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Diversifying Water Portfolios Through Stormwater Capture and Use: Contributing to a Water Resilient Future

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This research builds on the work of a focused assessment of the volumetric and economic potential of stormwater capture in Colorado as well as the national assessment of the volumetric potential of urban runoff available for capture. Over the course of more than a year, the Colorado project's Expert Review Panel and the national project's Advisory Group generously and graciously provided critical input to guide and inform those efforts; WRF 5236 has subsequently benefitted. The Team is grateful for the time and insight of all contributing parties. The Project Team takes full responsibility for the content included in this report.

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Acronyms and Abbreviations

ACS	American Community Survey
AFY	Acre feet per year
BAU	Business-as-usual
CLASIC	Community-enabled Lifecycle Analysis of Stormwater Infrastructure Costs
CSO	Combined sewer overflow
EROS	Earth Resources Observation and Science Center
FAMSL	Feet above mean sea level
GSI	Green stormwater infrastructure
MS4	Municipal Separate Storm Sewer
NBS	Nature-based solutions
NLCD	National Land Cover Dataset
NPDES	National Pollutant Discharge Elimination System
PRISM	Parameter-elevation Regressions on Independent Slopes Model
SWMM	Stormwater Management Model
TELR	Tool to Estimate Load Reductions
USEPA	United States Environmental Protection Agency
WMOST	Watershed Management Optimization Support Tool
WRAP	Water Reuse Action Plan
WRF	The Water Research Foundation

Executive Summary

ES.1 Key Benefits and Recommendations

This project benefits water utilities and water managers across the United States by providing adaptable and streamlined methodologies to navigate their unique legal, geographical, economic, volumetric landscapes when considering the incorporation of stormwater as a water resource development strategy.

These vetted methodologies support the integration of stormwater capture and use projects at the local, state, and regional scales by:

- Integrating co-benefits into water management and investment decisions
- Creating enabling conditions that contribute to safer, more water resilient communities
- Conducting deeper analysis of stormwater capture co-benefits: targeted areas, appropriate scale(s), and co-funding partnerships

These benefits provide utilities beyond Colorado with a straightforward approach to better understand and estimate to what extent stormwater capture and use can address challenges, such as water pollution, flooding, and urban heat island.

ES.2 Background and Objectives

In the face of a changing climate, shifting populations, and other uncertainties, urban stormwater capture and use can add flexibility and diversity to water supply portfolios. Once seen as a nuisance, stormwater is part of a modern-day paradigm shift that recognizes it as an asset. There is an estimated 59.5 million acre-feet per year of stormwater runoff potentially available in urban areas across the United States (Berhanu et al. 2024). When captured and used, stormwater can both supplement existing water supplies and provide multiple environmental and community co-benefits.

Some universal challenges that water utilities face when considering implementing stormwater capture and use projects are 1) uncertainty surrounding the legality of stormwater capture and use, 2) lack of knowledge of the potential volume of stormwater available, and 3) non-quantified costs and benefits of stormwater capture.

The objective of this project is to apply the lessons learned from stormwater capture and use analysis in Colorado, which has stringent water rights constraints, to address these challenges and develop a flexible framework that can be adapted by water utilities and water managers from across the country to meet their specific needs under various regulatory and geographical contexts.

This report leverages the learnings from the analysis conducted for Colorado and broadens its application so that water managers can employ and adapt these approaches to understand the volumetric and economic potential of urban stormwater capture and rainwater harvesting in their community.

ES.3 Project Approach

The Colorado project, *Diversifying Colorado's Water Portfolio: The Potential for Stormwater Capture and Use to Contribute to a Water Resilient Future* (Pacific Institute, Wright Water Engineers, Inc., One Water Econ 2024), was guided by a diverse group of experts with both Colorado-specific and national perspectives and it detailed the current regulatory environment for stormwater capture and use practices in Colorado, quantified the volumetric potential of stormwater available under different scenarios in the state, and conducted an economic analysis on the multiple benefits of scaling up such projects.

The results of the Colorado project are provided in a report to the Colorado Water Conservation Board. The methodologies detailed in this report are built upon that foundation and expanded in such a way that they take into consideration various and diverse geographies and contexts. Water utilities and practitioners should be able to apply each methodological approach in a way that is relevant and reflective of the communities in which they live and serve.

ES.4 Results

This WRF-sponsored report provides a process and sound approach to support a high-level assessment of stormwater capture and use as a potential source of water supply. Results are included from the following analyses:

- Assessing and incorporating the role of water rights, policies, and regulations.
- Estimating the volumetric potential of stormwater available for water supply.
- Applying an economic analysis and incorporating multiple benefits.

This framework provides water utilities with a starting point to navigate the sometimes undefined and complex legal landscape around stormwater as a water supply and conduct a high-level assessment of the feasibility of adopting stormwater capture and use projects. Key steps include:

1. **Assess and Incorporate the Role of Water Rights, Policies, and Regulations**: Conduct an initial assessment of the legal landscape, including laws, permits, and treatment requirements for stormwater.
2. **Estimate the Volumetric Potential of Stormwater Available for Water Supply**: Quantify the volumetric potential of precipitation runoff available for capture and use following these general steps:
    - Identify contextually relevant scenarios, such as the volumetric potential for residential rainwater harvesting or for larger-scale, urban stormwater runoff capture and use.
    - Develop a set of hydrologic assumptions and methods to estimate the volumetric potential of these scenarios considering factors such as precipitation patterns, usage patterns, roof area, impervious cover, capture efficiency, storage capacity, adoption rates and other factors.

  - Apply hydrologic methods across the relevant scenarios to estimate volumetric potential at scale using geospatial tools.
  - Contextualize the results within a water planning information. As an example, Figure ES-1 shows how the project team graphically compared estimated stormwater runoff volumes to baseline and projected residential outdoor demand in Colorado. The stormwater runoff scenario, “All Impervious Surfaces, 10% Surface Area” represents capture of 10% of the volume of stormwater runoff that would be generated on all urban impervious areas whereas the scenario, “All Impervious Surfaces Minus Roadways, 10% Surface Area” represents capture of 10% of the volume of stormwater runoff that would be generated from non-roadway impervious surfaces in urban areas.

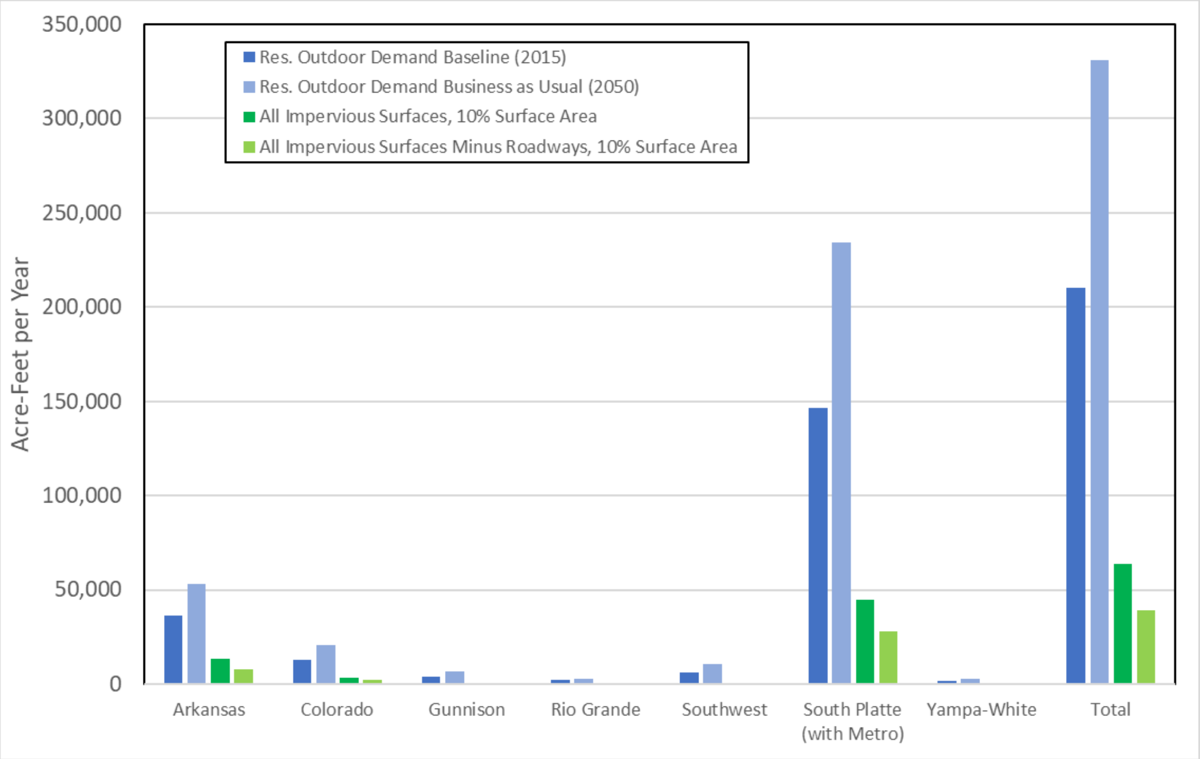

Figure ES-1. Baseline and projected (BAU) residential outdoor demand (blue bars) and two scenarios of urban stormwater runoff (green bars) by basin (AFY)

Residential outdoor demand, both baseline and BAU projections, from ELEMENT Water Consulting, Inc (2019).
Source: From Figure 15 from Pacific Institute, Wright Water Engineers, and OneWater Econ (2024).

