Holistic Approach to Sustainable Water Management in Northwest Douglas County

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EXECUTIVE SUMMARY

Coloradoans recognize that our long-term economic health hinges on the availability of adequate, clean, reliable water supplies. As future demands for municipal, recreational, agricultural, and industrial uses continue to increase throughout the state, providing adequate water supplies will become more challenging. The water supply situation in northwest Douglas County serves as an example of the challenge of providing an adequate municipal water supply. Current and future residents are faced with a declining nonrenewable groundwater supply and limited options for renewable water supplies. The recommendations in this report provide an innovative approach toward balancing water supply and demand.

This study identifies two water management techniques that, particularly when paired together, offer an overlooked renewable water supply alternative for Colorado: precipitation management through rainwater and snowmelt harvesting and outdoor water demand management through use of water efficient landscaping and irrigation practices. Rainwater harvesting is being practiced in at least seven other western states.

The study objectives were to research existing studies and apply identified algorithms to show:

- The potential of precipitation as a water supply,
- The potential water savings for a new residential development from outdoor water demand management and the ability of rainwater harvesting to meet the demands for the three landscape scenarios shown below, and

Traditional

Moderate Conservation

Water Wise

- The potential water savings from rainwater harvesting for existing developments that currently rely on nontributary groundwater supplies.

Recommendations are made for ways to implement rainwater harvesting and protect existing water rights through utilizing the legal framework of an augmentation plan.

Study Findings

1. The average annual yield from precipitation in northwest Douglas County is 17.5 inches and the "sustainable", or dry year, yield is over 10 inches per year.
2. Only a portion of the total precipitation that falls on an undeveloped site returns to the stream system through groundwater and surface water. At the study site, 100% of the annual precipitation is lost to evapotranspiration (ET) and sublimation in a dry year. A maximum of about 15% of the precipitation returns to the stream system in a wet year and on average, around 3% returns to the stream through groundwater and surface water.

3. Significant savings can be realized by managing the outdoor water demand through limiting irrigated area, using water efficient landscaping, and improving irrigation techniques. The outdoor water demand can be reduced by over 50% with moderate conservation and by over 75% with water wise conservation. With rainwater harvesting, outdoor water demand is reduced by approximately 65% with moderate conservation and approximately 88% with water wise conservation.
4. For existing well users, rainwater harvesting provides an opportunity to reduce withdrawals from non-tributary aquifers with declining water levels and to provide a supplemental supply, especially for irrigation and fire suppression.
5. Individual residential cisterns were evaluated in this study; other rainwater capture methods on a regional basis may provide additional options for particular projects.
6. Credit for the portion of precipitation that did not historically return to the stream system (i.e., lost to ET and sublimation) can be incorporated into augmentation plans without injuring existing water rights.

Although this study focuses on the water supply needs in northwest Douglas County, the methods presented are anticipated to be applicable throughout the county and state. A toolbox of algorithms is presented that can be used to: (a) calculate water supplies created through rainwater harvesting and the use of outdoor water demand management, and (b) calculate augmentation requirements that reflect historic stream contributions.

Study Recommendations

In summary, the study found that rainwater harvesting does have potential as a sustainable water management approach in northwest Douglas County, particularly when paired with outdoor water demand management practices. Existing literature shows that physically, not all of the precipitation falling on an undeveloped site returns to the stream system. However, current Colorado law does not allow rainwater harvesting to be utilized to its full advantage as one source of a sustainable water supply. Recommendations from the study include:

1. Douglas County should provide alternative water demand assumptions that recognize reduced outdoor water demand. Results of this study show that outdoor water demand can be reduced by more than 75% using only outdoor water demand management. Additional savings are possible with rainwater harvesting.
2. A pilot project should be identified that would incorporate rainwater harvesting with efficient landscaping and irrigation practices to verify the conclusions in this study. The pilot project would measure actual precipitation consumption and runoff patterns and verify the water savings created through outdoor demand management techniques.
3. Legislative action should be pursued to authorize a pilot program that would codify rainwater harvesting in a way that incorporates appropriate balancing and control considerations and harmonizes rainwater harvesting with protection of other valuable state resources.

ACKNOWLEDGEMENTS

Leonard Rice Engineers, Inc., Meurer and Associates, Inc., and Ryley, Carlock and Applewhite (**study team**) would like to acknowledge the funding agencies that made it possible to study precipitation management and outdoor water use conservation in Douglas County. Dominion Water and Sanitation District, Castle Pines North Metropolitan District, and Douglas County (**study applicants**) received matching funds from the Colorado Water Conservation Board (CWCB), pursuant to C.R.S. § 37-60-126, under the HB05-1254 Water Efficiency Grant Program. The study applicants were also financially supported by Thunderbird Water and Sanitation District and Plum Valley Heights Home Owners Association. A copy of the grant proposal is provided as **Attachment A**.

We would also like to thank the **Advisory Committee** and **Peer Review Committee** for their time, suggestions, and guidance during the study process. We appreciate the committee members' input, advice, and comments, which came from a variety of perspectives based upon the agencies they represented, as shown in **Table 1**. Mr. Isaac Piño shared information based on his experience with the Rancho Viejo project in Santa Fe, New Mexico and Mr. Terry McMains (President, AquaHarvest) provided information on rainwater harvesting systems and cistern installation. This information was particularly valuable from a practical standpoint and we appreciate all of their insights. Finally, we would like to thank several other interested parties who also contributed to the study in a variety of ways (Table 1).

Table 1. Advisory and Peer Review Committee Participants.

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Kevin Lusk	Colorado Springs Utilities
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Rod Kuharich	Colorado Water Conservation Board
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1.0 INTRODUCTION

Douglas County residents' primary water supply is provided by the Denver Basin Aquifers, a series of deep groundwater reserves located below the County. As future demands increase and groundwater supplies are depleted, it will become more difficult and costly to produce sufficient water to maintain delivery at existing demand levels, in addition to meeting projected future demands. Already, some individual well users located in northwestern portions of the County are witnessing dramatic drops in the water table and reduced production rates.

The purpose of the study is to evaluate the benefits of a more holistic approach to maximizing sustainable water supplies for outdoor water demands in the design of water supply systems in northwest Douglas County. This introduction provides general background information and an overview of the study process. The focus of each of the subsequent chapters is summarized as follows:

- Chapter 2 – The holistic benefits of precipitation capture as a water supply.
- Chapter 3 – Legal issues related to using precipitation as a water supply and the need for scientific algorithms to quantify the portion of the sustainable yield that can be utilized without injuring other water rights.
- Chapter 4 – Calculation of dependable yield of precipitation in northwest Douglas County, water budget components associated with precipitation under pre-development conditions, and identifying algorithms that can be used to quantify the individual components of precipitation.
- Chapter 5 – Outdoor water demands and identifying algorithms that can be used to quantify potential outdoor demand reductions with various combinations of water conservation measures.
- Chapter 6 – Components of rainwater harvesting infrastructure, with a focus on using cisterns to store precipitation.
- Chapter 7 – The algorithms developed in Chapters 4 and 5 are applied to illustrate potential water savings for a new residential development and existing well users.
- Chapter 8 – Information needed for a water court-approved augmentation plan to demonstrate that rainwater harvesting can be implemented without injuring other water rights.
- Chapter 9 – Summary of conclusions and recommendations.
- Chapter 10 – Bibliography and work cited.

Precipitation management[1] provides many benefits: 1) maximizes use of a sustainable water source, 2) reduces or delays construction of water infrastructure, 3) improves storm water quality to receiving streams, and 4) saves energy that does not have to be used to treat and transport that water. This study was conducted at a feasibility level. The goal was to investigate the pairing of one specific component of precipitation management (use of cisterns) with outdoor water demand management in northwest Douglas County to a level that allows others to decide whether they are interested in pursing this concept as a conservation alternative. Although this study focuses on the water supply needs in northwest Douglas County, the methodologies presented herein are applicable throughout the county and to a large extent, throughout the state. Depending on the specific water supply situation, there may be other opportunities for pairing rainwater harvesting and outdoor water demand management (or utilizing one without the other) than identified in this study. The information presented here provides concepts and a toolbox of algorithms that can be used to quantify the benefits of rainwater harvesting and outdoor demand management when conducting water supply studies.

1.1 Background

1.1.1 Study Area

With a focus on identifying sustainable and renewable water supplies, water supply planning in Douglas County, Colorado is shifting from being based on how much a given water source will cost to its long-term availability. The availability of local water supplies and water supply requirements within Douglas County is dependent on the specific location (**Attachment B**). The study area is generally bounded on the north by Chatfield Reservoir, Plum Creek on the east, the town of Sedalia on the south, and the foothills on the west (**Figure 1**). This area generally encompasses the water supply area referred to by the County as Margin A. In Margin A, deep aquifer well owners have experienced drops in groundwater levels and the County now requires new developments in this area to obtain renewable water supplies. The County defines renewable water as "water that is annually recharged through the hydrologic cycle, such as streams, and alluvial aquifers associated with streams so that the water supply is sustainable over time" (Douglas County, 2005).

Prior to this study, the focus on obtaining renewable water supplies for Douglas County has been in the area of acquiring senior irrigation water rights or filing for new surface water rights, both within Douglas County and from other areas of the State. The rainwater harvesting concept presented in this study offers an innovative alternative to this traditional approach.

1 The term 'precipitation management' is used interchangeably throughout this report with 'rainwater harvesting', which includes the capture of precipitation that falls as both rain and snow.

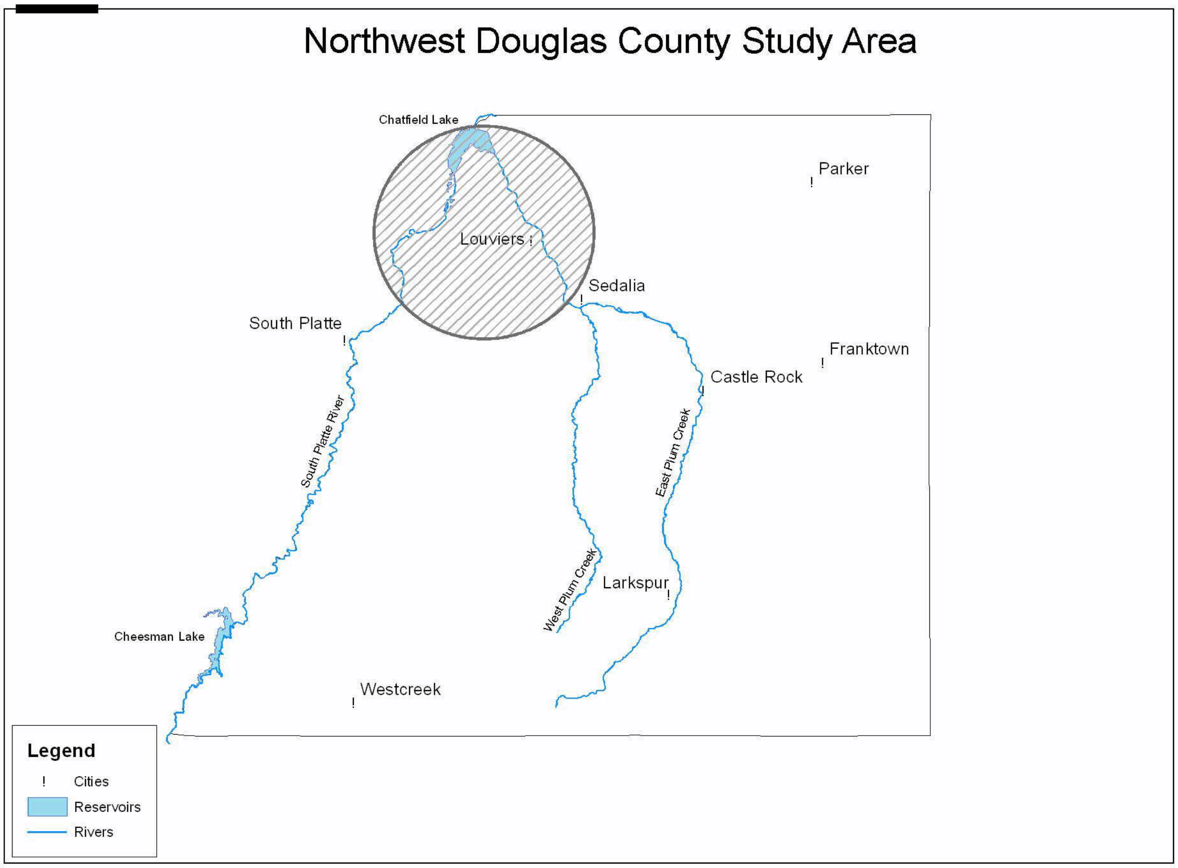


Figure 1. Northwest Douglas County Study Area

1.1.2 Rainwater Harvesting

Precipitation management through rainwater harvesting is an overlooked renewable water supply alternative for Douglas County. It is practiced in various forms in numerous other arid and semiarid states surrounding Colorado. It is the capture and temporary storage of precipitation for beneficial uses; in the case of this study, landscape irrigation. Rainwater harvesting represents a growing understanding of a "water conservation ethic" and progress towards more sustainable development. Over one-thousand years ago, ancient Americans living in the arid conditions of what is now Mesa Verde National Park collected and stored rainwater. Appreciating that we still live in an arid or semiarid climate, contemporary Americans recognize that conserving rainwater for landscape irrigation offers a number of benefits.

In Colorado, rainwater harvesting has been overlooked as a water supply resource for existing developments primarily for two reasons: 1) historically, relatively abundant and low-cost alternative water supplies have been available, and 2) current law requires 100 percent replacement of any precipitation captured, thereby requiring the user to find an equal amount of replacement water. However, existing literature shows that a portion of the precipitation that falls over an undeveloped site *never* reaches the stream system through surface water or groundwater return flows because it is consumed by native vegetation. This implies that for new developments, senior water rights could be protected by replacing *only the portion of precipitation that did* historically reach the stream system. If an undeveloped site is later developed, the portion of the precipitation falling over the site that *did not* historically reach the stream could be leveraged in innovative ways to help meet the water supply needs for the newly developed site, without injuring senior water rights, and while also reducing the amount of water to be acquired, changed, and/or imported to Douglas County.

