwater capture using municipal revenue bonds, Clean Water State Revolving Fund (SRF) loans, or other forms of debt (Kelly et al. 2021). For example, Colorado water providers should have the needed legal and accounting authority to bond finance incentives to replace turf with landscaping designed to use water wisely, including with rainwater harvested from rooftops or stormwater on properties with the appropriate water rights (Koch et al. 2022). And these types of incentives are eligible for Colorado SRF loans. Realizing the full range of benefits that stormwater capture offers may require a scale of investment that water providers cannot make with annual operating dollars. Using long-term financing to pay for the incentives needed to install distributed stormwater capture infrastructure can help cities and utilities get to scale.

Financial incentives and public funding specifically for stormwater capture can support local entities to plan, develop, and execute stormwater capture and use at the community scale. California is one state that offers a public funding program through the Department of Water

Resources for agencies pursuing community-scale stormwater capture and use projects.[7] These grants provide funding for planning, implementation, and involvement of what are designated as "Disadvantaged Communities" and tribes. At a regional level, Los Angeles County's Safe, Clean Water Program provides local funding raised through a special parcel tax for multi-benefit stormwater projects that increase water supply, improve water quality, and protect public health. Since 2020, their program dashboard shows that the program has supported more than 350 projects, 79% of which have been regional or municipal infrastructure projects and 21% have been either technical resources or scientific studies that support the infrastructure projects (Safe Clean Water Program n.d.). Of these, 98 (28%) are projects that provide groundwater recharge to aquifers used for water supply, 72 (21%) include on-site water use, and 50 (14%) have water reuse components. Altogether, 62,000 acre-feet per year (AF/YR) of stormwater is estimated to be captured on average from projects supported by this program. See the box for discussion of utility incentives and debt finance for stormwater capture.

## 2.3 National Policy and Practice Initiatives

Multiple national efforts are underway to explore the role of stormwater capture and use as part of a One Water approach. Several examples are described below because they may serve as resources for those interested in further advancing stormwater capture and use in Colorado.

At the federal level, the US Environmental Protection Agency's (EPA) National Water Reuse Action Plan (WRAP) includes numerous actions related to stormwater capture and use, including:

- Action 3.3: Convene Experts to Address Opportunities and Challenges Related to Urban Stormwater Capture and Use

- Action 5.5: Quantify the National Volumes of Water Potentially Available for Reuse for Municipal Wastewater and One Additional Source of Water (stormwater)

- Action 5.8: Evaluate the Potential of Urban Stormwater Capture and Use in Colorado (This action is an outgrowth of this CWCB project.)

(US EPA 2019). In WRAP Action 3.3, stormwater capture is identified as showing great potential for addressing water resource challenges imposed by drought, flood, and fire. As the climate changes and populations continue to grow, there is a pressing need to identify solutions and improve water resilience.[8] Stormwater capture and use is identified as one strategy that can help mitigate flooding and water shortage crises, while at the same time providing multiple benefits to create a thriving, resilient community.

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[7] For example, see the Integrated Regional Water Management Grant Programs, Round 2 Implementation Grant Solicitation: https://water.ca.gov/Work-With-Us/Grants-And-Loans/IRWM-Grant-Programs

[8] Water resilience is defined by the Pacific Institute as the ability of water systems to function so that nature and people, including those on the frontlines and disproportionately impacted, thrive under shocks, stresses, and change (Pacific Institute 2021).

WRAP Action 3.3 notes that the potential of stormwater to fulfill this role has been undervalued historically. The WRAP 3.3 Project Team sought to address this issue and in early 2022 published *Pure Potential: The Case for Stormwater Capture and Use* (US EPA 2022). This report elevated stormwater capture and use as a tool to contribute to a reliable water supply, while at the same time providing a host of co-benefits. Recommendations made in the *Pure Potential* report directly contributed to the creation of this project in Colorado, and the subsequent creation of WRAP Action 5.8.

Action 5.8 advances these specific recommendations:

- Advance the Nation's Commitment to Stormwater Capture and Use
- Build Trust, Understanding, and Partnerships
- Improve Regulations, Policy, and Guidance

In addition to EPA's WRAP Actions, there are numerous publications about the value of stormwater capture at the federal, state, and local levels. For example, WRF has provided funding to various projects that address the challenges and opportunities associated with implementing stormwater capture and use.

**Water Research Foundation Publications Related to Stormwater Capture and Use**

WRF 4841: Assessing the State of Knowledge and Research Needs for Stormwater Harvesting

WRF 4852: Economic Framework and Tools for Quantifying and Monetizing the Triple Bottom Line Benefits of Green Stormwater Infrastructure

WRF 5001: Climate-Resilient for Urban Stormwater and Wastewater Utilities: Workshop Proceedings

WRF 5034: Assessing the Microbial Risks and Impacts from Stormwater Capture and Use to Establish Appropriate Best Management Practices

WRF 5105: Advancing Benefits and Co-Benefits Quantification and Monetization for Green Stormwater Infrastructure: An Interactive Guidebook for Comparison Case Studies

WRF 5207: Establishing a Framework for Integrating Stormwater Capture into Water Supply Planning

WRF 5236: Diversifying Water Portfolios through Stormwater Capture and Use: Contributing to a Water Resilient Future (Note: this is an extension of this CWCB-funded project, with application at a national scale)

## 2.4 Summary

In summary, rainwater harvesting and stormwater capture and use are increasingly gaining awareness as viable strategies to improve water resiliency at national, regional, and local scales. There is a diverse array of approaches being taken to harvest, capture, and use rainwater and stormwater. These projects vary based on several factors, including but not limited to the site size, entities involved, drivers, and project goals and objectives. The examples illustrate how:

- Rainwater harvesting at the site-scale, using rain barrels or cisterns, can supply water for irrigation, fire suppression, and other on-site activities, which can help reduce demand of potable water supplies and improve resilience.
- Stormwater capture and use at the neighborhood- or medium-scale involves capture, storage, and treatment prior to reuse for irrigating large public and commercial spaces.
- Programmatic approaches, like tax-funded stormwater grants or rain barrel incentives, operate at large scales to spur rainwater and stormwater capture across a community.

As Colorado continues to explore the role that stormwater capture and use may play in its water plan, these resources and examples may be useful references for communities exploring stormwater capture and use.

# 3 Understanding Colorado Water Rights: Rainwater Harvesting, Stormwater Capture and Use, and Stormwater Management

Colorado follows the Prior Appropriation Doctrine for administering the right to use water. Unlike the Riparian Water Rights Doctrine followed in many eastern states, the right to use water under the Prior Appropriation Doctrine is based on the principle of "first in time, first in right," and is administered through the legal system (water court) in Colorado. For more information on rainwater harvesting laws throughout the United States, see the *Is it Illegal to Collect Rainwater: 2023 Complete State Guide*, which provides an overview of some of the key rules and regulations related to rainwater harvesting and stormwater capture across the nation (Zac 2024). Although a detailed discussion of Colorado water rights is beyond the scope of this report, there are fundamental aspects of Colorado water rights that need to be understood when examining the current volumetric potential of rainwater harvesting and stormwater capture and use in Colorado. This section provides a summary of the following:

- Basic water rights terminology and definitions
- Legally allowable approaches to rainwater harvesting and stormwater capture and use in Colorado
- Stormwater management in the context of Colorado water rights
- Evolving opportunities related to engineering analysis of the impacts of rainwater harvesting and stormwater capture and use, including concepts such as HNDs and Regionally Applicable Factors (or Regional Factors)

Case studies illustrating how rainwater harvesting and stormwater capture and use have been implemented to date in Colorado are provided in Section 4 of this report and illustrate some of the concepts introduced in this section.

## 3.1 Basic Water Rights Terminology and Definitions

Under Colorado's legal framework, most rainwater harvesting and stormwater capture and use practices beyond capture of 110 gallons of residential roof runoff require a decreed water right through water court. An augmentation plan to prevent "injury" to existing downstream water users is typically required to replace depletions to the stream system (including those caused by diversion of stormwater). An understanding of Colorado's water rights is important to explore the role that rainwater harvesting and stormwater capture and use can potentially play in meeting Colorado's water demands.

The prior appropriation system, affirmed by Colorado's Constitution and termed the Prior Appropriation Doctrine, is Colorado's legal framework for regulating surface water and tributary groundwater use. This system determines who uses how much water, the types of uses allowed, and when those waters can be used, with the main objectives of preventing water waste and providing a system of allocation around a scarce resource, according to the Colorado Division of Water Resources (CDWR) (2012). Provisions of the 1969 Water Right Determination and Administration Act, as well as the 1965 Ground Water Management Act, primarily govern the prior appropriation system (CDWR 2012).

A water right is a real property right that can be severed from land ownership that may allow for access to water and water use and is commonly adjudicated in perpetuity. Under this system, water rights that are filed at a later date (junior) are impacted by water shortages first. Types of water right uses include municipal, domestic, irrigation, industrial, recreational, dust suppression, fire protection, and storage, among others.

Water rights engineering and legal practice utilize terminology that is important to understand in the context of rainwater harvesting and stormwater capture and use projects. Appendix B provides definitions of common water rights terminology. Some of the key terms used throughout this report include:

- **Appropriation Date** – The date decreed by the court that the water was first put to the decreed beneficial use.

- **Augmentation Plan** – An augmentation plan, as approved in Colorado water court, authorizes out-of-priority diversions for beneficial use to the extent that a replacement supply of water is made available to substitute for the otherwise diminished amount of water available to supply other senior water rights. This allows junior diversion to operate without injury to senior vested water rights. Augmentation plans allow for flexibility and maximum utilization of water while protecting senior rights in over-appropriated stream systems throughout Colorado. Augmentation plans must be approved through a decree of the water court. Most of the rainwater harvesting and stormwater capture and use projects discussed in this report would, under current Colorado law, ultimately require an augmentation plan to legally use harvested water.

- **Beneficial Use** – Beneficial use is the use of that amount of water that is reasonable and appropriate under reasonably efficient practices to accomplish without waste the purpose for which the appropriation is lawfully made.

- **Consumptive Use** – Consumptive use is the portion of diverted water that is fully consumed (i.e., no portion of such water returns to the stream as run-off, irrigation return flows, or wastewater return flows).

- **Depletion** – The amount of water diverted for use that does not return to the stream or source from which it originated.

- **Free river** – Free river conditions occur when the water available exceeds demand, enabling any water user, with or without water rights, to use water from that waterway. A free river is most likely to occur during the spring runoff, during large storm events, or on streams that have few water users (Colorado River District n.d.).

- **Injury** – The action of another that causes or may cause the holders of decreed water rights to suffer loss of water in the time, place, or amount for which they are entitled to use that water.

- **Priority** – The ranking of a water right in relation to all other water rights drawing on the stream system. Priority is determined by the year in which the application for the water right was filed. The date the appropriation was initiated determines the relative priority for water rights for which applications were filed in the same year. Priority is the most valuable aspect of a water right because priorities determine who may divert and use water in times of short water supply (CFWE 2003). The terms senior and junior water rights are commonly used to refer to relative priority of rights to use water.

- **Substitute Water Supply Plan (SWSP)** – a State Engineer-approved temporary plan for replacement water supply allowing an out-of-priority diversion of water. SWSPs may be approved while a plan for augmentation is proceeding through the water court or for water exchanges, water uses that will not exceed five years, or in limited emergency situations (CFWE 2003). Authority to approve a SWSP is found in Section 37-92-308, C.R.S.

- **Water Court** – Under the Water Rights Adjudication and Administration Act of 1969, the Colorado legislature established seven water courts, one for each of the major river basins. These courts have exclusive jurisdiction over water rights in Colorado.

Terms specific to rainwater harvesting and stormwater capture and use in Colorado include:

- **Historic Natural Depletions (HNDs)** – HNDs are defined as the amount of rainwater that, under natural pre-development conditions, was consumed by evapotranspiration (ET) and did not enter the stream system. HND factors are based on the concept that HNDs are equal to water that infiltrated to soil moisture storage but did not become groundwater return flow; in other words, infiltration minus deep percolation (Gillion 2019). After development occurs, increased impervious area from pavement and rooftops results in much more surface runoff than occurred under undeveloped conditions, with less consumption of rainwater from vegetation and less return flow to groundwater (Figure 5). In the context of Colorado rainwater harvesting pilot projects, an applicant must estimate HNDs to determine the amount of precipitation that may be stored and reused for purposes within the new development. CDWR (2019) notes that in many cases, 80–90% of the rainfall on developed areas may be captured for reuse. This concept is important because HND "credits" can offset augmentation plan requirements. HND represents the amount of water that can be captured and reused without injury to senior water rights (Gilliom 2019). HNDs can be estimated using a Regionally Applicable Factor (described below).

- **Rainwater Harvesting Pilot Project** – Rainwater harvesting pilot projects allow the State of Colorado to evaluate rainwater harvesting as a water supply option in terms of physical and legal feasibility (CDWR 2019). As defined by CWCB, such projects collect precipitation from rooftops and other impermeable surfaces and utilize the collected water for non-potable uses to evaluate water conservation potential. Pilot projects must be designed such that data collection supports the purposes identified in Section 37-60-115(6)(a) C.R.S., and further evaluates water conservation potential through pairing rainwater harvesting with advanced outdoor water demand management. Projects must be in new residential or mixed-use development. The pilot project program was authorized for up to 10 projects for a set time period and is set to expire in 2026, unless extended. A pilot project sponsor may seek approval from the State Engineer based on replacing only the net depletion caused by the capture of precipitation. The net depletion must be calculated as the amount of precipitation captured minus the historical consumptive use from preexisting, natural vegetation cover on the impermeable area as demonstrated by analysis of the data collected by the sponsor during the pilot project. This differs from diversions of rainwater outside of the pilot program where all out-of-priority depletions, not just net depletions, must be replaced.

- **Regionally Appliable Factor (Regional Factor)** – In the context of HNDs, a Regional Factor is defined as one factor, or a set of factors, that specify the amount of precipitation consumed through ET of preexisting natural vegetative cover in a specific region of the state. (Regional Factors are discussed in more detail later in this section.)

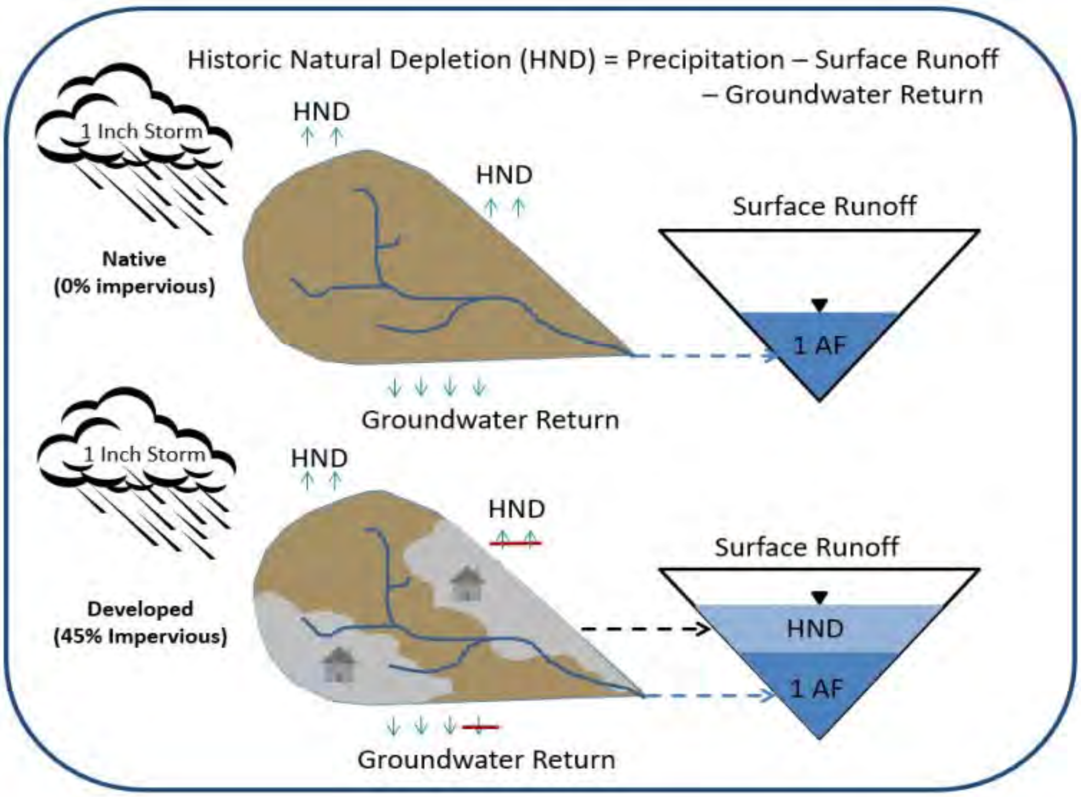



Figure 5. Colorado Division of Water Resources Historic Natural Depletions Concept Diagram
*Source*: CDWR 2019

## 3.2 Legally Allowable Approaches to Rainwater Harvesting and Stormwater Capture and Use in Colorado

Currently in Colorado, there are several pathways for legal rainwater harvesting, with some requiring water rights obtained through water court decrees and others allowed by specific legislation. These generally include:

1. **Residential Rooftop Rainwater Harvesting** (No Augmentation/No Water Right Required) – Residential rooftop rainwater harvesting is authorized under specific legislation, without additional water rights or monitoring requirements. Examples include residential rainwater harvesting for outdoor landscape use captured in two 55-gallon barrels, and allowances for certain rural residential properties with groundwater wells.

2. **Rainwater Harvesting Pilot Projects** (Partial Augmentation/Water Right Required) – Rainwater harvesting or stormwater capture and use from new development under a decreed augmentation plan or approved SWSP requiring only partial replacement (augmentation) of out-of-priority depletions. Up to 10 rainwater harvesting pilot projects under the CDWR, with SWSPs and monitoring and reporting requirements. The only example is Sterling Ranch in Douglas County discussed in Section 5.5.

3. **Fully Augmented Rainwater Harvesting and Stormwater Capture and Use** (Full Augmentation/Water Right Required) – Rainwater harvesting or stormwater capture and use under a decreed augmentation plan or approved SWSP requiring full replacement (augmentation) of out-of-priority depletions. An example would be CSU's Spur Campus at the National Western Complex in Denver discussed in Section 4.3.

4. **Rainwater Harvesting and Stormwater Capture and Use Under Free River Conditions** (No Augmentation Required) – As a variation to numbers 2 and 3 above, water rights holders can divert and store water under "free river" conditions. This scenario is addressed separately due to recent interest in this scenario related to extreme precipitation events in western states including California and Colorado.

Lastly, allowable "stormwater management" practices that are not subject to water rights requirements are discussed in this section for clarity and due to interest from the ERP in green infrastructure (GI) practices.

### 3.2.1 Summary of Legislation

Colorado's current legal framework allows a maximum of two rain barrels with a combined storage of 110 gallons at each single-family household. Rooftop rainwater collected with these systems may be used for non-potable uses such as outdoor irrigation of lawns, plants, or gardens. Individual homeowners may install rain barrels on downspouts for landscape irrigation. A water right is not required for this use, but any larger scale rainwater harvesting requires an augmentation plan because rainwater captured out-of-priority may deprive downstream and senior water right holders their right to use water from the natural stream.

Laws have been established in Colorado to allow limited collection of rooftop rainwater from residential households while safeguarding downstream uses by senior water rights holders. The primary rainwater harvesting legislative bills passed from 2009 through 2016 include:

- **Senate Bill 09-080**: In 2009, this Senate Bill allows rural residents with "exempt" wells to collect rainwater with a Rooftop Precipitation Collection System Permit (GWS-78) prepared by the CDWR. Uses of rainwater are to be the same as the well permit. The Rainwater Collection permit allows for substitute water that would ordinarily be pumped from a private exempt well and subject to the well permit limitations.

- **House Bill 09-1129:** In 2009, this bill authorized pilot projects for captured precipitation and gave the opportunity for developers to participate in pilot projects. Under this bill, rainwater harvesting pilot projects are allowed to collect precipitation from rooftops and other impermeable surfaces and utilize the collected water for non-potable uses to evaluate water conservation potential in new residential or mixed-use developments.[9] The goal of the pilot project program is to gain additional field-verified information about the feasibility of rainwater harvesting as a water conservation measure in Colorado through pairing it directly with advanced outdoor water demand management—particularly efficient landscaping and irrigation practices. This bill requires the CDWR State Engineer's Office approval for project operation and eventually the project may require water court approval. Existing developments are not eligible for pilot projects. Originally passed in 2010, the original bill has been updated several times. The updates were intended to incentivize rainwater harvesting pilot projects. The 2019 update incorporated "Regional Factors" in response to HB 15-1016. To participate as a pilot project, an application fee of $7,000 is required, along with a $1,000/year review fee. A case study on the only existing project authorized under this legislation to date, the Sterling Ranch Pilot Project, is provided in Section 4.4. This program expires in 2026, unless extended.

- **House Bill 15-1016**: In 2015, this House Bill summarized the CWCB criteria and guidelines that allow for establishment of Regional Factors to account for HNDs of precipitation present on undeveloped land when considering water rights requirements for new developments using rainwater harvesting systems. A Regional Factor is defined as one factor, or a set of factors, that specify the amount of precipitation consumed through ET of pre-existing natural vegetative cover in a specific region of the state.

- **House Bill 16-1005:** In 2016, this House Bill was approved to allow for rain barrel installation at single family households and multi-family households with four or fewer units. It allows use of two 55-gallon rain barrels to capture rainwater from rooftop downspouts with captured rainwater used for outdoor purposes and located on the same property the rainwater was captured.

### 3.2.2 Residential Rainwater Harvesting

As discussed above, residential rainwater harvesting is limited in both volume (two 55-gallon rain barrels) and use (non-potable outdoor use). Analysis of this rainwater harvesting volume using Storm Water Management Model (SWMM[10]) modeling showed that this limited volume of captured rainwater does not adversely impact (or "injure") downstream water users because the effect on runoff volumes from typical residences is negligible (Olson and Roesner 2015). CDWR (2020) provides guidance to residents considering rainwater harvesting projects, with

[9] In this report, rainwater harvesting and stormwater capture and use are defined differently (Section 2.1), with rainwater harvesting referring to runoff generated from rooftops and stormwater being generated from many kinds of urban surfaces, such as pavement and roofs. This specific legislation does not make this distinction and only uses the term rainwater.

[10] The US EPA's SWMM is widely used for planning, analysis, and design related to stormwater runoff. It can be used to evaluate gray infrastructure stormwater control strategies, such as pipes and storm drains, and is a useful tool for creating cost-effective green/gray hybrid stormwater control solutions. SWMM was developed to help support local, state, and national stormwater management objectives to reduce runoff through infiltration and retention, and to help reduce discharges that cause impairment of waterbodies. For more information, see https://www.epa.gov/water-research/storm-water-management-model-swmm.

several scenarios summarized in Table 1. Although residential rainwater harvesting has been allowed since 2016, adoption rates are believed to be very low on a per capita basis. See additional discussion in Section 4 case studies.

Table 1. Allowable Residential Rainwater Harvesting in Colorado

| Water Supply Scenario | Can I use rain barrels as allowed under HB 16-1005? (Limit of two rain barrels with a combined storage capacity not to exceed 110 gallons) | Can I have additional rain barrels in accordance with SB09-080? |
|---|---|---|
| A single-family house served by a community water system | Yes | No |
| 2-to-4-unit multi-family building (apartments or condominiums) served by a community water system | Yes, 110 gallons per building | No |
| 5-or-more-unit multi-family building (apartments or condominiums) served by a community water system | No | No |
| Townhome (one residence in a row of residences joined by common side walls) served by a community water system | Yes, 110 gallons per residence | No |
| A single-family house on an exempt/small-capacity domestic well | Yes | Maybe (See CDWR 2020 for details) |
| A single-family house on a well that is either non-exempt, large-capacity, or not permitted | Yes | No (See CDWR 2020 for details) |

*Source*: CDWR 2020
*Notes*: Community water systems are defined by the US EPA (2015b) as a public water system that supplies water to the same population year-round, with at least 15 service connections. A public water system may be publicly or privately owned.

### 3.2.3 Obtaining a Water Right for Rainwater Harvesting or Stormwater Capture and Use and Augmentation Plan Requirements

For rainwater harvesting or stormwater capture and use that would capture volumes greater than those allowed under the previously discussed legislation, the project must obtain appropriate water rights, which typically include some type of storage right and a plan for augmentation to fully replace all out-of-priority depletions. A SWSP can be used on a temporary basis, but ultimately an augmentation plan is needed.

To obtain a water right decree, an applicant typically needs to involve water engineers and a water attorney to navigate the water court process. Engineering and legal analysis is completed to support a water rights application submitted to the water court, which then triggers a legal process that may include objectors to the application, subsequent negotiations and stipulations, and potentially a water court trial with testifying experts. The cost of the process can be substantial and varies depending on the complexity of the water rights application and context. An order-of-magnitude range could be $50,000 to $500,000 for engineering and legal fees, plus the cost of lease or purchase of augmentation water and ongoing water accounting requirements. Although augmentation plan requirements vary, an example of common engineering analysis requirements includes:

- Identify the storage structure and provide a legal description of the storage structure
- Identify the source of water
- Identify the storage capacity
- Calculate the amount of water claimed
- Provide appropriation date description
- Identify place of use and uses
- Provide a plan for augmentation that identifies:
    - Sources of consumptive use (and historic consumptive use)
    - Timing, amount, and location of depletions
    - Replacement supply (e.g., typically a contract with a water provider)
    - Location(s) of replacement water

Various legal requirements apply, such as a finding of “no injury”, to assure that no injury to any water users will result from operation of the plan for augmentation. Additionally, measuring devices, storage/depletion calculations, water rights accounting, and filings apply in perpetuity once the water right decree is granted. These ongoing reporting requirements often require the involvement of a water engineer.

**“New Water”**

In the context of this report, the phrase “new water” is a concept used to describe water sources that are not already claimed by downstream water users and that do not require augmentation by other water sources for use.

In the context of the role that rainwater harvesting and stormwater capture and use projects can play in helping fill Colorado’s water gap, projects authorized with requirements for full augmentation to offset captured water are not actually providing “new water” for municipal water supplies in terms of reducing the water gap. Using the CSU Spur campus as an example, if Denver Water releases stored water to offset (augment) stormwater captured at the CSU Spur campus, then it would be “double-counting” to identify the stormwater captured at Spur as a “new” water source relative to closing the water gap. There may, however, be other benefits of water captured and used on-site, such as reduced use of treated potable water, which requires energy and chemical usage. Additionally, this water captured locally can be used where it is collected, potentially reducing energy and infrastructure requirements for transmission. Using local water sources, like stormwater, could ultimately reduce the need for imported water, depending on scale of implementation. See Section 6 for additional discussion of the economic aspects and co-benefits of rainwater harvesting and stormwater capture and use.

See additional discussion in Section 4 for case studies such as the CSU Spur campus (Section 4.2) and Denver Green School (Section 4.3) projects for examples of rainwater harvesting and stormwater capture and use projects that have been implemented after obtaining a water right decree with an augmentation plan or a SWSP, respectively.

### 3.2.4 Rainwater Harvesting and Stormwater Capture and Use Under Free River Conditions

In many of Colorado's river basins (e.g., the South Platte River), the right to use water is over-appropriated, which means that in most years, there is not enough water to meet the needs of existing water rights holders. As a result, rainwater harvesting and stormwater capture and use (beyond rainwater harvesting with 110-gallon storage) are illegal without a water right (e.g., typically involving an augmentation plan) because senior water users have the right to use water first, followed by junior water rights. As a recent example, Larry Elder with Denver Water reported, "Typically, anyone who doesn't have a water right from 1900 or before doesn't get to divert water. And in the past three years, that date has been closer to 1871 with the level of dryness we have experienced." (Hartman 2023)

Infrequently, conditions may exist where excess water is available due to multiple heavy rainfall events, heavy snowmelt, or a combination of these factors. These are known as "free river" conditions. When these conditions exist, anyone can divert as much water as they can use. This "free river" condition occurred in the South Platte River Basin May 11 to July 12, 2023. In this case, the water diverted would be "new water" in the context of water that could be counted against Colorado's water gap.