3. **Conduct an Economic Analysis, Including an Assessment of Co-benefits**: The costs and benefits of stormwater capture and use projects relative to various alternative water supplies are a key factor determining the viability of captured stormwater as a water supply. Key steps include:

    - Establish a baseline that includes current and future water demands without stormwater capture and use as a source of supply and with any comparable alternatives that would be implemented to ensure against any projected shortages.
    - Identify the full range of relevant benefits (and beneficiaries) associated with stormwater capture and use options. These may include water quality improvements,

    avoided (or reduced) risk of water supply shortages, energy savings, and/or other community benefits, among others.
    - Monetize those benefits that can be reasonably quantified given available data and methods.
    - Qualitatively assess non-monetized benefits.
    - Compare lifecycle benefits and costs over time.

These steps provide a screening level approach to support water supply planning and assess potential viability of stormwater harvesting. All steps in the process should include gathering and incorporating input from those who will be involved in managing and designing stormwater harvesting programs and/or projects, as well as those who will be using the harvested stormwater and/or those who might benefit from the project's multiple outcomes. This involvement is critical for providing an objective and transparent basis for comparing alternatives, identifying opportunities for cost-sharing, garnering support for the project, determining viability and avoiding unintended consequences (Diringer et al. 2020).

ES.5 Related WRF Research

- Assessing the State of Knowledge and Research Needs for Stormwater Harvesting (4841)
- Economic Framework and Tools for Quantifying and Monetizing the Triple Bottom Line Benefits of Green Stormwater Infrastructure (4852)
- Community-enabled Lifecycle Analysis of Stormwater Infrastructure Costs (CLASIC) (4798-4804)
- Risk-Based Framework for the Development of Public Health Guidance for Decentralized Non-potable Water Systems (4632)
- Assessing the Microbial Risks and Impacts from Stormwater Capture and Use to Establish Appropriate Best Management Practices (5034)
- Drivers, Hindrances, Planning and Benefits Quantification: Economic Pathways and Partners for Water Reuse and Stormwater Harvesting (1748)

CHAPTER 1

Introduction and Background

1.1 Introduction

As water utilities and the communities they serve across the United States adapt to the effects of climate change, shifting populations, and other uncertainties, they are seeking to develop new, alternative water supplies that bolster their ability to be water resilient. Stormwater, historically viewed as a nuisance, is part of a modern-day paradigm shift that recognizes stormwater as an asset. Stormwater, when captured and used, has the opportunity to both supplement existing water supplies and address community challenges through its many co-benefits (improving water quality, reducing some types of flood risk, increasing green spaces, and decreasing urban heat islands, for example).

As utilities explore the option of including stormwater in their water supply portfolio, there are key questions that must be addressed to understand the volumetric and economic potential. In Colorado, rigorous research and analysis was undertaken to understand the extent to which urban stormwater runoff and rainwater harvesting could contribute to the municipal and industrial supply demand gap.[1] Additionally, the economic potential of stormwater and rainwater harvesting was explored through a robust assessment of the myriad ways in which its co-benefits inform the analysis of stormwater as a viable water supply.

The methodologies used to assess the volumetric and economic potential of urban stormwater capture and rainwater harvesting in Colorado have broad applications and implications. Applying these methodologies, primarily at the residential scale, can benefit water managers throughout the United States in their quest to evaluate the extent to which stormwater capture can contribute to their water supply portfolio. This report leverages the learnings from the analysis conducted for Colorado and broadens its application so that water managers can employ and adapt these approaches to understand the volumetric and economic potential of urban stormwater capture and rainwater harvesting in their community.

1.2 Background

1.2.1 Colorado Water Conservation Board Project

The Colorado Water Plan “provides a framework for helping Colorado meet its water challenges through collaborative action around water development and water conservation” (Colorado Water Conservation Board 2023). Throughout the plan, actions are identified to help Colorado

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[1] Here, stormwater refers to rainwater or melted snow the runs off streets, buildings, lawns, and other surfaces. The term is inclusive of runoff from all surfaces within an urban area, whereas stormwater collected from residential rooftops is distinguished as rainwater harvesting. These terms are distinguished here because in Colorado rainwater is a legally distinct water that in certain circumstances can be captured and used without a water right permit. This distinction may not be necessary in all geographies.

narrow its supply demand gap and advance the development of alternative water supplies, such as stormwater and rainwater.

Until recently, the volumetric potential for urban stormwater capture and rainwater harvesting, and the economic potential for developing these resources, was not well documented in Colorado. In 2022, the Colorado Water Conservation Board funded *Diversifying Colorado's Water Portfolio: The Potential for Stormwater Capture and Use to Contribute to a Water Resilient Future"* to address uncertainties surrounding stormwater capture and use and rainwater harvesting, including questions related to water rights, volumetric potential, and economic viability, and the portion of captured rainwater that represents "new water" supplies.

Findings from the research and analysis approach used for that project can support efforts nationally as water managers assess the volumetric and economic potential of stormwater capture in their service areas. WRF 5236, *Diversifying Water Portfolios through Stormwater Capture and use: Contributing to a Water Resilient Future,* recognizes this opportunity and addresses these key challenges by building on the Colorado-based research. Inclusion of this work as part of the U.S. Environmental Protection Agency's (USEPA's) Water Reuse Action Plan (WRAP) as Action 5.8, *Evaluate Stormwater Capture and Use in Colorado,* further underscores the national applicability and importance of the stormwater and rainwater research in Colorado. Specifically, Action 5.8 frames the Colorado project as useful for water utilities beyond Colorado and couches the potential for stormwater capture and rainwater harvesting within the context of water reuse and recycling.

1.2.2 Colorado-Specific Constraints

In Colorado, the Prior Appropriation Doctrine is the 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 (Colorado Division of Water Resources 2024). The terms "senior" and "junior" water rights are commonly used to refer to relative priority of rights to use water, which are based on "first in time, first in right." Urban stormwater runoff from existing development to streams and rivers is relied upon by existing senior water rights holders for various beneficial uses, which restricts the amount of rainwater harvesting or stormwater capture and use that can be implemented without a water right, which typically requires a plan for augmentation to replace out of priority depletions to water bodies. Currently in Colorado, most rainwater harvesting is limited to two 55-gallon rain barrels capturing roof runoff at residential households unless a water right is obtained. (See Pacific Institute, Wright Water Engineers, Inc., One Water Econ 2024. for additional details on water rights and allowable rainwater harvesting in Colorado.)

In 2009, Colorado passed legislation authorizing up to ten larger scale (i.e. beyond single rain barrels at a single household) rainwater harvesting pilot projects for new development with substantial monitoring requirements. 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. To date, only one pilot project, known as Sterling Ranch, has been implemented. Sterling Ranch is a master planned community located on the Front Range of Colorado south of Denver. This mixed-use residential community will eventually have more than 12,000 homes on 3,400 acres and will use rainwater harvested from within the community to supplement water supply and offset non-potable outdoor irrigation demands. To date data collected from the project have been instrumental in improving the state's understanding of historic natural depletions (i.e., the amount of precipitation that was likely to make it to receiving bodies such as rivers and streams predevelopment).[2] By better understanding and quantifying historic natural depletions, there may be future opportunities in Colorado to further conversations regarding the potential to capture the difference between the increased water yield from new developments after accounting for the volume of water that would not have reached rivers and streams under pre-development conditions.

1.3 Objectives

Nationally, two of the biggest hurdles to implementing stormwater capture and use are quantifying both the volume of stormwater or rainwater available for reuse and the anticipated benefits and costs. This guidance document provides an initial framework for incorporating stormwater and rainwater into the water supply planning process. It distills the process and applies lessons from the Colorado-focused project to be flexible enough for utilities operating under different water rights, allowable uses, and with various drivers, opportunities, and challenges to use in their water supply planning.

The methods and framework in this report can be tailored to meet specific needs of a state, regional agency, or utility and the communities they serve by providing guidance on how to:

1. Conduct an initial assessment of the legal landscape for capturing, storing, and reusing stormwater.
2. Quantify the volume of precipitation runoff potentially available for reuse.
3. Assess the benefits and costs of stormwater capture and use and rainwater harvesting programs.

Water managers who are considering incorporating stormwater into their water supply portfolio or building out existing stormwater capture and rainwater harvesting programs, can use this resource as a starting point to assess the viability of projects.