For the purposes of this study, a distinction is made between new developments and existing developments. The potential water savings may not be the same for existing developments because runoff from impervious surfaces within the existing development may have become part of the historical supply to streams and aquifers. Junior water rights filed subsequent to the existing development are entitled to the conditions of the streams and aquifers at the time of the appropriation, which may include the increased runoff from the development.

1.1.3 Outdoor Water Demand Management

Under the Section 9 Goals of the Douglas County 2020 Comprehensive Master Plan (Douglas County, 2001), water conservation management is encouraged to help prolong the life of the groundwater resources. The implementation strategy includes developing, adopting, and applying county-wide water conservation standards to all land use and development activities. Douglas County states that water conservation standards should include: 1) low water demand landscaping, 2) efficient irrigation systems, 3) water reuse systems, and 4) low water use plumbing fixtures.

Existing literature shows that landscape irrigation demands can be significantly reduced through simple management practices including reduced irrigated areas, use of water efficient landscaping, and improving irrigation system efficiencies. Pairing these outdoor water demand management practices with rainwater harvesting can provide an innovative water supply alternative for Douglas County.

1.2 Study Process

The study consisted of two major components: precipitation management through rainwater harvesting and outdoor water demand management. Leonard Rice Engineers, Inc. took the engineering lead on the precipitation management portion of the study, with legal support from Ryley, Carlock and Applewhite. Meurer and Associates, Inc. took the engineering lead on outdoor water demand management portion of the study. All three firms (study team) worked in cooperation to apply the findings to examples and develop conclusions and recommendations. Guidance and valuable feedback during the study was provided through an Advisory Committee and Peer Review Committee (see **Attachment C** for committee charters). The study team met with both committees for an initial kick-off meeting, and at approximately 50%, 80%, and 95% completion of the study. An additional work session with the Peer Review Committee was held to discuss technical issues. The Advisory Committee provided valuable insight from a variety of perspectives based on the entities represented, while the Peer Review Committee provided technical feedback and recommendations on the scientific portion of the study.

This study considers precipitation management through rainwater harvesting and outdoor water demand management practices individually as stand alone concepts, and then explores the potential of combining the two under the following scenarios: a) new residential development, b) an existing residence which relies on groundwater, and c) an existing commercial occupancy which relies on groundwater. **Figure 2** illustrates the study components and inter-relationships.

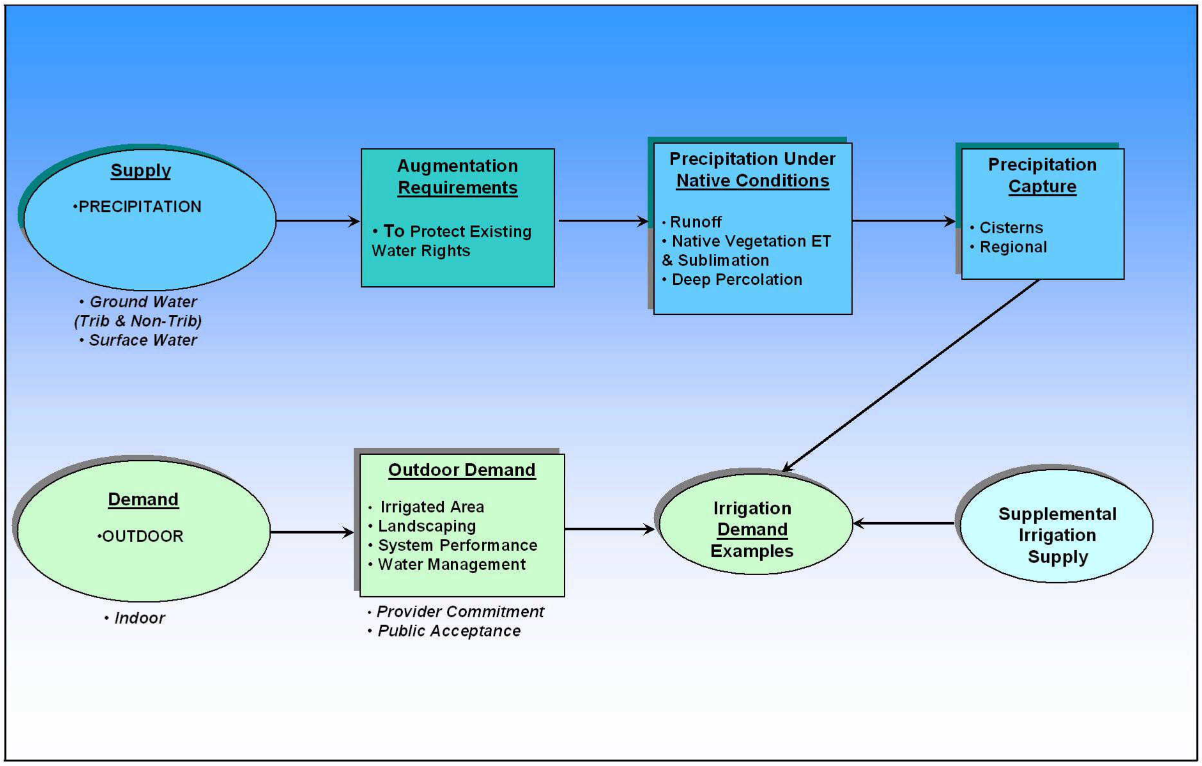


Figure 2. Study Flow Diagram

Following an initial Kick-Off Meeting with the Advisory and Peer Review Committees, the study team conducted an extensive literature review to answer the following basic questions:

- How much water could be captured and made available for other beneficial uses?
- What are the water quality benefits from use of precipitation?
- What is the current water law on augmentation requirements through rainwater harvesting?
- What portion of the precipitation historically returned to the stream system (i.e., what is the water demand of native vegetation)?
- What opportunities exist to reduce landscape irrigation demands?
- What portion of the landscape irrigation demand could be satisfied with the captured water?

Study team preliminary findings were presented at the 1st Milestone Meeting (approximately 50% completion) with the Advisory and Peer Review Committees, along with initial recommendations for scientific algorithms to quantify the following:

1. Water budget components of precipitation falling over an undeveloped site (surface water runoff, consumptive use by native vegetation, deep percolation) to determine the amounts that historically *did* and *did not* reach the stream system.

2. Physical supply available from rooftop capture of precipitation.

3. Irrigation demands for different types of landscape vegetation and application methods.

Details of the proposed methodology and algorithms for the water budget components of precipitation and precipitation capture were discussed in further detail at a follow-up meeting with the Peer Review Committee. A memo providing detailed responses to questions raised regarding sensitivity of results was distributed following the Peer Review Committee meeting.

Advisory and Peer Review Committee comments were taken under consideration and the study team refined the recommended algorithms and then applied them in an example using a new residential development to illustrate the potential water supply from rainwater harvesting and the range of water savings from various combinations of outdoor water demand management measures. These results were presented at the 2nd Milestone Meeting (approximately 80% completion).

A draft report was prepared and submitted to both the Advisory and Peer Review Committees for review and comment. A Third Milestone Meeting (approximately 95% completion) was held to take comments and suggestions for the final report.

1.3 Issues Raised by the Committees to be Addressed in the Future

Through the study review process, the Advisory and Peer Review Committees raised several questions that were not within this grant study. These questions primarily fall into the categories of provider commitment and public acceptance. While the scope of this study focused on quantifying the potential water savings through precipitation and outdoor water demand management, the study team recognizes that provider commitment and public acceptance are critical components to the successful implementation of any management strategy (further discussion, including several suggestions provided by the committees, are provided in Section 5.1.7 of this report). And while results from this study show that rainwater harvesting and outdoor water demand management offer a potential savings in water and costs associated with providing water, there is also a cost associated with implementing these management practices. Defining the entire system costs was beyond the scope of this study.

This study offers scientific evidence and estimates of the potential water savings so that water providers and users can decide whether they are ready to consider these practices as a holistic approach to sustainable water management in northwest Douglas County and other parts of the state.

2.0 BENEFITS OF PRECIPITATION AS AN ON-SITE WATER SUPPLY

As shown in Figure 2, the first component of the holistic approach to water management examines the benefits of using precipitation as an on-site water supply.

2.1 BENEFITS FROM USING PRECIPITATION AS A SUPPLY FOR OUTDOOR DEMANDS

Conserving precipitation for landscape irrigation offers a number of potential benefits:

- Reducing consumption of potable water for non-potable uses results in less water supply acquisitions (leaving more water in the source stream or aquifer), reduces the amount of storage infrastructure, and reduces energy costs to treat and distribute potable water.
- Reducing peak summer water treatment demands may help utilities delay expansion of treatment and distribution facilities and lower peak electrical energy demands associated with pumping throughout distribution systems.
- Reducing untreated flow to storm drains, improve water quality, and delay the need to upgrade drainage infrastructure and sanitary sewers (described further in Section 2.2).
- With low to nonexistent concentrations of dissolved salts, planted landscapes thrive with rainwater irrigation.

As water and energy resources become increasingly scarce, the practice of rainwater harvesting is becoming more prevalent. It is estimated that over one-half million people in the U.S. and its Territories use some type of rainwater collection system for indoor and/or outdoor purposes (Krishna, 2003). Neighboring states including Arizona, Texas, and New Mexico all allow, and even encourage through financial incentives, rainwater collection and use. In 2003, Santa Fe County, New Mexico adopted an ordinance *requiring* rainwater collection and use for landscaping associated with all new developments (Santa Fe County, 2003). The ordinance requires commercial developments to capture all roof drainage into cisterns and residential development to collect roof drainage from a minimum of 85% of the roof area. Several other western states, including California, Idaho, Montana, and Oregon also allow rainwater collection and reuse.

Rainwater harvesting may also provide a unique opportunity for water users who rely on groundwater. Past practices such as cyclical pumping are being re-evaluated and revised to protect the aquifer while still providing adequate water. Continuous pumping at lower flow rates requires installing storage tanks. Rainwater harvesting could utilize this common infrastructure and supplement a dwindling resource.

2.1.1 WATER QUALITY BENEFITS ASSOCIATED WITH RAINWATER HARVESTING

By maintaining and using precipitation on site, sustainable water practices also provide water quality benefits. Sustainable water management must consider not only the quantity of water available, but also the quality and the protection of stream systems.

In the New Development Planning chapter of the Urban Drainage and Flood Control District (UDFCD) Criteria Manual Volume 3 – Best Management Practices (BMPs), a four-step process is recommended for selecting structural BMPs in newly developed and redeveloped urban areas (UDFCD, 1999). The first step involves minimizing directly connected impervious areas (MDCIA) to route runoff over grassy areas to slow down runoff and promote infiltration. Traditional land development practices promote runoff from rooftops and other impervious areas to curb and gutter stormwater collection systems (**Figures 3A** and **3B**). The Criteria Manual discusses alternatives where runoff from rooftops should be directed to landscaped areas, infiltration areas, grassed buffer strips, and grass swales, effectively minimizing the directly connected impervious area (MDCIA).

Benefits from MDCIA include reduced runoff volumes and rates, improved stormwater quality through pollutant removal during the infiltration process, and lower drainage infrastructure costs. These benefits are beyond those obtained through current stormwater detention/retention requirements. However, even with standard MDCIA techniques, some pollutants inevitably pass through to the stream. Not all of the runoff can be absorbed into the ground, and the excess runoff continues as overland flow to the storm sewer system, carrying both particulate and soluble pollutant loads. UDFCD Volume 3 recognizes this, and notes that the effectiveness of pollutant removal for both the use of grass buffers (for sheet flow) and grass swales (for shallow concentrated flow) is only low to moderate.

Rainwater harvesting systems allow the removal of additional pollutants, including nitrogen and phosphorus, above and beyond levels achievable through the use of standard MDCIA techniques. Stormwater runoff from roofs is collected during storm events, and then released to landscaped areas, similar to grass buffers, only when needed to meet landscape irrigation demands (**Figure 3C**). Thus, there is very little excess runoff leaving the site carrying pollutants to surface waters. Also, because the stormwater is applied only at the rate needed for plant growth, there is little excess infiltration water leaving the site and carrying soluble pollutant loads to surface or groundwater sources. Rainwater harvesting offers an innovative extension of a BMP already encouraged by the Urban Drainage and Flood Control District in Colorado.

The Chatfield Reservoir Control Regulation, which regulates phosphorus contributions to Chatfield Reservoir (Water Quality Control Regulation No. 73), seeks to control phosphorous levels for controlling algae and dissolved oxygen levels in the reservoir, and to protect the reservoir's beneficial uses such as aquatic life, recreation, etc. (CDPHE, 2006). Members, including Douglas County, must implement non-point source control programs with a goal of reducing non-point source phosphorus to meet the allocated amount for the watershed. Precipitation management through rainwater harvesting is consistent with the Chatfield Reservoir Control Regulation, and would be an advantageous next step to implementing new non-point source control programs.