To take advantage of free river conditions for future use, a water user needs storage in order to hold captured water. Both municipal water providers and agricultural users utilize reservoirs with storage water rights to capture as much water as possible under these conditions. In the context of typical rainwater harvesting and stormwater capture and use practice (e.g., cisterns), reliance on free river conditions is not economically practical because it requires investment in large storage facilities for conditions that occur infrequently.

### 3.2.5 Aquifer Storage and Recovery

In some states, aquifer storage and recovery (ASR) is a practice being used to replenish aquifers using multiple water sources. In this context, water storage is provided in aquifers rather than building surface reservoirs. ASR programs often rely on reinjection of reclaimed wastewater to the subsurface (American Water Works Association 2015), but there is increasing interest by some states such as California in creating conditions that allow for stormwater recharge when stormwater is available. For example, in 2023, parts of California experienced extremely high snowfall and rainfall, creating conditions where depleted groundwater levels could be recharged by taking advantage of "atmospheric river" conditions that occurred in the state (Public Policy Institute of California 2023). An example of an active stormwater recharge project is the Chino Groundwater Basin in Southern California where the Chino Basin Water Conservation District seeks to harness the boom-bust hydrologic cycle.

In Colorado, there are currently eight "designated groundwater basins" where stormwater-related ASR could be physically viable, although most of these are in rural areas. Designated groundwater is water that under natural conditions would not be used to recharge or supplement continuously flowing surface streams (CFWE 2003). These basins are located on

Colorado's eastern plains and include Kiowa Bijou, Southern High Plains, Upper Black Squirrel Creek, Lost Creek, Camp Creek, Upper Big Sandy, Upper Crow Creek, and the Northern High Plains. Designated groundwater is allocated and administered by the State Engineer's Office, Colorado Groundwater Commission, and local groundwater management districts.

In Colorado, two recent ASR pilot projects include a study conducted by Denver Water and another underway by the City of Northglenn (Denver Water 2022; City of Northglenn 2024).

Exploration of ASR applications in Colorado is beyond the scope of this report but could be further explored in the future. Preventing contamination of groundwater is an important aspect of ASR applications.

## 3.3 Evolving Opportunities Related to Engineering Analysis of the Impacts of Rainwater Harvesting and Stormwater Capture and Use

As previously discussed, CWCB's rainwater harvesting pilot program established a framework for up to 10 pilot projects that could be useful for collecting key hydrologic data to better understand opportunities and impacts of rainwater harvesting. Concepts related to HNDs and Regional Factors included in updates to the law reduce some of the extensive monitoring and augmentation requirements under the pilot program. For example, a minimum two-year hydrologic data collection period is required unless Regional Factors have been developed for the area. Data collection, reporting, and analysis methods under the pilot project program in the absence of Regional Factors may include:

- Determining local weather and precipitation patterns that account for variations in hydrology and precipitation event intensity, frequency, and duration
- Quantifying preexisting natural vegetation consumption
- Measuring precipitation return flow amounts
- Identifying surface water versus groundwater return flow splits
- Identifying delayed groundwater return flow timing to receiving streams
- Quantifying the amount of precipitation that must be augmented to prevent injury to decreed water rights

Concepts related to HNDs and Regional Factors are described further below. For rainwater harvesting or stormwater capture and use to be implemented at scales beyond 110 gallons per residential household in Colorado for new developments, these concepts are essential building blocks; rainwater harvesting and stormwater capture and use cannot represent a "new water" supply due to augmentation requirements in the absence of these factors.

### 3.3.1 Historic Natural Depletion in the Context of Stormwater Capture and Use Opportunities

Currently in Colorado, any rainwater harvesting other than private rain barrels or cisterns requires 100% augmentation, which is the replacement of rainwater captured in equal time and place of depleted flow with water from a different source so as not to injure downstream water rights. Colorado's legislature made an exception to this rule in 2009 when it authorized a select number of rainwater harvesting pilot projects to harvest rainwater for non-potable outdoor use up to a certain volume, termed the HND or allowable harvest volume (as discussed above).

HND represents the volume of water that would have been consumed by evaporation and transpiration prior to site development but which is available for on-site consumption post-development. It is defined as the portion of a precipitation event that remains available for ET from the root zone of vegetation (i.e., does not become groundwater return flow) after precipitation has infiltrated into the ground. Once a site is developed, the HND becomes the volume of water equivalent to the decrease in ET associated with newly impervious area at the developed site (Gilliom 2019; Gilliom et al. 2019). Harvested rainwater exceeding the calculated HND of a specific site would require augmentation.

HND is controlled by the soil-hydraulic properties that determine soil infiltration rates and moisture storage volumes, the water usage characteristics of the transpiring vegetation, and the meteorologic conditions that drive atmospheric water vapor demand. HNDs are temporally and spatially variable because these aforementioned properties all vary over space and time. For example, where vapor pressure deficits are high, such as in the arid front range of Colorado, average annual HND has been calculated to be as high as 97% in a natural, undeveloped catchment (Gilliom et al. 2019). Where relative humidity is high and vapor pressure deficits are comparatively low, HND would represent a smaller fraction of precipitation. In 2015, Colorado's legislature asked the CWCB to provide "widely applicable 'factors' that estimate daily Historic Natural Depletion." (Gilliom et al. 2019). CWCB, in collaboration with stakeholders, developed an HND accounting tool that enables site-specific HNDs to be calculated according to storm duration and intensity, infiltration and groundwater percolation rates, hydrologic soil group type, and historical maximum monthly ET demand.

### 3.3.2 Regional Factors

As previously described, House Bill 15-1016 allowed for establishment of Regional Factors to account for HNDs of precipitation present on undeveloped land when considering water rights requirements for <u>new</u> developments using rainwater harvesting systems. Gilliom (2019) prepared these guidelines for CWCB in *HB15-1016 Rainwater Harvesting Pilot Project Regional Factors 2019*. A pilot project system may operate under a SWSP using the Regional Factors but would likely need to rely on site-specific data to operate permanently with an augmentation plan. In determining the quantity of water required for a SWSP to replace out-of-priority stream depletions, an applicant bears the burden of proving a Regional Factor through data-intensive monitoring.

In the context of approved pilot projects, Regional Factors are important because they significantly change the amount of augmentation water required for a rainwater harvesting and stormwater capture and use project. In the absence of Regional Factors, the out-of-priority water replacement requirement is:

> For the first two years of operation, sponsors of projects in areas where Regional Factors have not been adopted by the board are required to <u>replace an amount of water equal to the precipitation captured out-of-priority and measured from rooftops and impermeable surfaces.</u>

With Regional Factors, this requirement changes to:

> Sponsors of projects in areas where Regional Factors have been adopted by the Board may propose to use the Regional Factor to claim an evapotranspiration credit for the preexisting vegetative cover that was made impermeable through development associated with the pilot project. The evapotranspiration credit may be used prior to the sponsor completing two years of data collection and/or the sponsor's application to the water court. Proposed use of the credit will be reviewed as a part of the State Engineer's SWSP approval process.

Regional Factors also affect requirements for SWSPs. In the absence of Regional Factors, the requirement includes an explanation of how the applicant will engage resources necessary to determine:

1. the maximum amount of precipitation that will be captured during the year,
2. the timing with which that entire amount of precipitation would accrue to the stream system through overland flow and deep percolation,
3. the potential sources of replacement water that will be available to replace those depletions at the appropriate locations, and
4. how the plan will be operated.

With Regional Factors, this requirement changes to:

> Describe if the project will result in any out-of-priority depletions due to the storage of water in excess of the Historic Natural Depletion, and if so, describe the potential sources of replacement water that will be available to replace those depletions at the appropriate locations. The summary shall also describe how the replacement plan will be operated.

As described by Gilliom (2019), the basic concepts supporting Regional Factors includes these three components:

1. **Concept**: Allowed rainwater harvesting volumes are estimated using three calculations that require Natural Resources Conservation Service (NRCS) Hydrologic Soil Group information for the catchment area. The infiltration factor is the percentage of a precipitation event that infiltrates, which varies from 25% to 90% based on the soil group and the precipitation depth and duration. The groundwater factor is the percentage of a precipitation event that is a groundwater return flow, which varies from 3% to 6%, depending on the soil group. The ET/Soil factor is a 30-day limit on the rainwater harvesting volume, which varies depending on the month of the year.

2. **Data**: Use of Factors requires quantification and documentation of area made impervious in the development, area of NRCS Hydrologic Soil Groups A, B, C, & D, and on-site precipitation monitoring with 15-minute resolution.

3. **Accounting**. The Factors accounting process requires use of a daily accounting spreadsheet using the template provided by CDWR. The template applies the three calculations described above. The user inputs the 15-minute precipitation record, which is processed into individual storms. The accounting sheet uses event depth and

duration and soil group information to determine the volume of Historic Natural Depletion. The sheet is also used to maintain storage accounting with all gains and losses to assure accurate tracking of the volume of runoff harvested and any out-of-priority depletions. Lastly, the accounting tracks any replacement water provided to the stream for out-of-priority depletions.

Gilliom (2019) concluded that Regional Factors could be used throughout most of Colorado, with three significant limitations: 1) snowmelt may not be harvested, 2) pilot projects cannot claim HND in absence of pre-development vegetation, and 3) pilot projects cannot claim HND in areas of rock outcrop. For more information on Regional Factors, see *HB15-1016 Rainwater Harvesting Pilot Project Regional Factors* (Gilliom 2019).

## 3.4 Stormwater Management in the Context of Colorado Water Rights

Stormwater management in Colorado includes requirements for both flood control and water quality. These requirements are applicable regardless of whether rainwater harvesting or stormwater capture and use are being implemented. Borrowing the Mile High Flood District's mission statement, the purpose of these requirements is to "protect people, property, and our environment." Flood control practices typically use stormwater detention basins and retention ponds to attenuate (temporarily store and release) stormwater flows. Large-scale examples include reservoirs owned and operated by the US Army Corps of Engineers, such as Cherry Creek, Chatfield, and Bear Creek Reservoirs in the Denver metro area. Smaller scale stormwater management facilities are required by local governments to mitigate the impacts of increased runoff associated with impervious areas for new developments or redevelopments. Such practices not only help to protect upstream communities and manage flows in stormwater infrastructure such as storm drains/pipes, but also help to protect downstream agricultural users from damage to irrigation diversion structures.

From a water quality perspective, stormwater control measures (SCMs) are implemented to treat or manage runoff from frequently occurring smaller storm events, typically the 80$^{th}$ percentile runoff-producing storm event. In the Denver metro area, the water quality design storm is 0.6 inches of precipitation. Assuming 0.1 inches of depression storage for impervious areas, this equates to a runoff volume of approximately 0.5 inches of runoff over the area of the watershed (Mile High Flood District 2019). SCMs include a broad range of stormwater terminology such as best management practices (BMPs), green stormwater infrastructure (GSI), and Low Impact Development (LID). Provided that stormwater captured and temporarily detained or infiltrated by these practices is not "put to beneficial use," then these practices are not only allowed, but are required by local governments to comply with Municipal Separate Storm Sewer System (MS4) discharge permits issued by the CDPHE. SCMs can include many practices such as rain gardens and engineered bioretention systems, extended detention basins, retention ponds (wet ponds), wetland basins, sand filters, permeable pavement systems, green roofs, various manufactured treatment devices, and runoff reduction practices that promote infiltration of runoff that mimics natural conditions. SCMs are also important to help minimize channel degradation (erosion) that can result in increased sediment loading and damage to both urban and agricultural infrastructure.

Mile High Flood District, Storm Drainage Criteria Manual Volume 3 encourages runoff reduction followed by treatment of the water quality capture volume (WQCV). Design criteria are provided for both traditional and GI practices (Mile High Flood District 2024). Minimizing directly connected impervious area can include disconnecting roof downspouts from the storm drain system by directing downspouts to pervious landscape areas as part of a runoff-reduction approach. Rain barrels (limited to two 55-gallon barrels) can be a component of these approaches.

MS4 permits issued by the CDPHE provide stormwater quality management requirements including several performance standard options. One of these performance standard options is a 60% volume reduction (infiltration, ET) for the calculated WQCV. GI approaches, such as bioretention, grass swales, and use of receiving pervious areas, are allowed. Wetlands and retention ponds require water rights—these are being discouraged in some jurisdictions for this reason.

**Water Quality Capture Volume**

Mile High Flood District (2024) defines the Water Quality Event (WQE) as a design storm representing a rainfall depth equal to the 80th percentile runoff-producing storm event. For the Denver metro area, the design storm depth corresponding to the WQE is 0.60 inches. The WQCV is a storage volume intended to attenuate and treat runoff from the WQE and is calculated using a regression equation that relates the mean storm depth, imperviousness, and SCMs drain time to the WQCV. The WQCV is the design volume used to size most SCMs, with some exceptions for flow-based designs that utilize the WQE.

In 2016 under CRS §37-92-602(8), Colorado formally recognized the importance of flood detention and stormwater quality control measures. CRS §37-92-602(8) provides water rights-related legal protection for any regional or individual site stormwater detention and infiltration facility in Colorado, provided the facility meets these criteria:

1. It is owned or operated by a governmental entity or is subject to oversight by a governmental entity (e.g., required under an MS4 Permit)

2. It continuously releases or infiltrates at least 97% of all the runoff from a rainfall event that is less than or equal to a 5-year storm within 72 hours after the end of the event

3. It continuously releases or infiltrates as quickly as practicable, but in all cases releases or infiltrates at least 99% of the runoff within 120 hours after the end of events greater than a 5-year storm

4. It operates passively and does not subject the stormwater runoff to any active treatment process (e.g., coagulation, flocculation, disinfection, etc.)

This statute specifies that runoff treated in stormwater detention and infiltration facilities must not be used for any other purpose by the owner/operator/overseer (or that entity's designees), must not be released for subsequent diversion or storage by the owner/operator/overseer (or that entity's designees). and must not be the basis for a water right or credit (Mile High Flood District 2015).

Stormwater management practices recognized under CRS §37-92-602(8), including those that do and do not require reporting to the CDWR State Engineer's Office, are summarized in Table 2. Constructed wetland ponds and retention (wet) ponds require water rights; therefore, these facilities are subject to additional requirements beyond simply reporting under CRS §37-92-602(8).

Table 2. Summary of Stormwater Control Measures Requiring Water Rights Reporting

| Stormwater Control Measure | Water Quality Only | Detention Included |
|---|---|---|
| Grass Buffers | Not Required | Not Required |
| Grass Swales | Not Required | Not Required |
| Bioretention (with or without underdrain) | Not Required | Required |
| Green Roof | Not Required | Not Required |
| Extended Detention Basin | Required | Required |
| Sand Filter | Not Required | Required |
| Permeable Pavement Systems | Not Required | Required |
| Media Filter Drain | Not Required | Not Required |
| Underground Detention Vaults | Required | Required |
| Constructed Wetland Pond | N/A Subject to Water Rights | |
| Retention Pond | N/A Subject to Water Rights | |

## 3.5 Summary

Key takeaways from this section include:

- Only residential-scale rainwater harvesting (e.g., 110-gallon storage capacity) is allowed without a decreed water right. This strict regulation is consistent with Colorado water law that is based on the Prior Appropriation Doctrine and protects downstream water users from injury to their decreed water rights.

- Obtaining a water right for rainwater harvesting or stormwater capture and use beyond 110 gallons at a residential household in Colorado requires significant up-front legal and engineering costs on a project-specific basis, typically requiring an augmentation plan, purchase of replacement water for augmentation from a willing water provider, and ongoing engineering and legal costs for water rights accounting and filings with the State Engineer's Office.

- Only one rainwater harvesting pilot project has been applied for and approved in Colorado since legislation was passed in 2009. Deterrents for applying for pilot projects may include significant engineering and legal costs, intensive hydrologic monitoring requirements, cost of dual infrastructure, and uncertainty about the likelihood of long-term success of a project as a reliable water supply.

- Conceptually, the concepts of HNDs and Regional Factors accepted for CWCB pilot projects open the door to broader rainwater harvesting and stormwater capture and use projects for new developments in Colorado. Nonetheless, the current legal, scientific, and engineering burden along with uncertainty regarding success in water court likely deter new developments from pursuing rainwater harvesting or stormwater capture and use beyond 110-gallon rain barrels, unless no other water source is available, or a research/conservation objective motivates a pilot project. From a policy and water court process perspective, increased clarity on likelihood of success in water court and minimum data requirements for success would be a helpful next step if broader implementation of stormwater capture and use projects is desired in Colorado.
- Stormwater management is allowed (and required) in Colorado for both flood control and stormwater quality purposes. This “stormwater management” is allowed outside of the concepts of rainwater harvesting and stormwater capture and use because the stormwater that is detained or infiltrated is not allowed to be put to a beneficial use and is required to be released within 72 hours.

# 4 Colorado Case Studies

Currently, most rainwater harvesting in Colorado occurs at small scales on residential properties, limited to two 55-gallon rain barrels for landscape irrigation. Larger scale rainwater harvesting is restricted by water rights requirements, as discussed in Section 3 of this report. Nonetheless, several larger scale projects have been implemented in Colorado, typically in the context of research or pilot projects. Four case studies are provided below to illustrate the range of current rainwater harvesting projects in the state. These include basic residential rainwater harvesting (at the 110-gallon storage level), the CSU Hydro Building at the Spur campus, the Denver Green School, and Sterling Ranch.

## 4.1 Residential Rooftop Rainwater Harvesting in Colorado

In 2016, Colorado HB16-1005 officially allowed Colorado residents to implement rainwater harvesting on their properties for landscape irrigation; therefore, rainwater harvesting is still relatively new in terms of adoption. To date, while the practice is allowed across the state, the project team was not able to identify any database or other information source that has tracked or measured the implementation of residential rainwater harvesting. CSU's Colorado Stormwater Center (CSC) has provided guidance for residential rainwater harvesting, including a Rain Barrel Installation Guide (CSC 2022), an instructional video, and various workshops cosponsored by the Colorado Stormwater Council. Additionally, CSC maintains a webpage with resources related to rain barrels.[11] The Rain Barrel Installation Guide provides information on:

Photo 1. Two 55-gallon rain barrels at a residential household.
*Source*: CSU's Rain Barrel Installation Guide (CSC 2022

- Legally allowable rain barrel sizes and water uses
- Sources of rain barrels (e.g., vendors, stores)
- Materials and methods for installation
- Maintenance-related topics such as winterizing, cleaning, water quality (e.g., algae and debris), and mosquito control
- Cost estimates (~$70-90 per rain barrel with appurtenances)

Jessica Thrasher, former CSC Executive Director, reports that multiple trainings have been offered through the CSC and the Colorado Stormwater Council since passage of the residential rain barrel bill; however, current estimates of residential rain barrel installation were not readily available as of 2023. For broader scale adoption of residential rainwater harvesting in Colorado, continued outreach and training are needed. Outreach is needed to

[11] http://stormwatercenter.colostate.edu/resources/rain-barrels/

spread awareness of rainwater harvesting as a practice. Adopting households may also benefit from training on proper maintenance and operations. Informal interviews conducted during this project suggest that conservation-oriented homeowners may enthusiastically install residential rain barrels but sometimes abandon their use due to maintenance requirements related to clogging and manual watering effort. This informal finding is corroborated by research from Indiana that found 25% to 35% of households that adopted rain barrels ended the practice within five years following installation (Gao et al. 2016).

**Community Workshops Support Increased Retention Rates of Rainwater Harvesting and Other Water Conservation Practices**

The City of Tucson requires participants in the city's Rainwater Harvesting Rebate Program to attend an approved hands-on workshop (Tucson Water 2024). This incentivizes rainwater harvesting and educates customers on designing, installing, operating, and maintaining rainwater harvesting systems. Each system must be inspected and approved before customers receive the rebate. These practices increase knowledge about urban water conservation, decrease barriers to adoption, and sustain long-term participation and the accrued benefits at the residential, community, and regional scales (Gao et al. 2016; Ureta et al. 2021).

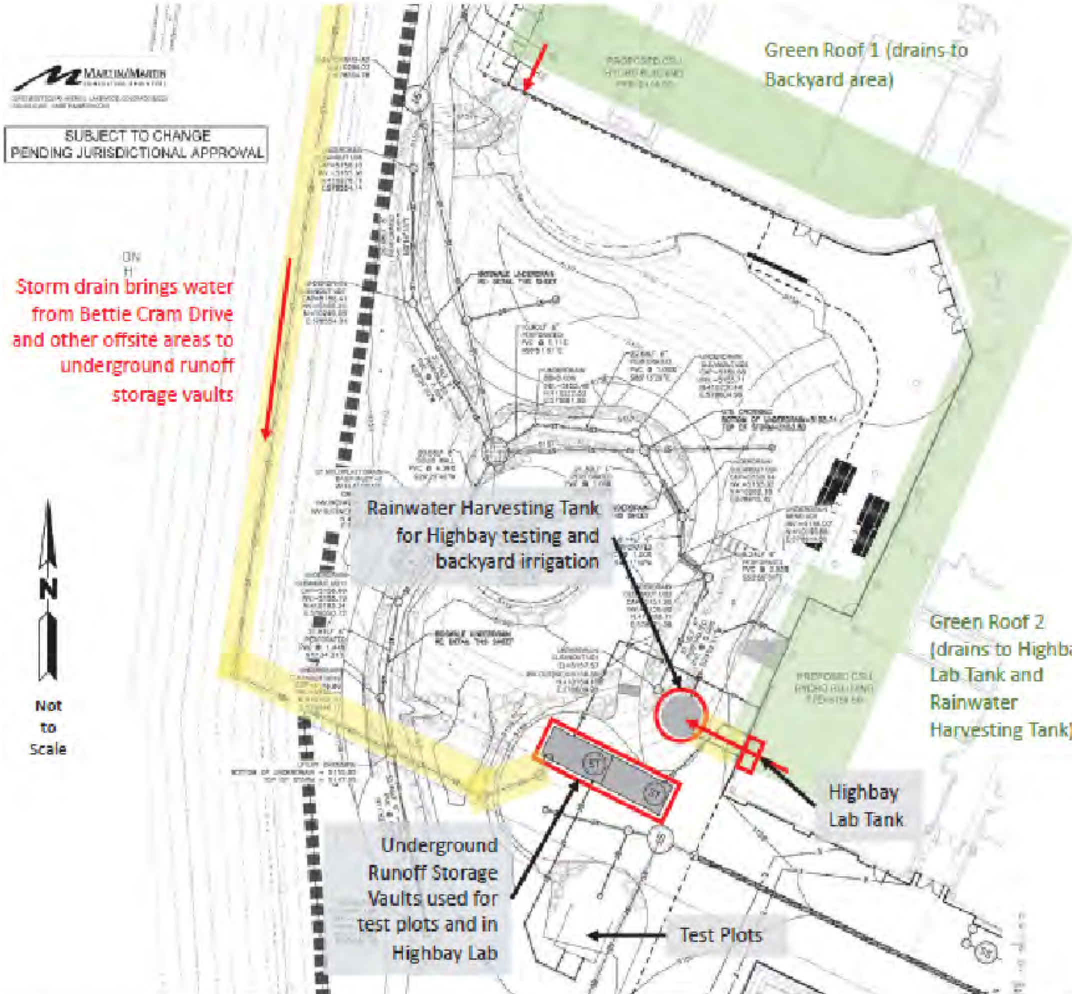
## 4.2 Colorado State University Spur

### 4.2.1 Description

The CSU Spur Campus Hydro Building Project is a 2.38-acre redevelopment project located within the National Western Complex in Denver, Colorado, which includes stormwater capture and use facilities for research and demonstration purposes. Stormwater capture facilities on the property include rainfall and runoff collection and storage components. An above-ground cistern, located in the project's "Backyard" area, stores rainwater harvested from the Hydro Building green roof and conventional roof sections. The green roof section, comprised of a vegetative layer, soil layer, gravel drainage layer, and an underdrain, does not include an internal storage system; therefore, all water captured by the green roof that is not lost to ET is stored in the above-ground rainwater harvesting tank. Water harvested from roof areas is used for experiments in a laboratory in the Hydro Building as well as for irrigation of a portion of the Backyard.

Photo 2. Cistern at the CSU Spur Campus. *Source*: Jane Clary

In addition to rainwater harvested from the rooftop, stormwater runoff is collected from the City and County of Denver's storm drainage system, which runs along Bettie Cram Drive and discharges to an underground runoff storage tank. Stormwater harvested from the storm drain system is available for testing and is used for testing different types of media and vegetation in bioretention test beds in the Backyard, or testing of different treatment processes in the Water Technology Accelerator Platform (TAP). The site drains to an on-site detention pond that discharges to the South Platte River which runs adjacent to the western edge of the project. Figure 6 provides an overview of the project, as summarized in the water rights application.




| Source Areas | |
|---|---|
| Green Roof 1 | Drains to Backyard (not harvested) |
| Green Roof 2 | Drains to Highbay Lab Tank |
| Betty Cram Dr. | Diversion from urban storm drain to Underground Runoff Storage Vaults |
| **Storage Facilities & Uses** | |
| Rainwater Harvesting Tank | 3,400-gallon above-ground tank, overflows to Backyard, water used in Highbay Lab and for demonstration irrigation project in Backyard |
| Highbay Lab Tank | 1,000-gallon lab storage tank |
| Underground Runoff Storage Tanks | 9,400-gallon tank stores runoff from Betty Cram Dr. for testing in Backyard Test Plots and Highbay Lab |


Figure 6. Colorado State University Spur Campus Rainwater Harvesting and Stormwater Capture and Use System Overview
*Source*: CSU 2022

### 4.2.2 Consumptive Uses and Storage Volumes

The storage volumes, contributing drainage areas, and consumptive uses for the rainwater and stormwater harvesting systems on the Spur Campus are summarized in Table 3 below. Consumptive uses for the stormwater harvesting system include:

- Runoff Reduction: ET from the Hydro Building green roof section is measured and accounted for as a consumptive use of the rainwater harvesting system (green roofs installed solely for stormwater management purposes following Mile High Flood District criteria typically do not require water rights).

- Research: Harvested rainwater used for laboratory experiments and irrigation of native vegetation. Stormwater harvested from the urban storm drain system is stored and used on bioretention test plots.

- Irrigation: A portion of the rainwater harvesting volume is used to irrigate the Hydro Building's Backyard landscaped area.

Table 3. Consumptive Use and Storage Volume Summary

| Storage Vessel | Contributing Runoff Area | Storage Volume | Uses |
|---|---|---|---|
| Above-Ground Rainwater Harvesting Cistern | Hydro Building conventional and green roof sections (0.31 acres) | 3,400 gal (0.01 AF) | • Runoff Reduction<br>• Research<br>• Irrigation |
| Underground Runoff Storage Tank | National Western Center Storm Drain System (26.2 acres) | 9,400 gal (0.03 AF) | • Research |
| **Total Storage Volume** | | 12,800 gal (0.04 AF) | |

## 4.2.3 Monitoring and Modeling

The system will be closely monitored to comply with the decreed augmentation plan. Monitoring of the harvesting system is anticipated to begin in 2024, following installation of monitoring equipment. Monitoring includes precipitation gauges, weirs (Photo 3), and pressure transducers so that the rainfall-runoff response is documented for stormwater research purposes and the inflows to the above-ground cistern and below-ground storage vault are thoroughly documented. This information will also support water rights-related accounting requirements under the augmentation plan.

Stormwater monitoring weir and drain at the CSU Spur Campus.
*Source:* Jane Clary

Wright Water Engineers, Inc. developed an EPA SWMM model prior to project construction to analyze the relationship between long-term rainfall and runoff. The model represents the stormwater conveyance network and the LID features of the project and uses continuous, hourly rainfall data for a period of record of 64 years between January 1949 and December 2012. Results of the modeling reported 139,000 gallons (0.43 AF) for the overall median annual depletion of the 64 years analyzed. Modeling results are summarized in Table 4 below and were the basis for calculating augmentation water requirements, as discussed in Section 4.2.5 below.

Table 4. Estimated Total Annual Depletions Related to the CSU Spur Campus Green Roof, Rainwater Harvesting Tank, and Storage Tank

| Month | All Years Median Depletion (gal) | Dry Years Median Depletion (gal) | Wet Years Median Depletion (gal) | Maximum Wet Year Depletion (gal) [1967] |
|---|---|---|---|---|
| Annual Total (gal) | 139,000 | 126,000 | 153,000 | 178,000 |
| Annual Total (AF) | 0.43 | 0.39 | 0.47 | 0.55 |

*Source*: Wright Water Engineers, Inc. 2022

## 4.2.4 Project Costs

Because this project is designed for research purposes, cost data is not directly transferable to other projects that might be established for purely water supply purposes; therefore, project costs have not been tabulated for purposes of this report. However, cost data for water rights-related requirements are available and are provided as part of the water rights discussion below.