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[2] Historic Natural Depletions 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. Historic Natural Depletion Factors are based on the concept that Historic Natural Depletions are equal to water that infiltrated to soil moisture storage but did not become groundwater return flow; in other words, infiltration minus deep percolation (Gilliom 2019). After development occurs, increased impervious area from pavement and rooftops results in more surface runoff than occurred under undeveloped conditions, as well as less consumption of rainwater from vegetation and less return flow to groundwater.

CHAPTER 2

A National Perspective

2.1 State of Stormwater Capture in the United States

Across the United States there is a shift in how stormwater management is viewed. Once viewed as a nuisance and the cause of damage and harm, stormwater is increasingly viewed as an asset that contributes to the vitality of a community. This is evident through the increase in stormwater capture projects that provide water supply and additional community benefits (e.g., on-site sources of water for irrigation, supplemental fire suppression water, etc.). Rainwater harvesting is also being embraced by more cities as a way to manage stormwater and decrease peak flows, thereby decreasing pressure on aging infrastructure and sewer systems, particularly in communities with Combined Sewer Overflow [CSO] challenges. The scale of application, availability of storage, and treatment requirements for end uses affects the extent to which captured stormwater can be used to meet water supply objectives.

At the federal level, USEPA's Water Reuse Action Plan (WRAP) facilitates collaboration across sectors to increase water reuse, including stormwater, across the United States. Several actions have been developed to address a range of challenges and opportunities related to stormwater capture and use.[3] The Water Research Foundation (WRF) has and continues to fund projects aimed to help utilities plan for the future across multiple scales. Outcomes include tools that water managers and city planners can use to better understand the full value and true costs of stormwater capture and use. See the Summary Box below for USEPA WRAP Actions and WRF-funded projects related to stormwater capture and use.

U.S. EPA WRAP Actions related to stormwater capture and use

WRAP Action 3.3: Convene Experts on Urban Stormwater Capture and Use

WRAP Action 5.5: Quantify the National Volumes of Water Potentially Available for Reuse for Municipal Wastewater and One Additional Source of Water – Urban stormwater runoff

WRAP Action 5.8: Evaluate Stormwater Capture and Use in Colorado

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[3] For additional information on these and other WRAP Actions, visit the U.S. EPA's "Water Reuse Action Plan" website (U.S. EPA 2019).

The Water Research Foundation projects related to stormwater capture and use

WRF 4841: Assessing the State of Knowledge and Research Needs for Stormwater Harvesting (Garvey et al. 2023)

WRF 4852: Economic Framework and Tools for Quantifying and Monetizing the Triple Bottom Line Benefits of Green Stormwater Infrastructure (Clements et al. 2021)

WRF 5001: Climate-Resilient for Urban Stormwater and Wastewater Utilities: Workshop Proceedings (van der Tak, 2013)

WRF 5034: Assessing the Microbial Risks and Impacts from Stormwater Capture and Use to Establish Appropriate Best Management Practices (Sharvelle et al. 2023)

WRF 5105: Advancing Benefits and Co-Benefits Quantification and Monetization for Green Stormwater Infrastructure: An Interactive Guidebook for Comparison Case Studies (Callahan and Bill 2023)

WRF 5197: Unlocking the Nationwide Potential of Water Reuse (Hacker et al. Forthcoming.)

WRF 5207: Establishing a Framework for Integrating Stormwater Capture in Water Supply Planning (Spurlock et al. Forthcoming.)

2.2 Role of Stormwater Capture in Water Supply Planning

It is estimated that there is a potential of 59.5 million acre-feet per year (AFY) of stormwater runoff available for capture in urban areas in the United States (Berhanu et al. 2024). This volumetric potential tells a powerful story of an underutilized resource that has the power to advance water resilience. Though it is unreasonable to assume that all stormwater runoff can be captured, or that it should be captured, it is reasonable to acknowledge that stormwater capture may offer a flexible strategy that can address a number of challenges facing a community. It can augment local water supplies such as for park irrigation, contribute to a reliable drinking water source through aquifer recharge, and reduce pollutant loading to receiving waters. Stormwater capture offers triple bottom line benefits - financial, social, and environmental.

Water managers in both water-scarce and water-rich regions are beginning to actively expand their water portfolio to include stormwater. Barriers to this process include a sound understanding of the often-ambiguous regulatory environment, access to funding and financing for required infrastructure, and knowledge of the volumetric potential and economic feasibility of stormwater capture, to name a few. Several communities across the United States have overcome these challenges to establish noteworthy stormwater management programs that supplement local water supplies and offer community benefits. Through the forthcoming WRF 5207 project, these communities are being engaged to tell their story and inform the creation of a framework that will help utilities and the communities they serve begin laying the foundation to explore and ultimately implement strategies to incorporate stormwater into their water supply planning.

2.3 Constraints to Assessing Stormwater Capture and Use as a Water Supply

There are many real constraints that hinder broader assessment of, and therefore pursuit of, the potential of stormwater to be used as a water supply. Many of these were identified by U.S. EPA (2022) in its *Pure Potential* report and by Garvey et al. (2023), in their stormwater harvesting report in support of WRAP Action 7.2, *Develop a Coordinated National Research Strategy on Water Reuse* (U.S. EPA, OW 2020). Here, the project team briefly discuss three of these constraints, including:

- Uncertainty of legality of the practice of stormwater capture and use
- Lack of knowledge of the potential volume of stormwater available
- Non-quantified costs and benefits of stormwater capture

The project team focuses on these three constraints because they currently exist across many places in the United States. Here, the project team provides a short description of each of these three barriers to assessing stormwater as a potential water supply source.

2.3.1 Uncertainty of Legality of the Practice of Stormwater Capture and Use

Reuse of stormwater is not explicitly addressed by water reuse regulations in most states (U.S. EPA 2022). This has created ambiguity for entities considering stormwater as a potential water supply. Some of the main questions that an agency or organization should ask prior to pursuing stormwater capture and use include:

- Does the state have any laws that restrict or require permits for capturing, storing, or diverting runoff from impervious surfaces (e.g., water rights considerations, storage volume restrictions)?
  - If stormwater capture is not explicitly prohibited, is it explicitly authorized?
- Are there instream flow requirements or other end uses that would be impacted by the use of stormwater capture and use?
- Are there restrictions or permits required for using stormwater as a water supply? (e.g., restrictions on end-uses or end-users?)
- Are there restrictions, permits, or regulations related to the treatment of stormwater?
- Are there monitoring and/or reporting requirements related to stormwater capture and use?
- Is infiltration of stormwater into the subsurface a regulated activity?
- Can stormwater be diverted from storm sewers for purposes of reusing (with treatment prior to use)?
- Can dry-weather flows be captured and used, along with runoff from precipitation events?[4]

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[4] Dry-weather flows are runoff from sprinkler systems, groundwater, and other sources that typically flow into storm sewers during times without rainfall.

Answering these questions will help to clarify whether stormwater capture may be pursued, and what steps will need to be taken to ensure stormwater capture and use projects are safe, legal, and not causing harm to other water users or the environment.

Water rights across the United States fall into two main categories. As described previously, the Prior Appropriation Doctrine, generally followed by western states, is sometimes summarized as “first in time, first in right” and prioritizes rights to use water to senior water rights holders. The Riparian Water Rights Doctrine is more commonly followed by eastern states and gives the right to use water to the owner of the land who borders the water, given that use does not unreasonably harm the riparian water rights of others. Some states follow a combination of the two or have additional legal requirements related to capturing, storing, and using stormwater or rainwater due to the potential harm to downstream senior water rights holders. Colorado, for example, arguably has the strictest laws regarding stormwater capture and use and rainwater harvesting.

There are more than 10 states that follow the Prior Appropriation Doctrine in some form, including Alaska, Arizona, Colorado, Idaho, Kansas, Oregon, Montana, New Mexico, Nevada, North Dakota, South Dakota, Texas, Utah, and Wyoming (U.S. Department of Energy 2014). However, these laws can evolve over time, so it is important to check the status of the state where an entity is considering implementing a stormwater capture or rainwater harvesting project.[5]

2.3.2 Lack of Knowledge of the Potential Volume of Stormwater Available

In arid and semi-arid parts of the country where precipitation and stormwater runoff are inconsistent or only available at certain times of the year, stormwater is often thought of as insufficient to be a reliable source of water. And where precipitation falls more reliably, it often is viewed as a flooding nuisance rather than as a resource. However, until stormwater runoff volume is quantified across specific spatial and temporal scales of interest, it cannot be equally compared to other water supply opportunities.

Approaches to quantifying the volumetric potential of stormwater available for capture and use require hydrologic modeling of precipitation and runoff conditions. Development of a program that utilizes captured stormwater as water supply requires water demand/end use analysis and other considerations such as storage and distribution system requirements, and infiltration capacity of soils for aquifer recharge projects, as a few examples. A few key considerations are as follows:

- What is the geographic area in which stormwater runoff will be generated that would be available (legally) for capture and use?
- What are the land use types across the geographic area and which are associated imperviousness?