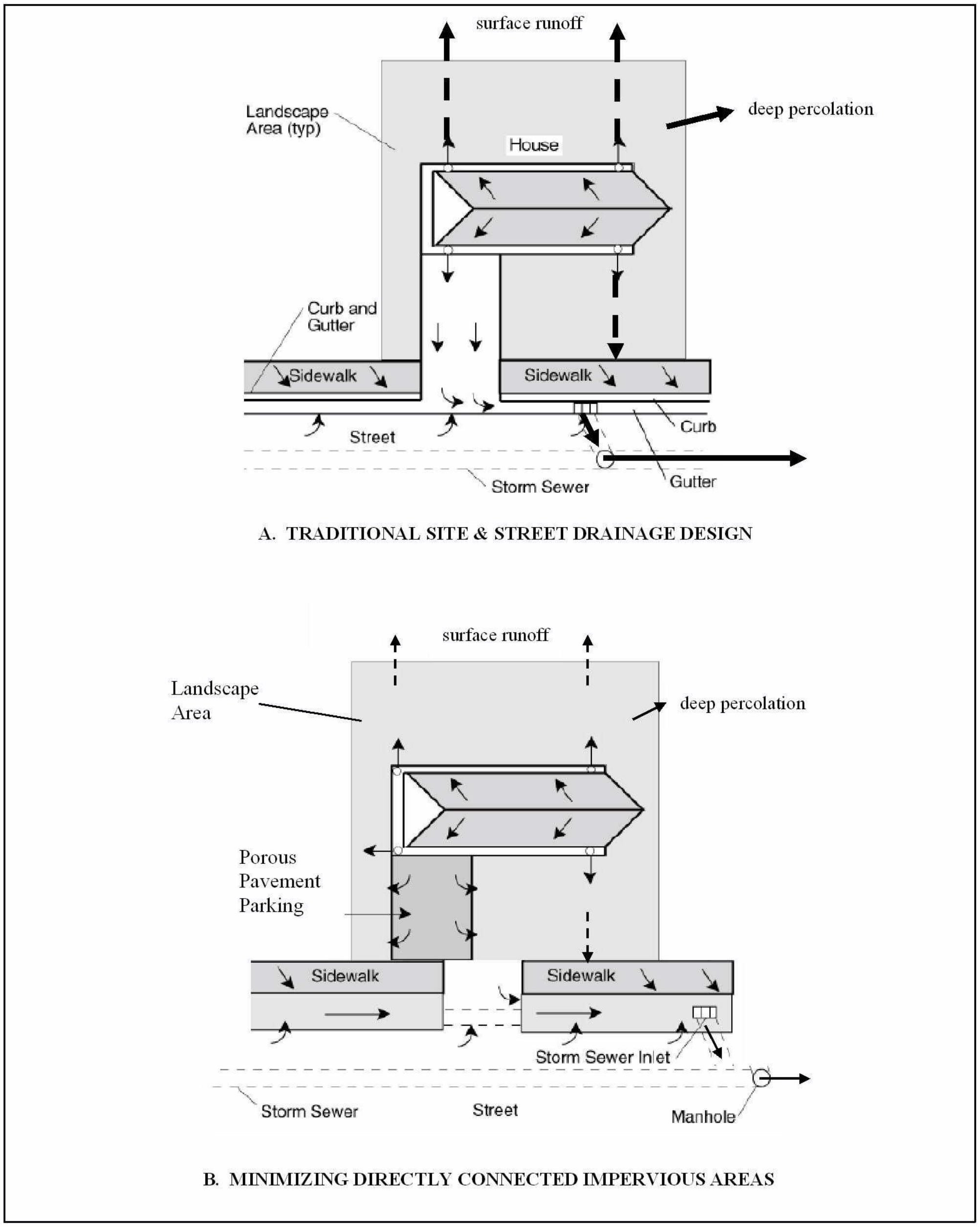
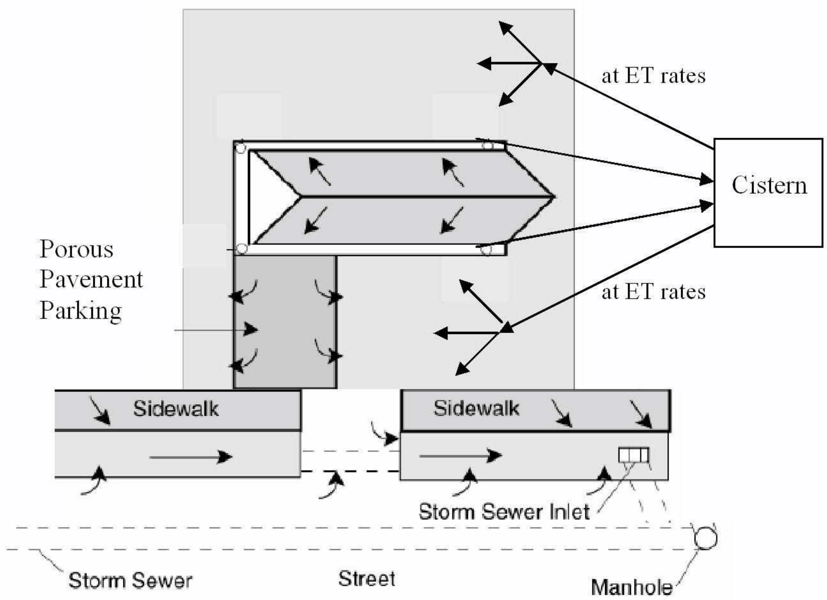


Figure 3. Additional Benefits of Using Cisterns for Rainwater Harvesting (figure adapted from UDFCD Volume 3 Criteria Manual Figure ND-2).



C. MINIMIZING DIRECTLY CONNECTED IMPERVIOUS AREAS WITH CISTERNS

Figure 3 (cont'd). Additional Benefits of Using Cisterns for Rainwater Harvesting (figure adapted from UDFCD Volume 3 Criteria Manual Figure ND-2).

Precipitation management through rainwater harvesting is also consistent with Douglas County stormwater management requirements. Minimum Control Measure #5, Post-Construction Stormwater Management in New Development and Redevelopment (PCSM), which is part of Douglas County's State-issued Stormwater Discharge Permit, describes requirements for water quality BMPs at newly developed sites. The county requires that, to the maximum extent practicable, stormwater must be controlled and the discharge of pollutants must be reduced. The County also recognizes in its Grading, Erosion, and Sediment Control (GESC) Manual that there will be new advances in the development of erosion and sediment control BMPs that may prove effective, or even out-perform currently accepted controls, and the County allows the use of alternative or innovative BMPs as pilot programs. Precipitation management through rainwater harvesting goes above and beyond standard non-point source control measures for stormwater quality.

3.0 LEGAL RIGHT TO USE PRECIPITATION

Water rights in Colorado are obtained under the doctrine of prior appropriation or "first in time, first in right," which requires that the quantities of water allotted to earlier, more senior rights must be protected. All water that falls as precipitation is assumed to ultimately contribute to flows in the stream, and is deemed to be part and parcel of the water that existing water rights are entitled to use in accordance with their decreed priorities. Intercepting precipitation that would have otherwise migrated to groundwater or surface water might interfere with the full allocation of existing water rights.

One of the primary purposes of this study is to identify the potential of precipitation as a water supply, including a recommended methodology to quantify the renewable/sustainable yield, and to quantify the augmentation requirements to protect existing water rights. Current Colorado law requires 100% of any precipitation captured out-of-priority for later beneficial use to be replaced to the stream system in like time, place, and amount. However, there are two statutory exceptions that expressly recognize that not all precipitation is a supply to existing water rights: C.R.S. §37-84-117(5) concerning on-stream reservoir evaporation, and C.R.S. §37-80-120(5) and C.R.S. §37-92-305(12)(a) concerning gravel pit pond evaporation. These statutes allow "credit" to be taken against the amount of water that would otherwise need to be provided to offset evaporation from the exposure of groundwater based on the portion of the precipitation that did not historically reach the stream system, due to consumption by native vegetation through evapotranspiration (ET).[2]

A procedure for estimating the ET credit is outlined in the Division of Water Resources' General Guidelines for Substitute Water Supply Plans for Sand and Gravel Pits Submitted to the State Engineer Pursuant to Senate Bill 89-120 & Senate Bill 93-260. As stated in the Guidelines, the Division of Water Resources generally accepts an ET Credit of 70% of the total precipitation for each month for non-irrigated native sites with a deep water table and without phreatophytes or subirrigation. The 70% is based on an effective precipitation calculation that suggests 70% of the total precipitation was historically effective at meeting consumptive use demands of native vegetation, and therefore *did not* return to the stream system. The Guidelines specify that higher ET credits must be supported by appropriate engineering documentation; according to the Division of Water Resources higher ET credits have been accepted in the past (Wolfe, 2006).

In contrast, in a series of court cases, summaries of which are contained in **Appendix A**, several would-be water rights appropriators attempted to obtain water rights by reducing or eliminating vegetation that consumed water. These appropriators argued that by eliminating such vegetation, additional water was made available to the river system that had not previously been available, and that they should get to use that water without regard to meeting the demands of senior appropriators. In each case, the Colorado Supreme Court rejected the attempted appropriations, but in doing so, has recognized, "No one on any river would be adverse to a schematic and integrated system of developing this kind of water supply with control and balancing considerations. But to create such a scheme is the work of the legislature . . ." *Southeastern Colo. Water Conservancy Dist. V. Shelton Farms, Inc.*, 187 Colo. 181, 192, 529 P.2d 1321, 1327 (1974); see also *R.J.A., Inc. v. Water Users Ass'n of Dist. No. 6*, 690 P.2d 823, 829 (Colo. 1984) and *State Engineer v. Castle Meadows, Inc.* 856 P.2d 496(1993). Before built-in controls and balances can be struck, an algorithm is needed that can be used to reliably calculate the amount of water potentially available from rainwater harvesting without injuring other water rights.

While Colorado's current law requires replacement (e.g., augmentation) of 100% of captured precipitation, the portion of the precipitation falling over a native site that was consumed by ET from

2 As described under the Colorado Division of Water Resources Policy 2004-3, evapotranspiration (ET) credit is defined as "ET Credit as utilized in the policy is equal to the sum of ET Credit from eradicated phreatophytes and ET Credit from effective precipitation on natural vegetation."

native vegetation and sublimation (loss of water through evaporation of snow) was not historically available to senior water rights. **Figure 4** depicts a comparison between augmentation requirements under current law versus actual conditions, which is that only the portion of the precipitation that historically returned to the stream system would need to be augmented in order to protect other water rights.

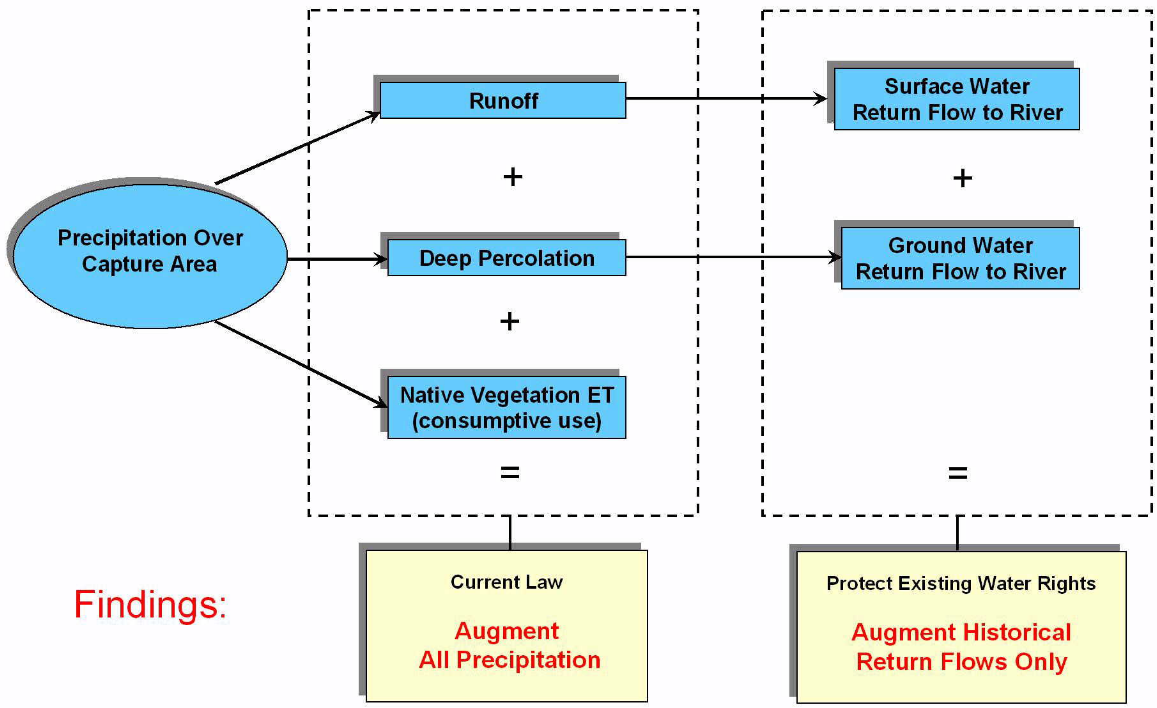


Figure 4. Components of Legal Versus Physical Augmentation Requirements to Protect Other Water Rights

While most scientists and engineers agree that there is a component of the total precipitation that did not historically reach the stream system and therefore could be used in new ways without injuring other water rights, an algorithm is needed to quantify that amount.

From this point forward the study focuses on the scientific methods we recommend to quantify the precipitation return flows from undeveloped areas that need to be augmented to protect existing water rights if captured and used as a new water supply.

4.0 PRECIPITATION WATER BUDGET UNDER PRE-DEVELOPED CONDITIONS

The Douglas County 2020 Comprehensive Master Plan (2001) indicates that less than 1 percent of the annual precipitation actually recharges the Denver Basin bedrock aquifers and that most of the precipitation is lost through evaporation, transpiration, and runoff. It also says that to a limited extent, the Denver Basin aquifers are indirectly recharged from water seepage through overlying soil or aquifers, but that direct recharge only occurs where the aquifer meets the surface stream.

A water budget can be used to quantify the portion of precipitation that was historically part of the physical supply to existing water rights when those water rights were appropriated. Of the total precipitation that falls on undeveloped lands, a portion runs off the land as surface water runoff, a portion is used to satisfy native vegetation evapotranspiration (ET) and sublimation requirements, and the remainder deep percolates to the groundwater aquifer (i.e., groundwater recharge) or is held in storage in the soil moisture zone for later use. This relationship is shown in equation 1 below.

$$\textbf{Total Precipitation} = \textbf{Runoff} + \textbf{Native Vegetation ET \& Sublimation} + \textbf{Deep Percolation} + \textbf{Change in Soil Moisture} \qquad \textbf{(1)}$$

The following factors affect the balance between surface water runoff, native vegetation ET/sublimation, and groundwater recharge:

- The precipitation amount, frequency, duration and intensity,
- Other climate data such as humidity and solar radiation,
- Topography and soil characteristics,
- Type of vegetation,
- Depth to groundwater, and
- Land management practices.