### 4.2.5 Water Rights

A Conditional Water Storage Right and Approval of Plan for Augmentation was filed by CSU's water attorneys on May 23, 2023, in Colorado Water Court (Case No. 2022CW3056), which allowed the project to commence. The approved augmentation plan states that replacements will be made to the total annual depletions from the South Platte River which includes all consumptive uses described above in Table 4. Figure 7 shows the delivery locations of replacement water furnished to the South Platte River through a lease from Denver Water totaling 2 AF/YR, along with the Spur building location. The 2 AF/YR is expected to cover more than the maximum modeled depletion and could potentially allow for expansion of the system in the future. Results of monitoring described above will be used to support an absolute water right in the future.

The cost of leased water from Denver Water includes a non-potable water system development charge (SDC) of $18,980 per acre-foot, with CSU paying Denver Water a one-time payment of $37,960 under the agreement. (Note: the non-potable SDC cost is partially offset by a smaller potable system tap fee.) Additionally, on an annual basis, a non-potable water service rate of $289.49 per acre-foot is also applied. Regardless of the amount of water used, 50% of the annual water service rate applies under the agreement. The agreement is subject to availability of non-potable water from Denver Water, recognizing that natural water sources are variable in quantity of supply from year to year. The delivery of non-potable water from Denver Water under the lease may be limited under periods of water shortages (various stages of drought restrictions) or other system emergencies. As part of the lease agreement, at the beginning of each month, CSU's representative must notify Denver Water of the amount of water required to be replaced in the coming month based on CSU's water accounting (CSU 2022).

Of note from a water supply perspective, the rainwater and stormwater captured at the Spur campus is a new local water source, but it is not a "new water" source relative to the overall basin water supply gap because the amount diverted under the rainwater harvesting and stormwater capture and use system is being replaced by releases from Denver Water to the South Platte River (Figure 7). Nonetheless, the project is valuable for research purposes, documenting the water court process for similar projects and collecting robust data to better understand future applications of similar systems in Colorado.

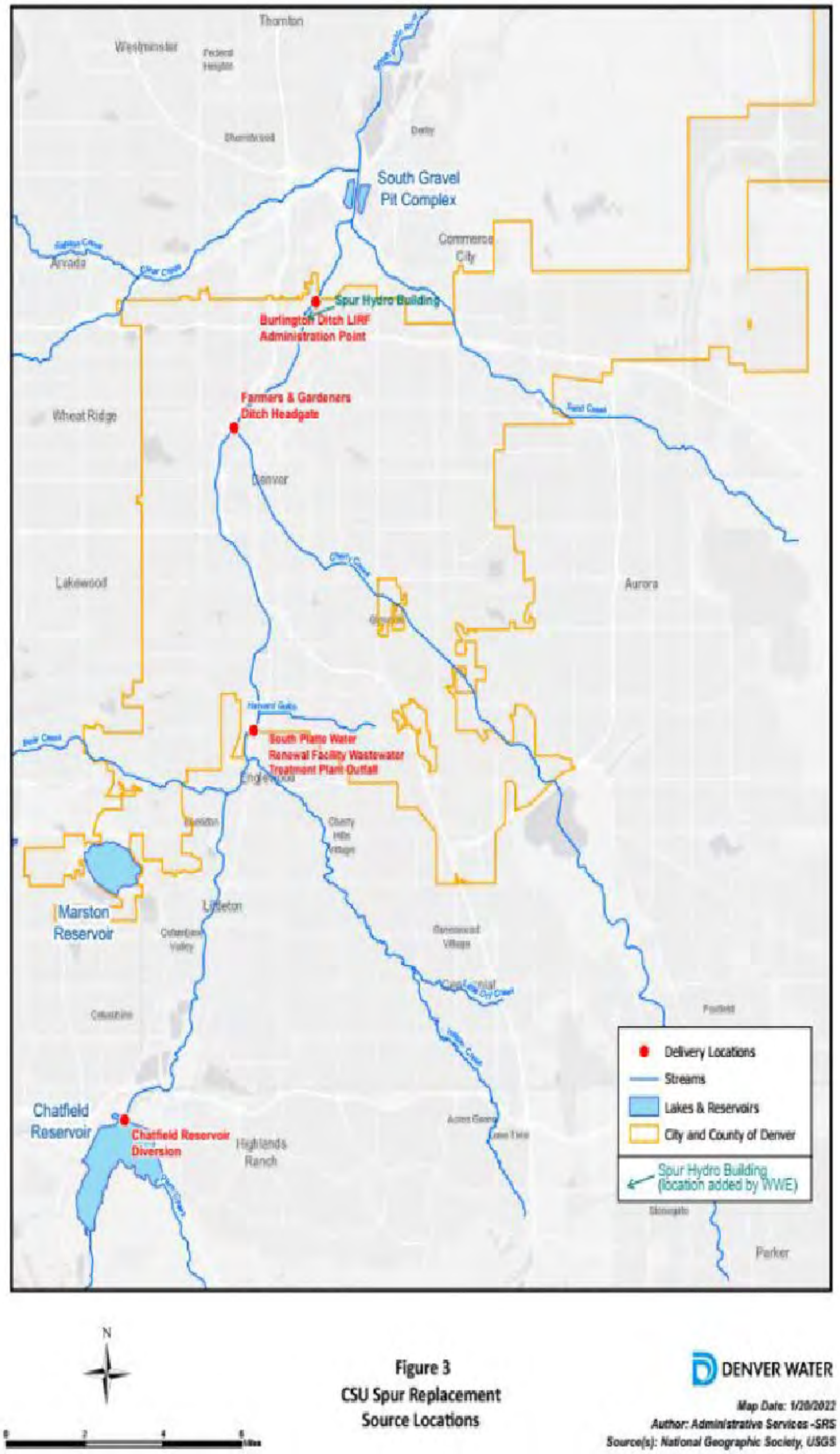



Figure 7. CSU Spur Replacement Source Locations
*Source*: Denver Water 2022

## 4.3 Denver Green School

### 4.3.1 Description

Photo 4. Cistern at Denver Green School. *Source:* Holly Piza

The Denver Green School Rainwater Harvesting System was a pilot project designed to explore the feasibility of using rainwater harvesting systems outfitted with cloud-based infrastructure as SCMs (i.e., to meet stormwater quality management requirements). The project was discontinued in 2014 due to water rights constraints. The project, located at the Denver Green School in Denver, Colorado, combined an automated control valve with weather forecasting to release water from a storage cistern in advance of a storm event (if needed) to provide storage capacity for the WQCV. One limitation of rainwater harvesting systems used as SCMs is that the storage tank may already be too full to capture the WQCV[12] for the drainage area depending on storm sequencing and water use. However, with the use of automated control valves linked to a sensor array in the cistern, discharges from the system can be made in tandem with real-time weather data to increase the efficiency of the storage tank and provide sufficient capacity for water quality storage and flood attenuation.

The rainwater harvesting system captured runoff from the roof of the Denver Green School building and discharged into a cistern for irrigation use. A pressure transducer monitored storage volumes in the cistern and transmitted the data to cloud-based software.[13] The software then used National Oceanic and Atmospheric Administration weather forecasting in tandem with the storage volume data to operate a solenoid valve to release water from the system based on estimated runoff volumes.

### 4.3.2 Consumptive Uses and Storage Volumes

The storage volumes, contributing drainage areas, and consumptive uses for the rainwater and runoff harvesting systems are summarized in Table 5. Consumptive uses for the rainwater harvesting system include:

- Irrigation: Harvested rainwater was used to irrigate 2,000 square feet (0.05 acres) of landscaping area adjacent to the Denver Green School building.

[12] See Section 3.5 for additional discussion of stormwater quality management objectives in Colorado. The WQCV is calculated based on 0.6 inches of precipitation, also known as the 80th percentile storm event, and is the basis of SCM design in Colorado (Mile High Flood District 2024).
[13] OptiRTC (https://optirtc.com/)

Table 5. Consumptive Use and Storage Volume Summary for Denver Green School

| Storage Vessel | Contributing Runoff Area | Storage Volume | Consumptive Uses |
|---|---|---|---|
| Cistern | Denver Green School building roof (0.17 acres) | 3,000 gal (0.01 AF) | Irrigation |

### 4.3.3 Monitoring and Modeling

Mile High Flood District applied for a SWSP from the CDWR to allow for construction of the Project in 2012. Monitoring of the system began September 2012 and ended in September 2014. Results of the monitoring for the 3-year period demonstrated the ability of the system to reduce runoff volumes and provide cost-effective supplemental irrigation. Results of the monitoring are presented in Table 6 below.

Table 6. Hydrologic Data for Denver Green School Monitoring (2012–2014)

| Year | Number of Storm Events | Total Precipitation (inches) | Average Runoff Reduction per Event | Percent of Total Irrigation Volume from Rainwater |
|---|---|---|---|---|
| 2012 | 6 | 0.9 | 77% | 100% |
| 2013 | 23 | 10.8 | 83% | 54% |
| 2014 | 43 | 7.7 | 92% | 91% |

*Source*: Piza 2015

A WQ-COSM continuous simulation model was developed for the project to optimize the cistern size to provide detention for the water quality event. A 30-year time series of precipitation data for the Denver area was input into the model, and the simulation determined that the WQCV for the 7,300 square foot roof drainage is the runoff volume from a 0.6-inch rainfall event, corresponding to the 80th percentile runoff-producing event. The selected 3,000-gallon cistern corresponds to a runoff volume for an approximately 0.7-inch rainfall event from the drainage area feeding the cistern.

### 4.3.4 Project Costs

The Denver Green School Project was part of a larger research project sponsored by WRF. Although engineering, water rights development and administrative costs are not provided, the costs for the system itself are provided in Table 7.

Table 7. Denver Green School Project Feature Costs

| Project Feature | Cost (2012 USD) |
| --- | --- |
| Cistern, Pump, and Downspout | $4,700 |
| OptiRTC Cloud-Based Control System. | $15,000 |
| Water Augmentation and Filling | $2,000 |
| Total | $21,700 |

*Notes*: Excludes administrative and engineering costs.

### 4.3.5 Water Rights

Mile High Flood District applied for a SWSP, which was approved by the CDWR on October 9, 2013. The plan was approved for August 2013 through July 2014. An agreement was reached for Denver Water to replace all water from depletions during the approval period under the SWSP. Use of the system was discontinued after this time period due to the ongoing cost and effort related to water rights requirements. The “contract water” used for the SWSP was not considered to be a suitable approach for the long-term augmentation plan.

Similar to the CSU Spur case study, the Denver Green School case study does not represent “new water” in terms of filling a water supply gap; however, it provided useful quantitative data applicable to other potential future projects related to how cisterns with real-time controls could be used to meet stormwater quality management requirements and reduce potable water demands for irrigation purposes.

## 4.4 Sterling Ranch[14]

### 4.4.1 Description

Sterling Ranch is a master planned community located in Northwest Douglas County, south of Chatfield Reservoir. This mixed-use residential community will eventually have more than 12,000 homes on 3,400 acres. From its inception, Sterling Ranch has included regional

[14] This case study description has been developed based on material provided by Andrea Cole of Dominion Water and Sanitation District and Dr. Ryan Gilliom and Mark Mitisek of LRE Water in 2023.

rainwater harvesting (also defined in this report as stormwater capture and use) in its planning as a supplemental renewable water supply used to offset non-potable outdoor irrigation demands. Located in a region historically reliant on declining Denver Basin groundwater with limited available renewable supplies, Sterling Ranch began evaluating rainwater harvesting as a viable water supply alternative in 2007 by helping to fund a study titled "Holistic Approach to Sustainable Water Management in Northwest Douglas County." The study evaluated the viability of precipitation as potential water supply for non-potable uses, potential savings for a new residential development incorporating outdoor water demand management and rainwater harvesting, and recommendations to implement rainwater and protect existing water rights through utilization of a legal framework and augmentation plan. As a result of the study's findings and recommendations, HB 09-1129 was introduced to the Colorado Legislature in 2009 authorizing up to 10 rainwater harvesting pilot projects throughout the state. The legislation authorizing projects under this program has a sunset date of July 1, 2026.

The Sterling Ranch rainwater harvesting program is one of the 10 pilot projects authorized by HB-09-1129 and is currently the only active pilot project in Colorado. Dominion Water & Sanitation District (Dominion), the water provider for Sterling Ranch, is the primary project sponsor. As a large-scale new residential development, the goal of the pilot project is to develop and integrate regional rainwater systems throughout the site to meet local and site-wide non-potable outdoor irrigation demands. Figure 8 is a map showing the major drainage basins within the Sterling Ranch boundary where rainwater harvesting opportunities are being evaluated. In total there are 12 projects (sites within the overall pilot project) with an estimated annual average yield of over 400 AF/YR if implemented as currently planned.

The primary objectives of the pilot project are to: 1) evaluate natural conditions (climate, hydrology, and ET) at Sterling Ranch and quantify the amount of precipitation physically and legally available as a water supply; 2) evaluate a variety of precipitation collection concepts and designs; 3) evaluate the potential water use savings of precipitation harvesting paired with advanced outdoor water demand management as a water conservation practice; and 4) develop a baseline data set and legal framework to support an engineering report and water court application for an augmentation plan to use harvested precipitation, and define a defensible water supply. In addition to these efforts, and partially funded by CWCB water plan grants, significant efforts have been made to set an example for the water community to make rainwater harvesting transferable and accessible. The pilot project has provided data and methods from the pilot project, which were used to support the development of Regional Factors as described in Section 3. In addition, the Sterling Ranch Rainwater Harvesting Feasibility Study and Operations Plan (LRE Water, Muller Engineering, and Opti 2022) identifies key project components and considerations, design criteria and requirements, operations and administration plan, and overall feasibility and permissibility of a regional rainwater project. Dominion and Sterling Ranch are proud of these efforts and remain committed to incorporating regional rainwater harvesting opportunities throughout their community and advancing rainwater harvesting as a legally obtainable water supply throughout Colorado.

Now in its 14th year, the pilot project has met the majority of the original objectives and continues to transition from planning and data collection to implementation of rainwater harvesting as a viable physical and legal supply. The remaining objectives of the project include: 1) completion of the engineering required to support a SWSP and augmentation plan;

2) design, construction, and implementation of a regional rainwater harvesting system at Sterling Gulch; and 3) completion of the final report for the pilot project. Below are the key steps and approximate timeline for completing the project:

- Sterling Ranch Rainwater Harvesting Integration Plan – July 2023
- Sterling Gulch/Providence Park Rainwater Harvesting Conceptual Design – August 2023
- Preliminary Engineering and Accounting – October 2023
- Water Court Application: Augmentation Plan and SWSP – March 2024
- Developed Conditions Monitoring Program Implementation – Spring 2024
- Sterling Gulch/Providence Park Rainwater Harvesting Final Design – Summer 2024
- Sterling Gulch/Providence Park Rainwater Harvesting Construction – Summer 2025
- Sterling Ranch Rainwater Harvesting Pilot Program Final Report – Summer 2026

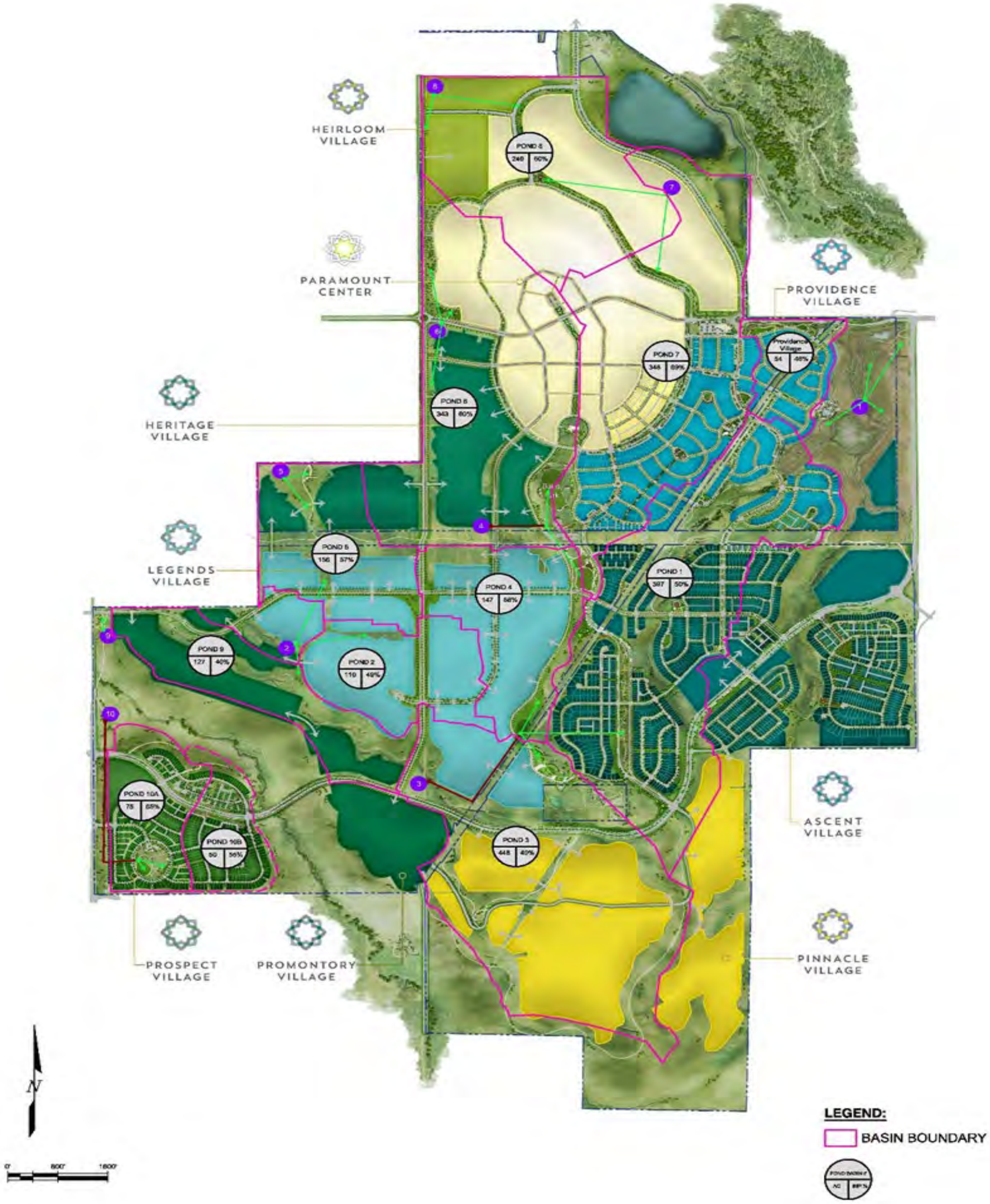



Figure 8. Sterling Ranch Vicinity Map and Location of Rainwater Harvesting Opportunities
*Source*: LRE Water 2023

### 4.4.2 Sterling Gulch Conceptual Design

After over a decade of data collection supporting the legal right to harvest rainwater as a water supply, Dominion is moving forward with the implementation of the state's first regional rainwater harvesting collection system at Sterling Ranch. Recognizing rainwater harvesting must be developed on a regional scale to be cost effective, Dominion has selected Sterling Gulch as the initial phase of this regional project. Sterling Gulch was selected as the location for the initial development demonstrating rainwater as a legally viable water supply for the following reasons:

1. Sterling Gulch is the original native basin where the majority of natural conditions data were collected supporting the site-specific factors and the legal right to harvest rainwater as a supply.
2. Sterling Gulch has a large collection area resulting in higher system yields allowing rainwater to be a cost-effective supply.
3. Dominion's augmentation supplies that will be utilized for the project are located on Plum Creek, allowing Dominion to operate under an approved SWSP/augmentation plan.
4. Sterling Gulch receives rainwater from portions of Providence Village (Filing No. 1) and portions of Ascent Village (Filing No. 2) from existing stormwater collection and conveyance systems.
5. Providence Park, a large regional park, is currently in the planning phase, allowing the rainwater system design to be easily integrated into the irrigation system and park design.
6. Existing corridors and easements allow for the conveyance and distribution of harvested rainwater from Sterling Gulch to non-potable outdoor irrigation demands at Providence Park or within the development.
7. Providence Park is located down gradient from the proposed rainwater harvesting facility, allowing for gravity operations and use of traditional irrigation pumps to reduce operational costs.
8. Lastly, the location of the rainwater harvesting facility allows for the flexibility to use rainwater directly at Providence Park, regionally through future non-potable infrastructure, or stored in other existing or future storage facilities for subsequent use.

The conceptual design of the Providence Park rainwater system at Sterling Ranch was completed in August 2023. The rainwater system includes diversion, storage, and conveyance of rainwater to meet non-potable uses. The system is designed to meet 80% of irrigation demand for the park in the driest year, requiring only 20% to be met from the potable water system. Potential uses for rainwater include irrigation for low water use plantings, trees, functional turf, and/or community supported agriculture (Figure 9). The rainwater system will be included in an augmentation plan and operate under an active SWSP to prevent injury to downstream water rights.

Figure 9. Sterling Ranch Rainwater Harvesting Project at Providence Park Features and Overview
*Source*: Dominion Water & Sanitation District 2023

### 4.4.3 Consumptive Uses and Storage Volumes[15]

There are two aspects of the Sterling Ranch Pilot Project that are noteworthy for this case study. One is the extensive hydrologic monitoring conducted at the site that supported development of HND concepts and Regional Factors (see Section 3), and the second is the 2022 Feasibility and Operation Plan to initiate a specific on-site rainwater harvesting system. Selected highlights for these two efforts are discussed briefly below, but the original reports should be reviewed to obtain a more in-depth understanding of the system.

#### Supply and Demand Estimates

For context of supply and demand, LRE Water compared observed precipitation events in the Sterling Ranch record for the years 2010–2017 in the months March–October to develop a water demand estimate. For hydrologic soil group (HSG) C, annual HND with this precipitation ranged from 0.61–2.19 inches. For 45 acres with HSG C, these depths convert to a monthly harvest volume of 2.28–8.20 AF. The median annual total harvest volume operating March–October is 42 AF, based on 2010–2017 precipitation observed at Sterling Ranch (see Table 8).

In an average Front Range residence, household water use is 0.4–0.5 AF/YR with 55% used outdoors (Waskom and Neibauer 2014). This equates to 0.22–0.25 AF of annual outdoor demand in an average home (Waskom and Neibauer 2014). At Sterling Ranch, water demand standards established from observed meter records show the average household is between 0.17 AF/YR (single-family attached) and 0.26 AF/YR (single-family detached). This is over a 50% reduction in water use when compared to an average Front Range residence. These drastic reductions in household water use are due to water-smart planning, aggressive water conservation, dual metering and outdoor water budgets, and advanced outdoor water demand management efforts.

Outdoor water use in pilot projects may be even lower than these estimates due to the combination of landscaping and irrigation system design. These estimates from Sterling Ranch precipitation demonstrate the potential for rainwater harvesting to meet outdoor water demand in Colorado and highlight the importance of pairing water conservation and advance water demand management with rainwater harvesting. Ultimately, beneficial use of rainwater harvested at pilot projects will depend on actual precipitation, storage pond sizing, and operations, and demand will depend on residential layout, landscape plantings, and irrigation system design. The sizing and usage of harvest facilities, as well as design and operation of the non-potable irrigation systems, are beyond the scope of this report.

[15] Dr. Ryan Gilliom completed the analysis and authored the summary included in this section. For additional information, see Gilliom (2019).

Table 8. Annual Historic Natural Depletion (HND) Supply Compared to Average Outdoor Demand at Sterling Ranch

| March–October | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | Median |
|---|---|---|---|---|---|---|---|---|---|
| HND supply (AF) | 19.2 | 45.3 | 26.3 | 42.4 | 52.7 | 58.1 | 29.5 | 41.6 | 42 |
| % of full demand | 22% | 51% | 30% | 48% | 60% | 66% | 34% | 47% | 48% |
| % of half demand | 44% | 103% | 60% | 96% | 120% | 132% | 67% | 95% | 95% |

*Source*: Gilliom 2019

### 4.4.4 Monitoring and Modeling

To support this project, over a decade of natural conditions data related to precipitation and runoff have been collected in support of the legal right to harvest rainwater at the site. Figure 10 shows the time period over which climate, precipitation, ET, surface water, and groundwater monitoring have been conducted to support the project.

Photo 5. Data collection at Sterling Ranch. *Source*: LRE Water

Natural conditions data collected at the site have been used in the development of site-specific factors and Regional Factors (Gilliom 2019) subsequently developed under HB-15-1016. These data have also been used to support the legal framework and water rights accounting to support development of the SWSP and augmentation plan for the project.

The estimated average annual cost for planning, administration, monitoring, and reporting for the current project implementation and water court phase is approximately $50,000 per year (LRE Water 2021). Project costs for earlier phases of the project specific to natural conditions monitoring and reporting ranged from approximately $15,000 to $30,000 per year. Cumulatively, the engineering, reporting, and monitoring costs for the pilot project over the last 13 years have exceeded $600,000, some of which was subsidized by CWCB grants. Lessons learned from this pilot project are invaluable to the water community, providing a legal framework and a path forward for future rainwater harvesting pilot projects by reducing the extent and cost of monitoring required when Regional Factors are applied.

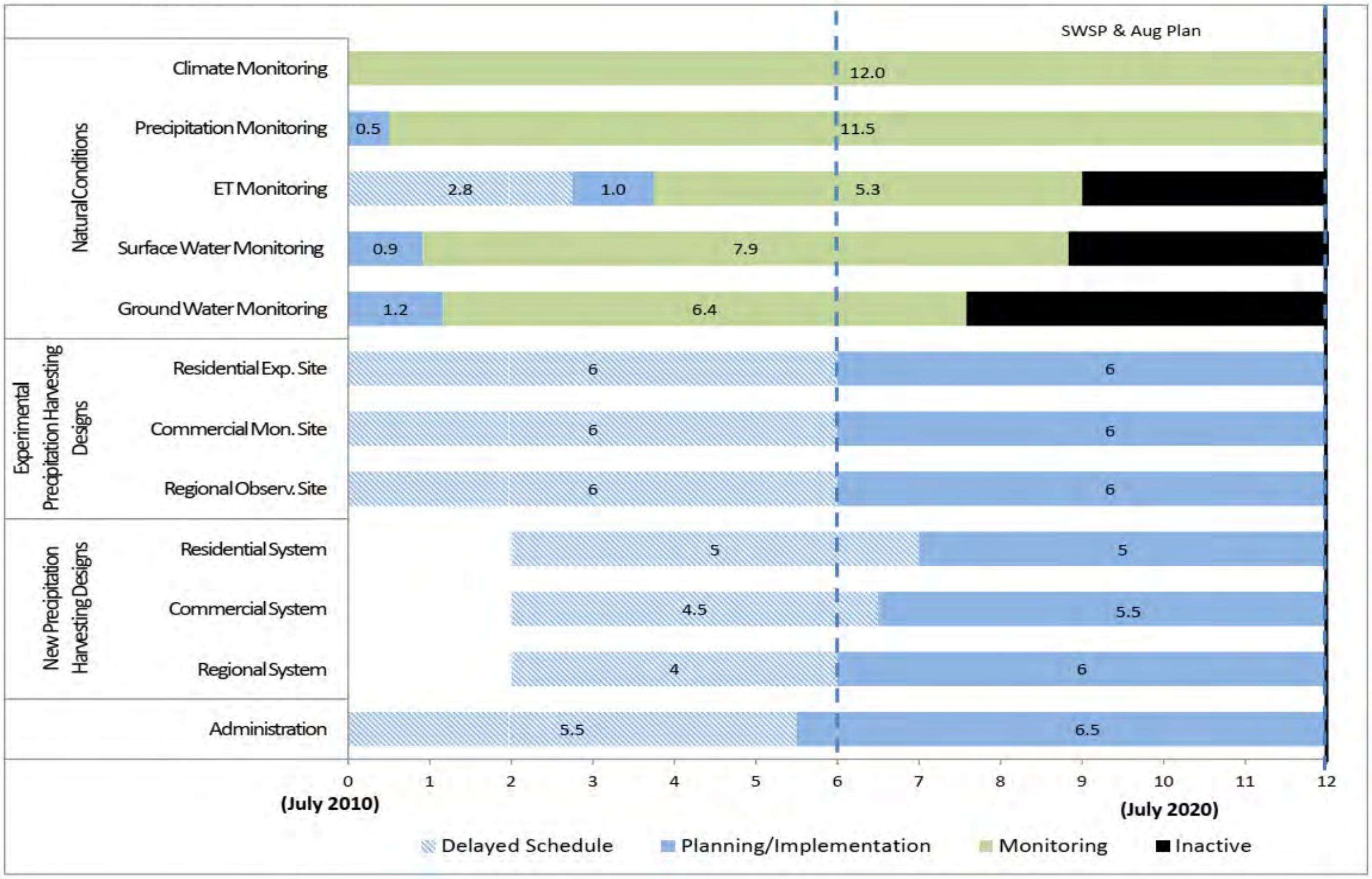



Figure 10. Sterling Ranch Rainwater Harvesting Project Monitoring, Planning, and Design Schedule
*Source*: LRE Water 2022

## 4.4.5 Project Costs

In 2023, Muller Engineering completed a conceptual design and engineer's opinion of probable cost for the design, construction, and implementation of a rainwater harvesting system at Providence Park, as shown in Table 9. This table represents the cost for only the retrofit of a large rainwater harvesting system and does not include the costs for monitoring, engineering, and legal work completed for the pilot project. Future rainwater harvesting system costs will vary based on the size and complexity of rainwater harvesting systems implemented. The two cost options presented in Table 9 represent the cost if rainwater harvesting and stormwater management requirements are integrated in a single facility versus if dual facilities are required.