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[5] The World Water Reserve provides a list of laws regarding rainwater harvesting for each state on their website (Zac 2024). This document should only be used for a cursory examination of water rights related to stormwater capture and use and is not a substitute for legal advice from licensed attorneys.

- What is the historical range of annual/monthly/daily precipitation for the geography of interest?
- Are there water supply aquifers in the watershed that may be able to provide natural storage spaces for captured water? If so, what regulatory and treatment requirements must be met?

These can be used as guiding questions for identifying the hydrologic model that will be used for the analysis, as well as the initial datasets that should be gathered.

Assessing the volumetric potential of stormwater available also may require understanding the current state of stormwater management in the area of interest. Most cities follow storm drainage criteria to protect the public health and ensure safety from flooding. Additionally, many cities are required to meet Municipal Separate Storm Sewer (MS4) permit requirements or CSO requirements. Master drainage plans and geospatial data for drainage networks can provide initial insight into how local governments are managing stormwater. These plans and data may help to ascertain how much stormwater is already being captured, either for treatment by stormwater quality control measures, infiltration, or for other purposes (e.g., irrigation). In some places, there is currently so little capture and use of stormwater that this information may not substantively alter the outcomes of the analysis. Furthermore, in many areas, there is not a centralized database that tracks stormwater infrastructure or capture and use, and therefore, assumptions may need to be made regarding the percentage of the total runoff volume that is already being captured and used based on best information available.

Climate change may be another source of unknowns in a first-step analysis of stormwater runoff potential for water supply. Where hydrologic models can incorporate climate change, it is highly recommended to do so to better understand the magnitude of expected changes in precipitation volume, timing, and type (rain vs snow) that would be expected in the future. Research by Nodine et al. (2024) provides an example of how climate change impacts to urban hydrology can be incorporated into stormwater runoff analyses as well as the implications of climate change for stormwater runoff across U.S. cities.

There are other key considerations to assessing stormwater capture potential, such as those surrounding public health. But those are not immediately relevant to the initial question regarding the volume of water that may be available for capture from stormwater runoff.

2.3.3 Unquantified Costs and Benefits of Stormwater Capture

All water management decisions have costs and benefits; accounting for these prior to designing a project or choosing an approach is considered best practice (Diringer et al. 2020). Stormwater capture for water supply may be costly, depending on location, climate, project type, and other factors. However, projects designed to achieve multiple benefits (e.g., water quality and water supply benefits) can result in more cost-effective outcomes compared to a siloed approach. To evaluate stormwater as a potential water supply opportunity it is important to assess and quantify (when feasible) the full range of costs and benefits that may accrue and to put those values in comparable terms.

As will be described in Chapter 3, the costs and benefits included in the analysis will depend on the scale of the analysis, the data available for quantification, the legal and regulatory context in which the practice may be pursued, and potentially many other context-specific factors. Please see Appendix A for a list of tools and other resources that can be used for cost-benefit accounting relevant to stormwater capture and incorporating multiple benefits into water management decision making.

CHAPTER 3

Assessing Stormwater Capture as a Source of Water Supply in Your State

As described by Chapter 2, there are three common constraints to assessing stormwater capture as a water supply: uncertainty of legality of the practice, lack of knowledge of the potential volume of stormwater available, and unquantified costs and benefits of stormwater capture. To address these three constraints this chapter offers a high-level overview of the process taken by the project team to assess the stormwater capture and use potential for the state of Colorado. This chapter includes a discussion on:

- Assessing and incorporating the role of water rights, policies, and regulations
- Estimating the volumetric potential of stormwater available for water supply
- Applying an economic analysis and incorporating multiple benefits

While the examples given are Colorado-specific, the process involved, and components of each step, can be adapted and made relevant for similar analyses across the United States. Current methodologies reflect the limited capture volumes permitted under current Colorado law that effectively restricts rainwater harvesting to residential properties with 110-gallon rain barrels. For states without these restrictions, projects at larger scales can be explored.

3.1 The Role of Water Rights, Policies, and Regulations

While stormwater capture and use and rainwater harvesting programs are increasingly being developed across the country, in Colorado and other western states that follow the Prior Appropriation Doctrine for water rights administration, collecting and storing stormwater (and rainwater) for later use is highly managed and often restricted to protect existing downstream water users. This results in additional engineering and legal requirements for larger scale stormwater capture and use related to physical availability of the water and augmentation plans for out-of-priority stream depletions (i.e., diversion and use of water out of the legally established order), which can deter water providers from pursuing stormwater as a water source.

In Colorado, there has been uncertainty surrounding whether or not there are viable, streamlined legal pathways for pursuing stormwater capture and use beyond the allowed two 55-gallon rain barrels on residential properties. Although legal pathways exist to obtain water rights through the water court process including use of augmentation plans, the cost and complexity of this process is a significant deterrent to larger-scale projects. Additionally, when augmentation plans are required, questions regarding “double-counting” of water supplies can arise (e.g., the water captured is being replaced [augmented] from another existing source).

In a few western states and all eastern states, water use is governed, at least in part, by the Riparian Doctrine (U.S. Department of Energy 2014). Under this approach, water rights are tied to the land and therefore, landowners adjacent to water bodies hold the rights to the water in those streams, lakes, or rivers. Case law and other legislatively derived changes have occurred over time for the Prior Appropriation Doctrine and Riparian Doctrine; therefore, each state has a unique form of rules and legal requirements related to stormwater capture and use.[6]

3.2 Estimating the Volumetric Potential of Stormwater Available for Water Supply

To quantify the volumetric potential of stormwater runoff for capture and use for a state, or other geographic region, the first step is to identify scenarios relevant to the context of the region, next, develop a set of hydrologic assumptions and methods relevant to the scenarios, and then, finally, apply the methods across the scenarios to create a range of estimates. These estimates are then most useful if contextualized within other water planning information, such as water demand for the same geographic region. This section describes the three steps used to quantify the volumetric potential of stormwater runoff applied in *Diversifying Colorado's Water Portfolio* report (Pacific Institute, Wright Water Engineers, Inc., and One Water Econ 2024), and presents some of the key results in comparison with relevant water planning values.

One important note on the process described below: due to the legal structure of water management in Colorado, including existing laws and policies, it was necessary to develop two different estimates of stormwater volumes. The first was for stormwater generated by residential rooftops and only of the volume that could be held in rain barrels or cisterns, distinguished as "rainwater" here in the report. The second was for a broader volume of stormwater runoff generated across impervious surfaces in urban areas with no specified capture approach, here called "stormwater." This second set of estimates also includes runoff from residential rooftops and therefore, the results of the stormwater runoff estimates are inclusive of rainwater harvesting volumes. In other parts of the country, this separation may not be necessary; however, both have been discussed below as the "rainwater" scenario may be useful for entities specifically interested in understanding opportunities for rain barrel and cistern programs or incentives, which this analysis would support.

3.2.1 Identify Relevant Scenarios

A first step along the path of estimating the volumetric potential of stormwater is to identify relevant scenarios under which it may be used for water supply. In *Diversifying Colorado's Water Portfolio* report (Pacific Institute, Wright Water Engineers, Inc., and One Water Econ 2024), there were three main scenarios of interest:

1. Rainwater harvesting estimates for the currently allowable two 55-gallon residential rain barrels (totaling 110 gallons) and a hypothetical 500-gallon residential rainwater harvesting scenario, with various adoption rates applied to each scenario. The 110-gallon scenario

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[6] For more information on state-by-state rules and restrictions related to rainwater harvesting, please see World Water Reserve's "Is it Illegal to Collect Rainwater: 2024 Complete State Guide (Zac 2024). This document should only be used for a cursory examination of water rights related to stormwater capture and use and is not a substitute for legal advice from licensed attorneys.

does not require a water right; conversely, the 500-gallon scenario would require water rights in Colorado.

2. Urban stormwater runoff estimates from 1) existing impervious surfaces, including rooftops; and 2) urban stormwater runoff from existing impervious surfaces minus roadways. These stormwater runoff estimates for existing impervious areas would require water rights to be implemented in Colorado.
3. Building on estimates from #2, stormwater runoff estimates for future (new) urban impervious areas were adjusted to Historic Natural Depletions in hypothetical land development scenarios in one river basin as an example.

The first scenario was chosen because it provided the volumetric potential for the currently allowed practice of using 110 gallons of storage at residential households, as well as a slightly altered, hypothetical scenario of 500 gallons of storage at the same residential households.

The second scenario looked at urban stormwater runoff from existing impervious surfaces without any specification of how much is feasible to capture, water rights, or other considerations. It was used to present a range of volumes that offer first-order estimates ranging from more “optimistic” to more “feasible” volumes available for capture.