A literature review was conducted to identify generally accepted methods for estimating the surface water runoff, native vegetation ET/sublimation, and groundwater recharge associated with precipitation occurring over undeveloped sites. **Figure 5** provides an example of the native vegetation at an undeveloped site (study area) in northwest Douglas County. While on-site field measurements provide the most reliable data, the goal of this research effort was to identify methods that could be used with readily available climate data and physical site property data to make reasonable predictions at a feasibility level. The methods reviewed and selected for this study are described in the sections below.

Figure 5. Undeveloped Site in Northwest Douglas County Depicting Native Vegetation

4.1 Physical Supply from Precipitation in Northwest Douglas County

In this section, we address the question of: *"What is the sustainable yield of precipitation in the study area of northwest Douglas County?"* The State Climatologist was interviewed and we conducted an analysis of readily available climate data from the National Oceanic and Atmospheric Administration (NOAA). We define sustainable yield as the minimum amount of precipitation that can be expected in a given year.

Based on discussions with Mr. Nolan Doeskin (State Climatologist), a rule of thumb that he uses to estimate annual precipitation in a dry year (an event with an expected return period of 50 to 100 years) is that the dry-year total is approximately 50% of the long-term average. Mr. Doeskin also said there may be isolated areas in Colorado where the dry-year total precipitation is closer to 30% to 40% of the long-term average.

Readily available NOAA records were reviewed and the historical averages for fourteen NOAA climate stations located in and adjacent to Douglas County are shown below in **Figure 6**. The Kassler station, a long-term climate station, was selected to represent precipitation in northwest Douglas County. A summary of monthly precipitation records for the readily available period of 1950 through 2004 is provided in **Appendix B**. The annual precipitation at the Kassler station ranges from 10.68 inches to 28.11 inches, with an average of 17.52 inches per year (**Figure 7**). Based on the lowest recorded amount for the period 1950 through 2004, the estimated "sustainable" yield from precipitation in northwest Douglas County is over 10 inches.

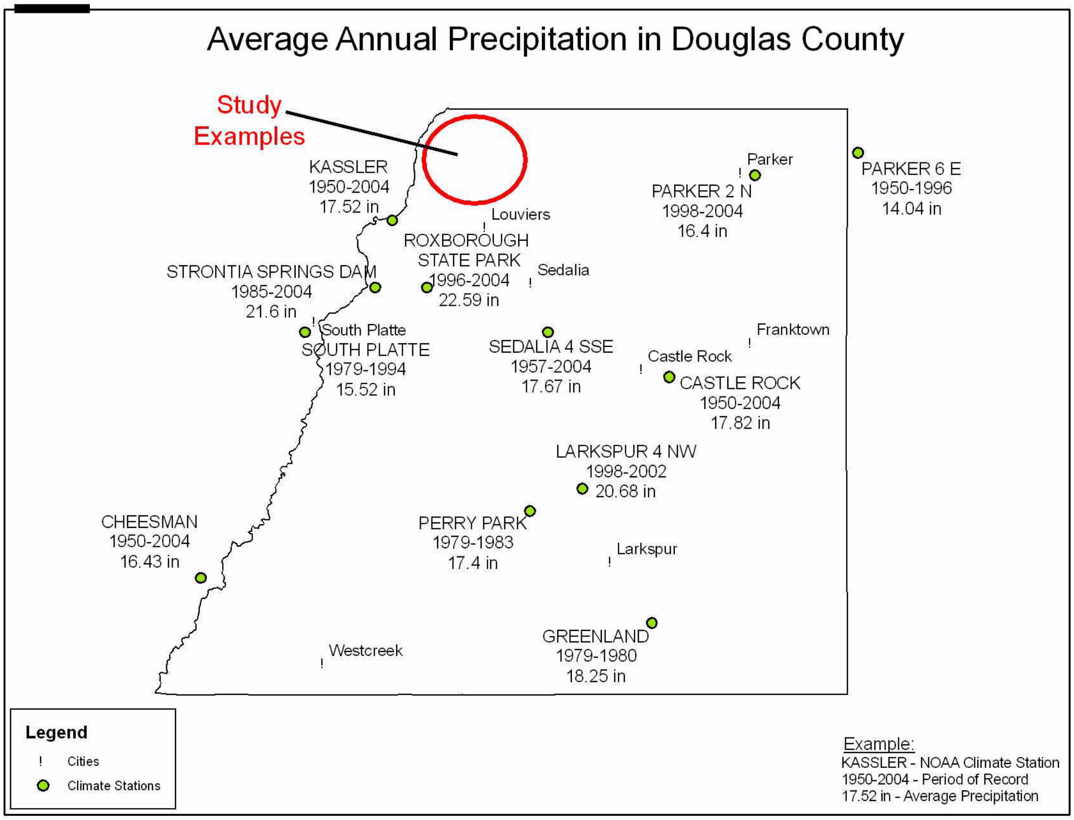


Figure 6. Historical Average Annual Total Precipitation in Douglas County

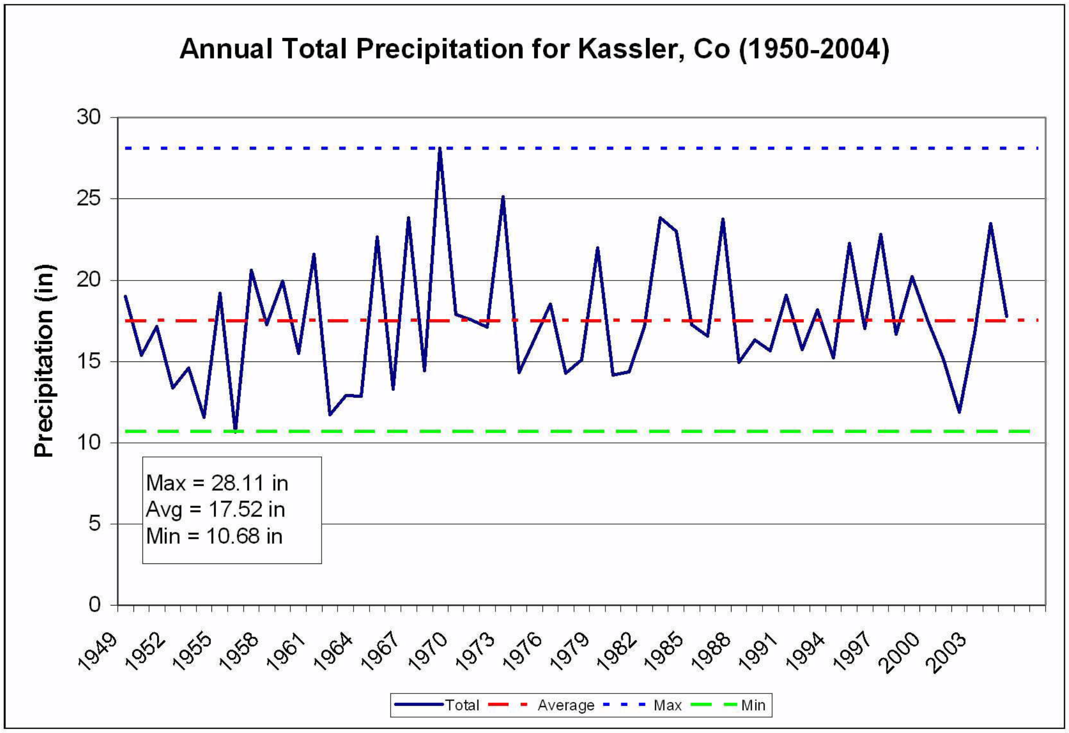


Figure 7. Annual Total Precipitation in Douglas County

In addition to analyzing the annual variation in precipitation, the variation of daily precipitation events was analyzed and is characterized in **Table 2**. This summary shows that over 88% of the daily events occur as small events (less than 0.5 inches per day). In the following section, we evaluate the threshold amount for which runoff occurs at the study area, which is a function of numerous variables including antecedent moisture condition.

Table 2. Characteristics of Daily Precipitation at the Kassler Climate Station

Precipitation Range	Percent of Days with Precipitation, 1950-2004		
(in)	Entire Period	Growing Season	Non-Growing Season
0.01 – 0.10	48.2%	48.3%	48.0%
0.11 – 0.50	40.1%	38.1%	44.2%
0.51 – 1.00	8.9%	9.9%	6.9%
1.01 – 1.50	1.8%	2.3%	0.6%
1.51 – 2.00	0.6%	0.9%	0.2%
2.01+	0.4%	0.5%	0.1%

4.2 Surface Water Runoff

Surface water runoff can be estimated using volume-based methods or event-based methods. Event driven (e.g., 15-minute interval) methods provide peak flow rate estimates and are often used in site development applications to design stormwater infrastructure. A member of the Peer Review Committee indicated that the event-based methods are more accurate because they consider storm intensity. However, based on our research of the Rational Method and the Colorado Urban Hydrograph Procedure (CUHP) event-based methods and discussions with UDFCD, other members of the Peer Review Committee, and other water resources experts, we concluded that for the purpose of this feasibility study, a simpler volume-based method such as the Soil Conservation Service (SCS) Curve Number Method provides sufficient information to estimate daily runoff from an undeveloped site.

The SCS Curve Number Method was developed in the 1950s and modified in the 1960s by a USDA-SCS scientist for determining the portion of total precipitation that becomes surface water runoff in ungaged watersheds. The equation was developed to predict how land use changes affect watershed runoff, usually in the context of problems caused by large precipitation events, but its use has been broadened to include general watershed modeling. The SCS Curve Number Method is based on the potential of the soil to absorb moisture. Based on field observations, runoff from a field or farm was related to watershed storage capacity (S) which was in turn related to a soil curve number. Curve numbers were developed as a function of soil type, land use, and antecedent moisture content (AMC).

The SCS Curve Number methodology is documented in the National Engineering Handbook Volume 4 (USDA, 1985) and is shown in equations 2 and 3 below:

$$\mathbf{Q} = \frac{(\mathbf{P} - 0.2\mathbf{S})^2}{(\mathbf{P} + 0.8\mathbf{S})} \qquad \mathbf{(2)}$$

$$\textbf{for } \mathbf{P} \geq \mathbf{Ia} \quad \textbf{where} \quad \mathbf{Ia} = \mathbf{0.2S} \qquad \mathbf{(3)}$$

Where:

Q = total daily runoff volume
P = total daily precipitation volume
S = potential maximum retention = (1000/CN) – 10
Ia = initial abstraction
CN = Curve Number (function of land use description, soil group classification, and antecedent moisture condition)

The following sources were used to develop input data for the SCS Curve Number Method that represents conditions at the example site in northwest Douglas County:

- Raw (unfilled) total daily precipitation data from the NOAA Kassler climate station.
- SCS Soil Types selected from the Water Features (K1) Report of SSURGO Soil data from the Castle Rock Area, Colorado report (approximately 50% Class B – shallow loess, sandy loam and 50% Class C – clay loams, shallow sandy loam, soils low in organic content, and soils usually high in clay).
- AMC I (dry), II (average), and III (wet soils) selected based on previous 5-day total precipitation.

- Dormant versus growing season based on growing season for grass pasture at Kassler climate station (typically around April 1 through October 31).
- Curve Number selected using the SCS recommended number for "Pasture or Range" under the "Fair" Hydrologic Condition (versus Poor or Good).
- Curve Number adjusted for AMC by linearly interpolating between values provided by SCS.

A spreadsheet model was developed to estimate runoff on a daily basis for the period of 1950 through 2004, incorporating the above algorithms and representative site data for northwest Douglas County. The results show that for the study area in northwest Douglas County, it takes up to 0.1 inches of precipitation before any runoff occurs under wet soil conditions (AMC = III) and up to 1.5 inches of precipitation before any runoff occurs under dry soil conditions (AMC = I). Referring back to Table 2, almost 50% of precipitation events produce no runoff.

Application of the SCS Curve Number Methodology shows that for the period of 1950 through 2004, the average annual runoff is equivalent to 2% of the annual precipitation. A summary of monthly runoff values for the period of 1950 through 2004 is provided in Appendix B. The maximum runoff in a wet year (1969) was 12% and the minimum runoff in a dry year (1956) was 0%. This means that on average, only 2% of the annual precipitation historically returned to the stream system via surface water return flows.

During times of no runoff, the observed stream flows can be the result of many sources, including delayed returns from precipitation that previously percolated into the local geology and reaches the stream in a delayed pattern as groundwater returns, reservoir releases, wastewater treatment plant discharges, deep aquifer groundwater returns from individual septic systems, and return flows from outdoor water uses.

The runoff analysis findings are consistent with other studies we reviewed in the literature research. A study performed for the Denver Water Board (Walter et. Al, 1990) on formerly irrigated mountain meadows in South Park attributed a maximum of 1% to 3% of the total precipitation to runoff. A study performed in the Turkey Creek Watershed of Jefferson County (Bossong et. Al, 2003) considered surface water flow from both the forested site and meadow sites near Conifer to be zero.

A sensitivity analysis of the soil types and land use conditions used for this study was conducted, based on questions raised by the Peer Review Committee. While the runoff estimates are sensitive to the soil types and the land use conditions, the results show that the soil properties and land use characteristics used for the examples in this study do not significantly increase or decrease the runoff analysis estimates.

4.3 Native Vegetation Evapotranspiration (ET) and Sublimation

Precipitation falling on undeveloped sites is consumed during the growing season (typically April through October at this location) by native vegetation evapotranspiration processes and is lost through evaporation and sublimation processes during the non-growing season.