Table 9. Opinion of cCost Options for Design, Construction, and Implementation of a Rainwater Harvesting Facility at Providence Park in Sterling Ranch

| Task Description | Single Integrated Facility | Dual Facility |
|---|---|---|
| Regional Rainwater Harvesting System Design | $318,000 | $381,000 |
| Regional Rainwater Harvesting System Construction | $1,526,793 | $1,829,445 |
| Administration, Monitoring, Operations, and Accounting Protocols | $75,178 | $93,149 |
| **Total** | **$1,919,971** | **$2,303,593** |

*Source*: Mitisek et al. 2023, updated based on personal communication with Mark Mitisek December 2023

A major project constraint that increases costs for the project is that existing stormwater ponds cannot be integrated with harvested rainwater due to the state stormwater statute (C.R.S. 37-92-602(8)(e)), which limits the use of stormwater detention and infiltration facilities.

Another cost-related lesson from the feasibility study was that planning, design, and construction of rainwater facilities should be done concurrently with new development layouts and runoff collection systems to reduce rainwater harvesting system cost. Retrofitting facilities can result in an increase in costs and reductions in project yield if storage options are limited at a site (LRE Water, Muller Engineering, and Opti 2022).

### 4.4.6 Water Rights

As discussed in Section 3, the concept of HNDs is central to the Sterling Ranch pilot project. A significant benefit of the Sterling Ranch pilot project has been the development of key technical documents related to HNDs and Regional Factors, which are discussed in more detail in Section 3.

The water rights discussion for this project is complicated and not easily synthesized in a simple case study. However, the guiding principles for the system are stated as simply as possible below:

1. The HND volume available for each rainfall event will be quantified based on observed rainfall and established site-specific factors.

2. The total physical inflow volume into the rainwater harvesting facility from the rainfall event will be quantified based on observed (metered) inflows.

3. The lesser of the HNDs volume or physical inflow volume is the amount that legally can be harvested without augmentation. Physical inflow volumes greater than the HNDs will need to be augmented or released (i.e., surface water augmentation).

4. Groundwater augmentation requirements are accounted for separately based on observed rainfall.

5. Any physical inflows captured in priority (free river) do not need to be replaced.

6. All legally harvested or augmented volumes can be put directly to beneficial use or stored for subsequent use.

Detailed daily water rights accounting is required, providing the following information to local water administrators:

7. All new inflow will have been allocated to the legal harvest, augmented, or out-of-priority volumes.

8. The out-of-priority volume will be released.

## 4.5 Summary

As of 2024, rainwater harvesting and stormwater capture and use projects remain relatively limited in Colorado. The case studies included in this section illustrate some of the challenges with broad-scale implementation of rainwater harvesting and the importance of empirical data in determining actual downstream impacts on senior water rights holders (who are also harvesting water).

Recommendations and lessons learned to date in Colorado include:

- If broader adoption of site-scale residential rain barrel use is desired in Colorado, then additional outreach and incentives are needed to increase usage. This includes outreach to municipal entities to establish education and implementation assistance. Continued partnerships between water conservation and stormwater managers in outreach efforts may help to encourage broader adoption of rain barrels.

- For rainwater harvesting and stormwater capture and use beyond 110 gallons per residential household, water rights requirements must be addressed through the water court process, which requires both engineering and legal support. Costs associated with engineering and legal support to navigate this process, the cost of purchase or lease of augmentation water, ongoing cost of water rights accounting and lease requirements, and uncertainty related to water court remain barriers to implementation of larger scale rainwater harvesting and stormwater capture and use in Colorado.

- The Sterling Ranch pilot project will continue to be a key case study to advance dialogue about downstream impacts of rainwater harvesting and to better understand what volumes of augmentation water are needed for rainwater harvesting projects in new development to prevent injury to downstream water users. This science-based approach based on empirical data is a necessary foundation for future rules and policies related to rainwater harvesting.

# 5 Quantifying the Volumetric Potential of Rainwater Harvesting and Urban Stormwater Runoff in Colorado

To quantify the volumetric potential of rainwater harvesting and stormwater runoff for potential capture and use in Urban Areas[16] in Colorado, the project team developed a common set of hydrologic assumptions and methods and then applied these methods to several potential scenarios to create a range of estimates. These estimates are then compared to various water demands from the Colorado Water Plan in Colorado's river basins with urbanized areas. This section includes the following information:

1. Methods and assumptions used in the hydrologic analysis.

2. Rainwater harvesting estimates for the currently allowable 110-gallon rainwater harvesting scenario and a hypothetical 500-gallon rainwater harvesting scenario, with various adoption rates applied to each scenario. The 110-gallon scenario does not require a water right; conversely, the 500-gallon scenario would require water rights.

3. Urban stormwater runoff from 1) existing impervious surfaces, including rooftops; and 2) urban stormwater runoff from existing impervious surfaces minus roadways. These stormwater runoff scenarios for existing impervious areas are not indicative of "new water" supplies, and any capture and use of this urban stormwater would require water rights to implement.

4. Building on estimates from #3, stormwater runoff estimates for future (new) urban impervious areas adjusted to HNDs in hypothetical land development scenarios using the South Platte River Basin as an example.

These selected rainwater harvesting and urban stormwater runoff volume scenarios are then compared to various basin-level residential outdoor water demand estimates from the Colorado Water Plan.

## 5.1 Methods and Assumptions for Precipitation and Stormwater Runoff Calculations

Hydrologic analysis supporting this report focused on estimating stormwater runoff volumes from residential rooftops and other impervious surfaces in Urban Areas at both the basin and statewide scales. Unlike models used to design stormwater infrastructure to help reduce water quality impacts from runoff and meet regulatory requirements, the outcomes of this work are intended for conceptual-level water planning. Appendix E describes the techniques and procedures used for this analysis in detail, with a simplified summary of key assumptions provided below. In this section, estimates are summarized at the basin scale and totaled for urbanized areas in the state; however, supporting tables with precipitation and runoff estimates at the urban area scale are provided in Appendices F-1 and F-2.

[16] For this report, Urban Area is defined by the US Census Bureau's 2020 urban-rural classification as described in US Census Bureau (2022). In general, urban areas under this classification represent land areas with densely developed territory, including residential, commercial, and other non-residential urban land uses.

The project team used ArcGIS Pro for the geospatial components of the analysis, beginning with the Colorado's Basin Roundtable Boundary polygons, which demarcate the major river basins across the state, and the US Census Bureau's 2020 urban-rural polygons (CWCB and CDWR 2020; US Census Bureau 2023). The only exception to the major river basins is the Metro basin, which is a subsection of the South Platte River basin, but for simplicity we refer to it as a basin, like the others. Where Urban Areas crossed basin boundaries, they were split for estimating stormwater runoff. Based on the geospatial processing, 65 unique Urban Area polygons and associated acreages were defined for use in the analysis.[17] No Urban Area polygons were in the North Platte basin, so no results are presented for this basin. Figure 11 provides a map of Colorado's nine major basins and Urban Areas.

Other assumptions used in the geospatial analysis include:

- **Impervious Cover:** Impervious cover percentages were calculated based on the 2019 National Land Cover Database (NLCD) (Dewitz and US Geological Survey 2021) for each of the 65 urban polygons. Land use classifications include "Pervious" and numerous impervious (e.g., "Primary Road," "Secondary Road," "Tertiary Road," "Thinned Road," and "Non-Road Impervious") land cover classifications. For all calculations, "Primary Road" impervious areas were removed as these represent major highways and freeways, which generate stormwater that would require substantial treatment prior to use.

- **Elevation:** Elevation was used to delineate the "winter months" for each Urban Area polygon (LANDFIRE, Earth Resources Observation and Science Center (EROS), USGS 2022) so that snowfall would be excluded from stormwater runoff estimates. Non-winter months were defined as April through October for polygons with mean elevations less than 8,500 feet above mean sea level (FAMSL) and June through September for polygons with mean elevations greater than or equal to 8,500 FAMSL.

- **Precipitation:** Daily one kilometer precipitation depth rasters were used to estimate average annual precipitation for each Urban Area for January 1, 1990 through July 31, 2022 (the most recent day Parameter-elevation Regressions on Independent Slopes Model (PRISM) rasters were available at time of download) (PRISM Climate Group 2022).

[17] The Urban Area polygons that were split by the Identity tool (into noted basins) included: Colorado Springs (Arkansas, Metro), Denver–Aurora (Metro, South Platte), Grand Junction (Colorado, Gunnison), Lafayette-Erie-Louisville (Metro, South Platte), and Woodland Park (Arkansas, Metro).

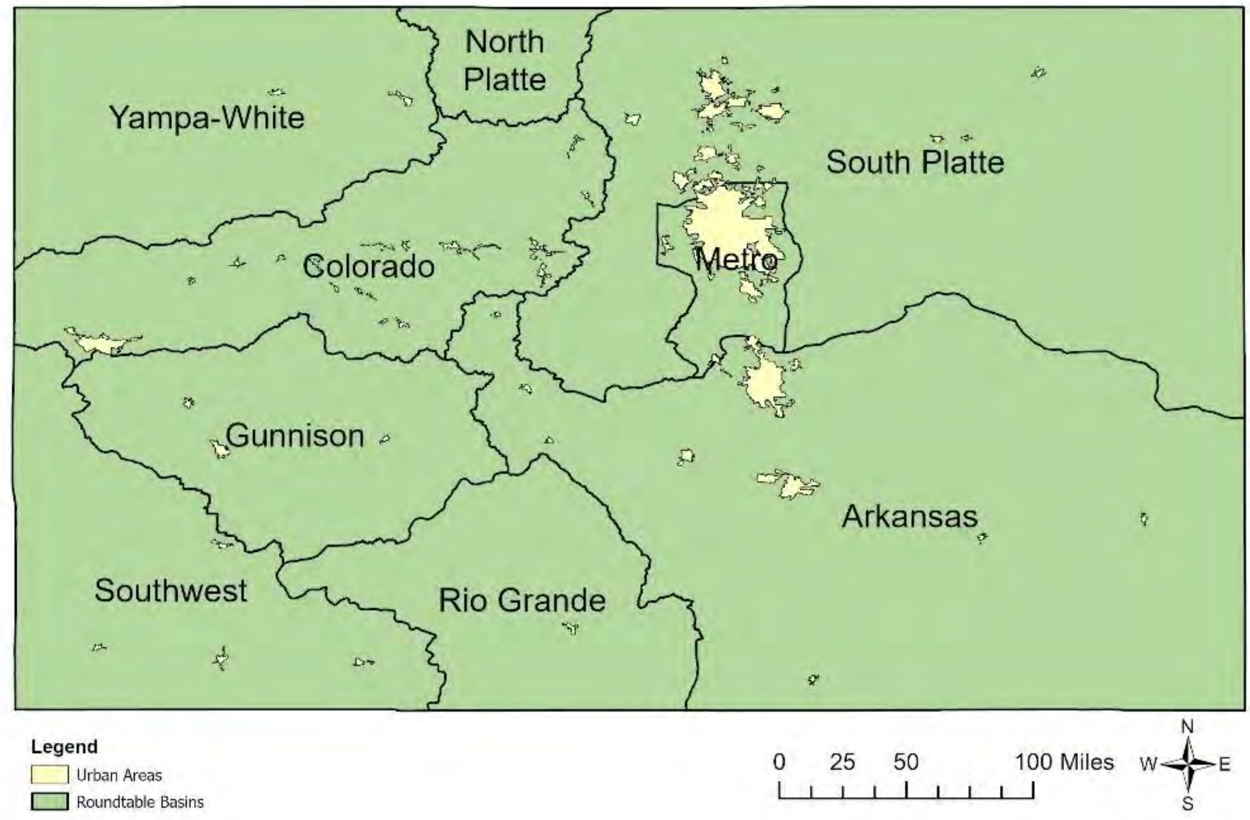



Figure 11. Map of Colorado River Basins Showing Location of Urban Areas (yellow) and River Basins (black outlines)
*Sources*: CWCB and CDWR 2020; US Census Bureau 2023

Using the R programming environment, daily precipitation time series were generated for each urban polygon based on the PRISM precipitation data, then the precipitation time series was transformed into a runoff time series using volumetric runoff coefficients (Rv) developed by Pitt (1987). Because volumetric runoff coefficients vary by storm depth and impervious area type, they provide a more refined approach for estimating runoff than other simplified methods while still being general enough to apply to a basin scale analysis. The appropriate runoff coefficient for each Urban Area was determined by the daily precipitation depth. Runoff was forced to zero inches per day if the daily precipitation depth was less than or equal to 0.08 inches per day since events of this magnitude and smaller do not typically produce runoff (Mile High Flood District 2024).

The runoff time series was then converted to runoff volumes from impervious areas by multiplying the mean daily runoff depth of each urban polygon by the number of impervious acres comprising the polygon. Precipitation that likely fell as snow was removed from the runoff volume calculation by removing precipitation from "winter" months. While harvesting runoff from snowmelt is possible, water harvesting in winter months is challenging in Colorado due to freezing conditions, requiring many systems to be winterized. Additionally, this study focuses on irrigation uses of captured water; the lack of irrigation demand outside the growing season is another reason that winter months were excluded from this analysis. In a future analysis, other uses of captured stormwater could be considered with different assumptions related to winterized systems, if desired.

Based on this analysis, yearly and period-of-record statistical summaries of the runoff time series were generated for each Urban Area polygon and for each basin using "R" software. Summaries include the mean annual volume of impervious runoff produced over the 32-year period of record, the mean annual depth (normalized by area) of impervious runoff produced over the 32-year period of record, and metrics that describe the distribution of the runoff series (e.g., standard deviation, 5th percentile, 50th percentile, 95th percentile, etc.).

**Volumetric Runoff Coefficients**

Dr. Robert Pitt developed volumetric runoff coefficients ($R_v$) as an approach to estimate runoff generated by various rainfall event depths for various types of land cover, as summarized below. These coefficients were developed to support the Small Storm Hydrology Method (Pitt 1987) used to estimate the runoff volume from urban and suburban land uses for relatively small storm events. The coefficients were developed based on extensive field research conducted in the Midwestern United States, the Southeastern United States, and Ontario, Canada, over a wide range of land uses and storm events. Runoff coefficients for individual source areas generally vary with the rainfall amount. Larger storms have higher coefficients.

| Rain Depth mm | Rain Depth inches | Flat roofs* (or large unpaved parking areas) | Pitched roofs* | Large impervious areas• | Small impervious areas and streets | Sandy soils | Typical urban soils | Clayey soil |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.04 | 0.00 | 0.25 | 0.93 | 0.26 | 0.00 | 0.00 | 0.00 |
| 3 | 0.12 | 0.30 | 0.75 | 0.96 | 0.49 | 0.00 | 0.00 | 0.00 |
| 5 | 0.20 | 0.54 | 0.85 | 0.97 | 0.55 | 0.00 | 0.05 | 0.10 |
| 10 | 0.39 | 0.72 | 0.93 | 0.97 | 0.60 | 0.01 | 0.08 | 0.15 |
| 15 | 0.59 | 0.79 | 0.95 | 0.97 | 0.64 | 0.02 | 0.10 | 0.19 |
| 20 | 0.79 | 0.83 | 0.96 | 0.97 | 0.67 | 0.02 | 0.11 | 0.20 |
| 30 | 1.2 | 0.86 | 0.98 | 0.98 | 0.73 | 0.03 | 0.12 | 0.22 |
| 50 | 2.0 | 0.90 | 0.99 | 0.99 | 0.84 | 0.07 | 0.17 | 0.26 |
| 80 | 3.2 | 0.94 | 0.99 | 0.99 | 0.90 | 0.15 | 0.24 | 0.33 |
| 125 | 4.9 | 0.96 | 0.99 | 0.99 | 0.93 | 0.25 | 0.35 | 0.45 |

## 5.2 Methods for Residential Rooftop Rainwater Harvesting Estimates in Urban Areas

Estimating rainwater harvesting potential provides a baseline for understanding the current allowable volume of stormwater available for capture and use in Colorado. These estimates were based on the current allowance (without a water right) of up to 110 gallons of harvested rainwater per residential household with four or fewer units. The project team also used a hypothetical scenario of rainwater harvesting potential using 500 gallons per residential household to understand the volumetric potential of larger capture volumes, recognizing that this would require water rights. Estimates are provided for basins for wet, dry, and average rainfall years, and are based on a range of rain barrel adoption rates for residential households that currently exist within Urban Areas in Colorado.

Building on the analysis in Section 5.1, rainwater harvesting estimates required two additional steps: determination of housing units in each basin and additional hydrologic analysis using continuous simulation to account for rain barrel filling and emptying, as described below.

### 5.2.1 Determination of Housing Units by Urban Area and Basin

The project team calculated the total number of residential households (1–4 units in size) in each Urban Area by combining county-level housing data from the American Community Survey (US Census Bureau 2021a) with data from the 2020 US Census and the same Urban Area polygons used in the previous analysis (US Census Bureau 2022; 2023).[18] In GIS, the project team matched county-level housing data to Urban Areas and assigned Urban Areas to a single basin using a majority rule.[19] The final output of this step was a table summarizing the number of 1–4 unit households in each basin (Table 10). For detailed methods, see Appendix E-2 and for the number of residential households per Urban Area, see Appendix F.

Table 10. Estimated Number of Residential Households (1–4 Units) by Basin

| Basin | Number of Residential Households (1-4 units) |
|---|---|
| Arkansas | 307,003 |
| Colorado | 112,190 |
| Gunnison | 16,719 |
| Metro | 869,666 |
| Rio Grande | 4,027 |
| South Platte | 304,129 |
| Southwest | 18,880 |
| Yampa-White | 11,550 |

*Sources*: US Census Bureau 2021b; 2022

### 5.2.2 Rain Barrel Storage Assumptions for Residential Roof Runoff

As an additional exercise related to the stormwater runoff calculations described in Section 5.2.1, the project team developed a continuous simulation model to estimate the volume of rainwater that could be harvested from an "average" household roof in Colorado, incorporating storm frequency rain barrel filling and emptying. The rain barrel filling/emptying model was built in "R" software using the precipitation and runoff time series described above. First, to understand the typical duration of inter-event periods in Colorado, the

[18] For this analysis, the total number of units included in the American Community Survey data in the following size ranges were used: 1 unit detached, 1 unit attached, 2 units, 3 or 4 units, and mobile homes.
[19] There was one exception to this rule which we applied to Woodland Park. Woodland Park fell slightly more in the Metro Basin, but the project team assigned it to the Arkansas Basin under the assumption that a majority of runoff from the Urban Area flows into Fountain Creek, which is part of the Arkansas Basin.

number of dry days (24-hour precipitation depth less than 0.08 inches) between rain events was calculated for each Urban Area polygon over the entire precipitation time series (1990 to 2022) (excluding wintertime precipitation). The median number of dry days between precipitation events was calculated for each Urban Area polygon from the remaining dataset, which was used in a later step for the number of days before rain barrels or cisterns were considered emptied and able to collect additional water.

For each step in the precipitation time series, the daily precipitation depth was transformed to a runoff volume in gallons based on average roof area. Runoff then accumulated in the barrel until the rain barrel capture volume was reached. Once full, the rain barrel could not capture additional runoff until it emptied. Similarly, if rain began accumulating in the rain barrel but then it stopped raining before the full capture volume was reached, the volume in the barrel remained static until the barrel emptied or it started raining again, whichever happened first. A rain barrel emptied once the number of consecutive dry days calculated in the previous step occurred. Specifically, the median duration of the calculated interevent (dry) period for each urban polygon was used as the required number of consecutive dry days, meaning this input value varied by Urban Area (other methods could also be used to estimate emptying and filling.) Summary statistics were calculated from the model output, including the annual runoff volume captured in a single barrel or cistern for each Urban Area polygon along with average annual volume captured in a dry ($10^{th}$ percentile precipitation) and wet ($90^{th}$ percentile precipitation) year.

### 5.2.3 Storage Volume, Roof Area, and Capture Efficiency

The continuous simulation model was designed to evaluate the volume of rainwater captured in the rain barrel of a residential household with a given roof size and capture utilization rate. For each model run, the project team defined the storage capture volume (gallons), roof area size (square feet), and capture efficiency rate (%). For all simulations, the project team used the same values for roof area size and capture efficiency as there was little information in the literature to determine how these factors might vary across the state. Assumptions used in the analysis include:

- **Rain Barrel Capture Volume:** For the rain barrel capture volume, the project team assumed that each house would have two 55-gallon rain barrels for a total of 110 gallons per household, but also that the total functional storage space of these two barrels was 88 gallons. This was based on the observation that for many rain barrels, head space above the level of the inflow valve and dead space below the bottom of the outflow point reduce the storage capacity of the barrels (Thrasher 2023). The amount reduced for these estimates represents 11 gallons per barrel, which is approximately equal to the area within a cylinder that is 6 inches tall and 2 feet in diameter. A similar deduction was applied to the 500-gallon cistern scenario. The total functional storage space assumed for the cistern was 450 gallons, a 10% reduction.

- **Residential Roof Size:** The project team could not identify measured or scientifically derived data on residential household roof sizes in Colorado (especially for roofs of 2–4-unit households), and a full geospatial analysis of satellite data to quantify household roof sizes for the state was beyond the scope of the project. To determine a reasonable roof size for the analysis, we analyzed the impact of roof size on the estimated annual volume of capture from a 110-gallon barrel. This revealed that beyond approximately 1,800 square feet, the volume of the barrel is the largest constraint on the total volume of runoff captured and stored. Ultimately, the project team chose to use a roof area of 1,500 square feet for all calculations, which provides a more conservative estimate of total rooftop rainwater capture potential.

- **Capture Efficiency:** We assumed that two 55-gallon barrels or one 500-gallon cistern would only be able to capture rainwater from 85% of each roof, i.e., a capture efficiency rate of 85% was used for all rainwater harvesting calculations. This was based on an assumption that a majority, but not all, of a residential roof is connected to a downspout.

### 5.2.4 Rain Barrel Adoption Rates

Adoption rates of rain barrels by residential households in Colorado affect rainwater harvesting capture volume estimates. For the analysis, the project team used a range of hypothetical adoption rates of households installing rain barrels or cisterns (5%, 10%, 25%, and 50%), to evaluate the variation in the volume that could be captured. We chose the upper limit of 50% adoption as an optimistic and ambitious rate; existing studies of rain barrel adoption rates more commonly find rates of <1% to 30% (Thurston et al. 2010; Olson and Roesner 2015; Shin and McCann 2018). Furthermore, evidence suggests that rain barrel adoption is positively correlated with income and environmental attitudes (Ando and Freitas 2011; Gao et al. 2016). Table 11 shows the potential number of 55-gallon rain barrels in each basin across various adoption rates. See Appendix F-3 for the potential number of 55-gallon rain barrels across adoption rates by each Urban Area polygon.

Table 11. Potential Number of 55-Gallon Rain Barrels by Basin Across Adoption Rates

| Basin | Number of Residential Households (1–4 units) | Percent (%) of Households Adopting | | | |
|---|---|---|---|---|---|
| | | 5% | 10% | 25% | 50% |
| Arkansas | 307,003 | 30,695 | 61,395 | 153,497 | 307,003 |
| Colorado | 112,190 | 11,211 | 22,430 | 56,085 | 112,190 |
| Gunnison | 16,719 | 1,669 | 3,343 | 8,357 | 16,719 |
| Metro | 869,666 | 86,963 | 173,932 | 434,829 | 869,666 |
| Rio Grande | 4,027 | 402 | 805 | 2,013 | 4,027 |
| South Platte | 304,129 | 20,401 | 60,821 | 152,054 | 304,129 |
| Southwest | 18,880 | 1,886 | 3,774 | 9,436 | 18,880 |
| Yampa-White | 11,550 | 1,154 | 2,309 | 5,773 | 11,550 |

*Notes*: Assumes each adopting household installs two barrels, but rounding errors have in some cases led to estimates being off by one barrel per basin.

## 5.3 Potential Rainwater Harvesting and Stormwater Capture Volumes

This section summarizes results of statewide hydrologic analysis by basin for these scenarios:

1. Residential rainwater harvesting potential allowed without a water right under current Colorado water law (in two 55-gallon rain barrels, totaling 110 gallons of capture, and 88 gallons of functional capture).

2. Residential rainwater harvesting potential with a larger hypothetical capture volume in a 500-gallon cistern (and 450 gallons of functional capture), which would require water rights to implement.

3. Estimated annual urban stormwater runoff volumes from existing impervious areas by basin.

4. Estimated annual urban stormwater runoff volumes per impervious acre (from #3) applied to hypothetical land development scenarios in the South Platte River Basin with volumes adjusted by Regional Factors. This scenario provides an example of how stormwater capture and use potential could be estimated for other basins in Colorado.

These results are intended to be considered by Basin Roundtables, urban water suppliers, and policymakers to begin to assess opportunities for stormwater capture and use as part of water supply planning in Colorado.

### 5.3.1 110-gallon Rainwater Harvesting Scenario

Table 12 summarizes the annual rainwater harvesting volumes that may be collected in two 55-gallon (functionally 88-gallons total) rain barrels per residential household by basin for an average, dry, and wet rainfall year. The values presented in the table were calculated as weighted averages based on the number of 1–4-unit residential households in each Urban Area within the basin. See Appendices F-1 and F-2 for a summary of average rainwater volumes by Urban Area.

Table 12. Annual Rainwater Harvesting Potential per Residential Household in Two 55-Gallon Rain Barrels by Basin

| | Potential Annual Rainwater Capture Volume per Residential Household (Gallons) | | |
|---|---|---|---|
| **Basin** | **Average Year** | **Dry Year** | **Wet Year** |
| Arkansas | 896 | 735 | 1,092 |
| Colorado | 663 | 486 | 803 |
| Gunnison | 605 | 442 | 745 |
| Metro | 885 | 672 | 1,136 |
| Rio Grande | 578 | 440 | 705 |
| South Platte | 797 | 568 | 1,004 |
| Southwest | 677 | 458 | 885 |
| Yampa-White | 879 | 739 | 1,051 |

*Notes*: An average year represents the mean precipitation for the basin, dry is 10$^{th}$ percentile, and wet is 90$^{th}$ percentile. These represent volumes that do not require water rights to capture and use.

Table 13 summarizes estimates by basin of residential rainwater harvesting potential for existing development in Colorado's Urban Areas using two 55-gallon rain barrels. This scenario is legally allowed without requiring water rights. Corresponding to Table 13, Figure 12 provides a bar chart showing average annual rainwater harvesting potential by basin, and for the state, across several hypothetical rain barrel adoption rates. Error bars indicate the range from a dry to wet year. The differences between wet, average, and dry years are more pronounced at higher adoption rates and at the statewide level. At smaller adoption rates and for basins with a small potential overall, the wet and dry year differences are not very pronounced.