The third scenario was conceived in direct response to the legal requirements in Colorado that make capture and use of stormwater from existing urban surfaces, except residential rooftops, almost always cost prohibitive. This third scenario, therefore, provided a hypothetical demonstration of an opportunity for capturing and using stormwater on future development as created by Colorado House Bill 15-1016. This bill established a process by which developers may obtain water rights for capturing and using a portion of stormwater from new developments by establishing that capture and use of the portion of stormwater runoff that had historically been evaporated or transpired by vegetation (i.e., Historic Natural Depletion) may be allowed under certain circumstances such as for developers participating in state-authorized pilot projects.

3.2.2 Develop Hydrologic Methods and Assumptions

After identifying the scenarios of interest, the second step in estimating the volumetric potential for stormwater available for water supply is to identify a method and basic assumptions for quantifying the amount of precipitation transformed to runoff within the geographic region of interest.

3.2.2.1 Stormwater Runoff Model

There are many runoff models that could be used for this estimate and the best one to use depends on the objective of the exercises, the spatial and temporal scale of interest, and the data availability for that geographic area. In some states, or at the municipal level, there may already be locally developed and approved stormwater runoff models that can be used for this step.

For the runoff model in *Diversifying Colorado’s Water Portfoli*o report (Pacific Institute, Wright Water Engineers, Inc., and One Water Econ 2024), the project team was interested in quantifying stormwater runoff for all urban areas in the state of Colorado. They defined urban areas following the urban-rural classification by the U.S. Census Bureau (U.S. Census Bureau 2023). Stormwater runoff from urban areas was summed up and presented at the river basin scale to help with comparison to other volumetric estimates from state water supply planning.

Other data sets used, along with the assumptions for their use are described below.

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 urban polygons. Land use classifications included “Pervious” and numerous impervious classifications (e.g., “Primary Road,” “Secondary Road,” “Tertiary Road,” “Thinned Road,” and “Non-road Impervious”). 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. This assumption may not be relevant in all geographies.

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. This step may not be necessary for other geographies where temperatures stay above freezing year-round.

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).

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 focused 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 other geographies, 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.). Other stormwater runoff models that have been used for water supply planning can be found in Beck et al. (2017), Aguilar and Brown (2020), Cooley et al. (2022), and Berhanu et al. (2024).

3.2.2.2 Residential Rooftop Rainwater Harvesting Estimates

Additional assumptions are required for understanding the total volume of stormwater from residential rooftops available for capture, here referred to as rainwater harvesting. The parameters needed for estimating rainwater harvesting potential in the Colorado project context included the number of residential households in each urban area, the size of the roofs, capture efficiency from the roofs (i.e., the proportion of the roof that connected to a rain barrel), rain barrel size, rain barrel adoption rates, and rain barrel refilling/storage assumptions.

The number of residential households per urban area were determined using American Community Survey (ACS) housing data in combination with data from the 2020 U.S. Census and the urban area polygons (U.S. Census Bureau 2021, 2022, 2023). In Colorado, only housing units with four or less units are allowed to harvest rainwater, and the ACS data provides information on the total number of residential households in various unit sizes.

Other parameters used for estimating rainwater harvesting potential and the associated assumptions that the project team made were as follows:

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. Residential roof size might be available for some municipalities, especially those that have a stormwater utility fee. To determine a reasonable roof size for the analysis, the project team 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 was 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 provided a more conservative estimate of total rooftop rainwater capture potential.

Capture Efficiency

The project team assumed that two 55-gallon barrels or one 500-gallon cistern (or equivalent storage) 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 assumed that a majority, but not all, of a residential roof is connected to a downspout.

Rain Barrel Size and 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 six inches tall and two 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.

Rain Barrel Adoption Rates

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. The project team 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).

Rain Barrel Storage and Refilling

As an additional exercise related to the stormwater runoff calculations, the project team developed a continuous simulation model to estimate the volume of rainwater that could be harvested from a 1,500 square foot household roof in Colorado, incorporating storm frequency for rain barrel filling and emptying. The rain barrel filling/emptying model was built using the precipitation and runoff time series described above. First, to understand the typical duration of inter-event periods in Colorado, the 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 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. This assumes a rain barrel is emptied and used for irrigation of the property's landscape 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. 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 an average (50th percentile precipitation), dry (10th percentile precipitation), and wet (90th percentile precipitation) year.

3.2.3 Apply the Methods Across Scenarios

Once the scenarios of interest, methods (including data needed for those methods), and assumptions have all been identified, the methods can be applied. This step will likely require using geospatial tools, that that perform the analyses and then summarize the results across over the geographic area of interest. One example of such a geospatial tool is the stormwater Tool to Estimate Load Reductions (TELR), as seen in Figure 3-1, developed by 2NDNATURE. TELR is a flexible modelling framework designed to estimate stormwater runoff (and pollution loading) that can be run using a variety of different geospatial datasets as inputs. The method preserves the spatial resolution of the available data and generates location specific results that can be summarized to any larger area of interest.

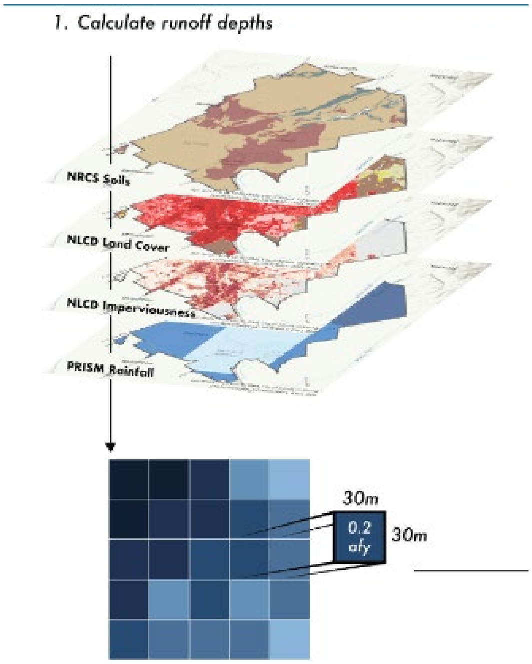

Figure 3-1. Conceptual demonstration of the stormwater runoff generation portion of the Tool to Estimate Load Reductions (TELR) by 2NDNATURE.
Source: 2NDNATURE n.d.

3.2.4 Contextualize Results within Water Planning Information

Results from the above three steps will be more useful once contextualized within existing water supply and demand estimates for the area of interest. Comparisons to both historical and future or projected supply and demand will help to inform water supply planners considering new supply options. Here, the project team provides two examples from the *Diversifying Colorado's Water Portfoli*o report (Pacific Institute, Wright Water Engineers, Inc., and One Water Econ 2024) that demonstrate how the project team compared the stormwater estimates to Colorado-specific water demand volumes.

3.2.4.1 Rainwater Harvesting Comparison

Table 3-1 demonstrates one of the comparisons used in the *Diversifying Colorado's Water Portfoli*o report (Pacific Institute, Wright Water Engineers, Inc., and One Water Econ 2024) of rainwater harvesting estimates to demand. For this comparison the project team presented existing residential outdoor demand (from 2015) and future projected outdoor demand (for 2050), in acre-feet per year (AFY), at the river basin scale next to the potential for rainwater harvesting in two 55-gallon barrels at two different adoption rates (scenario 1: 10% adoption of rain barrels; scenario 2: 50% adoption of rain barrels). The project team chose this comparison because in Colorado rainwater harvested from residential roofs is only allowed to be applied to the landscape at the property where it was captured so this was the most relevant end use for comparison. Other analyses in geographies that allow for broader use of stormwater and rainwater may want to consider uses beyond landscaping for comparison. The baseline and projected demand was obtained from the 2019 Technical Update to the Colorado Water Plan (ELEMENT Water Consulting, Inc 2019).

Table 3-1. Comparison of basin baseline (2015) and projected (2050 BAU) demand for residential outdoor use (AFY) with two 55-gallon rain barrels at the 10% and 50% adoption rates and proportions (%) these volumes represent.

Residential outdoor demand, both baseline and BAU projections, from ELEMENT Water Consulting, Inc. (2019).
Source: From Table 14 from Pacific Institute, Wright Water Engineers, Inc., and OneWater Econ (2024)

Basin	Res. Outdoor Demand Baseline (2015)	Res. Outdoor Demand BAU (2050)	Scenario 1: Two 55-gallon Rain Barrels 10% Adoption Rates			Scenario 2: Two 55-gallon Rain Barrels 50% Adoption Rates		
			RWH Potential	% of Baseline	% of BAU Projection	RWH Potential	% of Baseline	% of BAU Projection
	AFY	AFY	AFY	%	%	AFY	%	%
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%

This example demonstrates that in Colorado, the currently allowed approach to rainwater harvesting (without obtaining a water right) using two 55-gallon barrels to capture runoff from residential rooftops can only potentially meet a small proportion of the total baseline and future residential outdoor demand by basin. However, as the report authors state, "[n]onetheless, there are other potential benefits of rainwater harvesting at this scale that could make pursuing this strategy a beneficial endeavor…" (p. 70-71). The next section of this report (3.3) will discuss methods that can be used for quantifying these other potential benefits.