4.3.1 Growing Season

Far more research has been conducted on the consumptive use of precipitation by irrigated agricultural crops and irrigated landscape than native vegetation. The "default" ET Credit of 70% that DWR accepts for gravel pit applications was based on using the Soil Conservation Service methodology for calculating effective precipitation, as outlined in Technical Release 21 (USDA, 1970). This is the most common approach for estimating effective precipitation in water rights transfers. With this method, effective precipitation is estimated as a function of the total monthly precipitation, the estimated crop evapotranspiration (i.e., consumptive use), and the net irrigation application depth. The method was developed for use on irrigated lands and is based on a full water supply. On native lands, where the water supply is limited to the precipitation, the effectiveness of the precipitation increases because it is the only supply available to meet the native vegetation demand.

The methods that are commonly used to estimate ET or consumptive use on irrigated lands rely on crop coefficients that represent specific crop types. Based on our literature review and discussions with the Peer Review Committee and other water resources experts, we concluded that for the purpose of this study, the ET from native vegetation during the growing season (typically April through October at this location) could be approximated using the potential consumptive use of pasture grass. The modified Blaney-Criddle method was used, with an elevation adjustment, to estimate the potential consumptive use of pasture grass. The following sources were used to develop input data for the modified Blaney-Criddle procedure that represent conditions at the example site in northwest Douglas County:

- Raw (unfilled) monthly temperature, precipitation, and frost date data from the NOAA Kassler climate station,
- Crop coefficients for pasture grass published in Soil Conservation Service Technical Release-21,
- SSURGO Soil data from the Castle Rock Area, Colorado report were used to estimate field capacity,
- Root depth for grass pasture was estimated to be 3.3 ft (Jensen et. Al., 1990).

The full potential consumptive use (PCU) of grass pasture, under an unlimited water supply condition, was computed on a monthly basis. Consumptive use of precipitation by native vegetation ET was then computed by 1) estimating the monthly supply available from precipitation as the total monthly precipitation reduced by the portion of precipitation estimated as runoff (using the SCS Curve Number Method as described in the previous section), and 2) comparing the available supply from precipitation to the PCU of grass pasture. Available precipitation in excess of native vegetation ET demands was used to fill a soil moisture reservoir; likewise, when available, water was extracted from the soil moisture reservoir in months native ET demands were not fully met by precipitation. A summary of the monthly total precipitation, runoff, PCU of grass pasture, soil moisture reservoir storage, and native ET met is provided in **Appendix C**. Annual results of the analysis are presented in **Figure 8**. On the average, the precipitation was able to meet approximately half of the PCU associated with pasture grass (an average of 1.2 acre-feet per acre as opposed to the pasture grass potential consumptive use of 2.7 acre-feet per acre). The results show that for the period of 1950 through 2004, the growing season ET averaged 1.2 acre-feet per acre, which is 81% of the average annual precipitation.

The ET findings are consistent with other studies we reviewed in the literature research. Using the 1950 through 2004 study period, the average annual PCU for buffalo grass, a native grass used in landscaping applications, at the same location is estimated to be 1.2 acre-feet per year. This supports the notion that native grasses have adapted to the locally available precipitation. A study performed for the Denver Water Board (Walter et. Al, 1990) on formerly irrigated mountain meadows in South Park showed 97% to 99% of the May though September (1962-1986) precipitation was effective at meeting crop demands. The study performed in the Turkey Creek Watershed of Jefferson County (Bossong et. Al, 2003) showed on average 83% of precipitation was consumed at the forest site and essentially 100% at the meadow site.

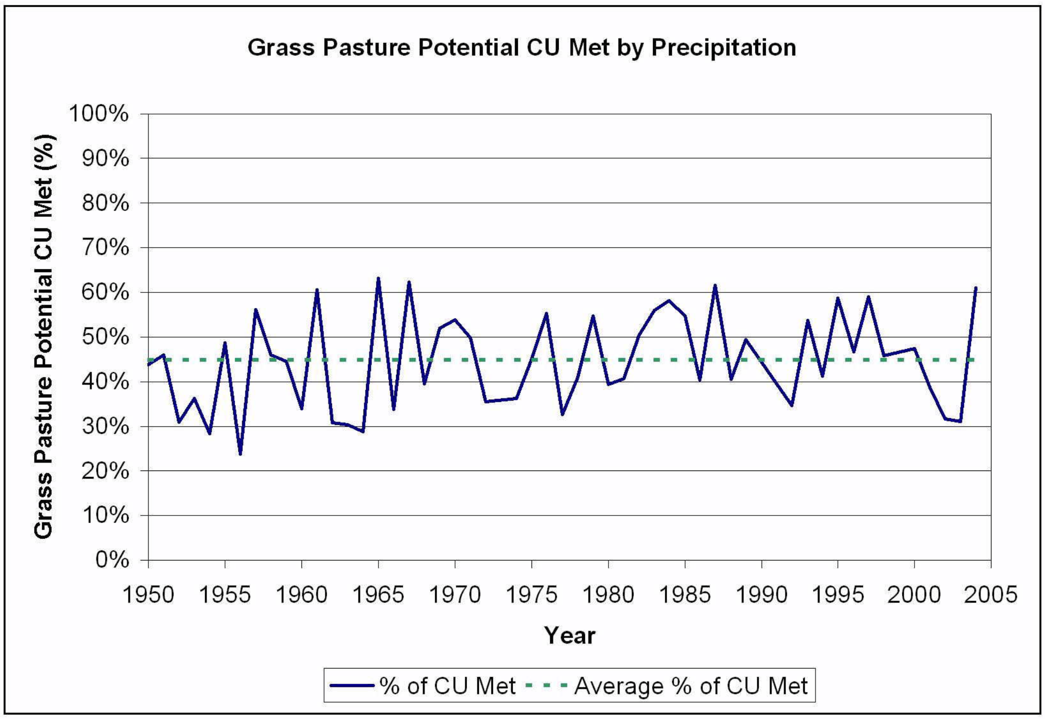


Figure 8. Pasture Grass Potential Consumptive Use Met by Precipitation

4.3.2 Non-Growing Season

In addition to growing season consumption, precipitation can be lost to the stream system during the non-growing season by evaporation and sublimation. Even less research has been conducted in this area. However, based on discussions with the Peer Review Committee and other water resources experts, the results from a study conducted in Akron, Colorado have been used by other water resources professionals for water rights related work in Colorado. Based on data collected during twelve winter seasons from 1965 through 1979, the measured snowmelt intake efficiency on ungrazed native grass pasture averaged 38% (Greb, 1980). The results from the Akron study were applied in this study to estimate the evaporation and sublimation during the non-growing season. Up to 38% of the total monthly precipitation was made available to recharge the soil moisture reservoir;

the remainder was considered to be either runoff, evaporate, or sublimate. If the soil moisture reservoir was full, excess recharge amounts were passed through as deep percolation to the underlying aquifer. The results show that for the period of 1950 through 2004, the annual non-growing season losses to evaporation and sublimation averaged 0.24 acre-feet per acre, which is 16% of the average annual precipitation.

The combined growing season and non-growing season results show that for the period of 1950 through 2004, the average ET and sublimation is equivalent to 97% of the total precipitation. The maximum ET and sublimation in a wet year (1969) was 85% and the minimum ET in a dry year (1956) was 100%.

4.4 Deep Percolation

Deep percolation is that amount of total precipitation that infiltrates the soil and is not evapotranspired or held in the soil moisture reservoir. It is often estimated using the water balance approach shown in equation 4:

$$\textbf{Monthly Deep Percolation} = \textbf{Total Precipitation} - \textbf{Runoff} - \textbf{Native Vegetation ET/Sublimation} \qquad \textbf{(4)}$$

The water balance approach shows that for the period of 1950 through 2004, the average deep percolation is equivalent to 1% of the total precipitation. The maximum ET and sublimation in a wet year (1969) was 3% and the minimum runoff in a dry year (1956) was 0%. This means that on average, only 1% of the annual precipitation historically returned to the stream system via groundwater return flows.

The deep percolation findings are consistent with other studies conducted in Colorado. Under the Rio Grande Decision Support System, Wilson et. Al (2000) recommended a value of 3 percent total groundwater recharge from precipitation be used to represent non-irrigated lands. This recommendation was based on other studies that showed a range of 0 to 4 percent recharge from precipitation over non-irrigated (i.e., undeveloped) lands.

4.4.1 Delayed Groundwater Return Flows

For an augmentation plan to successfully protect existing water rights, it is important to define the amount, timing, and location of the return flows. Depending on the location and local geology, groundwater recharge from deep percolation can take much longer to reach the stream system than surface water return flows. Several methods have been applied in Colorado to approximate the delay time; selection of the appropriate method depends on the location being evaluated. For example, if the undeveloped lands are overlying saturated alluvium, the Glover Method may be an appropriate option for estimating the lag time between when the deep percolation first occurs and when the associated water reaches the stream. In more complex groundwater situations located outside stream alluviums, it may be necessary to use a program known as MODFLOW, a three-dimensional groundwater simulation model, to estimate the lag time. For the study area in northwest Douglas County, the undeveloped lands are believed to overlie unsaturated alluvium. In this case, until sufficient deep percolation return flows accumulate and establish a water table, it may take an indefinite amount of time for the deep percolation to reach the stream system. This could be confirmed using a MODFLOW model. For the feasibility level of this study, to be conservative with respect to protecting the stream system and other water rights under this type of situation, an alternative to developing a detailed groundwater model is to assume there is an alluvium through which water moves toward the stream and consider the groundwater return flows to be at steady state condition with a uniform return flow pattern, as described below in equation 5. This is something that should be evaluated on a site-specific basis.

$$\text{Monthly Stream Return Flow} = \frac{\text{Annual Deep Percolation (previous year)}}{12} \quad (5)$$

4.5 Augmentation Requirements for Rainwater Harvesting

Under current law, 100% of any precipitation captured and put to use must to be replaced (i.e., augmented). From a scientific perspective, this legal requirement may apply to existing developments where runoff from impervious areas has become part of the physical water supply for existing water rights. However, the science shows that for undeveloped areas, only the portion of the precipitation that historically returned to the stream system as surface runoff or delayed groundwater returns from deep percolation would need to be augmented in order to protect the yield relied upon by existing water rights. The remaining portion that did not historically return to the stream system represents an innovative new water supply alternative for new developments.

The runoff and water budget analysis shows that for the period of 1950 through 2004, the average annual return flow to the stream was 3% (2% from runoff and 1% from deep percolation). The maximum return flow to the stream in a wet year (1969) was 15% (12% from runoff and 3% from deep percolation) and the minimum return flow in a dry year (1956) was 0%. This means that for previously undeveloped areas, on average, only 3% of the annual precipitation historically returned to the stream system via surface and groundwater return flows.

Under current law, for every acre-foot of precipitation captured, one acre-foot of replacement water must be acquired and returned to the stream. However, our scientific literature review shows that for new developments, the average leverage potential from rainwater harvesting is on the order of 28 fold. In other words, for every acre-foot of replacement water available, one could capture and use 28 acre-feet of precipitation without injury to existing water rights.

To better understand the potential supply from rainwater harvesting and its augmentation requirements, we applied the algorithms described in Sections 4.1 through 4.4 to an example development site with 1,000 new residences, each with a rooftop surface area of 1,500 square feet. Prior to development, the historical average annual precipitation of 17.5 inches that fell over the roof areas was equivalent to 50 acre-feet. On average, only 2 acre-feet (3%) returned to the stream system via surface and groundwater return flows. The difference of 48 acre-feet was consumed by native vegetation and never reached the stream system. However, current law requires the full 50 acre-feet to be replaced through an augmentation plan. **Figure 9** depicts the potential savings in augmentation water under current law versus the physical requirement to protect existing water rights under dry (minimum replacement), average, and wet (maximum replacement) year conditions.

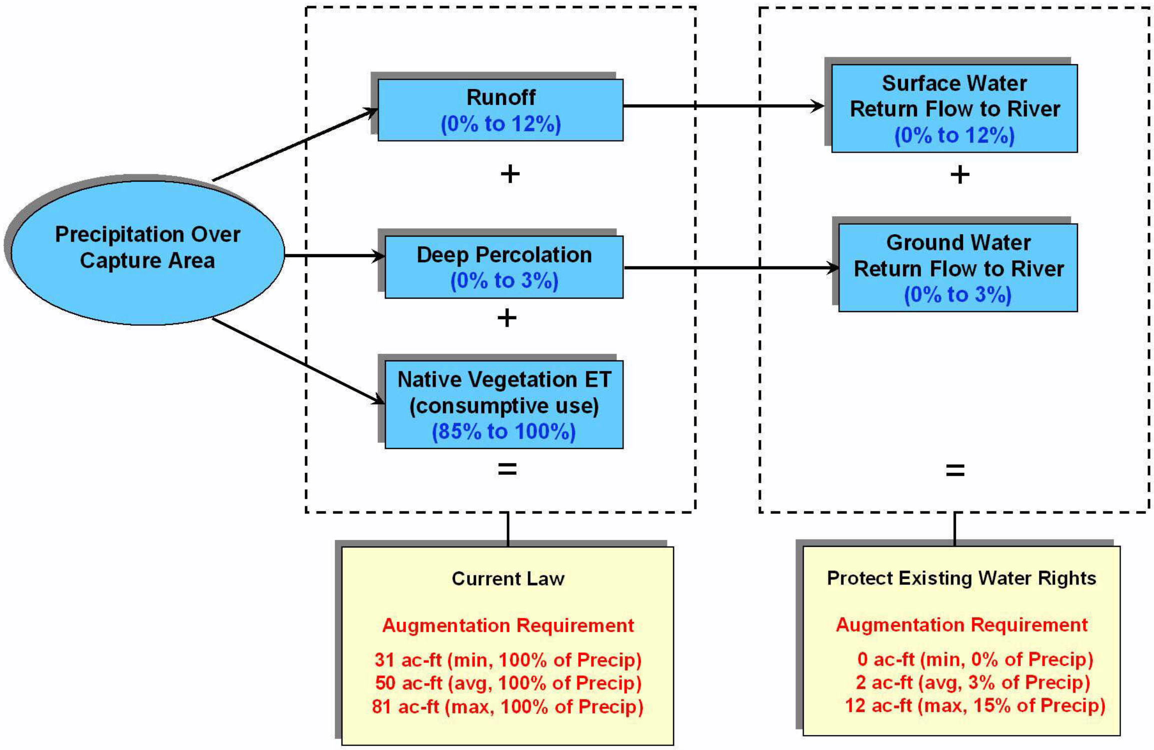


Figure 9. Legal Versus Physical Augmentation Requirement Estimates at Example Site

5.0 OUTDOOR WATER DEMAND CONSERVATION

As shown in Figure 2, the second component of the holistic approach to water management focuses on outdoor water demands and how water efficient landscaping and irrigation practices can be used to reduce outdoor demands. Outdoor water use conservation includes well-known concepts such as soil analysis, appropriate plant selection, and use of practical turf areas. It can also extend to the design of the landscaped area itself. The micro-topography of a landscaped area can enhance the flow of irrigation water through the use of subtle grade changes, guided swales, terraces, and shallow infiltration impoundments. Irrigation system efficiency can be maximized through the use of properly designed and located sprinklers, micro-irrigation (also known as drip irrigation), hand watering, and appropriate watering intervals. Water savings can be identified and quantified through proactive (coordinated) irrigation system audits followed by recommended improvements.