The Metro Basin has the highest estimated rainwater harvesting potential of all basins ranging from 118 AF/YR at an adoption rate of 5% to 1,180 AF/YR at a 50% adoption rate. The Rio Grande has the lowest potential with zero (less than 1 AF/YR) estimated potential at a 5% adoption rate and 4 AF/YR at a 50% adoption rate. This variation is due to the large difference in the number of households in Urban Areas in these basins (see Table 10 for number of households per Urban Area and basin), and, to a lesser degree, by the average annual precipitation in non-winter months. Statewide, the average annual residential rainwater harvesting potential using two 55-gallon rain barrels at a 5% adoption rate is 214 AF/YR, or 2,143 AF/YR at a 50% adoption rate.

Table 13. Annual Rainwater Harvesting Potential by Basin for Two 55-Gallon Rain Barrels at Existing Residences in Urban Areas Across Adoption Rates

| Basin | Percent (%) of Households Adopting Two 55-Gallon Rain Barrels | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 5% | | 10% | | 25% | | 50% | |
| | AF/YR | MG/YR | AF/YR | MG/YR | AF/YR | MG/YR | AF/YR | MG/YR |
| Arkansas | 42 (35-51) | 13.8 (11.3-16.8) | 84 (69-103) | 27.5 (22.6-33.5) | 211 (173-257) | 68.8 (56.4-83.8) | 422 (346-515) | 137.6 (112.8-167.7) |
| Colorado | 11 (8-14) | 3.7 (2.7-4.5) | 23 (17-28) | 7.4 (5.5-9.0) | 57 (42-69) | 18.6 (13.6-22.5) | 114 (84-138) | 37.2 (27.3-45.1) |
| Gunnison | 2 (1-2) | 0.5 (0.4-0.6) | 3 (2-4) | 1.0 (0.7-1.2) | 8 (6-10) | 2.5 (1.8-3.1) | 16 (11-19) | 5.1 (3.7-6.2) |
| Metro | 118 (90-152) | 38.5 (29.2-49.4) | 236 (179-303) | 76.9 (58.5-98.8) | 590 (448-758) | 192.3 (146.1-246.9) | 1,180 (897-1,515) | 384.6 (292.3-493.8) |
| Rio Grande | 0 (NA) | 0.1 (0.1-0.1) | 1 (1-1) | 0.2 (0.2-0.3) | 2 (1-2) | 0.6 (0.4-0.7) | 4 (3-4) | 1.2 (0.9-1.4) |
| Southwest | 2 (1-3) | 0.6 (0.4-0.8) | 4 (3-5) | 1.3 (0.9-1.7) | 10 (7-13) | 3.2 (2.2-4.2) | 20 (13-26) | 6.4 (4.3-8.4) |
| South Platte | 37 (26-47) | 12.1 (8.6-15.3) | 74 (53-94) | 24.2 (17.3-30.5) | 186 (132-234) | 60.6 (43.2-76.3) | 372 (265-469) | 121.2 (86.3-152.7) |
| Yampa/ White | 2 (1-2) | 0.5 (0.4-0.6) | 3 (3-4) | 1.0 (0.9-1.2) | 8 (7-9) | 2.5 (2.1-3.0) | 16 (13-19) | 5.1 (4.3-6.1) |
| Total | 214 (163-270) | 69.8 (53.2-88.1) | 428 (326-541) | 139.7 (106.4-176.2) | 1,072 (816-1,352) | 349.2 (265.9-440.6) | 2,142 (1,632-2,704) | 698.3 (531.8-881.2) |

*Notes*: Values provided in AF/YR and MG/YR. Values presented include a year with average rainfall, while values in parenthesis represent $10^{th}$ percentile rainfall amount and $90^{th}$ percentile rainfall amount, respectively.

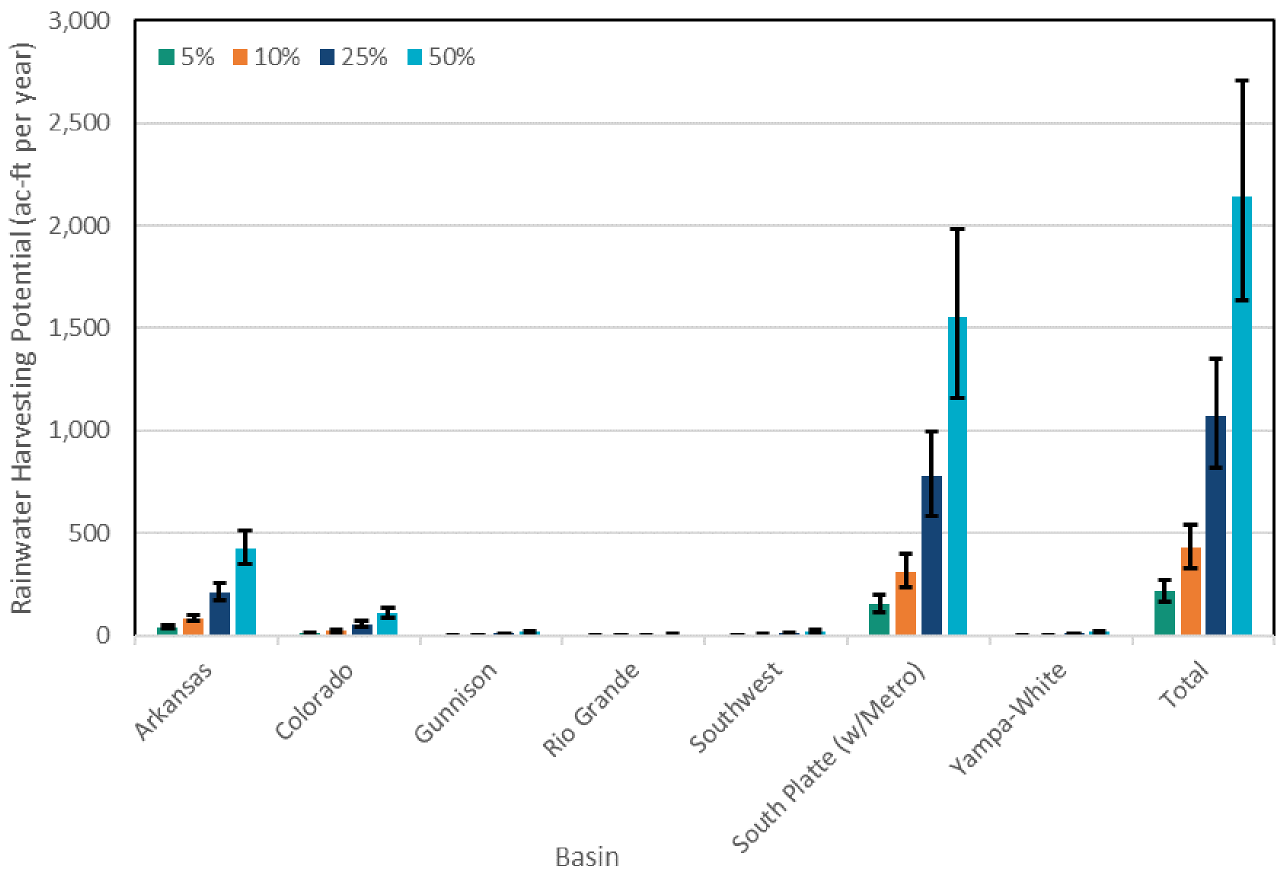



Figure 12. Estimated Rainwater Harvesting Potential by Basin from Two 55-Gallon Rain Barrels Across Adoption Rates

*Notes*: Error bars show the range in potential between a dry year (bottom, $10^{th}$ percentile) and a wet year (top, $90^{th}$ percentile). Harvesting potential presented in AF/YR.

Table 14 summarizes the estimated rainwater harvesting potential for two hypothetical rain barrel adoption rates alongside Colorado Water Plan's 2015 Residential Outdoor Demand Baseline and the 2050 Residential Outdoor Business as Usual (BAU) outdoor landscape irrigation estimates (ELEMENT Water Consulting, Inc 2019). While some states allow rainwater and stormwater to be treated and used for purposes beyond irrigation, Colorado law currently restricts rainwater captured on residential properties in rain barrels to be used for landscape irrigation only. At a 10% adoption rate, rainwater harvesting for the 110-gallon scenario would only meet up to 0.2% of the baseline or the BAU projected outdoor demand across the basins with Urban Areas. At the 50% adoption rate, rainwater harvesting would meet 0.2-1.2% of the baseline residential outdoor use, or 0.1–0.8% of BAU projected residential outdoor demand. This analysis shows that residential rainwater harvesting at currently allowed volumes would be a relatively small water source in basin water supply planning.

Table 14. Comparison of Basin Baseline (2015) and Projected (2050 BAU) Demand for Residential Outdoor Use (AF/YR) with Two 55-Gallon Rain Barrels at the 10% and 50% Adoption Rates and Associated Proportions (%)

| Basin | Residential Outdoor Demand Baseline (2015) | Residential Outdoor Demand BAU (2050) | Scenario 1: Two 55-Gallon Rain Barrels 10% Adoption Rate | | | Scenario 2: Two 55-Gallon Rain Barrels 50% Adoption Rate | | |
|---|---|---|---|---|---|---|---|---|
| | | | RWH Potential | % of Baseline | % of BAU Projection | RWH Potential | % of Baseline | % of BAU Projection |
| | AF/YR | AF/YR | AF/YR | % | % | AF/YR | % | % |
| Arkansas | 36,404 | 53,107 | 84 | 0.2% | 0.2% | 422 | 1.2% | 0.8% |
| Colorado | 12,796 | 20,907 | 23 | 0.2% | 0.1% | 114 | 0.9% | 0.5% |
| Gunnison | 4,158 | 6,681 | 3 | 0.1% | 0.0% | 16 | 0.4% | 0.2% |
| Rio Grande | 2,191 | 2,621 | 1 | 0.0% | 0.0% | 4 | 0.2% | 0.1% |
| Southwest | 5,986 | 10,879 | 4 | 0.1% | 0.0% | 20 | 0.3% | 0.2% |
| South Platte (with Metro) | 146,739 | 234,077 | 310 | 0.2% | 0.1% | 1,552 | 1.1% | 0.7% |
| Yampa-White | 1,804 | 2,736 | 3 | 0.2% | 0.1% | 16 | 0.9% | 0.6% |
| Total | 210,078 | 331,008 | 428 | 0.2% | 0.1% | 2,142 | 1.0% | 0.6% |

*Source*: ELEMENT Water Consulting, Inc 2019

*Notes*: “Total” is equal to the sum of the rows for the basins presented, not the actual statewide total, because this analysis only includes basins with urbanized areas. RWH = rainwater harvesting.

### 5.3.2 500-Gallon Cistern Rainwater Harvesting Scenario (Requires Water Rights)

Given the relatively low volumes of rainwater harvesting under the 110-gallon scenario, the project team explored a scenario using 500-gallon cisterns to capture rainwater from residential households for existing development across the state. This scenario would require water rights to be implemented, apart from rural households with “exempt” well status, as discussed in Section 3 above.

Table 15 summarizes the annual rainwater harvesting volumes collected in a 500-gallon (functionally 450-gallon) cistern per residential household by basin. As was the case for the 110-gallon scenario, the values presented in the tables were calculated as weighted averages based on the number of 1–4-unit residential households in each Urban Area within the basin. See Appendices F-1 and F-2 for a summary of average rainwater volumes by Urban Area for both size categories. Table 16 shows the total annual volume of rainwater that could be harvested at the basin scale across different household adoption rates and water year types (average, dry, and wet).

In general, increasing the size of the capture vessel from a functional capture volume of 88 gallons to 450 gallons leads to an approximately 300% increase in capture potential across basins. At the 5% adoption rate, residential rainwater harvesting in the Metro Basin could supply 389 AF/YR, and up to 3,892 AF/YR at a 50% adoption rate. At the other end of the spectrum, in the Rio Grande Basin, residential rainwater harvesting in 500-gallon cisterns could supply approximately 1 AF/YR at the 5% adoption rate and 10 AF/YR at the 50% adoption rate. Statewide, the total rainwater harvesting potential using 500-gallon cisterns for existing residential development ranges from 704 AF/YR at the 5% adoption rate to 7,039 AF/YR at the 50% adoption rate.

Table 15. Annual Rainwater Harvesting Potential in a 500-Gallon Cistern per Residential Household by Basin

| | Potential Annual Rainwater Capture Volume per Residential Household (Gallons) | | |
|---|---|---|---|
| **Basin** | **Average Year** | **Dry Year** | **Wet Year** |
| Arkansas | 2,970 | 2,248 | 3,702 |
| Colorado | 1,984 | 1,479 | 2,542 |
| Gunnison | 1,713 | 1,145 | 2,311 |
| Metro | 2,916 | 2,184 | 3,508 |
| Rio Grande | 1,588 | 1,080 | 2,014 |
| South Platte | 2,650 | 1,948 | 3,298 |
| Southwest | 2,279 | 1,346 | 3,028 |
| Yampa-White | 2,814 | 2,097 | 3,477 |

*Notes*: An average year represents the mean precipitation for the basin, dry is $10^{th}$ percentile, and wet is $90^{th}$ percentile. These represent volumes that require water rights prior to capture and use.

Table 16. Annual Rainwater Harvesting Potential by Basin in a 500-Gallon Cistern at Existing Residences in Urban Areas Across Adoption Rates

| | Percent (%) of Households Adopting a 500-Gallon Cistern | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 5% | | 10% | | 25% | | 50% | |
| **Basin** | **AF/YR** | **MG/YR** | **AF/YR** | **MG/YR** | **AF/YR** | **MG/YR** | **AF/YR** | **MG/YR** |
| Arkansas | 140 (106–174) | 45.6 (34.5–56.8) | 280 (212–349) | 91.2 (69.0–113.7) | 700 (529–872) | 228.0 (172.5–284.2) | 1,399 (1,059–1,744) | 455.9 (345.1–568.3) |
| Colorado | 34 (25–44) | 11.1 (8.3–14.3) | 68 (51–88) | 22.3 (16.6–28.5) | 171 (127–219) | 55.6 (41.5–71.3) | 341 (255–438) | 111.3 (83.0–142.6) |
| Gunnison | 4 (3–6) | 1.4 (1.0–1.9) | 9 (6–12) | 2.9 (1.9–3.9) | 22 (15–30) | 7.2 (4.8–9.7) | 44 (29–59) | 14.3 (9.6–19.3) |
| Metro | 389 (291–468) | 126.8 (95.0–152.6) | 778 (583–936) | 253.6 (189.9–305.1) | 1,946 (1,457–2,914) | 634.1 (474.8–762.8) | 3,892 (2,914–4,682) | 1,268.1 (949.5–1,525.6) |
| Rio Grande | 1 (1–1) | 0.3 (0.2–0.4) | 2 (1–2) | 0.6 (0.4–0.8) | 5 (3–6) | 1.6 (1.1–2.0) | 10 (7–12) | 3.2 (2.2–4.1) |
| Southwest | 7 (4–9) | 2.2 (1.3–2.9) | 13 (8–18) | 4.3 (2.5–5.7) | 33 (19–44) | 10.8 (6.4–14.3) | 66 (39–88) | 21.5 (12.7–28.6) |
| South Platte | 124 (91–154) | 40.3 (29.6–50.1) | 247 (182–308) | 80.6 (59.2–100.3) | 618 (455–769) | 201.5 (148.1–250.7) | 1,237 (909–1,539) | 403.0 (296.2–501.5) |
| Yampa/ White | 5 (4–6) | 1.6 (1.2–2.0) | 10 (7–12) | 3.2 (2.4–4.0) | 25 (19–31) | 8.1 (6.1–10.0) | 50 (37–62) | 16.2 (12.1–20.1) |
| Total | 704 (525–862) | 229.4 (171.0–281.0) | 1,408 (1,050–1,725) | 458.7 (342.1–562.0) | 3,519 (2,624–4,312) | 1,146.8 (855.2–1,405.0) | 7,039 (5,249–8,624) | 2,293.6 (1,710.4–2,810.0) |

*Notes*: This scenario would require water rights. Main value presented represents a year with average rainfall, while values in parenthesis represent 10th-percentile rainfall amount and 90th-percentile rainfall amount, respectively.

### 5.3.3 Stormwater Runoff Potential for Existing Impervious Surfaces Without Capture/Storage Limitations (Capture and Use Requires Water Rights)

Here we present the results by basin of the volume of urban stormwater runoff from non-winter months.[20] These volumes are inclusive of rainwater from residential roofs, and therefore, these estimates are not mutually exclusive from the rainwater harvesting volumes reported in Tables 13 and 16 above. It is important to state that the majority of the stormwater runoff from existing Urban Areas in Colorado is not new supply and is not legally available for capture and use due to water rights owned by downstream entities, as described in Section 3. Furthermore, before pursuing stormwater capture and use for water supply there are multiple other factors to consider, such as the cost relative to other water alternatives and the environmental impact of the practice. The volumes reported here provide a useful starting point from which further economic, environmental, and other evaluations can be performed on a site-by-site basis. See Section 5.3.4 for a case study of the potential for stormwater capture on future urban development. See Section 6 for an economic evaluation of stormwater capture and use based on these volumes and the volumes of rainwater harvesting potential from above.

Table 17 presents stormwater runoff volumes by basin across a range of modeled scenarios. These scenarios range from the unconstrained to the more constrained, including runoff generated on all types of impervious surfaces within Urban Areas in each basin, to more constrained estimates that reflect runoff from a reduced proportion of the total impervious surface area, such as by removing stormwater runoff generated by impervious roadway surfaces. The more constrained values are more practical for understanding the potential for stormwater capture and use, but still do not account for legal or economic constraints or other considerations. These reflect the project team's and expert panel's desire to provide more realistic estimates of the volumetric potential of stormwater capture and use. The scenario of removing runoff from roadways is included because these surfaces produce stormwater that is more difficult to store (space-constrained) and that would require significant treatment before most uses.

[20] As noted previously, this analysis focused on non-winter stormwater capture with water used for landscape irrigation purposes. Other analysis assumptions could include year-round capture with larger scale underground storage, which would increase the volumetric potential results.

Table 17. Annual Stormwater Runoff from Impervious Surfaces in Urban Areas by Basin (AF/YR)

| **Basin** | **Annual Stormwater Runoff from Impervious Surfaces in Urban Areas (AF/YR) Under Various Scenarios** | | | | | |
|---|---|---|---|---|---|---|
| Surface Type | Percentage of Impervious Surface Captured | | | Percentage of Impervious Surface Captured Excluding Roadways | | |
| Percentage of Surface Area | 100% | 50% | 10% | 100% | 50% | 10% |
| Arkansas | 135,495 | 67,747 | 13,549 | 81,513 | 40,756 | 8,151 |
| Colorado | 34,319 | 17,160 | 3,432 | 21,852 | 10,926 | 2,185 |
| Gunnison | 5,978 | 2,989 | 598 | 3,934 | 1,967 | 393 |
| Metro | 326,660 | 163,330 | 32,666 | 200,409 | 100,204 | 20,041 |
| Rio Grande | 1,261 | 630 | 126 | 855 | 428 | 86 |
| Southwest | 6,746 | 3,373 | 675 | 3,856 | 1,928 | 386 |
| South Platte | 123,038 | 61,519 | 12,304 | 77,335 | 38,668 | 7,734 |
| Yampa-White | 4,768 | 2,384 | 477 | 2,837 | 1,419 | 284 |
| Total | 638,264 | 319,132 | 63,826 | 392,591 | 196,296 | 39,259 |

*Notes*: Estimates are hypothetical and range from unconstrained to more constrained. However, all total volumes are higher than what is allowed for capture and use under current Colorado law without new water rights.

These stormwater runoff volumes are significantly higher than the amount of water that is legally harvestable without water rights in rain barrels. Comparisons of stormwater runoff estimates from one western-slope basin, the Colorado Basin (Figure 13), and one eastern-slope basin, the South Platte (including the Metro) Basin (Figure 14), demonstrate the difference between these estimates and the rainwater harvesting estimates.

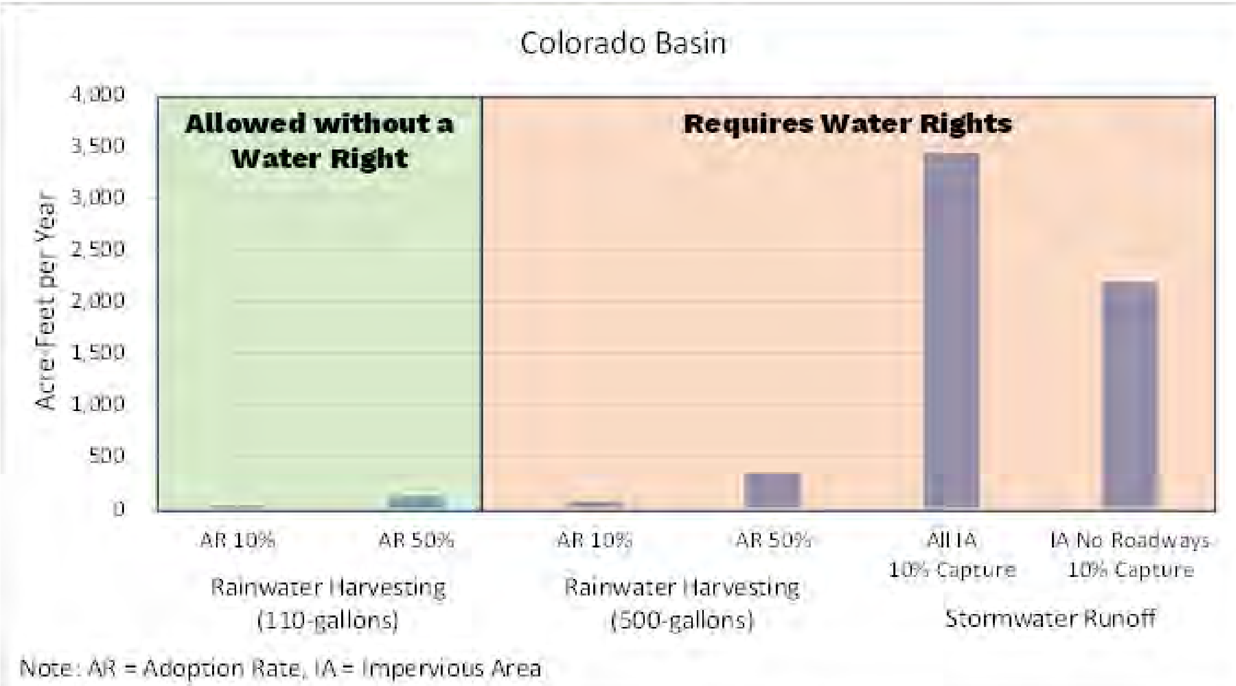



Figure 13. Comparison of Rainwater Harvesting Potential with Stormwater Runoff Volumes from Existing Impervious Surfaces in Colorado Basin Urbanized Areas

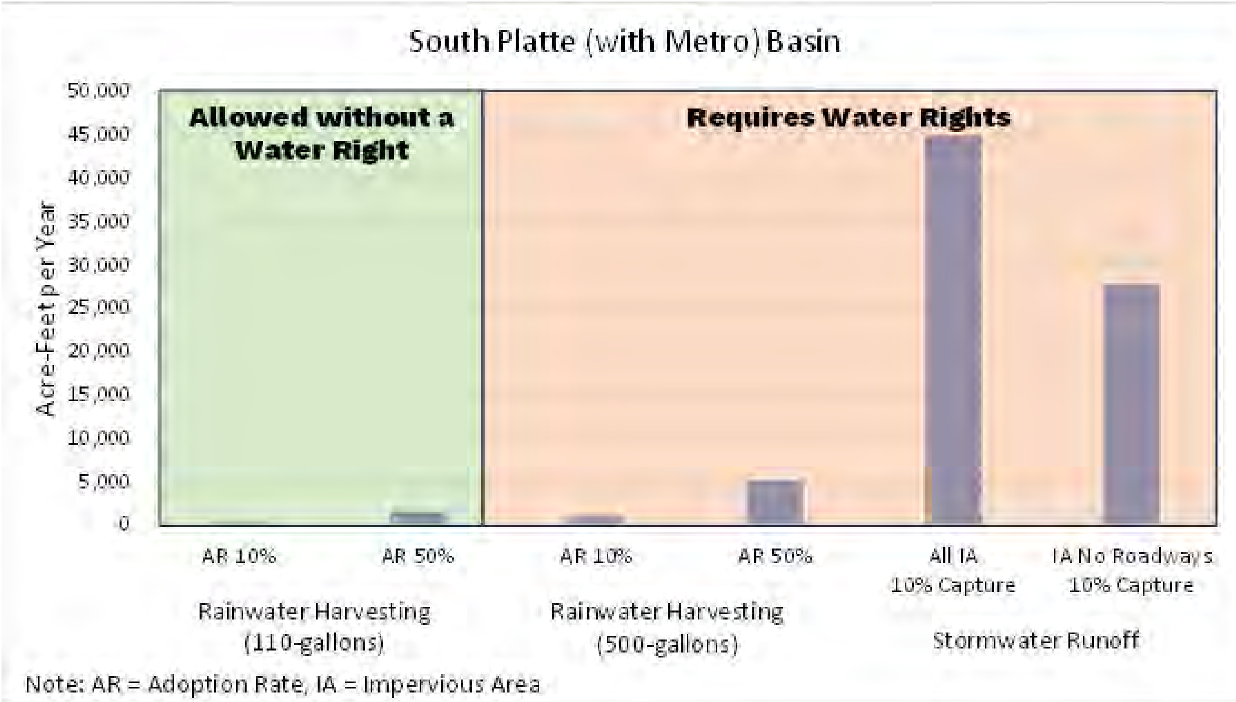



Figure 14. Comparison of Rainwater Harvesting Potential with Stormwater Runoff Volumes from Existing Impervious Surfaces in South Platte (with Metro) Basin Urbanized Areas

For additional context, stormwater runoff volumes from existing impervious surfaces in urbanized areas can be compared to baseline and future outdoor irrigation water demands.[21] Table 18 and Figure 15 compare 10% of stormwater runoff volumes for two scenarios of impervious surface runoff against outdoor demand projections. The first scenario, which includes runoff from unconstrained impervious surfaces, urban stormwater runoff volumes reflect 6–37% of baseline residential outdoor demand and 5–26% of projected BAU residential outdoor demand. In the second scenario, where urban stormwater runoff is limited to non-roadway surfaces, the volumes reflect 4–22% of baseline residential outdoor demand and 3–15% of projected BAU residential outdoor demand. Although these estimates do not reflect solely "new" water that has not already been claimed under existing water rights, these estimates support proof of concept that larger scale stormwater capture provides runoff volumes that could be used to meet a meaningful portion of outdoor residential water demand, especially when paired with water conservation practices and outdoor water demand management. Legal, economic, environmental, public health, and other site-specific constraints would need to be evaluated before pursuing stormwater capture and use at specific locations across the state. See Section 6 for basin- and state-level evaluations of the economic benefits of stormwater capture and use, including quantifiable non-water supply benefits that can influence decision-making.

[21] The project team chose to make all comparisons of estimated rainwater and stormwater volumes for outdoor use because current Colorado law does not allow for indoor use of these waters. However, in other parts of the country, rainwater and stormwater are treated and used for indoor purposes, like toilet flushing.