3.2.4.2 Stormwater Runoff Comparison

As another example, Figure 3-2 shows how the project team graphically compared estimated stormwater runoff volumes to baseline and projected residential outdoor demand, the same as were compared to the rainwater harvesting estimates in Table 3-1 above. The stormwater runoff scenario, "All Impervious Surfaces, 10% Surface Area" represents capture of 10% of the volume of stormwater runoff that would be generated on all urban impervious areas whereas the scenario, "All Impervious Surfaces Minus Roadways, 10% Surface Area" represents capture of 10% of the volume of stormwater runoff that would be generated from non-roadway impervious surfaces in urban areas.

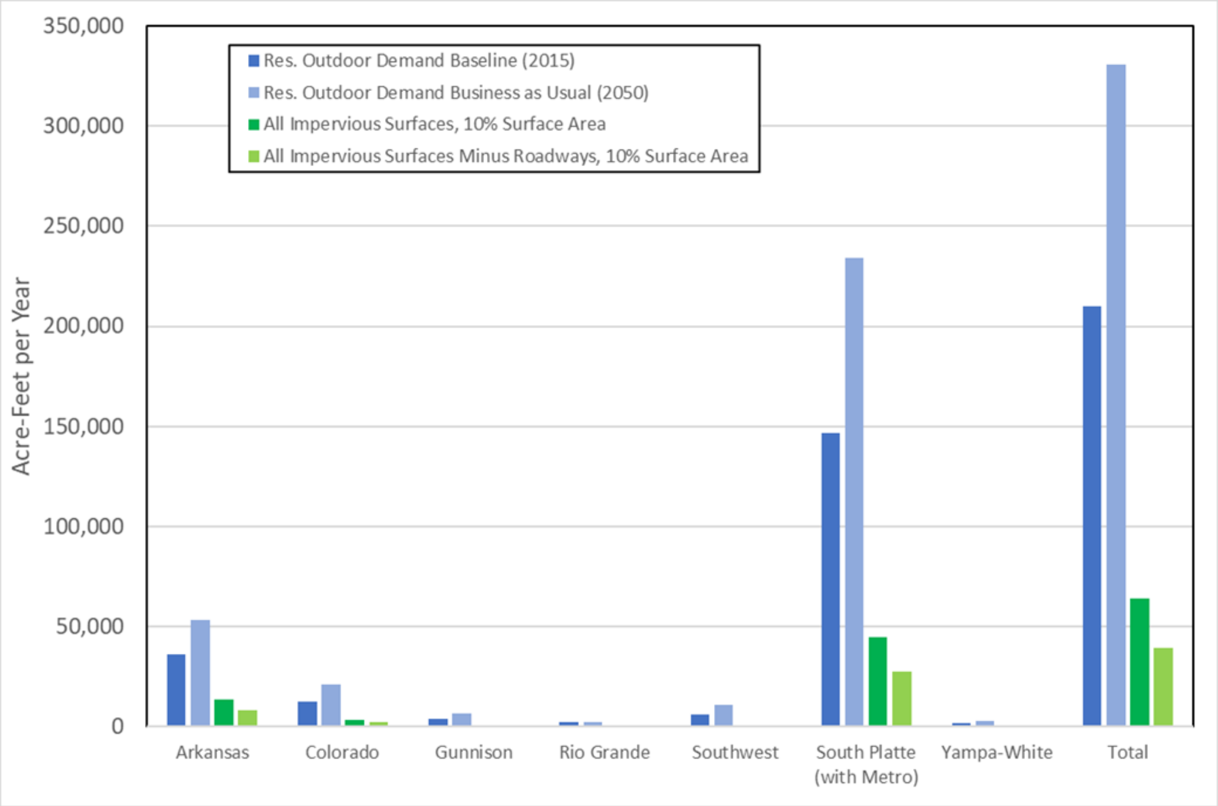

Figure 3-2. Baseline and projected (Business as Usual) residential outdoor demand (blue bars) and two scenarios of urban stormwater runoff (green bars) by basin (AFY).

Residential outdoor demand, both baseline and BAU projections, from ELEMENT Water Consulting, Inc (2019).

Source: From Figure 15 from Pacific Institute, Wright Water Engineers, Inc., and OneWater Econ (2024).

Stormwater runoff at a 10% capture rate represents about one third of existing residential outdoor demand in Colorado, and about one fifth of projected future residential outdoor demand in 2050. Legal, economic, environmental, public health, and other site-specific constraints would need to be evaluated to determine what level of stormwater capture and use would be viable before pursuing stormwater capture and use at any specific location in the state.

Another approach that can be applied to help stakeholders better contextualize the volume of stormwater runoff is to compare it to a known volume. For example, Dillion Reservoir on the Blue River in Colorado that holds water for the City of Denver has a storage capacity of approximately 257,000 acre-feet (Denver Water 2024). Based on the graphic above, this indicates that the volume of urban stormwater from all impervious surfaces (10% Surface Area) in the state total to around half the volume of Dillion Reservoir. The known volume selected for comparison should be relevant to the intended audience of the report.

Stormwater runoff volumes can also be compared to rainwater harvesting volumes to demonstrate the relative differences in opportunity across different approaches to capture. From the *Diversifying Colorado's Water Portfoli*o report (Pacific Institute, Wright Water Engineers, Inc., and One Water Econ 2024), Figure 3-3 compares rainwater harvesting potential for both 110-gallon rain barrels and 500-gallon cisterns to stormwater runoff volumes from existing impervious surfaces in the highly urbanized South Platte (including Metro area) Basin. This comparison reveals the large differences between rainwater harvesting and stormwater capture opportunities in the basin. Figure 3-3 indicates that rainwater harvesting in 110-gallon barrels is allowed without a water right, while the other approaches require water rights; this may not be relevant in other geographies.

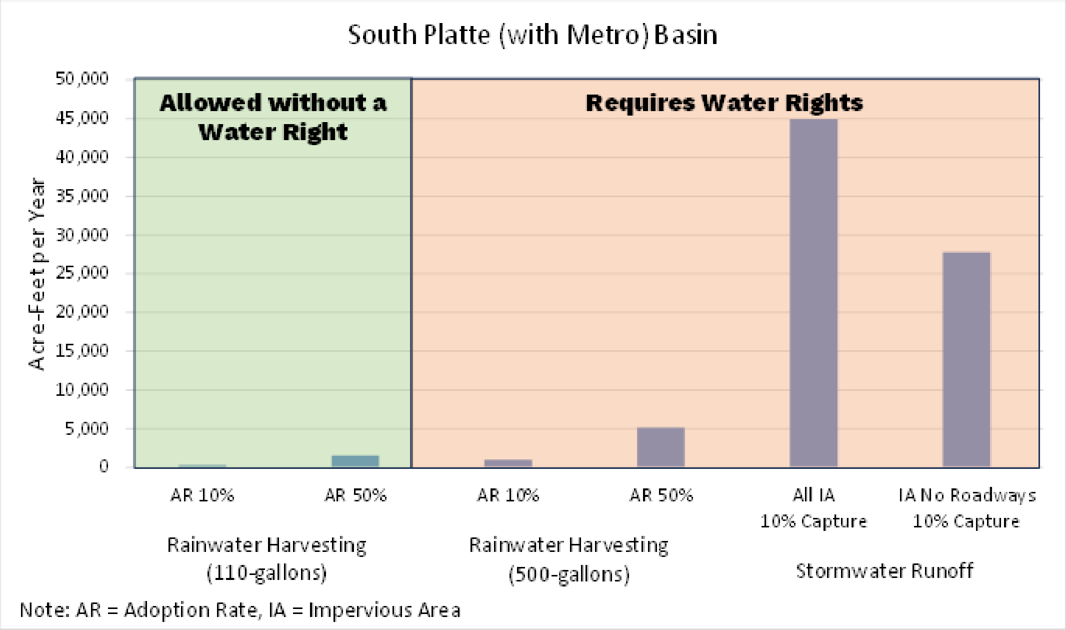

Figure 3-3. Comparison of Rainwater Harvesting Potential with Stormwater Runoff Volumes from Existing Impervious Surfaces in South Platte (with Metro) Basin Urbanize Areas

Source: From Figure 14 from Pacific Institute, Wright Water Engineers, Inc., and OneWater Econ (2024).

3.3 Economic Analysis

A critical piece of information in water management decisions is understanding the costs and benefits of different supply opportunities. This section describes a general process for evaluating and quantifying (in economic terms) the multiple benefits associated with stormwater capture and use, and appropriately comparing them to costs. Key steps include:

- Establish a baseline
- Identify the full range of relevant benefits and beneficiaries
- Monetize those benefits that can be reasonably quantified given available data and methods
- Qualitatively assess non-monetized benefits
- Compare lifecycle benefits and costs

These steps are sufficient for a conceptual/high level exercise that is seeking to provide a first order estimate for water supply planning discussions. All steps in the process should include gathering and incorporating input from the expected beneficiaries of the project; this is critical for providing a more objective and transparent basis for comparison, identifying opportunities for cost-sharing, garnering support for the project, and avoiding unintended consequences (Diringer et al. 2020).