5.1 Components of Outdoor Water Demand

There are a multitude of factors that affect outdoor water demands. The literary review and interviews performed for this study identified five main factors that combine to encompass a holistic approach to outdoor water demand. The factors are:

1. Irrigated area,
2. Landscaping,
3. System performance,

4. Water management, and
5. Provider commitment and public acceptance.

The first four factors are combined as coefficients in an outdoor water demand calculation algorithm to derive the total outdoor water demand based on the water user's design choices. While the primary focus of the study is for residential use, this algorithm can be applied to any outdoor water demand situation. The fifth factor is more subjective coefficient, but can significantly impact the outdoor water demand.

5.1.1 Irrigated Area

The irrigated area for landscaping is represented by the amount of turf and plantings that will be installed and maintained. A typical lot can be divided into four areas:

- Impervious area (building footprint, walkways, driveway, and deck),
- Irrigated turf area,
- Irrigated planting area, and
- Non-irrigated area.

The impervious area includes the building foot print, walkways, driveway, and deck. Based on Urban Drainage Flood Control District (UDFCD) runoff criteria (UDFCD, 2001), 50% of a two-story 3,000 square foot house (1,500 square foot rooftop) lot is impervious and will not have planting or turf. The remaining 50% of the property is divided between turf, plantings, and non-irrigated areas. A 3,000 square foot house size and related impervious area was used for the study.

Using the UDFCD criteria, the amount of impervious area is dependent on the lot size. An analysis of the existing developments in northwest Douglas County identifies a typical density of five dwelling units per acre. The developments reviewed for the lot analysis and calculations of their average units per acre are identified in **Appendix D**.

Using five dwelling units per acre with a 20% reduction for roads results in a lot size of 6,970 square feet. Applying the UDFCD criteria results in 50% available for landscaping, or 3,485 square feet. The irrigated portion of the lot is divided between turf, plantings, and non-irrigated areas. The turf and planting areas are described in the Landscaping Section 5.1.2 of this report. The non-irrigated area can also include impervious areas such as decorative rock, decking or non-irrigated plantings. The use of this space is dependent on the preference of the property owner.

5.1.2 Landscaping

Landscaping is divided between turf and planting areas. The landscaping system includes the largest number of combinations to obtain water efficiency, given the large number of turf and planting opportunities. The choice of landscaping is only one factor that must be considered to create water efficiency. The landscaping design and maintenance also significantly impact the water efficiency.

To calculate the water demand associated with a particular type of landscaping, a reference crop is used to establish the baseline evapotranspiration (ET). ET is a combination of water transpired from the plantings and turf and evaporated from the soil and plant surfaces (ASAE, 1998). This reference value is then multiplied by a turf or planting coefficient to calculate the water demand for a particular type of turf or planting. The landscape water use calculation is identified in equations 6 and 7.

$$\textbf{Turf Demand} = \textbf{Reference ET x Turf Coefficient} \quad (6)$$

$$\textbf{Planting Demand} = \textbf{Reference ET x Planting Coefficient} \quad (7)$$

Reference ET

Reference ET was calculated using the ASCE Standardized Penman-Monteith method, using a tall reference crop (alfalfa). However, the turf and plant coefficients were developed for use with short cool season grasses. Based on his experience along the front-range of Colorado, Mr. Brent Mecham of the Northern Colorado Water Conservancy District (Mecham, 2006) indicated that the reference ET calculated with the tall reference crop can be multiplied by an adjustment factor of 0.8 to reasonably approximate the reference ET for a short cool season grass ($ET_{ref,\ short\ crop} = 0.8 \times ET_{ref,\ tall\ crop}$).

The ASCE Standardized Penman-Monteith method requires daily minimum and maximum air temperature, dewpoint temperature, solar radiation, vapor pressure, and wind speed. While daily minimum and maximum air temperature data were available from the Kassler climate station, data representing the other variables were not readily available in Douglas County. The examples for this study used filled daily dewpoint temperature, solar radiation, vapor pressure, and wind speeds from the Fort Lupton CoAgMet climate station, the closest location available through the State of Colorado's Decision Support System.

Turf and Planting Coefficients

The choices of landscaping (plantings and turf) are virtually limitless because they can be mixed and matched. A survey completed by Green Industries of Colorado (GreenCO) and Colorado State University (GreenCO, 2004) divided the landscape choices by estimated water usage, as a percentage of the reference ET and plant type (**Appendix E**). **Tables 3** and **4** identify the water usage categories, percent of water use compared to reference ET, and landscape choices.

Table 3. Landscape Water Usage Categories

Estimated Water Usage	Percentage of Reference ET
Very Low	<25%
Low	25-50%
Medium	50-75%
High	>75%

Table 4. Landscape Choices

1	Annual
2	Perennial
3	Tree
4	Vine
5	Ground Cover
6	Shrub
7	Turf

For this study, the landscaping was divided into turf and plantings which include all of the non-turf options shown in Table 4. **Table 5** describes the type of landscaping and the percent of ET based on the reference ET. The turf coefficients are based on the water demand for the specific plant. The planting choices represent an average of the total planting area. A planting area that has a native water use may include high, medium, low, or very low plant choices, but the average of the total planting area equals 30% of the reference ET.

Table 5. Turf and Planting Coefficients

Turf Coefficient		Planting Coefficient	
Description	**% Reference ET**	**Description**	**% Reference ET**
Bluegrass	90%	Traditional	70%
Fescue	70%	Moderate	50%
Buffalograss	50%	Native	30%

The basic premise for the turf and plant coefficients is that the landscaping is well maintained, as represented by routine watering, mowing, trimming, and fertilizing. The percentages identified in the tables represent the amount of water required to keep the desired "look" of the landscaping.

The following are additional factors affecting the turf and planting coefficients:

- The planting coefficients assume a water demand for mature planting and account for the varied densities of plantings.
- Planting in a turf zone is assumed to be watered by the turf, such as a tree that shades the grass. The grass will need less water because of the tree, but it is assumed that the tree will use the water saved from the turf.
- The affects of the microclimate of the turf and planting are included in the coefficients. The microclimate includes the location of the landscaping such as the side of the structure, amount of daily sun, and wind protection.

5.1.3 System Performance

The system performance coefficient is a combination of the installed irrigation system application method and its installation and operations method (equation 8). These two sub-coefficients cover the Irrigation Association's ranking system for irrigation system performance (Mecham, 2004).

$$\textbf{System Performance} = \textbf{Application Method Efficiency} \times \textbf{Installation \& Operations Method Adjustment} \quad (8)$$

Application Method

The application method is divided into three types of irrigation systems. The efficiency of each of the systems is identified in **Table 6** below. An application method can be applied to turf and planting areas separately or the same method can be applied to both.

Table 6. Application Method Efficiencies

Irrigation System	Efficiency
Spray	75%
Rotor	80%
Subsurface Drip	95%

The operational life of the irrigation systems identified in Table 6 are similar and dependent on the quality of the materials, installation, and maintenance of the systems. The cost of installation can vary widely between the systems, depending on the chosen irrigation system. In general, drip systems are more cost effective than spray or rotor systems in areas that are less than 12 feet wide, but can be cost effective in a large open area in new installations. Further review of the operational life and installation costs for the irrigation systems should be addressed in a pilot program.

Installation & Operations Method

Once the landscape and irrigation systems are installed, they must be operated and maintained properly. These two guidelines are the critical factors for water efficiency. Without them, the best-designed system will ultimately become a water waster. The installation and operations of the landscaping and application method affects the ET of the landscaping and the efficiency of the application method. **Table 7** provides factors that can be used to adjust the application method efficiency for the specific installation and operations method. The factors provide an evaluation of the application method based on the optimum efficiency identified in Table 6. The ranking represents an indication of the quality of the irrigation system such as area covered by the sprinkler heads, quality of the components, system design, system installation, long-term maintenance of the system (Mecham, 2004), soil type and preparation, fertilization, and care methods (e.g., mowing and trimming). The values provided in Tables 8 and 9 were developed from the Irrigation Association rating system of sprinkler system efficiency (Mecham, 2004).

Table 7. Installation & Operations Method Adjustments

Description	Installation & Operations Method Adjustment
Excellent	100%
Good	80%
Poor	60%

5.1.4 Water Management

The water management coefficient accounts for the amount of effective precipitation that is used to reduce the outdoor demand from the irrigation system over the irrigation season. The water management factor is calculated by multiplying effective precipitation by the technology used to adjust the application method, as identified in equation 9.

$$\text{Water Management} = \text{Effective Precipitation X Technology Adjustment} \qquad (9)$$

Effective Precipitation

The effective precipitation is the portion of the total precipitation that falls on the irrigated area during the growing season which is effective at reducing the irrigation water requirement (irrigation water requirement = outdoor water demand – effective precipitation). The SCS effective precipitation method outlined in Technical Release 21 (USDA, 1970) method was used to calculate the effective precipitation (previously described in Section 4.3.1)

Irrigation System Technology

The use of technology allows the effective precipitation that falls on the landscaping to be accounted for in the water demand. Without technology, the study's assumption is that a typical user will not adjust their irrigation application method to account for rainfall on a regular basis. **Table 8** identifies the type of technology used and the percentage of effective precipitation that can be used to reduce the outdoor water demand.

Table 8. Technology Affects on Effective Precipitation

Technology Type	Technology Adjustment Factor
Active	80%
Passive	40%
No Technology	0%

The use of new technology can help to improve a new or existing irrigation system. The research shows the use of technology that can adjust the amount of water applied to the landscaping based on its water needs. Typically, landscaping requires less water in the spring and fall with the most water demand occurring during the summer. The technology used to adjust the amount of water applied is classified into passive, active, and no technology subcategories. The portion of the effective rainfall applied for each technology (technology adjustment factor) is identified in Table 8.

The percentages applied are based on information from several articles and interviews (Aquacraft Inc., 2003; DeOreo et. Al, 1997; Mecham, 2006). If technology is used to reduce the outdoor water demand, it should be installed and programmed by a knowledgeable technician to maximize the water savings. The percentages in Table 8 assume installation by a knowledgeable technician.

Passive technology typically uses historical water demand data to set a watering amount during the season. This technology cannot automatically adjust for changes in weather patterns, such as a drought or rainfall. It adjusts the amount of watering by typical average demand, such as monthly, over the irrigation season. The system operator must manually adjust the amount of water applied for events outside the limits of the average event. This could lead to over watering so only a portion of the effective rainfall is credited for use of this type of technology. Single-family residential units typically only use a passive controller like a preprogrammed average ET controller or rain stop controller.

Active technology can automatically adjust the amount of water delivered to the landscaping with changing weather patterns. This is typically done with a soil moister sensor, rain gauge, and/or a connection to a weather monitoring station that tells the controller how much rainfall has occurred. The active technology removes the human interface in the system, which can lead to efficient water use. However, there is still some inefficiency in the technology so a full credit for the effective precipitation was not given. Per Mr. Brent Mecham of Northern Colorado Water Conservancy District, currently large parks are the typical user of active controllers like weather radio data and soil moisture sensors.

The use of no technology can be either hand watering or a traditional irrigation system controller. A traditional controller allows for the setting of watering dates (e.g., every other day), but does not adjust for the seasonal variation of the landscaping demands over the course of the irrigation season. A user can manually set this by reducing the water time per irrigated zone to achieve a passive controller status. However, it was assumed that an average irrigator will not adjust their controller over the irrigation season, so no credit was given for no-technology use.

5.1.5 Water Demand Calculation Algorithm

The irrigated area, landscaping, system performance, and water management components described above can be combined to calculate a total annual outdoor water demand. The total outdoor water demand (equation 10) is the sum of the turf demand (equation 11) and the planting demand (equation 12).

$$\text{Outdoor Water Demand} = \text{Turf Demand} + \text{Planting Demand} \qquad (10)$$

$$\text{Turf Demand} = \frac{[(\text{Ref ET X Turf Coeff}) - \text{Water Management}]}{\text{System Performance}} \quad \text{X} \quad \text{Irr Acres} \qquad (11)$$

$$\text{Planting Demand} = \frac{[(\text{Ref ET X Planting Coeff}) - \text{Water Management}]}{\text{System Performance}} \quad \text{X} \quad \text{Irr Acres} \qquad (12)$$

There are multiple combinations of examples that can be developed by using these outdoor water demand coefficients. **Table 9** summarizes the coefficients as identified in the report.