Table 18. Comparison of Basin Baseline (2015) and Projected (2050 BAU) Demands for Residential Outdoor Use (AF/YR) with Urban Stormwater Runoff Volumes (would require water rights to capture and use).

| Basin | Residential Outdoor Demand Baseline (2015) | Residential Outdoor Demand BAU (2050) | Scenario 1: Stormwater Runoff from 10% of Existing Impervious Surface Area | | | Scenario 2: Stormwater Runoff from 10% of Existing Impervious Surfaces Excluding Roadways | | |
|---|---|---|---|---|---|---|---|---|
| | | | Runoff | % of Baseline Outdoor Demand | % of BAU 2050 Outdoor Demand | Runoff | % of Baseline Outdoor Demand | % of BAU 2050 Outdoor Demand |
| | AF/YR | AF/YR | AF/YR | % | % | AF/YR | % | % |
| Arkansas | 36,404 | 53,107 | 13,549 | 37% | 26% | 8,151 | 22% | 15% |
| Colorado | 12,796 | 20,907 | 3,432 | 27% | 16% | 2,185 | 17% | 10% |
| Gunnison | 4,158 | 6,681 | 598 | 14% | 9% | 393 | 9% | 6% |
| Rio Grande | 2,191 | 2,621 | 126 | 6% | 5% | 86 | 4% | 3% |
| South-west | 5,986 | 10,879 | 675 | 11% | 6% | 386 | 6% | 4% |
| South Platte (w/ Metro) | 146,739 | 234,077 | 44,970 | 31% | 19% | 27,774 | 19% | 12% |
| Yampa-White | 1,804 | 2,736 | 411 | 23% | 15% | 284 | 16% | 10% |
| Total | 210,078 | 331,008 | 63,82 | 30% | 19% | 39,259 | 19% | 12% |

*Source*: ELEMENT Water Consulting, Inc 2019

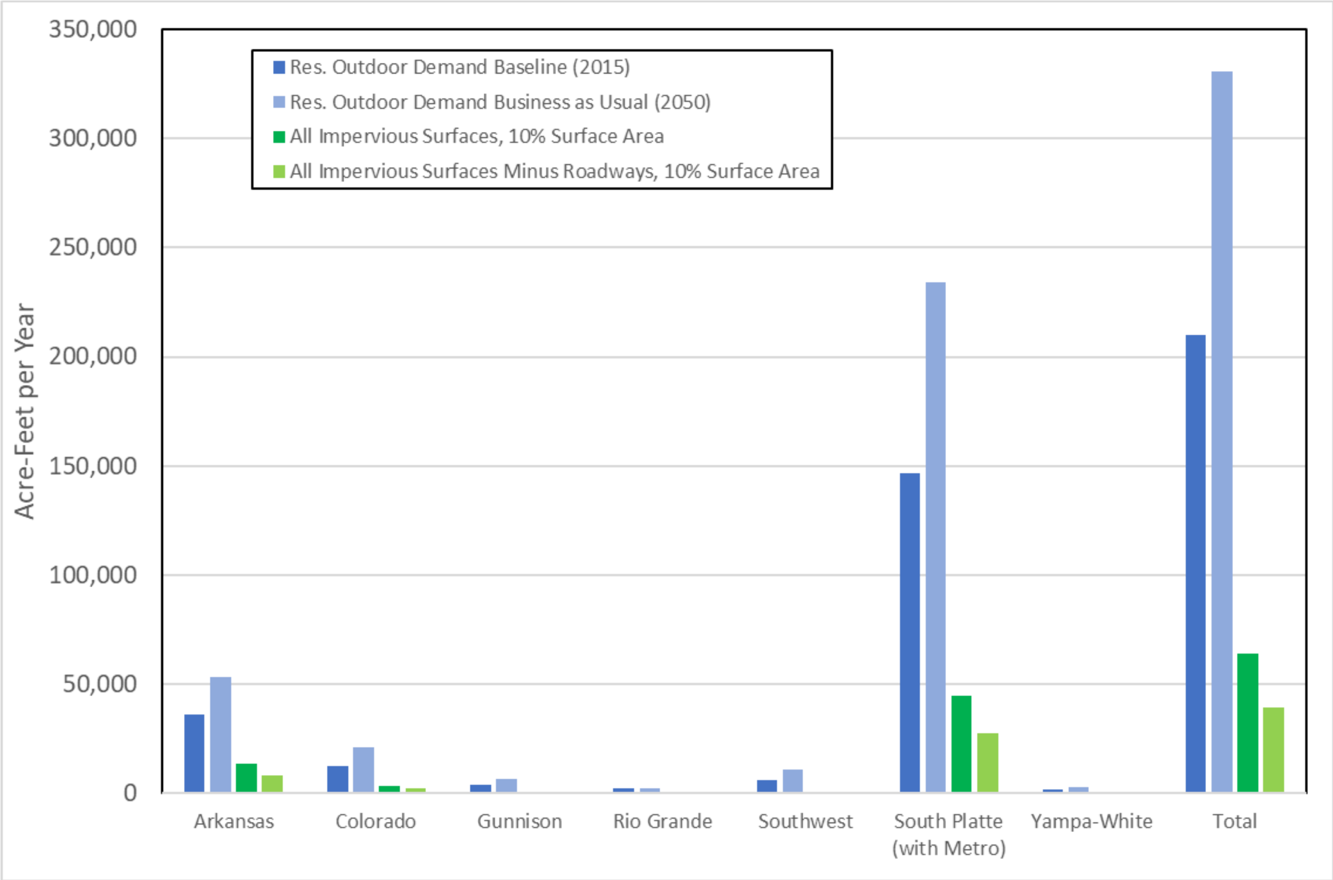



Figure 15. Baseline and Projected (BAU) Residential Outdoor Demand and Urban Stormwater Runoff (Including Constrained Scenarios) by Basin (AF/YR)
*Source*: ELEMENT Water Consulting, Inc 2019

### 5.3.4 South Platte River Basin Case Study Stormwater Capture Scenarios from Impervious Areas for New Development

Building on the analysis related to stormwater runoff volumes in Section 5.3.3, this section provides a case study of two hypothetical growth scenarios in the South Platte River Basin and the potential harvestable stormwater runoff volumes using Regional Factors (Gilliom 2019). This water, therefore, represents "new" water that is not currently relied upon by downstream users. Key assumptions for this case study include:

- For each basin, using runoff data from Section 5.3.3, a stormwater runoff rate in AF/acre was estimated and then applied to new impervious area growth projections to estimate future potential for stormwater runoff in new development. These values were then adjusted by a Regional Factor using simplified assumptions from Gilliom (2019). These assumptions included:
    - Regional Factors for HSG C, which is relatively conservative.
    - The 90% Regional Factor curve for HSG C was selected and applied to the runoff volume for purposes of an order-of-magnitude estimate only.

- o 3% loss to groundwater (G) assumed.

- The Colorado Water Plan does not currently provide growth projections in terms of land areas by basin (Reidy 2023). For purposes of this example, hypothetical 10% and 25% increases in existing impervious area were used to approximate future projected development.

- Stormwater runoff capture scenarios used a low-end capture scenario of 10% and an upper-end capture scenario of 25% to provide a range of estimates for potential stormwater capture from hypothetical future new development in the South Platte River Basin.

Based on this example in Table 19, applying Regional Factors to hypothetical 10% and 25% increases in impervious area and using 10% to 25% capture rates for impervious area, the volumetric potential for urban stormwater runoff to serve as a "new water" source in the South Platte River Basin would be on the order of 3,100 to 19,600 AF/YR. Other assumptions could also be applied to evaluate other scenarios, but this range of scenarios would represent 4% to 22% of the projected increase in South Platte River Basin water demand from baseline (2015) to BAU (2050) as described in the Colorado Water Plan (as shown in Table 18 above).

Table 19. Potential Stormwater Capture Volumes for New Development in the South Platte River Basin (Hypothetical Scenarios). Impervious Area = IA.

| South Platte/Metro Basin | 10% IA Increase | 25% IA Increase | 10% IA Increase | 25% IA Increase |
|---|---|---|---|---|
| | AF/YR | AF/YR | MG/YR | MG/YR |
| Potential Harvestable Runoff—100% Runoff Capture (AF/YR) | 31,324 | 78,309 | 10,207 | 25,517 |
| 10% Capture (AF/YR) | 3,132 | 7,831 | 1,021 | 2,552 |
| 25% Capture (AF/YR) | 7,831 | 19,577 | 2,552 | 6,379 |

Using an example scenario to put this into context, a 100-acre development with 400 homes (45 acres of which are impervious surface) would result in 88-100 AF of average annual outdoor demand. Based on Table 8, the median 2010–2017 rainwater harvesting amount of 42 AF would meet 42–48% of this demand. Assuming a water-smart household uses 50% of this average outdoor use estimate, similar to households in Sterling Ranch or other parts of the state like Castle Rock and Aurora where more efficient landscapes have been mandated, the annual outdoor demand for the example development would be 44–50 AF. In this case, the median allowed rainwater harvesting almost fully meets demand, and for five of the eight years at Sterling Ranch, it nearly met or exceeded this demand estimate.

## 5.4 Summary

Based on analysis of several rainwater harvesting and stormwater capture and use scenarios, we find:

1. For rainwater harvesting implemented at currently allowed 1–4-unit residential households in two 55-gallon rain barrels and for a hypothetical rainwater harvesting

scenario in 500-gallon cisterns at the same households, the potentially captured stormwater volumes by basin represent a small source of water for meeting basin demand gaps. The volume of water from these two scenarios is generally on the order of less than 1% of residential outdoor water demand from 2015. This proportion may change, and improve, as outdoor landscapes become more sustainable and irrigation demand is reduced. Nonetheless, there are other potential benefits of rainwater harvesting at this scale that could make pursuing this strategy a beneficial endeavor, as discussed further in Section 6.

2. Stormwater runoff from existing impervious surfaces (e.g., rooftops, roads, parking lots) in Colorado's Urban Areas represents a substantial water source. However, this water that returns to streams through surface runoff or alluvial groundwater is not considered a "new" water source in over-appropriated basins because this water has essentially already been claimed for use under existing water rights filed in water court. Although there are some exceptions to this general statement, claiming the right to use this runoff would require site-specific water rights analysis, a plan for augmentation of out-of-priority depletions, and water court processes, or changes to existing water law. Nonetheless, these estimates suggest that larger scale stormwater capture could provide runoff volumes that could be used to meet a meaningful portion of outdoor residential water demand. Legal, economic, environmental, public health, and other site-specific constraints would need to be evaluated before pursuing stormwater capture and use at specific locations across the state.

3. Based on hydrologic analysis completed as part of the Sterling Ranch pilot project, the concepts of HNDs and Regional Factors (Gilliom 2019) provide a framework for larger scale implementation of stormwater capture and use for new greenfield developments (e.g., development scale, neighborhood scale). If these methods are adopted beyond the pilot project framework, there is potential for a new development to claim the right to capture and use a portion of the runoff from new impervious surfaces. For example, in the South Platte Basin, applying Regional Factors to hypothetical 10% and 25% increases in impervious area and using 10% to 25% capture rates for impervious area, the volumetric potential for urban stormwater runoff to serve as a “new water” source would be on the order of 3,100 to 19,600 AF/YR. More refined land development projections and Regional Factors in other river basins would be needed to refine this estimate or broaden it for use in other basins.

While this analysis provides reasonable estimates of stormwater runoff and rainwater harvesting potential for a variety of scenarios, the following limitations of this analysis are noted:

- Rural areas in the state make up a large proportion of the total land area but have much less developed impervious surfaces. However, there is a need for more research to understand the opportunity for stormwater capture and rainwater harvesting in non-urban parts of the state. Notably, under Senate Bill 09-080, there is an exemption from the standard rain barrel harvesting rules that allows rural households with an “exempt” well (or a well that is legally entitled to be exempt) to obtain a Rooftop Precipitation Collection System Permit to collect rainwater from their household rooftop. This permit does not limit the barrel size (Cabot et al. 2016).

- This rain barrel analysis and stormwater runoff analysis focused on existing development and does not provide information on the volumetric potential for stormwater runoff or rainwater harvesting in future development other than for the South Platte River Basin case study.

- This analysis is only inclusive of precipitation that falls in non-winter months, from March–October in Urban Areas below 8,500 FAMSL and April–September in Urban Areas above 8,500 FAMSL. This is a conservative assumption and a reasonable limitation due to the lack of demand for irrigation in non-winter months and due to the need for some rainwater systems to be winterized due to freezing temperatures; however, it does lead to lower capture potential than is technically available when including year-round precipitation.

- This study used water demand from residential landscapes, as estimated in 2015, compared to rainwater harvesting potential and stormwater runoff volumes. This work therefore does not account for other types of demand, such as non-potable indoor uses, which are not currently allowed uses for rainwater or stormwater in Colorado but are allowed in other parts of the country. Additionally, it does not reflect future potential for rainwater and stormwater compared to more sustainable practices that continue to lead to declines in residential and commercial demand both indoors and outdoors.

- Finally, the current analysis may not represent future capturable runoff volumes because it does not account for any potential future impacts of climate variability on rainfall and temperature patterns.

# 6 Exploring the Economic Potential of Urban Stormwater Capture and Use in Colorado

This section builds on estimates of the water supply that could be provided by various types of rainwater harvesting and stormwater capture and use and evaluates the costs and benefits of these practices. As described in previous sections, stormwater capture and use can provide multiple benefits, including:

- **Potable water savings and enhanced water supply reliability** – stormwater capture and use can reduce demand for potable water supplies from centralized treatment and distribution networks, freeing up that water for other uses and/or reducing the need for alternative water supplies.

- **Energy savings** – reusing stormwater on-site (particularly through gravity-based systems) reduces the amount of energy that would otherwise be needed to treat and distribute water through centralized water distribution networks.

- **Reduced pollutant loads in urban runoff** – stormwater capture practices reduce the rate and volume of stormwater runoff and associated transported pollutants from urban land uses that would otherwise flow into local waterways.

- **Wildfire-related damage reduction** – stormwater captured and stored on-site in sufficient volumes can provide water to ensure hydration of landscape areas around a home or other buildings. This can reduce damages associated with a wildfire event.

- **Increased education and awareness** – Decentralized stormwater capture and use can increase public awareness around water supply and stormwater issues. In some cases, it can also provide a "sustainability premium" that is reflected in the value of homes or buildings where stormwater capture and use is applied.

- **Localized flood risk reduction** - Although small-scale rain barrel installation is unlikely to have a meaningful flood control benefit, larger scale stormwater capture projects have the potential to help mitigate localized flooding during smaller events. Localized flooding occurs when rain overwhelms drainage systems and waterways in direct proximity to a precipitation event. In some cases, practices that capture and reuse stormwater on-site can help to reduce localized flooding in urban and suburban areas. However, questions remain on the effectiveness of distributed practices for managing localized flooding under different storm events (i.e., of varying rainfall depths and intensity), as well as the scale of application necessary to reduce flood-related impacts. Flood risk reduction benefits are also highly site- and watershed-specific. For these reasons, the project team did not quantitatively evaluate this benefit (Clements et al. forthcoming).

For the purposes of this analysis, we assume that the volumes of water associated with the various scenarios evaluated in Section 5 are physically and legally available. However, the 110-gallon rain barrel capture scenario is the only scenario that currently meets Colorado's current water rights environment. To simplify the economic analysis, the cost of obtaining and maintaining water rights for scenarios beyond 110 gallons of rainwater harvesting is not evaluated. Additionally, in over-appropriated basins, the estimated water supply volumes may not be available for harvest by existing development because stormwater runoff is already being “harvested” by downstream senior water users.

Finally, the cost of treating stormwater for subsequent uses is not considered in this simplified analysis. While rainwater harvested from rooftops can typically be used for landscape irrigation without additional treatment, stormwater runoff from other impervious surfaces typically requires treatment. Per Deng (2021) however found that treatment of roof runoff may also be needed for some uses. Treatment costs also vary based on the level of treatment required, which depends on the use (e.g., landscape irrigation, indoor toilet flushing, cooling tower usage). For more information on treatment requirements, see Sharvelle et al. (2023).

## 6.1 Potable Water Savings and Enhanced Water Supply Reliability

Stormwater capture and use reduces reliance on potable water supplies and infrastructure; this in turn can decrease water costs for households, reduce the need to develop alternative supplies, reduce water infrastructure requirements, and enhance overall water supply reliability within a community.

### 6.1.1 Water Supply Benefits of Rainwater Harvesting

The water supply benefits of rainwater harvesting depend on the quantity and timing of on-site water demand relative to the quantity and timing of stormwater runoff available for capture. These factors are influenced by local climate, total rainfall, distribution of rainfall depths, and system storage capacity (NAS 2016). The viability of rainwater harvesting can be limited when there is not enough storage available to meet irrigation demands during dry periods and/or in areas where the timing and intensity of rainfall limits the capacity of stormwater collection (NAS 2016). In addition, the operation and maintenance of rainwater harvesting systems is key to realizing benefits. This is particularly relevant for rain barrels, as many utilities have reported very low rates of maintenance and upkeep by households (Clements et al. 2018; Crisostomo, Ellis, and Rendon 2014).

Despite these limitations, several studies have demonstrated meaningful potable water supply savings associated with rainwater harvesting systems. For example, NAS (2016) explored the amount of stormwater potentially available for various beneficial uses at different scales in six US cities. The authors conducted an original analysis using WinSLAMM (the Source Loading and Management Model) to approximate potential water savings from household-scale stormwater capture and reuse in medium-density, residential developments. In each location, the authors analyzed the use of rainwater harvesting to meet on-site irrigation and toilet-flushing demands under two storage volume scenarios: 70 gallons per household and 2,200 gallons per household. Results confirmed that water savings associated with the beneficial use of stormwater are largely dependent on tank size and the amount and timing of precipitation relative to water demand. In four of the six cities, the authors found substantial potential household water savings, ranging from 24% to 28% of total household water use under the 2,200-gallon storage tank scenario. These cities—Lincoln, NE; Madison, WI; Birmingham, AL; and Newark, NJ (all located in the Midwest or East Coast)—have year-round rainfall closely matching irrigation demands. Los Angeles and Seattle had lower water savings potential (5% and 15% of total household water use, respectively), largely because the timing and intensity of rainfall limits the capacity of stormwater collection and is not commensurate with irrigation demand (NAS 2016). In addition, small stormwater water storage capacities result in much lower potable water savings. Under the 70-gallon storage capacity scenario, savings ranged from less than 2% of household use in Los Angeles to 10% in Newark. As discussed in more detail below (e.g., see Table 20), these findings are relatively consistent with the findings presented in Section 5 regarding the potential water savings associated with 110-gallon and 500-gallon storage systems.

Steffen et al. (2013) also assessed the potential benefits of residential rainwater harvesting across geographic regions. For this study, the authors used the US EPA's Stormwater Management Model (SWMM) to examine water supply and stormwater management benefits of residential rainwater harvesting in 23 US cities across seven climate regions. The analysis was conducted for standard residential parcel and rooftop sizes using daily precipitation records and water demand patterns developed for each city. Water-saving efficiency benefits were determined for a range of tank sizes, including a single 50-gallon rain barrel. Results indicate that in semi-arid regions of the country (i.e., Southwest, Mountain West, and West Coast) rainwater harvesting has the potential to capture a relatively large percentage of rooftop runoff compared with areas that experience higher levels of precipitation (i.e., the East Coast, Midwest, Southeast, and Pacific Northwest). However, the potential water savings in semi-arid regions are much lower. This is largely because of the mismatch between the timing of on-site water demand and the volume of stormwater runoff available for use during peak demand periods.

In a 2014 study, Litofsky and Jennings evaluated rain barrel performance (in terms of stormwater capture and use for outdoor irrigation) in residential settings across 70 cities within the United States. This study applied an original model to simulate stormwater capture associated with a 62-gallon rain barrel servicing 500 square feet of roof area. The authors estimated irrigation demand associated with a 150 square foot garden, while accounting for length of the growing season and daily precipitation patterns in each location. Results of the analysis indicate that rain barrel performance is highly variable, with the percentage of outdoor irrigation demand satisfied ranging from 5% to 73%. However, results for Denver indicate that a single rain barrel could meet 42% of irrigation demand for the assumed small garden size (Litofsky and Jennings 2014).

In a 2020 study of the tradeoffs associated with various water conservation and alternative water supply strategies in Denver, Tucson, and Miami, Neale et al. (2020) concluded that stormwater can serve as substantial water supply, even where annual precipitation is low, such as in Denver and Tucson, when there is adequate storage (3,000 gallons per household was assumed for the study). However, the authors note that advancements to reduce costs for stormwater storage are needed to realize stormwater's potential for demand reduction. Results of the study also indicated that harvesting of rooftop runoff, assuming a storage capacity of 200 gallons per household, offered minimal benefit for water demand reduction in all three cities studied.

While the studies of residential rainwater harvesting described above rely on extensive modeling and provide estimates of potential savings, many real-world examples of rainwater harvesting systems have documented significant potable water supply offsets. The case studies included in this report present relevant examples within Colorado. For example, as discussed in Section 4.5, the Sterling Ranch pilot project is projected to yield an estimated 400 AF/YR for outdoor/non-potable uses. Additional studies document benefits realized at development sites in various locations across the country (Burgess 2017; Foster, Lowe, and Winkelman 2011).

### 6.1.2 Water Supply Benefits of Residential Rainwater Harvesting in Colorado

The project team's results for this study are in line with the general themes presented above—namely, in Colorado, rainwater harvesting under the current legal framework (110-gallons of storage allowed without a water right) results in a relatively small volume of potable water supply savings for individual households. Water supply benefits associated with this level of storage are limited due to capacity constraints and the timing and intensity of rainfall events. For example, on the Front Range, the 80$^{th}$ percentile storm event (0.6 inches) generates more than 450 gallons of runoff from a 1,500 square foot roof. With a functional capacity of 88 gallons of storage, rain barrels will capture a relatively small percentage of this amount. Increased storage capacity (i.e., 500-gallon cisterns) results in larger savings that can be stretched further to meet additional irrigation demand during dry periods; however, water rights must be obtained to use larger volume cisterns. Captured stormwater may also be able to keep high priority landscape areas green (e.g., gardens, play areas) during critical periods.

Table 20 shows the average potable water savings per household associated with 110-gallon and 500-gallon storage capacity scenarios, as modeled by the project team, and presented in Section 5. It also shows the percentage of each household's outdoor irrigation demand met under each scenario based on order-of-magnitude estimates of outdoor household water use (ranging from approximately 35,700 gallons per year in the Metro area to 44,800 gallons per year in the Colorado Basin, 0.11 to 0.14 AF, respectively).[22] The modeling performed for this study requires a minimum number of dry days for a rain barrel to empty and assumes that rain barrels are not manually emptied ahead of a storm event. Thus, the numbers below (Table 20) reflect the volume of water used to meet irrigation demand (i.e., resulting in potable water supply offsets).

[22] Denver Water reports an average residential use of 94 gallons per capita per day and reports that approximately half of all residential use is for outdoor purposes. We applied this assumption to the average household size for the primary Urban Area(s) within each basin to estimate average outdoor household water use.

Table 20. Average Annual Roof Runoff Captured per Household (hh) with Percentage of Typical Household Outdoor Water Use for 110- and 500-Gallon Storage Scenarios

| Basin | 110-gallon storage | | 500-gallon storage | |
|---|---|---|---|---|
| | Roof runoff volume captured (gal/hh/yr) | % of outdoor use | Roof runoff volume captured (gal/hh/yr) | % of outdoor use |
| Arkansas | 896 | 2.2% | 2,970 | 7.4% |
| Colorado | 663 | 1.5% | 1,984 | 4.4% |
| Gunnison | 605 | 1.4% | 1,713 | 4.0% |
| Metro | 884 | 2.5% | 2,916 | 8.2% |
| Rio Grande | 578 | 1.5% | 1,588 | 4.1% |
| South Platte | 796 | 1.9% | 2,641 | 6.2% |
| Southwest | 677 | 1.8% | 2,279 | 6.1% |
| Yampa-White | 879 | 2.2% | 2,814 | 7.0% |
| Grand Total | 846 | 2.0% | 2,788 | 6.7% |

At the individual household level, the potable water supply offsets are relatively minimal (particularly under the 110-gallon scenario); however, when implemented at scale, rainwater harvesting has the potential to make meaningful contributions to the overall water supply portfolio in some basins. For example, the Basin Implementation Plan (BIP) for the South Platte/Metro area identifies specific Municipal and Industrial (M&I) conservation goals for reducing the projected supply/demand gap under the Colorado Water Plan's various growth scenarios. Under the BAU 2050 scenario, the conservation target amounts to 25,000 AF/YR.[23] The BIP also estimates that residential outdoor water use will increase by approximately 87,300 AF/YR from 2015 to 2050. Figure 16 shows how rainwater harvesting could contribute to the BIP conservation goal, as well as how it could reduce expected increases in residential outdoor water use, under the 10% and 50% adoption scenarios.

[23] Under this scenario, the projected shortage with additional identified supplies (including conservation) is 41,000 AF/YR. Thus, additional conservation beyond 25,000 AF/YR would further reduce the project shortage.

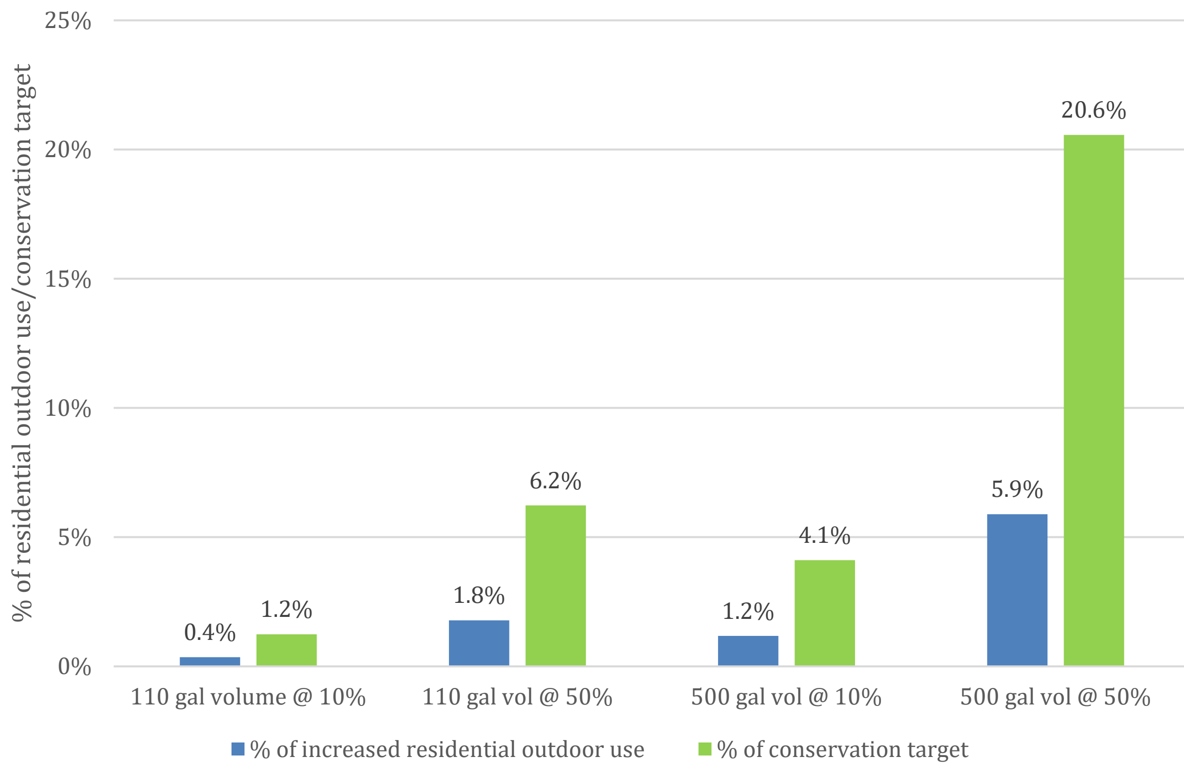



Figure 16. Rainwater Harvesting Potable Water Supply Offsets as a Percentage of Expected Increase in Residential Outdoor Water Use and BIP Conservation Target (BAU Growth Scenario, South Platte/Metro Basin)

In the NAS (2016) study referenced above, the authors note that if the goal of a stormwater capture program is to reduce potable demand for outdoor irrigation, it should be implemented in parallel with other outdoor water conservation measures. Specifically, the authors state that significantly reducing or eliminating irrigation demand using xeriscaping or similar interventions would provide much larger reductions in water demand in arid regions. Otherwise, the capture and use of stormwater may increase overall water use and facilitate the continued use of landscaping that is not sustainable in the long term and inappropriate for local climate conditions (NAS 2016). In municipalities that have passed ordinances mandating the use of more water-efficient landscapes for new development (e.g., Castle Rock and Aurora), stormwater capture and use could serve to further reduce outdoor irrigation demands.

### 6.1.3 Value of Water Supply Benefits in Colorado

#### Avoided Potable Water Supply Costs

The value of potable water supply offsets realized through rainwater harvesting can be monetized in several ways. First, there is a direct benefit to households in terms of reduced water costs. This benefit also accrues to utilities, which no longer need to supply the equivalent amount of potable water to households and businesses. To estimate this value, we rely on retail water costs because they reflect the full value of avoided water use for households and utilities (assuming utilities adopt standard cost of service pricing). However, this method does not capture any avoided (or reduced) costs associated with the development of *new* supplies that would be necessary in the absence of wide-scale stormwater capture and use. The cost of these supplies would be accounted for in future rate increases.