3.3.1 Establish a Baseline

Defining the baseline scenario is a critical first step to conducting a comprehensive economic analysis; it is often the key to revealing the benefits of a project or program. Defining the baseline involves identifying the steps or actions that would be taken to meet the same objectives if stormwater capture and use is not implemented. For example, a "without-project" baseline may include securing alternative water supplies, decreased water supply reliability (as reflected in an increased risk of water shortages), and/or increased "gray infrastructure" for managing stormwater runoff. In these instances, avoided costs from the 'without project' baseline become benefits of the project.

An important aspect of defining the baseline is that it must reflect the future. The baseline is not the same thing as the "current" situation. Defining the baseline means looking into the years ahead, and since the useful lifetime of most water supply/stormwater investments typically is 20 or more years, a matching long-term timeframe needs to be applied for the baseline option. In addition, the baseline scenario has implications, and must be applied consistently, across benefit categories. In the simplified example of a baseline scenario that includes the use of gray infrastructure to meet water quality or quantity goals, the cost savings from foregoing the baseline gray infrastructure option should be included as a benefit of stormwater capture and use.

3.3.2 Identify Project Benefits and Beneficiaries

There is a growing body of literature on the co-benefits derived from stormwater management projects, especially those that use green stormwater infrastructure (GSI) and other nature-based solutions (NBS) (see resources listed in Appendix A for some examples). Here, the project team does not provide a literature review, but instead offers an example list of several of the key co-benefits that are relevant to consider when pursuing stormwater as a water supply.

The benefits presented here are those explored for the *Diversifying Colorado's Water Portfoli*o report (Pacific Institute, Wright Water Engineers, Inc., and One Water Econ 2024), and therefore, may be most applicable in geographies with similar drivers and challenges. In addition, the Colorado study primarily analyzed benefits associated with rainwater harvesting through rain barrels and cisterns; the project team did not analyze the benefits associated with larger scale and/or nature-based solutions for stormwater capture and use. Detailed guidance on quantifying the benefits of nature-based solutions for stormwater management (including for water supply) can be found in WRF 4852: *Economic Framework and Tools for Quantifying and Monetizing the Triple Bottom Line Benefits of Green Stormwater Infrastructure*.

The benefits identified for assessment in the *Diversifying Colorado's Water Portfoli*o report (Pacific Institute, Wright Water Engineers, Inc., and One Water Econ 2024) included:

- **Potable water savings and enhanced water supply reliability** – distributed stormwater capture and use projects 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. Larger scale projects that incorporate more centralized treatment (and sufficient storage) can enhance a community's water supply portfolio by increasing water supply reliability and reducing the need for more costly sources of supply.
- **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 urban runoff and improved water quality** – 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 damage associated with a wildfire event.
- **Increased education and environmental ethos** – 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.

This list of co-benefits was identified by the project team with direct input from a diverse group of stakeholders that engaged with the project as experts in relevant topical areas from within and outside of the state of Colorado. A robust stakeholder engagement process is a necessary and helpful part of stormwater management projects. When done well, it will include input from and give decision-making power to project beneficiaries; these stakeholders can help identify the potential list of co-benefits, discover opportunities for sharing costs, reveal and mitigate unintended consequences, and serve other important roles.

One other co-benefit identified but not quantified for the Colorado project was 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 precipitation 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). Furthermore, in addition to other benefits, other costs that may be considered in this process, but were not included in the Colorado project, are the cost of alternative water supplies, treatment, and distribution.

Another component of this step is the consideration of the distribution of the benefits and trade-offs across all impacted groups (i.e. stakeholders). The Pacific Institute and other partners have stated that equity is not simply a “benefit” inherent to any one water management approach, it is the just distribution of benefits and trade-offs from a water management approach among stakeholders (Diringer et al. 2020). While achieving true equity in any project may not be possible, best practice indicates that creating more equitable outcomes requires directly engaging those impacted by the decisions, especially those who have historically been left out of the decision-making process.

3.3.3 Quantify and/or Qualitatively Assess Benefits and Costs

Once identified, co-benefits can be quantified and/or qualitatively assessed based on the volume of stormwater or rainwater that may be captured and used and/or other key inputs. The first step to valuing a benefit is to establish the physical quantities or outcomes associated with it. Physical outcomes associated with the benefits of stormwater capture and use may include, for example, acre-feet or gallons of stormwater captured, acre-feet or gallons of potable water supply offsets realized, and/or energy savings (relative to a baseline scenario), among others. These metrics serve as the initial step in the valuation process; it is therefore important to match the quantity units of measurement to whatever metric is available for the corresponding dollar values.

Once the physical benefits have been estimated, a per unit dollar value often can be assigned to the benefit to reach a total value (quantity times per unit value). Economists have developed different methods for valuing the benefits provided by stormwater management projects (Clements et al. 2021). Market prices can be used to value benefits that are directly traded in markets, including avoided costs. For example, the value of energy savings based on the local price for electricity and natural gas (i.e., $/kWh or $/Btu). However, many of the benefits associated with stormwater capture and use need to be estimated using valuation techniques that elicit or infer an individual's or households’ willingness to pay for non-market goods and services (e.g., improved water supply reliability or reduced risk of shortages). These values can be evaluated at a high level based on estimates from the literature - an application known as benefits transfer.

A summary of benefits associated with site-level rainwater harvesting in Colorado (i.e., through rain barrels and cisterns) are presented in Table 3-2. Note that most of these represent costs that stormwater capture and use would help to avoid, including household costs for potable water supplies and costs associated with managing an equivalent volume of stormwater in another way.

Table 3-2. Benefits of rain barrels and cistern use in Colorado

Values are derived based on certain assumptions regarding the volume of stormwater or rainwater captured and used. See the source for further information. All values are in 2023 USD.

Source: Pacific Institute, Wright Water Engineers, Inc., and OneWater Econ 2024

Metric	Geographic Scale of Reported Values	Value/Range of Values	Units
Avoided water supply costs (Value per AF per year of utility provided water (retail costs))	Basin	$847-$2,471	$/AF/year
Avoided stormwater management costs per AF of stormwater capture	Basin	$3,029-$8,743	$/AF
Public health benefits from energy savings associated with potable water supply offsets (i.e., from pollution and GHG emissions reduction)	State	$41	$/AF
Avoided damages from wildfire in the study area from passive fire risk reduction through stormwater capture	All Census tracts in study area (urban areas)	$7.17	$M/year

It may not be feasible or desirable to express some types of benefits or costs in quantitative or monetary terms. However, it is important to describe any non-quantifiable benefits and costs in a meaningful, qualitative manner. Benefits and costs may be described qualitatively in part, by using a simple scale indicating the likely impact on net project benefits. For example, impacts can be qualitatively ranked on a 5-point scale, ranging from -2 to +2, to reflect unquantified relative outcomes that span from very negative to very positive (e.g., a “-1” may signify an outcome with moderate unquantified costs, and a “+2” may represent a high unquantified benefit). More complex or sophisticated rankings or methods, such as multi-criteria decision analysis, can also be applied (but may not be necessary). In any case, qualitative ratings should be accompanied by descriptions of the impact and should be explicitly carried through the analysis.

Cost values will need to be derived either from literature or from experimental data. Valuation tools, such as those presented in Appendix A, may also have cost values already pre-programed into them from data from existing literature. Typically for high-level exercises at the early stages of water supply planning, literature-derived values are sufficient. For the *Diversifying Colorado’s Water Portfoli*o report (Pacific Institute, Wright Water Engineers, Inc., and One Water Econ 2024), the project team used cost data from literature as well from several valuation tools such as the U.S. EPA's Stormwater Management Model (SWMM), the REALCOST tool from the Mile High Flood District, and the CLASIC tool by The Water Research Foundation.[7]

3.3.4 Compare Benefits and Costs Over Time

The third step is to compare the life-cycle benefits of alternative stormwater capture and use projects to the expected life-cycle costs. Life-cycle benefits and costs include those that accrue over the expected useful life of a project**.** In economic analysis, all values should be compared in present value terms (in current year dollars), applying an appropriate discount rate.

For the Colorado project, the research team calculated the benefit cost ratio for water quality and water supply benefits of rain barrels and cisterns (Table 3-4). The project team calculated these ratios based on the assumption that the benefits of water quality and water supply would accrue over a 10- and 20-year design life for rain barrels and cisterns, respectively, and applied a 3% discount rate. The benefits associated with the rain barrels ranged by basin from 72% to 99% of total costs, while the benefits of cisterns were slightly higher, ranging from 90%-114%.