Table 9. Outdoor Water Demand Coefficient Summary

Irrigated Area (5 Units per Acre)		Landscaping		System Performance		Water Management
Turf (Square Feet)	**Landscape (Square Feet)**	**Turf (% of Ref ET)**	**Plantings (% of Ref ET)**	**Application Method Efficiency**	**Installation & Operations Method Adjustment**	**Technology Adjustment for Effective Precipitation**
0 to 3,500	0 to 3,500	Bluegrass 90%	Traditional 70%	Spray 75%	Excellent 100%	Active 80%
		Fescue 70%	Moderate 50%	Rotor 80%	Good 80%	Passive 40%
		Buffalograss 50%	Native 30%	Drip 95%	Poor 60%	None 0%

Using the components, an outdoor water demand can be calculated. The example provided in **Table 10** below is for a traditional landscape outdoor water demand representative of northwest Douglas County.

Table 10. Traditional Landscape Outdoor Water Demand Scenario

	Coefficient	Sub Coefficient	Coefficient Description
1	Irrigated Area	Turf Irrigated Area	2,000 square feet
		Planting Irrigated Area	1,500 square feet
2	Landscaping	Turf Coefficient	Bluegrass with Reference ET of 90%
		Planting Coefficient	Traditional with Reference ET of 70%
3	System Performance	Application Method Efficiency	Spray with an efficiency of 75%
		Installation & Operations Method Adjustment	Good with an efficiency of 80%
4	Water Management	Technology Adjustment	None used

The parameters used in the traditional landscape example result in a total annual outdoor water demand of 0.35 acre-feet per year per residence or approximately 32 gallons per square foot per year. This is a conservative criteria that provides a planning number for water providers to determine an outdoor water demand. The City of Boulder and Colorado State University (CSU) have calculated lower water demands, in the range of 20 gallons per square foot per year. A detailed calculation of the water demand example can be found in **Appendix F**.

5.1.6 Sensitivity Analysis

A sensitivity analysis of the four coefficients of the outdoor water demand was performed based on the traditional landscape outdoor water demand described above. The analysis varied an individual coefficient from the scenario identified in Table 10, while the remaining coefficients were held constant. The sensitivity analysis and results are generally stated below and identified in **Appendix G**. Below is a summary of the water savings by coefficient (note that the savings are not necessarily directly additive). The effectiveness of the components is listed below from most effective to least.

1. Irrigated Area – A 57% water savings is obtained when the combined turf and planting areas are reduced from 3,500 square feet to 1,500 square feet.
2. System Performance – A 52% water savings is obtained when the application method (spray, rotor, subsurface drip) and operations method is varied. The savings is highly dependent on the operations method practiced (excellent, good, poor).
3. Water Management – A 34% water savings is obtained when water management is implemented to utilize the effective precipitation via active irrigation controller technology.
4. Landscape – A 34% water savings is obtained when the landscaping choices are changed to lower water demand landscaping. An example is from bluegrass turf and traditional plantings to fescue turf and native plantings. The buffalograss and native plantings option was not chosen because research indicated that this landscape option is not the most desirable from the homeowner.

5.1.7 Provider Commitment and Public Acceptance

The calculation of the total outdoor water demand is academic in nature and adjusts for the water user by using the coefficients and algorithms. However, this equation must be filtered through the subjective factor of the water provider's commitment and public acceptance. These two factors have a major influence on the final water demand and are highly variable. The following two sections provide insight and points to consider when evaluating a provider's commitment and the public's acceptance of outdoor water demand conservation.

Provider Commitment

The information, education, and resources supplied to the customers from the water provider will affect how much water can be saved. These guidelines serve as a connection point between the customer and the water provider. Points to consider for water providers are identified below.

Information and Education
1. Water budget calculations
2. Approved water saving landscaping and irrigation equipment
3. Water savings seminars
4. Demonstration gardens
5. Frequent communication - mailings and/or handouts

Resources
1. Tiered water rates
2. Individual irrigation meters
3. Water resources staffing
4. System design support (landscape design specifications)
5. Real time water usage data
6. Water system inspections (new and existing systems)
7. Water conservation incentives
8. Subsidies for water efficiency

Public Acceptance

Public acceptance of water conservation measures may be the most difficult factor to track and implement. It will require a paradigm shift by the residents of northwest Douglas County and the Colorado Front Range. The public can use the information, education, and resources provided by the water provider as guidelines when they perform their design, operations, and maintenance on their landscape and irrigation systems. There is a willingness of the public to implement water savings methods as identified in public opinion surveys.

- Residents support additional water-saving actions, including conservation education, ensuring all new development has adequate water and limits on new lawns (Ciruli Associates, 2006).
- Residents will invest in water conservation and supply programs and projects (Ciruli Associates, 2006).
- 97% of homeowners rate their landscaping as a somewhat important aspect of their home (GreenCO, 2003).
- 51% of homeowners said they would be very likely to make changes to their landscaping to conserve water (GreenCO, 2003).
- 86% of homeowners said that they would be somewhat or much more likely to make water conservation changes if rebates were offered (GreenCO, 2003).

5.1.8 Summary of Outdoor Water Demand Components

Significant outdoor water demand savings can be realized by choosing greater water conserving coefficients of the Water Demand Calculation Algorithm. A sensitivity analysis of each individual coefficient identified water savings from the traditional northwest Douglas County outdoor water demands. The four coefficients used in the algorithm and their individual water savings from the traditional Douglas County water demand scenario are:

1. Irrigated Area – 57% water savings
2. System Performance – 52% water savings
3. Water Management – 34% water savings
4. Landscaping – 34% water savings

A fifth factor that is not included in the algorithm which has a significant impact on water savings. This highly variable coefficient is:

5. Provider Commitment and Public Acceptance

The coefficients must all be combined to provide a real picture the total outdoor water demand.

5.2 OUTDOOR WATER DEMAND SCENARIOS

There are many variables and options for calculating the outdoor water demand using the Outdoor Water Demand Calculation Algorithms. This study considers three scenarios to describe the outdoor water demand for a typical residence located in northwest Douglas County. The Douglas County Total Water Demand base scenario is provided in the next section to compare the algorithm to Douglas County's current minimum water supply standard.

5.2.1 Douglas County Total Water Demand

Douglas County has a total (combined indoor and outdoor) water demand requirement of 0.75 acre-feet per year for a residential unit (Douglas County, 2005). Assuming 0.30 acre-feet per year of the water is used for indoor water demand then the outside water demand is 0.45 acre-feet per year. The traditional water demand scenario and the Water Demand Calculation Algorithm (equation 10) calculated a lot density of 3.8 residential units per acre (**Appendix H**). The density of 5.0 units per acre used in this study provides a lower water usage per lot (0.35 acre-feet per year outdoor water demand) using the traditional water demand scenario and the Water Demand Calculation Algorithm.

The total water demand, consisting of indoor water demand and outdoor water demand, varies among water providers. Denver Water uses a total water demand of 0.46 acre-feet per year, Castle Pines North Metropolitan District uses a total water demand of 0.40 acre-feet per year, the Town of Castle Rock uses a total water demand of 0.55 acre-feet per year, and the Centennial Water and Sanitation District uses a total water demand of 0.50 acre-feet per year. By comparison, the total water demand used in this study is 0.65 acre-feet per year, which is still a conservative planning number compared to other nearby communities.

5.2.2 Water Use Scenarios

Three examples were used to define the outdoor water demand for the typical northwest Douglas County lot. The examples were chosen based on an acceptable look of the landscaping to the public. The examples start with a traditional landscape that can be found along the Front Range. This includes bluegrass and traditional plantings with a spray irrigation system. A detail for this scenario and all of the examples can be found in **Appendix I**. The moderate scenario uses fescue turf that has a lower water demand than bluegrass and plantings that are classified as moderate and has a portion of the potential landscaped area as non-irrigated area. The water wise scenario uses fescue turf and native plantings with an increase in non-irrigated area. The term "water wise" is used by several groups such as the Colorado Water Wise Council, Colorado State University, and others to describe different conservation techniques, typically related to outdoor water use. For the purposes of this study, water wise encompasses a publicly acceptable outdoor water demand conservation scenario. It does not incorporate the lowest possible water using landscape and irrigation systems, but a practical application of the outdoor water demand practices discussed above. The total outdoor water demand for the three scenarios and Douglas County Outdoor Water Demand is summarized in **Table 11**. The percentage of water savings from the Douglas County scenario and traditional scenario are summarized below. The percentage savings to both scenarios is presented, since the lot density varies from the Douglas County scenario (3.8 units per acre) and the other three scenarios (5.0 units per acre).

Table 11. Summary of Outdoor Water Demand Scenarios

Water Use Scenario	Outdoor Water Demand (acre-feet per year)	Savings from Douglas County Scenario	Saving from Traditional Scenario
Douglas County	0.45	0%	NA
Traditional	0.35	22%	0%
Moderate	0.16	64%	53%
Water Wise	0.08	82%	76%

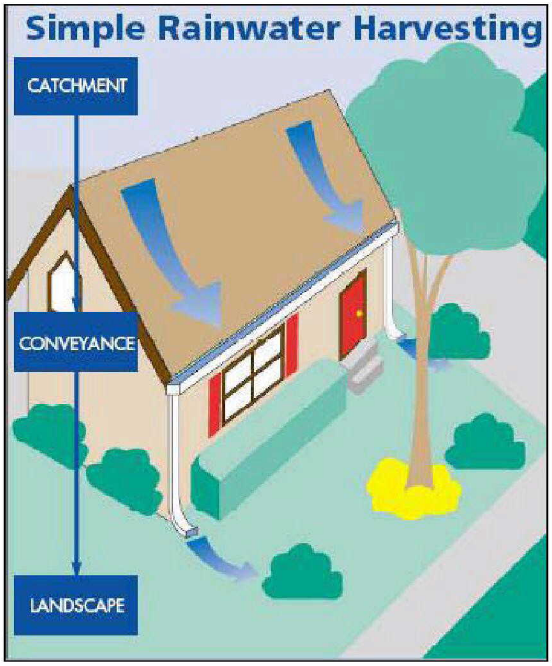
The outdoor water demands calculated from the Water Demand Calculation Algorithm represent planning numbers, which may vary between providers and may change the percent savings between the Water Use Scenarios.

6.0 RAINWATER HARVESTING

The amount of precipitation that can physically be captured and put to use depends on the amount and timing of the precipitation, the amount and timing of the demand, and the system storage capacity.

6.1 System Components

Water harvesting systems are typically characterized as either simple or complex (**Figure 10**). Simple systems distribute precipitation immediately to landscaped areas whereas complex systems store some or all of the precipitation in a container for later use. Complex systems are more expensive to construct and maintain, but yield higher water savings.



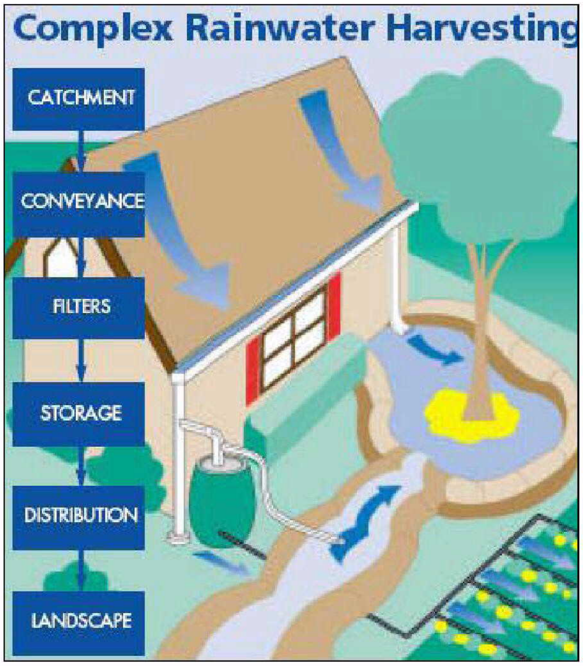


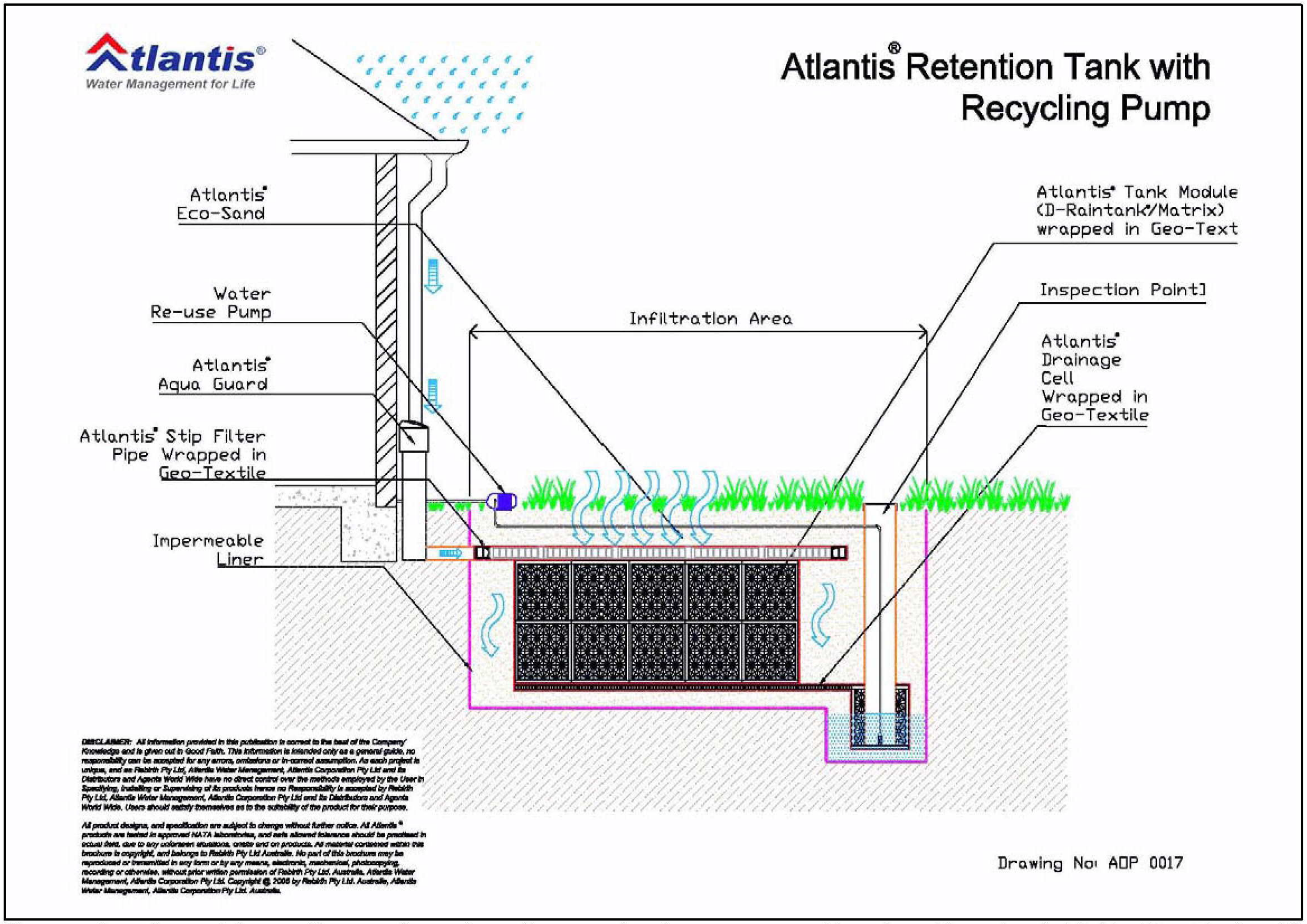
Figure 10. Components of Simple and Complex Systems
(figures taken from *A Waterwise Guide to Rainwater Harvesting, New Mexico Office of the State Engineer*).