Table 21 shows avoided household water costs associated with 1 AF of potable water supply offsets, based on 2023 water rates for the major utilities within each basin. It also shows the number of installations needed to achieve 1 AF of potable water savings under the 110- and 500-gallon household capture installation scenarios.

Table 21. Avoided Household Water Costs ($/AF, 2023 USD) and Number of Installations Necessary to Achieve 1 AF of Savings

| Basin | Value per AF per year of utility provided water (retail cost) | Number of 110-gal installations to achieve 1 AF of offset | Number of 500-gal installations to achieve 1 AF of offset |
|---|---|---|---|
| Arkansas | $2,471 | 363 | 110 |
| Colorado | $1,676 | 492 | 164 |
| Gunnison | $2,470 | 539 | 190 |
| Metro | $1,540 | 368 | 112 |
| Rio Grande | $847 | 564 | 205 |
| South Platte | $1,466 | 410 | 123 |
| Southwest | $1,186 | 482 | 143 |
| Yampa/White | $2,190 | 371 | 116 |

*Notes*: cost per AF calculated based on variable water rates for selected urban areas within each basin. Where applicable, the variable rate applied reflects the rate tier that outdoor use would likely fall within. Rates were obtained from individual utility websites.

Figure 17 presents total annual avoided costs at the 10% and 50% adoption scenarios for 110-gallon rain barrels and 500-gallon cisterns. In line with results presented in Section 5, the

Metro area holds the most potential for water supply benefits in terms of total offsets and, therefore, total annual avoided costs for potable water supplies.

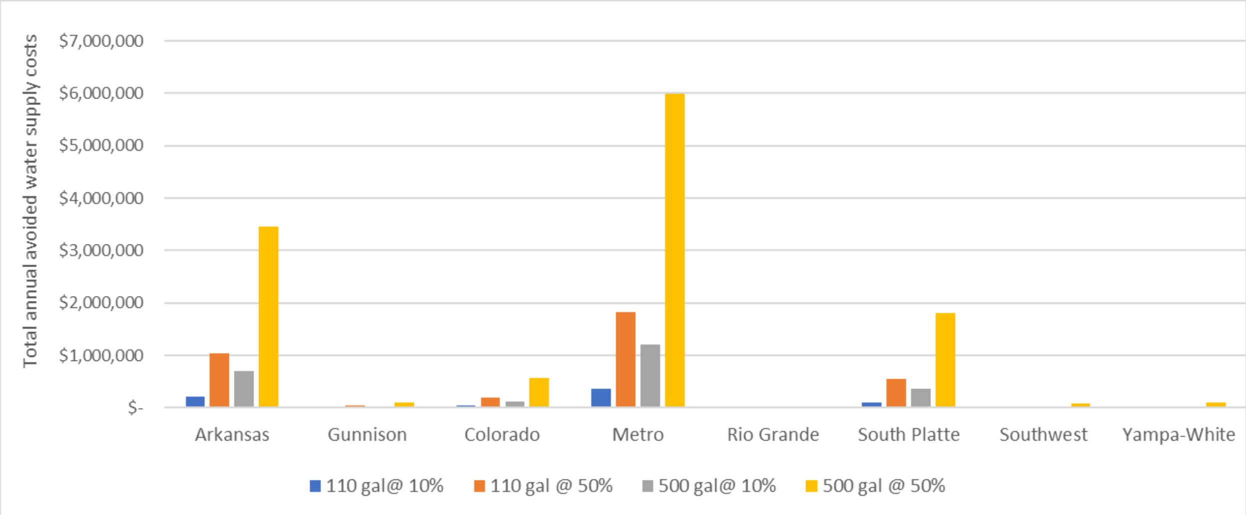



Figure 17. Annual Avoided Costs Associated with Potable Water Supply Offsets

## Energy Savings and Associated Emissions Reductions

The potable water savings realized through rainwater harvesting also result in avoided energy use due to utilities no longer having to pump, treat, and distribute the equivalent amount of water to homes and businesses. The avoided costs associated with this energy use are captured in the values reported above (Table 21) (i.e., energy costs are recovered through retail water rates). However, avoided energy use reduces energy-related pollutant emissions, including sulfur dioxide and nitrogen oxides ($SO_2$, $NO_x$), particulate matter, and greenhouse gasses (GHGs), which in turn reduces related cardiovascular and respiratory illnesses and associated healthcare costs.

To evaluate this benefit, the project team applied standard (national) assumptions for the average energy use associated with the treatment and pumping of potable water supplies—1,725 kWh/MG, based on estimates developed by WRF and the Electric Power Research Institute (Arzbaecher et al. 2013). Next, we applied pollution and GHG emission rates from the EPA for the Colorado region to estimate the resulting avoided emissions. Finally, we applied EPA values for the avoided health care costs that result from reduced emissions ($NO_x$, $SO_2$, and $PM_{2.5}$), as well as the social cost of carbon (applied to GHGs), to estimate the value of this benefit. Relative to many other regions of the country, Colorado has relatively low emissions rates for these pollutants; thus, the public health benefits are also relatively low, amounting to $41 per AF of potable water supply offset. This analysis assumes that captured stormwater is used for non-potable purposes only and does not require on-site treatment.

It is important to note that these benefits could be offset by the need for on-site treatment for stormwater capture and use systems. For this analysis, which focuses primarily on rainwater harvesting to supplement outdoor irrigation, the project team assumes that no on-site treatment would be needed.

## Enhanced Water Supply Reliability

In water-scarce regions, the value of stormwater capture and use goes beyond the avoided costs of alternative water supplies and associated energy savings. In this context, stormwater capture and use can serve as an additive or marginal source of supply, where every acre-foot captured means that more water is available for basic household needs and/or to support economic activity. In practice, ensuring water supply reliability means that coverage for necessary uses is available when another source of supply is at risk. This typically involves adding multiple sources to a community's overall water supply portfolio (including stormwater where it makes sense) and understanding the risks associated with each source, as well as the consequences of water shortages or disruptions.

Economists have valued water supply reliability in different ways, including by estimating the economic impact associated with water shortages. In 2016, the Water Environment Federation (WEF) and WateReuse Association (WRA) released a study through the Value of Water Campaign (VOWC) on the economic impact of water supply disruptions. The authors report that at a national scale, every day without water would result in an aggregate daily loss of $54.8 billion in sales. An average US business would lose $290 in sales per employee. In businesses most reliant on water, such as many manufacturing sectors, laundry services, and others, sales could drop by up to 75%, increasing losses to $7,300 per employee, on average (WEF and WRA 2016). A 2021 VOWC update to this study evaluated the "cost of inaction" if the funding gap in water and wastewater infrastructure is not addressed. The authors estimated that if investments continue at current levels (i.e., covering only about one-third of total need), water service disruptions would cost water-dependent industries $296 billion in 2039, up from an estimated $60 billion in 2019 (American Society of Civil Engineers and Value of Water Campaign 2021).

In an earlier study, EDAW and M.Cubed (2008) examined the economic impact of drought-related restrictions in the East Bay area of Central California (within the service area of the East Bay Municipal Utility District). This study found that a 15% drought-related curtailment would result in the loss of 1,200 jobs and $580 million in economic output (updated to 2022 USD), while a 25% curtailment would result in the loss of 6,900 jobs and $20.2 billion in economic output. Thus, reducing the level of shortage/curtailment from 25% to 15% would save $19.7 billion dollars in economic output. This translated to a savings of close to $800,000 per AF. Figure 18 conceptually demonstrates the relationship between increased shortages and economic impacts based on the findings of this study.

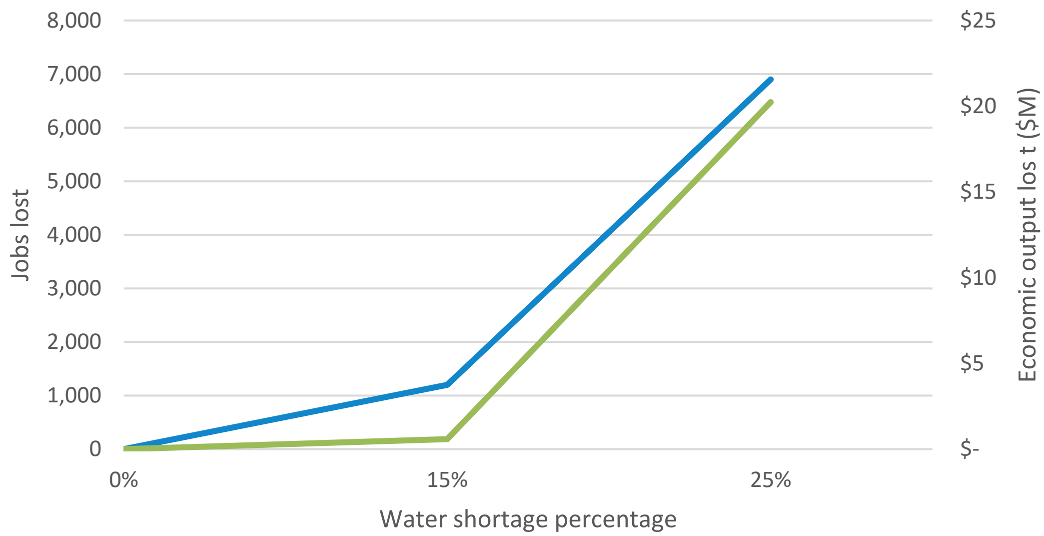



Figure 18. Conceptual Relationship Between the Level of Water Shortage and Economic Impacts
*Source*: EDAW and M.Cubed 2008

Within the context of this Colorado study, the level of rainwater harvesting examined (i.e., the 110- and 500-gallon scenarios) will not enhance water supplies enough to substantially reduce the potential for water shortages that would result in significant economic impacts. However, larger scale stormwater capture and use (and/or potentially expanded allowable uses—e.g., indoor non-potable uses) presents some opportunity to enhance water supply reliability at the community or basin scale. Consistent with the graph above, this is particularly true in areas where shortages exceed 15% and larger stormwater capture and use can make meaningful contributions to reducing shortage-related impacts on local economies. However, during times of drought, when supplies are most scarce, there will also be decreases in the volume of stormwater runoff available. Without significant storage, the ability of stormwater capture and use to provide meaningful reductions in the supply/demand gap will also be limited.

For example, the first column of Table 22 shows the expected municipal supply/demand gap in each basin under the 2050 BAU scenario, while the second shows the expected gap as a percentage of total projected demand. The subsequent columns show 1) the estimated volume (AF) associated with capturing 10% of stormwater from all impervious surfaces within each basin (Table 17), and 2) how this level of capture would change the gap as a percentage of total demand. So, for example, in the South Platte/Metro region, the expected gap amounts to 192,800 AF, which is approximately 19% of total demand. The 10% stormwater capture scenario would reduce this gap by 44,970 AF, thereby reducing the supply/demand gap to 15% of total demand (a 4 percent reduction).

In several basins—most notably, the Arkansas and South Platte/Metro (bolded in Table 22)—the supply/demand gap amounts to more than 15% of total demand (gaps in the Rio Grande and Yampa also exceed 15%, but the absolute gaps are relatively small). The volume of stormwater captured under the 10% capture scenario could enhance water supply reliability in these basins and meaningfully contribute to reducing the projected supply/demand gap (recognizing that water rights requirements would apply).

Table 22. Expected Municipal Supply/Demand Gap by Basin Under the 2050 BAU Scenario

| Basin | M&I supply/ demand gap BAU 2050 scenario (AF) | Gap as percentage of total BAU M&I demand | Potential stormwater volume from 10% capture scenario (AF) | Gap as a percentage of total demand, with 10% stormwater capture |
|---|---|---|---|---|
| **Arkansas[a]** | **57,300** | **19%** | **13,549** | **14%** |
| Colorado | 1,100 | 1% | 3,432 | -3%[b] |
| Gunnison | 1,000 | 4% | 598 | 2% |
| Rio Grande | 3,300 | 28% | 126 | 27% |
| Southwest | 3,300 | 8% | 675 | 7% |
| **South Platte (w/Metro)** | **192,800** | **20%** | **44,970** | **15%** |
| Yampa-White | 3,000 | 22% | 477 | 19% |
| Total | 261,800 | 18% | 63,826 | 13% |

a. Bolded basins indicate areas where projected shortages exceed 15% (the level at which economic impacts begin to significantly increase) and where 10% capture scenario could make a meaningful reduction in percent shortage and related adverse impacts.
b. Negative number means that 10% stormwater capture scenario will cover supply/demand gap, such that there is excess supply.

To demonstrate the value of water supply reliability, we used the IMPLAN model to examine the economic activity of water-dependent industries and evaluate the impacts associated with a hypothetical water supply shortage in the South Platte/Metro Basin. Very few studies have been conducted on this topic, and the relationship between the level of shortage (e.g., 15%, 25%, complete disruption) and economic impacts is difficult to estimate. However, in line with findings from the EDAW and M-Cubed 2008 study described above, evidence from interviews conducted for a WRF study on the value of supply reliability for commercial, industrial, and institutional (CII) customers (Raucher 2015) indicate that shortages of 10% to 15% result in relatively minimal impacts for local businesses and industries. Beyond that point, impacts begin to increase substantially, although this varies by industry.

The South Platte/Metro Basin encompasses 18 counties. Businesses and industries within these counties produce approximately $594 billion per year in economic output, supporting more than 2.8 million jobs (IMPLAN 2021 data). Many of these businesses rely heavily on reliable water services from local utilities to grow. These so-called "water-dependent" industries (e.g., manufacturing, universities, health care, car washes, breweries, see (Value of Water Campaign 2017)) account for 32% of economic output within the basin (more than $179 billion) and for close to 900,000 jobs.

To estimate the economic impact of shortages, the project team applied "resiliency factors" developed by Chang, Svekla, and Shinozuka (2002). Resiliency factors reflect the percentage of economic output that can be achieved in different industry sectors when water service is reduced to zero. Resiliency factors vary depending on the length of service disruption (e.g., one week, two weeks, greater than two weeks), with impacts increasing with the duration of the shortage. As a conservative estimate, we applied resiliency factors associated with a one-week shortage to estimate the daily loss in direct economic output associated with a one-day water service disruption. This information was entered into IMPLAN to estimate total economic impacts across the 482 relevant IMPLAN-defined sectors present within the South Platte/Metro Basin.

Results indicate that a one-day water shortage in the basin would result in a loss of more than $1.29 billion (2023 USD) in economic output and 7,100 jobs. Based on data from the BIP for the Baseline scenario, non-residential water use amounts to approximately 733 AF per day. Thus, on a per-AF basis, a one-day shortage would result in an economic impact of $1.7 million per AF. Assuming a linear relationship between impacts and level of shortage, every percentage point decrease in the South Platte/Metro projected water supply gap (above the 15% threshold, assuming minimal impacts below this point) would avoid the loss of $19.3 billion in economic output (in the South Platte/Metro this would amount to a total of $77.2 billion annually for the 44,970 AF decrease (or 4% gap reduction) shown in Table 22).

As an important note, this analysis is intended to provide an order-of-magnitude estimate of the economic value associated with ensuring water supply reliability and closing the water supply gap. The values presented above would apply to all new potential supply sources introduced into the basin's water supply portfolio and are not limited to stormwater capture and use. A more comprehensive assessment of the risks and benefits associated with each potential source, and the diversity of sources in the basin, would be needed to further assess benefits specific to stormwater capture and use. Additionally, for stormwater runoff captured from existing development, the runoff quantified in this analysis is not considered to be "new" water supply, whereas the runoff from new developments may be considered new supply.

## 6.2 Water Quality Benefits of Stormwater Capture

In addition to water supply benefits, stormwater capture can play an important role in protecting and restoring the quality of local waterways. Stormwater runoff from developed areas is one of the leading sources of water pollution across the nation. Stormwater transports pollutants—including pathogens, nutrients, sediment, and heavy metals—from streets, roads, parking lots, rooftops and other impervious areas to nearby rivers, lakes, and streams. Due in part to significant efforts over the past 50 years to reduce point-source pollution from wastewater treatment plants and industrial sources, approximately 85% of current watershed impairments are caused by non-point source pollution and urban stormwater discharges (WEF 2015).

### 6.2.1 Urban Stormwater Treatment Requirements in Colorado

Colorado MS4 permits issued by CDPHE to local governments with urbanized areas include requirements for permanent stormwater quality treatment on new development and redevelopment projects with 1 acre or more of land disturbance. The most recently issued permits include several options for meeting performance-based effluent limits using permanent SCMs (i.e., SCMs or BMPs). The primary options for meeting the MS4 permit design standards include treating the WQCV,[24] reducing surface runoff (through infiltration) by 60% of the calculated WQCV, or meeting a 30 mg/L total suspended solids standard.[25] For meeting the runoff reduction option, the permit encourages the use of GSI, which include practices that mimic natural processes to reduce, manage, and treat stormwater; rain barrels and cisterns are practices that provide this functionality. The US EPA includes rainwater harvesting in its National Stormwater Calculator.[26]

A review of the Total Maximum Daily Loads (TMDLs) adopted by CDPHE shows that municipal stormwater is commonly included in wasteload allocations and wasteload reduction targets in urban areas.[27] Phosphorus and bacteria are examples of pollutants with wasteload allocations and wasteload reduction targets for urban stormwater runoff that are currently included in TMDLs and MS4 permits in Colorado. Because pollutant loads have both a pollutant concentration and volume component, practices that reduce surface runoff volumes (e.g., to storm sewer systems) can help to meet TMDL load reduction targets.[28] This includes capturing rooftop runoff in rain barrels and cisterns. Imteaz et al. (2022) observed that numerous studies show declines in levels of phosphorus, nitrate, and suspended and dissolved solids, as well as copper and zinc, in collected rooftop runoff due to in-tank sedimentation processes. These findings were confirmed in monitoring and modeling results comparing direct rooftop runoff to harvested rainwater in Melbourne (Australia) (Imteaz et al. 2022).

### 6.2.2 Value of Water Quality Benefits

As described above, capture of rooftop runoff in rain barrels or larger cisterns can result in reduced pollutant loading to nearby surface waters. For the Denver metro area, the water quality design storm corresponds to 0.6 inches of precipitation and approximately 0.5 watershed inches of runoff from impervious surfaces. Table 23 summarizes the runoff generated from a range of roof sizes for this design storm and the number of various sized rain barrels or cisterns that would be needed to capture the WQCV for the rooftop. For

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[24] The WQCV is designed to treat the 80th percentile of runoff-producing storm events, which corresponds to approximately 0.6 inches of precipitation in the Denver area (Mile High Flood District 2019).
[25] Criteria for calculating the WQCV and designing urban SCMs are presented in the Mile High Flood District's Urban Storm Drainage Criteria Manual (2010, as updated in 2023). Most local governments in Colorado typically follow Mile High Flood District's procedures for calculating the WQCV and either adopt Mile High Flood District's manual or develop a local version of the manual, with modifications.
[26] Available at https://www.epa.gov/sites/default/files/2019-04/documents/swc_users_guide_desktop_v1.2.0.3_april_2019.pdf.
[27] See https://cdphe.colorado.gov/total-maximum-daily-loads-tmdls for more information on TMDLs in Colorado.
[28] As discussed in Section 3.4, stormwater management is allowed without water rights for many SCMs, provided that water is not detained for more than 72 hours or put to beneficial use, along with other requirements.

purposes of this table, the rain barrels are assumed to be fully emptied between storm events with full storage capacity available, although there are several reasons that assumption would not hold in all circumstances (e.g., back-to-back storm events).

Table 23. Denver Metro Area Water Quality Capture Volume for Various Roof Sizes and Minimum Number of Storage Containers Needed

| | | Roof Size (Square Feet) | | | | | |
|---|---|---|---|---|---|---|---|
| | 500 | 1,000 | 1,500 | 2,000 | 2,500 | 5,000 | 10,000 |
| Calculated WQCV (gallons) | 156 | 312 | 468 | 623 | 779 | 1,558 | 3,117 |
| Minimum Number of Rain Barrels to Capture the WQCV | | | | | | | |
| # of 55-Gallon Rain Barrels | 3 | 6 | 9 | 12 | 15 | 29 | 57 |
| # of 125-Gallon Rain Barrels | 2 | 3 | 4 | 5 | 7 | 13 | 25 |
| # of 500-Gallon Cisterns | | - | - | - | 2 | 4 | 7 |

*Notes*: Assumes that rain barrels or cisterns are fully emptied between storm events, which is an assumption that would not be met for all storm events.

To determine water quality benefits for the various stormwater capture and use scenarios, we first calculated the total storage capacity that would be provided by rain barrels and cisterns, assuming 88- and 450-gallons of storage capacity per household/installation, respectively. This is consistent with the assumption used to calculate the total stormwater capture potential presented in Section 5. Table 24 shows the total storage capacity for rain barrels and cisterns under the 10% and 50% adoption scenarios.

Table 24. Total Storage Capacity for 55-Gallon Rain Barrels and 500-Gallon Cisterns Under the 10% and 50% Adoption Scenarios

| Basin | Total rain barrel capacity, 10% participation (AF/YR) | Total rain barrel capacity, 50% participation (AF/YR) | Total cistern capacity, 10% participation (AF/YR) | Total cistern capacity, 50% participation (AF/YR) |
|---|---|---|---|---|
| Arkansas | 8.3 | 41.5 | 42.4 | 212.0 |
| Colorado | 3.0 | 15.1 | 15.5 | 77.5 |
| Gunnison | 0.5 | 2.3 | 2.3 | 11.5 |
| Metro | 23.5 | 117.4 | 120.1 | 600.5 |
| Rio Grande | 0.1 | 0.5 | 0.6 | 2.8 |
| South Platte | 8.2 | 41.1 | 42.0 | 210.0 |
| Southwest | 0.5 | 2.5 | 2.6 | 13.0 |
| Yampa-White | 0.3 | 1.6 | 1.6 | 8.0 |

The economic value of the stormwater management benefits provided by stormwater capture and use can be calculated based on costs that would be incurred to provide the same degree of stormwater management in another way (i.e., applying avoided cost analysis). Recognizing that the factors influencing stormwater BMP costs vary across the state according to soil type, rainfall amount and intensity, slope, and other features, the project applied average costs from the Mile High Flood District's REALCOST tool to estimate avoided costs. Specifically, we calculated average costs for bioretention BMPs capable of managing and infiltrating stormwater on-site, or across multiple sites (based on a size that would be sufficient to manage 5 acres of impervious area). We selected bioretention as the baseline BMP because it provides both runoff reduction and treatment of the WQCV. Bioretention does not require water rights reporting.

The REALCOST tool reports a capital cost for bioretention of approximately $666,000 per AF of storage capacity for installations that manage 5 acres of impervious area. In addition, the tool reports that rehabilitation should occur every 10 years at a cost of 30% of total (initial) capital. Based on these assumptions, Table 25 shows the total avoided capital and rehabilitation costs of stormwater management that can be attributed to the installation of rain barrels and cisterns under the 10% and 50% adoption scenarios, in present value terms. Table 26 shows the total annual avoided stormwater management costs per AF of stormwater capture under these scenarios, assuming a 30-year useful life for bioretention BMPs.

Table 25. Total Avoided Stormwater Management Capital Costs ($M 2023 USD)

| | 55-Gallon Rain Barrels | | 500-Gallon Cisterns | |
|---|---|---|---|---|
| **Basin** | **10% participation** | **50% participation** | **10% participation** | **50% participation** |
| Arkansas | $7.7 | $38.4 | $39.2 | $196.2 |
| Colorado | $2.8 | $14.0 | $14.3 | $71.7 |
| Gunnison | $0.4 | $2.1 | $2.1 | $10.7 |
| Metro | $21.7 | $108.7 | $111.2 | $555.9 |
| Rio Grande | $0.1 | $0.5 | $0.5 | $2.6 |
| South Platte | $7.6 | $38.0 | $38.9 | $194.4 |
| Southwest | $0.5 | $2.4 | $2.4 | $12.1 |
| Yampa-White | $0.3 | $1.4 | $1.5 | $7.4 |

*Notes*: the costs above are not "net" costs; the cost of rain barrels and cisterns have not yet been subtracted from the avoided costs of treatment. In addition, they reflect present value costs assuming a 3% discount rate and rehabilitation occurring every 10 years.

Table 26. Avoided Stormwater Management Costs per Acre-Feet of Stormwater Capture Over 30-Year Period ($/AF)

| Basin | 55-Gallon Rain Barrels | 500-Gallon Cisterns |
|---|---|---|
| Arkansas | $3,029 | $4,674 |
| Colorado | $4,096 | $6,999 |
| Gunnison | $4,490 | $8,107 |
| Metro | $3,070 | $4,761 |
| Rio Grande | $4,698 | $8,743 |
| South Platte | $3,412 | $5,258 |
| Southwest | $4,013 | $6,092 |
| Yampa-White | $3,088 | $4,935 |

The costs presented above illustrate the value of water quality benefits that could be provided by rainwater harvesting as currently permitted without water rights and under a scenario that would require water rights. Future residential developments will be required to implement retention-based (or other) stormwater BMPs. However, there are no regulations that require local governments or property owners to install stormwater BMPs to manage preexisting stormwater discharges. Thus, the avoided costs presented here may not ever be incurred; however, the value of pollutant removal from additional stormwater control remains. Regardless of whether alternative controls are implemented, the avoided cost calculations provide a low-end value for willingness to pay by cities and MS4 permittees to improve water quality.

## 6.3 Stormwater Capture for Maintaining Defensible Space in Areas with High Wildfire Risk

There is an emerging interest in many western states in the value of capturing and storing rooftop runoff as a wildfire risk reduction strategy. This interest falls into two categories: (1) supplying water for active fire suppression, and (2) storing water for application to a residential or commercial landscape as part of a passive "defensible space" strategy. Both strategies reduce damages in the event of a wildfire. Both also require collection of sufficient rainwater volumes to attain the intended benefit. In all cases this volume is greater than the amount currently permitted under Colorado law without a water right. Discussion of this benefit is, therefore, purely hypothetical.

An active fire damage reduction strategy entails capture of rooftop runoff in cisterns coupled with equipment to pressurize and distribute this volume to a rooftop and landscape sprinkler system.[29] Alternatively, the cisterns can provide water for firefighting crews and equipment to access. Passive wildfire damage reduction focuses on collecting rainwater for application to the on-site landscape during dry conditions, "red flag" periods, or active fire situations. A defensible space landscape is broken into multiple zones radiating outward from the

[29] See US Department of Energy, Office of Energy Efficiency and Renewable Energy, Building America Solutions Center, "Cisterns for Fire Suppression." Accessible at https://basc.pnnl.gov/resource-guides/cisterns-fire-suppression#edit-group-scope.

structure (see Figure 19 (Colorado State Forest Service 2021)).[30] The intention is to create a damp environment that prevents ember ignition to at least 30 feet from the structure (encompassing Zones 1 and Zone 2).