Table 3-4. Benefit cost ratio for water supply and water quality benefits of rain barrels and cisterns. Values are derived based on certain assumptions regarding the volume of stormwater or rainwater captured and used. See the source for further information.

Source: Pacific Institute, Wright Water Engineers, and OneWater Econ 2024.

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

In general, 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 was constrained by the limited capture volumes permitted under current Colorado law that effectively restricts rainwater harvesting to residential properties with 110-gallon rain barrels. The project team concluded that larger scale applications of stormwater would be required for economic viability along with water rights.

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[7] See Appendix A for further information.

CHAPTER 4

Key Findings

4.1 Considerations, Key Benefits, and Recommendations for Advancing Stormwater Capture and Use

This chapter summarizes key findings and recommendations for practitioners considering stormwater capture and use in their communities. They are informed by water practitioners from across the United States and reflective of findings that came to light during the research and analysis portions of both the Colorado and national (Berhanu et al. 2024) stormwater assessments.

4.1.1 Support Integration of Co-benefits into Water Management and Investment Decisions

- Expand the types of benefits, costs, and trade-offs evaluated in water management decisions, and meaningfully engage with stakeholders in these evaluations. 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.
- Consider the role that stormwater capture and use can play not only in terms of water supply but also in the context of green infrastructure and low impact development strategies under National Pollution Discharge Elimination System (NPDES) municipal stormwater management requirements.
- Foster collaboration and build on existing collaborations at the watershed scale to incorporate stormwater as part of an integrated water resources management ("one water") approach that includes alternative water supplies.

4.1.2 Create the Enabling Conditions that Contribute to Safer, More Water Resilient Communities

- Partner with local agencies and organizations to seek co-funding and joint implementation opportunities, where cost-benefit analysis demonstrates that stormwater capture and use is viable and provides meaningful benefits to the community.
- Offer incentives that account for the multiple benefits produced by stormwater capture projects including water supply, water quality, and stormwater management.
- Reduce the financial burden placed on any single agency and increase the overall funding by providing "stacked incentives'' from multiple agencies (though caution should be taken such that public funds are not awarded for the same co-benefit more than once).
- Pair rainwater harvesting for outdoor irrigation 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 or commercial-lot scale. Wide-scale adoption could contribute to meaningful reductions in the municipal supply-demand gap.

- Expand the allowed uses of stormwater runoff to include more indoor applications, thereby advancing opportunities for onsite reuse and capitalizing on stormwater runoff volumes.
- Provide guidance to land use planners and housing developers on how to incorporate rainwater harvesting and stormwater capture and use as a water source in new developments. For these practices to be viable at a development scale, they must be considered in the early planning stages before the site layout is completed.
- Encourage site-scale, one-water approaches to provide irrigation requirements for vegetated stormwater control measures using site-generated stormwater. This is similar to "carbon neutral" approaches in the climate change arena, and examples could include using captured roof runoff to irrigate an adjacent green roof or using roof-generated runoff to irrigate a grass swale.
- Incentivize households and other properties by providing rebates, in-kind installation, and financing to reduce upfront costs and increase on-site adoption.

4.1.3 Conduct a Deeper Analysis of Stormwater Capture Co-benefits: Targeted Areas, Appropriate Scale(s), and Co-Funding Partnerships

- This report's high-level overview of several of the multiple benefits associated with stormwater capture and use are limited to those considered in the project team's evaluation of rainwater harvesting in Colorado. A more detailed assessment of co-benefits at the appropriate regional or local scale, and/or for different types of stormwater capture and use (e.g., through nature-based solutions and/or for different end uses) could result in a wider range of co-benefits and greater benefit cost ratios.
- Compare and further analyze different stormwater capture and rainwater harvesting approaches and their associated co-benefits for site-specific projects. This can help determine which strategies, such as storage size (cistern, rain barrel, other), end use (irrigation, cooling tower, potable uses, etc.), and other factors, have the greatest cost-benefit ratio.
- Utilize benefit assessments to help identify potential co-funding opportunities based on co-benefits, such as the distribution of water supply, water quality, or fire risk reduction benefits.
- Increase understanding of the potential role for stormwater capture and use within a utility's overall supply portfolio by directly comparing the benefits and costs of stormwater capture and use to those associated with alternative supply options.
- Evaluate regulatory constraints that may exist at the state or local levels. These may be driven by water quality, public health protection, local land use, or other regulatory concerns. Stormwater as a potential supply source could then be more fully integrated into future local, regional, and state planning efforts.

4.2 Recommendations for Future Research

In 2024, the Pacific Institute published their national assessment, Untapped Potential: An Assessment of Urban Stormwater Runoff Potential in the United States (Berhanu et al. 2024). In this assessment, research gaps were identified which, if filled, would contribute to the ability of water utilities and water managers to more accurately assess the potential of stormwater capture to contribute to their water supply.

Addressing these research gaps continues to be timely and relevant for water utilities and managers. Select recommendations taken directly from Untapped Potential: An Assessment of Urban Stormwater Runoff Potential in the United States (Berhanu et al. 2024) include:

1. **Draft Project Title:** Holistically Quantifying Opportunities for Stormwater Capture at the Regional Scale
   Problem Statement/Research Question: Opportunities to quantify the volumetric potential for stormwater capture are often taken at a scale that is not reflective of local, regional, and watershed contexts. Incorporating these contexts and their myriad of considerations will provide a volumetric potential which is fine tuned and more reflective of the geographic and legal landscape.
   Project Objectives: Future quantification efforts should include considerations for:
   - Downstream water rights holders and instream flow requirements for environmental protection.
   - Anticipated impacts of climate change on precipitation frequency, duration, and intensity.
   - The extent to which stormwater runoff currently contributes to regional water supplies.
   - Current levels of stormwater capture to develop estimates of addition “new” supply.
   - Temporal alignment between urban stormwater runoff availability and time of use (i.e., how do storage capacity requirements change for hourly, daily, weekly time scales).

2. **Draft Project Title:** Differentiating Between Real and Perceived Barriers to Implementing Stormwater Capture Project
   Problem Statement/Research Question: Real and perceived barriers (financial, regulatory, social, etc.) impede implementation of stormwater capture projects and the co-development of resources to support overcoming these barriers.
   Project Objectives: Identify the extent to which surmountable barriers are misconstrued as perceived or real impediments to stormwater capture and use projects

3. **Draft Project Title:** Understanding the potential effects of and ways to mitigate stormwater capture and recharge impacts on the water quality of public supply aquifers.
   Problem Statement/Research Question: Stormwater capture and use project have the ability to augment local and regional water supplies; however, the varied water quality of stormwater projects may put the protection of public health and the environment at risk if the stormwater quality is not adequately treated.
   Project Objectives: This report will demonstrate strategies to mitigate poor stormwater quality and optimize treatment approaches that ensure public supply aquifers receive appropriately treated stormwater that is protective of public health and the environment**.**

4. **Draft Project Title:** Holistically Accounting for the Co-benefits of Stormwater Capture Projects

Problem Statement/Research Question: To best prioritize water resource development strategies, a true accounting of the co-benefits of varying alternative water supplies and the communities they benefit must be considered.

Project Objectives: This project will develop tools and resources to support communities in accounting for the co-benefits of stormwater capture projects, such as case studies and a library of project-level cost-benefit analyses.

APPENDIX A

Cost Benefit Analysis Tools and Resources

A.1 Tools

A list of tools that can be used for quantifying and/or monetizing the costs and benefits of stormwater capture and use.

Center for Neighborhood Technology Green Values Stormwater Management Calculator - https://greenvalues.cnt.org/

CEO Water Mandate and Pacific Institute NBS Benefits Explorer Tool - https://nbsbenefitsexplorer.net/

Earth Economics Green Infrastructure Valuation Tool - https://www.eartheconomics.org/evtoolkit

i-Tree Hydro Model - https://www.itreetools.org/tools/hydro

2NDNATURE Software's Rainsteward web-tool - https://www.2ndnaturewater.com/2ndnature-software/product-rainsteward/

The Water Research Foundation Green Stormwater Infrastructure Triple Bottom Line Tool (GSI TBL Tool) - https://www.waterrf.org/research/projects/advancing-benefits-and-co-benefits-quantification-and-monetization-green

U.S. EPA Storm Water Management Model (SWMM) - https://www.epa.gov/water-research/storm-water-management-model-swmm

U.S. EPA Watershed Management Optimization Support Tool (WMOST) - https://www.epa.gov/hydrowq/wmost

Water Research Foundation, The - Community-enabled Lifecycle Analysis of Stormwater Infrastructure Costs (CLASIC) https://www.waterrf.org/CLASIC

A.2 Resources & References

A list of resources and references that are relevant to quantifying the costs and benefits of stormwater capture and use.

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Clements et al 2021. Economic Framework and Tools for Quantifying and Monetizing the Triple Bottom Line Benefits of Green Stormwater Infrastructure. https://www.waterrf.org/research/projects/economic-framework-and-tools-quantifying-and-monetizing-triple-bottom-line

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