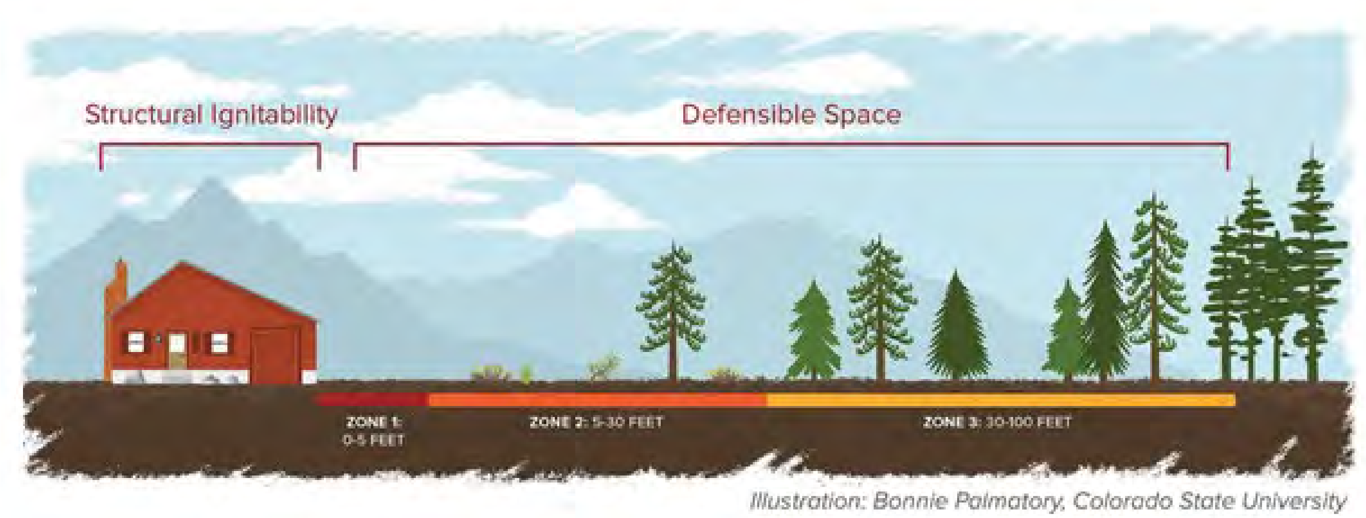


Figure 19. Wildfire Defensible Space Zones
*Source*: Colorado State Forest Service 2021

The volume needed to keep Zones 1 and 2 damp enough to resist ignition depends on soil moisture conditions as well as vegetative cover density. Research in the Santa Monica Mountains of Southern California estimates that irrigating all of Zone 2 would require 7,000 to 7,500 gallons.[31] It is important to note that Southern California has a "Mediterranean Climate," with a long dry season (May–Oct) coupled with a winter rainy season. Storms during this rainy season can deliver rainfall amounts that compare with levels experienced in Colorado. For example, the average annual rainfall in the Santa Monica Mountains is 14.2 inches compared to 14.3 inches in Denver.

The Federal Emergency Management Agency (FEMA) has standard procedures and methods for estimating the value of wildfire risk reduction activities. The agency publishes annual fire risk by Census tract for fire prone areas. This represents the chance that a wildfire would occur within the Census tract in any given year. Figure 20 shows annual fire risk for Census tracts in Colorado that fall within the urbanized areas included in this report. Across the state, fire risk tends to be higher in areas located out of these urbanized areas; however, several urban areas intersect with these higher risk fire zones in wildland urban interface (WUI) areas.

[30] See CalFire, Defensible Space, at https://www.fire.ca.gov/dspace.
[31] Personal communication with Clark Stevens, Resource Conservation District of the Santa Monica Mountains, 2023.

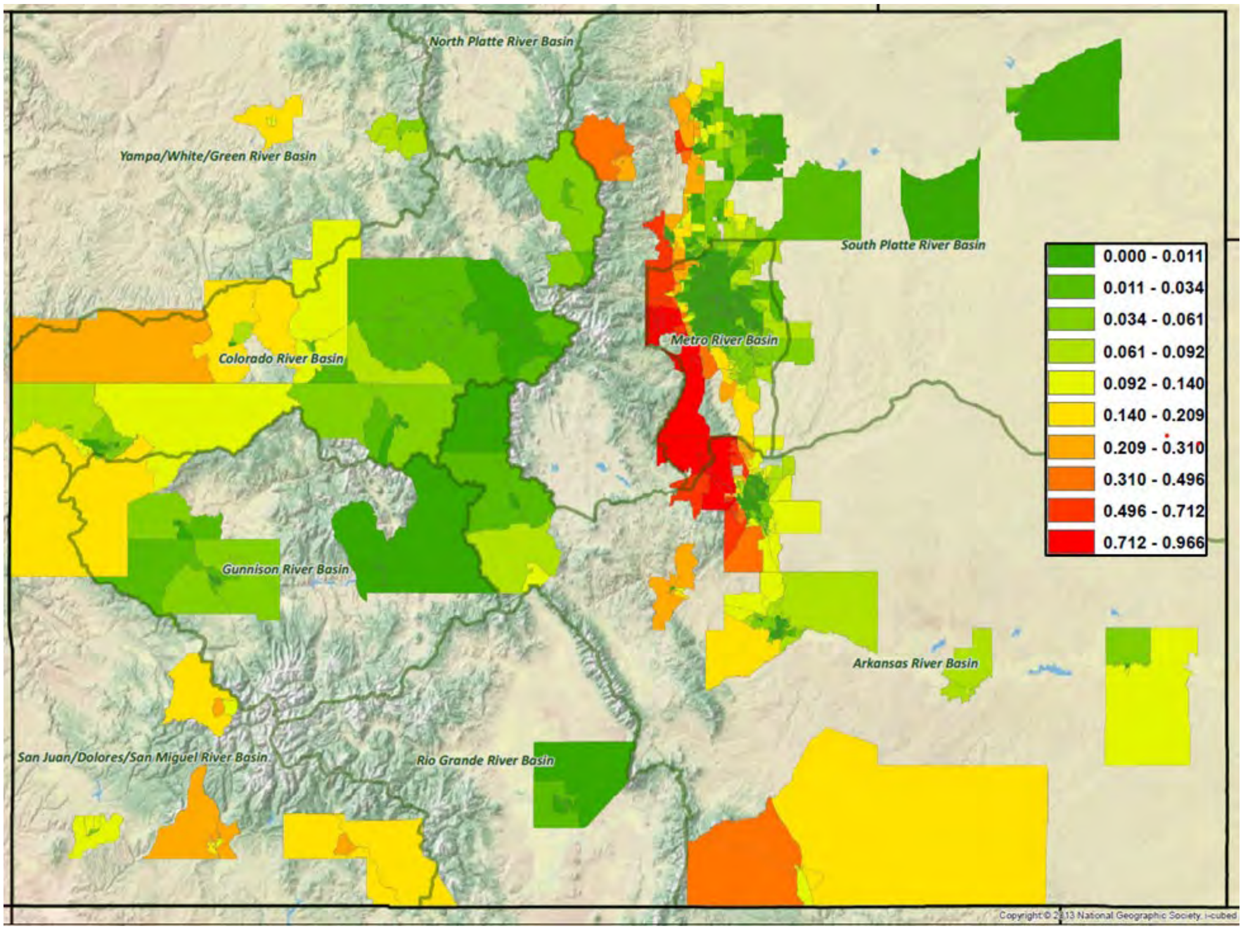


Figure 20. Annual Fire Risk for Census Tracts in Colorado that Intersect Urbanized Areas

FEMA also publishes the area within each Census tract that is exposed to fire risk and the expected annual building damage loss associated with that risk. For the Census tracts shown in Figure 20 above, the total expected annual building damage losses amount to $71.7 million. This includes damages to all buildings, not just residential properties.

In its guidance for benefit-cost analysis, FEMA recommends that any one strategy can only account for up to 10% of avoided fire damages. Applying this guideline to the Census tracts within our study area indicates that passive fire risk reduction through stormwater capture could result in up to $7.17 million in avoided damages per year. This value assumes 100% adoption: with 10% adoption, annual expected damages would be $717,000 per year; with 50% adoption, $3.59 million. Again, this calculation is for demonstration purposes only and is intended as an exploration of potential value. Fire risk reduction benefits are not included in the comparison of costs and benefits in Section 6.6.

## 6.4 Educational & Cultural Benefits of Stormwater Capture

Installation of rain barrels and cisterns can have educational and cultural benefits. In some cases, this can translate into increased willingness to adopt other conservation or stormwater strategies. For example, Bakacs et al. (2013) conducted a survey to assess the educational impacts of rain barrel programs in Northern Virginia and New Jersey. Approximately half of respondents (48% in Virginia and 58% in New Jersey) indicated they had adopted at least one other BMP after participating in a rain barrel program. Other studies have provided more detail on this topic, reporting that rain barrels encourage additional conservation in “high-income attitudinally green populations,” “people with more positive attitudes towards the environment,” and among people with a “higher level of knowledge about practices” (Ando and Freitas 2011).

There is evidence that the benefits of rain barrels decline over time, with 25–35% of barrel usage discontinued within five years (Gao et al. 2016). Technical assistance and public outreach and engagement programs can be useful in extending the educational value and effectiveness of stormwater capture practices. Gao’s research notes that “Informational signage stating adopters’ commitment to practices and support for the environment is a potential strategy for fostering practice maintenance over time.” Crisostomo et al. (2014) concludes that if the rain barrel program is solely an educational one, then care must be taken to design the program in such a way that emphasizes additional interventions (e.g., rain gardens, downspout disconnects, efficiency measures) and associated co-benefits.

Rainwater harvesting and stormwater capture and use can also provide a “sustainability premium” for homes and rental properties. Several studies have found that properties demonstrating a sustainability commitment can command higher rents and sales prices (Clements, St. Juliana, and Davis 2013). In a recent survey, the National Association of Realtors (2021) also reported a trend toward sustainability, finding that 63% of respondents thought eco-friendly features were important when choosing a rental or purchase (The Water Scrooge 2023). In a 2017 study, the Urban Land Institute found that water-efficient features, including graywater and stormwater reuse, can increase property values by up to 11%. These benefits typically accrue to larger scale stormwater capture and use efforts, such as large cistern systems or community-scale infrastructure.

## 6.5 Benefit-Cost Comparison

Based on data from the Colorado Stormwater Center (CSC), the cost of installing two 55-gallon rain barrels averages approximately $170. Costs for basic cisterns are typically around $1.96 per gallon of storage (US EPA 2013, updated to 2023 USD), although this can vary significantly depending on materials used, permitting, and other factors. Based on these high-level estimates, Table 27 shows the cost of installation for rain barrels and cisterns by basin under the 10% and 50% adoption scenarios. Table 28 shows the cost per AF of stormwater capture over the assumed design life for each practice—10 years for rain barrels and 20 years for cisterns.

Table 27. Present Value Capital and Rehabilitation Costs of Rainwater Harvesting Implementation Across Storage/Adoption Scenarios ($M 2023 USD, 30-Year Analysis Period)

| | Costs of Implementation ($ millions) | | | |
|---|---|---|---|---|
| **Basin** | **110-gal storage, 10% adoption** | **110-gal storage, 50% adoption** | **500-gal storage, 10% adoption** | **500-gal storage, 50% adoption** |
| Arkansas | $12.0 | $60.0 | $46.7 | $233.7 |
| Colorado | $4.4 | $21.9 | $17.1 | $85.4 |
| Gunnison | $0.7 | $3.3 | $2.5 | $12.7 |
| Metro | $34.0 | $169.9 | $132.4 | $662.1 |
| Rio Grande | $0.2 | $0.8 | $0.6 | $3.1 |
| South Platte | $11.9 | $59.4 | $46.3 | $231.5 |
| Southwest | $0.7 | $3.7 | $2.9 | $14.4 |
| Yampa/White | $0.5 | $2.3 | $1.8 | $8.8 |
| Total | $64.2 | $321.1 | $250.3 | $1,251.7 |

*Notes*: Lifecycle analysis assumes rain barrels are replaced (at full cost) every 10 years and cisterns are replaced (at full cost) every 20 years, and applies a 3% discount rate.

Table 28. Capital Costs per Acre-Foot of Rainwater Capture Over 30-Year Analysis Period (2023 USD)

| Basin | Cost per AF of Capture ($/AF) | |
|---|---|---|
| | 110-gallon storage | 500-gallon storage |
| Arkansas | $4,733 | $5,568 |
| Colorado | $6,401 | $8,337 |
| Gunnison | $7,016 | $9,657 |
| Metro | $4,797 | $5,671 |
| Rio Grande | $7,340 | $10,414 |
| South Platte | $5,332 | $6,262 |
| Southwest | $6,271 | $7,256 |
| Yampa/White | $4,826 | $5,878 |
| Average | $4,996 | $5,931 |

*Notes*: Lifecycle analysis assumes rain barrels are replaced (at full cost) every 10 years and cisterns are replaced (at full cost) every 20 years, and applies a 3% discount rate.

Table 29 shows the benefit-cost ratio associated with rain barrels and cisterns, based on the water supply and water quality benefits described earlier in this section. To calculate these ratios, the project team assumed that benefits would accrue over the 10- and 20-year design life for rain barrels and cisterns, respectively, and applied a 3% discount rate. As shown, the quantified benefits associated with rain barrels range from 72% (Rio Grande) to 99% (Arkansas) of total costs, while the benefits of cisterns relative to costs are slightly higher (with benefit-cost ratios ranging from 0.90 to 1.14). These benefit-cost ratios are based on high level estimates; additional research is needed to better understand how and where to maximize effectiveness.

Table 29. Benefit-Cost Ratio for Water Supply and Water Quality Benefits of Rain Barrels and Cisterns

| Basin | Rain Barrels (55-gallon) | Cisterns (500-gallon) |
|---|---|---|
| Arkansas | 1.0 | 1.14 |
| Colorado | 0.82 | 0.98 |
| Gunnison | 0.88 | 1.02 |
| Metro | 0.86 | 1.03 |
| Rio Grande | 0.72 | 0.90 |
| South Platte | 0.83 | 1.00 |
| Southwest | 0.77 | 0.95 |
| Yampa-White | 0.95 | 1.10 |

While the quantifiable monetized benefits of some rainwater harvesting practices may be relatively low, evidence suggests that larger scale stormwater capture and use has greater benefits (relative to costs). This is the case for several reasons. For example, as demonstrated in the Sterling Ranch case study, higher volume systems can store more water (and capture rainfall from a larger area), resulting in significantly greater volume of potable water supply offsets and water quality benefits. Higher volume systems are also more likely to provide fire risk reduction benefits and/or carry a "sustainability premium," the value of which is reflected in increased property values and rental rates. Finally, larger scale systems can benefit from lower costs due to economies of scale and more flexible design, as shown with several regional-scale capture projects in Southern California.

## 6.6 Summary

This assessment of the economic value of rainwater harvesting and stormwater capture and use in Colorado focused on the avoided costs of providing potable water for outdoor landscape uses, the value of the water quality improvements associated with rainwater and stormwater capture, and the value of other associated benefits, such as reduced risk of property loss due to wildfire. Overall, the value of these benefits is constrained by the limited capture volumes permitted under current Colorado law under the 110-gallon residential rainwater harvesting scenario. Larger scale applications of stormwater would be required for economic viability along with water rights. Specific findings in the preceding section can be summarized as follows:

- In several regions of the United States (and internationally) rainwater harvesting and stormwater capture and use practices have demonstrated their ability to provide sufficient water to meet residential outdoor water demands, offsetting the need for water providers to provide potable water for this purpose. In some studies, these potable water offsets are significant.

- Although rainwater harvesting and stormwater capture and use have the potential to provide alternative or complementary sources of water supply in Colorado's urbanized areas, the 110-gallon residential capture volume currently allowed without water rights is insufficient to meaningfully contribute to overall water system resilience.

- When implemented at scale, rainwater harvesting has the potential to make more meaningful contributions to the overall water supply portfolio and conservation targets in some basins. This is particularly true for scenarios envisioning the possible offsets created by widespread adoption of 500-gallon or larger cisterns, which would require water rights under current water law.

- Captured rainwater can offset costs to residential water customers as well as retail water providers. Water providers can avoid energy, treatment, and infrastructure costs associated with delivering potable water for residential landscape irrigation. Legal limitations on stormwater capture and use in Colorado create unfavorable conditions for realizing these avoided cost benefits.

- As exemplified for the scenario examining the capture of runoff from 10% of impervious surfaces, neighborhood- or regional-scale stormwater capture can contribute to water supply reliability by creating additive or marginal sources of supply, creating flexibility and redundancy within the supply system. The analysis shows that allowing for greater capture volumes could meaningfully reduce the water supply gaps projected by several of the Basin Plans and associated economic impacts. However, larger scale infrastructure and storage would be needed to realize this potential.

- The rainwater harvesting practices reviewed in this report (i.e., the 110- and 500-gallon storage volumes) may have limited practical potential to reduce water quality impairments in Colorado's urbanized areas. Implementation challenges (e.g., reliance on homeowners to maintain practices) and relatively low capture volumes may prevent this benefit from being fully realized.

- Available evidence suggests that larger scale stormwater capture and use adoption will have greater benefits (relative to costs). As demonstrated by Sterling Ranch and other case studies, capture in larger volume systems either at the site- or neighborhood-scales can provide sufficient volumes to meaningfully offset potable water demand, reduce water quality impacts, and potentially provide additional, high-value benefits.

# 7 Findings, Recommendations, and Next Steps

## 7.1 Key Findings

**Stormwater capture and use offers potential to provide water supply and improve water resilience in many geographies. In Colorado, its application is limited by the current legal and regulatory frameworks.**

- Stormwater capture and use is increasingly part of national discussions to diversify water supplies and improve water resilience. In several regions of the United States (and internationally) rainwater harvesting and stormwater capture and use practices have demonstrated their ability to provide sufficient water to meet a portion of residential outdoor water demands, offsetting the need for using potable water for this purpose. In some studies, these potable water offsets are potentially significant. As Colorado continues to explore the role that stormwater capture and use may play in its Water Plan, these national resources and examples may be useful references for communities exploring stormwater capture and use.

- When considering stormwater capture and use as a potential water supply, you must carefully consider the legal, economic, social, and environmental impacts. Colorado has an arid climate which has contributed to stringent water laws. Additionally, large municipalities, which would be most likely to implement large-scale stormwater capture and use, are located upstream of the productive agricultural areas with senior water rights for irrigation and others with senior water rights. In Colorado, these two factors will be key considerations when further investigating and developing stormwater capture and use projects.

- Currently, rainwater harvesting and stormwater capture and use projects in Colorado are strictly regulated. Only residential rainwater harvesting (i.e., 110-gallon storage capacity) is allowed without a water right (with an augmented water supply). This regulation is consistent with Colorado water law that is based on the Prior Appropriation Doctrine and intended to protect downstream water users from injury to their water rights.

- Obtaining a water right for larger scale rainwater harvesting and stormwater capture and use in Colorado requires significant up-front legal and engineering costs and is based on site-specific characteristics, typically requiring an augmentation plan, purchase of replacement water for augmentation and ongoing engineering, and legal costs for water rights accounting and filings with the CDWR.

- Only one pilot project has been applied for and approved under HB 09-1129 in Colorado (the Sterling Ranch pilot project) since legislation was passed in 2009. Deterrents for applying for pilot projects may include significant engineering and legal costs, intensive hydrologic monitoring requirements, cost of dual infrastructure, and other uncertainties.

- The Sterling Ranch pilot project will continue to be a key case study to advance dialogue about downstream impacts of rainwater harvesting and stormwater capture and use and to better understand what volumes of augmentation water are needed for these projects in new development to prevent injury to downstream water users. This science-based approach and use of empirical data is a necessary foundation for future rules and policies related to rainwater harvesting and stormwater capture and use. The concepts of HNDs and Regional Factors accepted for CWCB pilot projects as a result of the Sterling Ranch project open the door to broader rainwater harvesting and stormwater capture and use projects in Colorado.

**Legally allowable rainwater harvesting does not notably reduce (existing) outdoor potable water demands. Larger cisterns increase capture and use potential.**

- Rainwater harvesting collected from residential rooftops for landscape irrigation use as currently allowed in two 55-gallon rain barrels (functionally allowing only 88 gallons of total capacity) does not represent a significant source of water for meeting basin supply/demand gaps. The volume of water captured and available for use in rain barrels amounts to between 1.5% and 2.5% of typical household outdoor water use, depending on location within the state. Larger cisterns (500 gallons) increase capture and storage potential and can reduce typical potable outdoor water demands by up to 8%. The analysis shows that wide-scale adoption of cisterns could also make meaningful contributions to outdoor water conservation targets in some basins. Cisterns storing more than 110 gallons currently require a water right.

**Neighborhood- or regional-scale capture have the potential to provide meaningful and cost-effective water supply benefits for new development.**

- Neighborhood- or regional-scale stormwater capture could enhance water supply reliability in urban areas across the state by serving as an additive or marginal source of supply and/or creating flexibility and redundancy within supply systems. For example, in the South Platte/Metro region, the expected municipal supply/demand gap under the 2050 BAU scenario is 192,800 AF—approximately 19% of total demand. Capturing stormwater runoff from 10% of impervious area within the Basin would reduce this gap by 44,970 AF, thereby reducing the supply/demand gap to 15% of total demand. The extent to which this captured stormwater is “new water” not already claimed by a downstream water right would require additional analysis. The project team’s economic analysis (Section 6) indicates that this captured volume could significantly reduce the adverse economic impacts associated with water shortages. Additionally, greater water supply potential is possible with larger scale stormwater capture and use; however, larger scale projects have more regulatory/water rights constraints compared to rainwater capture that is allowable but has lower potential as a water supply.

- While stormwater runoff from existing impervious surfaces (e.g., rooftops, roads, parking lots) in Colorado's Urban Areas represents a substantial water source, this water is not considered a "new water” source in over-appropriated basins because it has essentially already been claimed for use under water rights filed in water court.

- Based on hydrologic analysis completed as part of the Sterling Ranch pilot project, the concepts of HNDs and Regional Factors (Gilliom 2019) provide a framework for larger scale implementation of stormwater capture and use for new greenfield developments. If adopted beyond the pilot scale framework, there is potential for a new development to claim the right to use a portion of the runoff from new impervious surfaces. For example, in the South Platte Basin, applying Regional Factors to hypothetical 10% and 25% increases in impervious area and using 10% to 25% capture rates for impervious area, the volumetric potential for urban stormwater runoff to serve as a "new water" source would be on the order of 3,100 to 19,600 AF/YR. More refined land development projections and Regional Factors in other river basins would be needed to refine this estimate or broaden it for use in other river basins.

**Rainwater harvesting and stormwater capture and use can provide multiple benefits that increase return on investment. Evidence suggests that larger scale capture systems have a greater benefit-cost ratio.**

- Captured rainwater can offset costs to residential water customers as well as retail water providers. Water providers can avoid energy, treatment, and infrastructure costs associated with delivering potable water for residential landscape irrigation. For the rain barrel and cistern scenarios analyzed as part of this research, the monetized value associated with these benefits does not fully offset the cost of residential stormwater capture.

- However, capture of rooftop runoff in rain barrels or larger cisterns can result in reduced pollutant loadings to nearby surface waters. The project team calculated the economic value of this benefit based on the costs that would be incurred to provide the same level of water quality controls in another way. Accounting for this benefit significantly increases the return on investment for household-level rainwater harvesting. Together, the water supply and water quality benefits result in a benefit-cost ratio of close to or more than one in most basins.

- Rainwater harvesting practices reviewed in this report (i.e., the 110- and 500-gallon storage volumes) may have limited practical potential to reduce water quality impairments due to current limitations on allowable harvest volumes. From a stormwater regulatory perspective, implementation challenges related to ensuring operation and maintenance (e.g., reliance on homeowners to maintain practices) may prevent this benefit from being fully realized.

- Available evidence suggests that larger scale stormwater capture and use adoption will have greater benefits (relative to costs). As demonstrated in the Sterling Ranch pilot project, larger scale systems can store more water (and capture rainfall from a larger area), resulting in significantly greater volume of potable water supply offsets and water quality benefits. Larger scale systems are also more likely to provide fire risk reduction benefits and/or carry a "sustainability premium," the value of which is reflected in increased property values and rental rates. Finally, larger scale systems can benefit from lower costs due to economies of scale and more flexible design.

## 7.2 Recommendations

**Build on existing legal pathways to allow stormwater and rainwater to meaningfully contribute to and diversify water portfolios.**

- Extend the legislation allowing stormwater capture and use pilot projects for 10 additional years to allow time for use of Regional Factors in other new development projects. In particular, consider expanding this legislation to remove unnecessary barriers and allow easier implementation for educational and research purposes. Utilize lessons learned from Sterling Ranch to simplify pilot project requirements (e.g., is there a way to make requirements less onerous while still protecting senior downstream water users?). For example, there may be opportunities to streamline the process for augmentation plans for new developments by expanding on concepts and tools developed around Regional Factors.

- Expand legislation to allow new developments to consolidate 110-gallon residential rainwater harvesting allowances to more centralized locations for irrigation of community spaces. For example, if a new development had a community center adjacent to an irrigated community park, allow stormwater to be captured and used for non-potable irrigation equivalent to the sum of total volume that would be available to all homes served by the community center (with an accompanying restriction on those homes from having their own residential rain barrels).

- Expand existing legislation to allow greater flexibility for rainwater harvesting to be allowed at academic and educational sites for the purpose of promoting water conservation behaviors and educating students and the greater public about Colorado's water environment.

- For development-scale stormwater capture and use projects, better integrate CDWR requirements related to rainwater harvesting legislation and stormwater management requirements so that both operations can occur within the same facilities and infrastructure. This could reduce costs of stormwater management at these developments.

- Develop clear guidance on treatment requirements necessary to protect public health for use of stormwater for indoor water uses similar to comparable efforts for graywater use in Colorado under Regulation 86.

**Provide guidance to land use planners and housing developers on how to include stormwater and rainwater as alternative water supplies to offset potable water use.**

- Provide guidance to new developments considering rainwater harvesting and stormwater capture and use as a water source. For these practices to be viable at a development scale, they must be considered in the early planning stages before site layout is completed. Additionally, developers need up-front certainty that rainwater harvesting and stormwater capture and use will be approved by relevant jurisdictions and have a reasonable likelihood of success in water court.

- Further explore how rain barrels and cisterns may be used to meet stormwater quality requirements, particularly on redevelopment sites in areas where local governments require stormwater quality to be provided if 500 square feet or more of impervious surfaces are added. For example, CDPHE requires stormwater quality at 1 acre of disturbed area, but local governments may require stormwater quality control measures at much lower thresholds tied to impervious cover. Partners in such an effort could include CDPHE, the Mile High Flood District, City and County of Denver, state universities, and other organizations actively encouraging One Water planning approaches.

- Stormwater capture and use and rainwater harvesting offer multiple benefits, especially at the community scale. When seeking to develop alternative water supplies, these co-benefits should be integrated into any cost-benefit analysis, along with treatment and distribution system costs.

**Create the enabling conditions to advance stormwater capture and use and rainwater harvesting as strategies to contribute to safer, more water-resilient communities.**

- Similar to "carbon neutral" approaches in the climate change arena, encourage site-scale, One Water approaches to provide irrigation requirements for vegetated SCMs using site-generated stormwater. Examples could include using captured roof runoff to irrigate an adjacent green roof or using roof-generated runoff to irrigate a grass swale.

- Using the concept of HNDs, consider allowing greater use of cisterns for maintaining defensible space. This could contribute to reduced demand on water supply systems in times of emergency as well as potentially reduce the impact of wildfires on residential property.

- Colorado has made limited adjustments to its water rights system in the past to enable implementation of specific types of wastewater recycling and residential rainwater harvesting. Evaluations that further explore the potential for stormwater capture and use within this context could help inform policy discussions about the costs, benefits, and distributional impacts of changing or maintaining water rights restrictions currently applicable to stormwater capture and use, while still protecting senior water rights.

- This analysis was conducted within the context of current and projected outdoor water demands. However, rainwater harvesting for outdoor irrigation purposes should be paired with other landscape water conservation practices, such as converting non-functional turf grass areas to water-wise landscapes that require less water and efficient irrigation practices. Combined, these practices can significantly reduce outdoor water use at the household scale. Wide-scale adoption could contribute to meaningful reductions in the municipal supply-demand gap.

**Conduct a more detailed assessment of the co-benefits of stormwater capture and use to identify targeted areas for implementation and potential co-funding partnerships.**

- This report provides a high-level overview of the multiple benefits associated with stormwater capture and use at the basin scale. A more detailed assessment of co-benefits could further identify targeted areas for implementation (i.e., areas where co-benefits are maximized) and incorporate quantitative values for additional co-benefits. Additional assessment of co-benefits could focus on specific case studies or basins.

- Building on the role that water supply plays in the provision of housing, including affordable housing, assess the potential benefits of stormwater capture in increasing water supply, and/or reducing the costs of water, and the potential resultant effect on housing availability and cost.

- A more detailed assessment could inform the potential for co-funding by different agencies/interests based on co-benefits. For example, based on the distribution of water supply, water quality, and fire risk reduction benefits.

- Finally, to better understand the potential role for stormwater capture and use within the state's overall supply portfolio, the benefits and costs of stormwater capture and use should be directly compared to those associated with alternative supply options. As part of such an effort, regulatory constraints that may exist at the state or local levels driven by water quality, public health protection, local land use, or other regulatory concerns should also be evaluated. Stormwater as a potential supply source could then be more fully integrated into future planning efforts associated with the Colorado Water Plan.

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