A simple system can be limited to a catchment area (e.g., roof), conveyance system (e.g., gutters), and bermed landscaped holding area. The basic components of a complex system include:

- catchment area (e.g., roofs),
- conveyance (e.g., gutters and downspouts),
- filters (e.g., gutter leaf screen, first flush roof washing system, or additional filtration for a drip irrigation system),
- storage (e.g., rain barrels, cisterns),
- distribution system (e.g., water faucet, valve, water lines, electric pump), and
- landscape area.

In addition to gutter leaf screens and first flush devices that prevent large items from entering the storage tank, complex system designs may include liners and sand filter traps that help maintain good water quality (**Figure 11**).

Figure 11. Atlantis Cistern System



(figure taken from *Atlantis Corp website*; http://www.atlantiscorp.com.au/drawings/downloads15 (Re Use Tank.pdf).

This study focuses on the use of local (residential) cisterns to capture precipitation in a holistic approach to sustainable water management. In certain situations, other capture approaches such as regional cisterns, regional infiltration ponds, or modified detention/retention facilities may be more advantageous from a management, maintenance, and/or cost perspective. Some of these alternative approaches are being implemented in other states, such as the Daybreak Community in Salt Lake City, Utah. Evaluation of alternative approaches may be necessary to find the best system for a given project, depending on the precipitation timing, irrigation demand, storage capacity, and economics of the proposed project. Regardless of the capture mechanism, the concepts from this study can be used to further evaluate incorporating precipitation management through rainwater harvesting into particular water supply scenarios.

6.2 System Sizing

Cistern sizing depends on the amount and timing of the supply and the demand. The supply is a function of the precipitation, the catchment (e.g., roof) area, and the catchment material. For this study, where the demand is associated with landscape irrigation, the demand is a function of the amount of landscaped area, planting density and grouping, type of landscape, and irrigation practices.

The literature suggests using a water budget approach for system sizing where the monthly supply is compared to the monthly demand (City of Albuquerque, 1995; Cunliffe, 1998; Texas Water Development Board, 2005). Most of the literature recommends using average monthly precipitation to estimate the supply, as shown in equation 13 below.

$$\textbf{Supply} = \underset{\textbf{(ft)}}{\textbf{Precipitation}} \times \underset{(\textbf{ft}^2)}{\textbf{Roof Area}} \times \underset{\textbf{(\%)}}{\textbf{Collection Efficiency}} \quad \textbf{(13)}$$

The collection efficiency represents losses due to wetting the roof, filling the roof washer, gutter overshoot and spilling from the gutters during heavy downpours, and water that cannot be collected because the storage tank is already full. Composite roofs can have an approximate 10 percent loss due to inefficient flow or evaporation (Krishna, 2005). Efficiencies were cited in other publications ranging from 75 percent to 95 percent, depending on the system design and capacity; an average of 85 percent was used for the examples in this study.

The demand can be estimated using the formulas outlined in the previous section. The closer the supply and demand match, in terms of amount and timing, the smaller the storage capacity needed. For a given supply situation, a larger demand typically requires a smaller storage capacity (water is pulled out of storage faster, therefore making capacity available when the supply occurs). This relationship is illustrated by the set of curves shown in **Figure 12**.

Cistern sizing ultimately comes down to an economic decision: whether to install a larger, more costly cistern to capture the maximum possible amount or to install a smaller, less expensive cistern and capture only a portion of the available precipitation. This decision will be driven in part by the particular water supply situation and whether other cost-effective water supply options are available. A range of storage solutions are shown in Figure 12 for a typical residence with a 1,500 square foot capture area and an 85% capture efficiency. In this case, a 5,000 gallon cistern results in around

10,000 to 16,000 gallons of precipitation captured (depending on the landscape demand and the rate at which precipitation is withdrawn from storage) over an average season, almost 85% of the total precipitation. A 5,000 -gallon cistern is approximately equivalent in area to a one-car garage (12 feet by 30 feet at 4 feet deep).

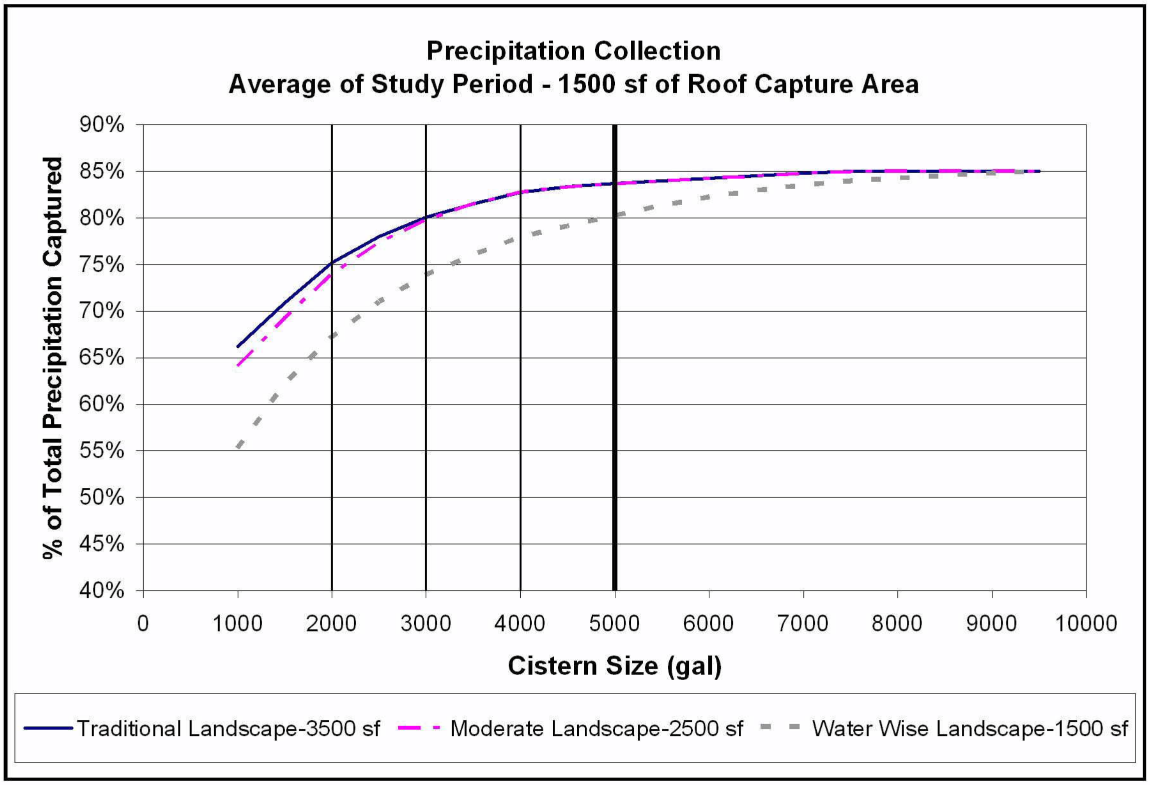


Figure 12. Cistern Sizing Alternatives

6.3 SYSTEM COSTS

Costs to install rainwater harvesting systems depend on the type of system, degree of filtration, and distance between the storage container and the place of use. The storage vessel is typically the most expensive component in the system.

Krishna indicates the total costs generally range from $5,000 to $8,000 including the gutters, cistern, pump, and treatment system (Krishna, 2004). More specific cost information from Krishna (2005) includes:

- Storage tank costs depend on the size and material, ranging from $0.50 per gallon for large fiberglass tanks to $4.00 per gallon for welded steel tanks.
- Gutters range from $0.30 per foot for do-it-yourself installations to professionally installed gutters ranging from $3.50 to $12 per foot, including materials and installation.
- Roof washer costs range from $50 to over $800.

- Pumps needed for drip irrigation systems range from around $400 to over $1,000 for combined high-end pump and pressure tanks.
- Filtration, also important for drip irrigation systems, costs around $50 per filter. Filter cartridges have to be replaced regularly.

Based on communication with AquaHarvest (2006), there is an economy of scale in storage tank costs:

- @ 1,000 gallon capacity ~ $5.50 to $6.50 per gallon,
- @ 5,000 gallon capacity ~ $2.00 to $2.40 per gallon,
- @ 10,000 gallon capacity (e.g., regional storage) ~ $1.00 to $1.75 per gallon.

AquaHarvest is currently installing these systems in the Rancho Viejo development outside of Santa Fe, New Mexico (**Figure 13**). The storage tanks have an average life of around 30 years, while the pumping equipment has a life of approximately 5 years. A detailed cost/benefit analysis was not included in this study. As previously mentioned, the cistern size will most likely be dictated by an economic decision based on an individual's situation, in terms of alternative supplies. If the cistern provides the only source of water (e.g., wells going dry), then a larger cistern may be well worth the additional capital cost. Further, the water supply provided by rainwater harvesting may serve to offset other project costs such as reduced water rights acquisitions, fewer wells for pumping, and reduced system sizing.

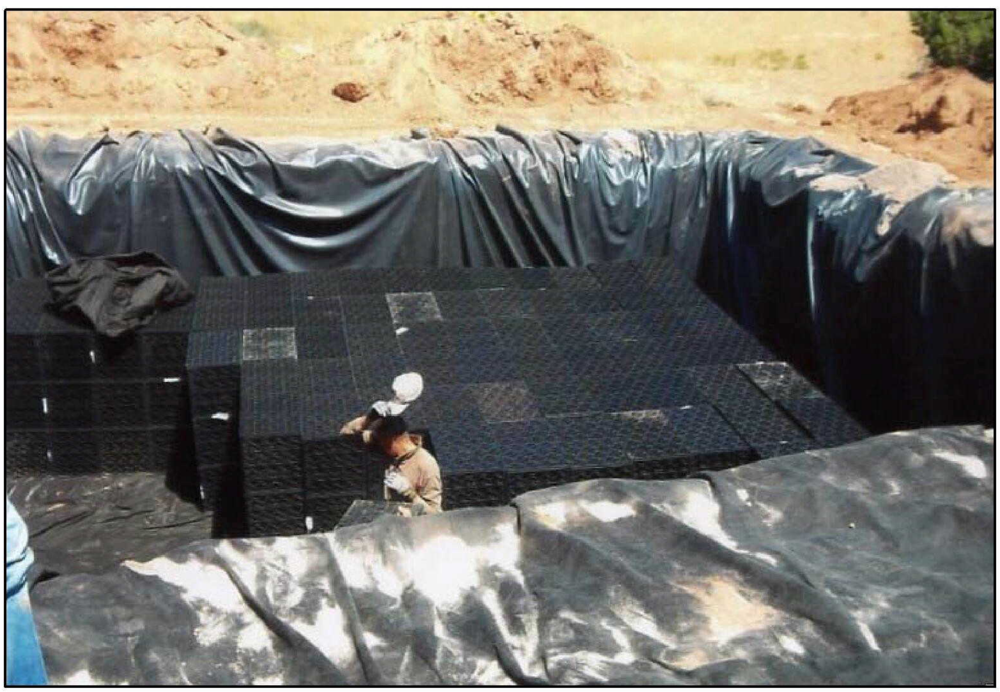


Figure 13. Cistern Installation

7.0 COMBINING RAINWATER HARVESTING WITH OUTDOOR WATER DEMAND MANAGEMENT

In this chapter, we investigate precipitation as a water supply for outdoor water demands and the different augmentation requirements for existing and new development examples. The relationship between the amount of precipitation captured and the landscape demand is illustrated, on a conceptual basis, in **Figure 14**. In Colorado, precipitation typically peaks in early to mid spring while landscape demands peak later in the summer.

If the outdoor water demand is managed such that the total outdoor water demand is less than or equal to the supply from precipitation, cisterns or alternative storage options could be used to simply capture the precipitation when it is available and re-time the storage releases to match the demands. Alternatively, if the outdoor water demand exceeds the captured precipitation, then some amount of supplemental irrigation water may still be needed, as depicted in Figure 14. In this case, the captured precipitation reduces the amount of supplemental supply that would otherwise be needed.

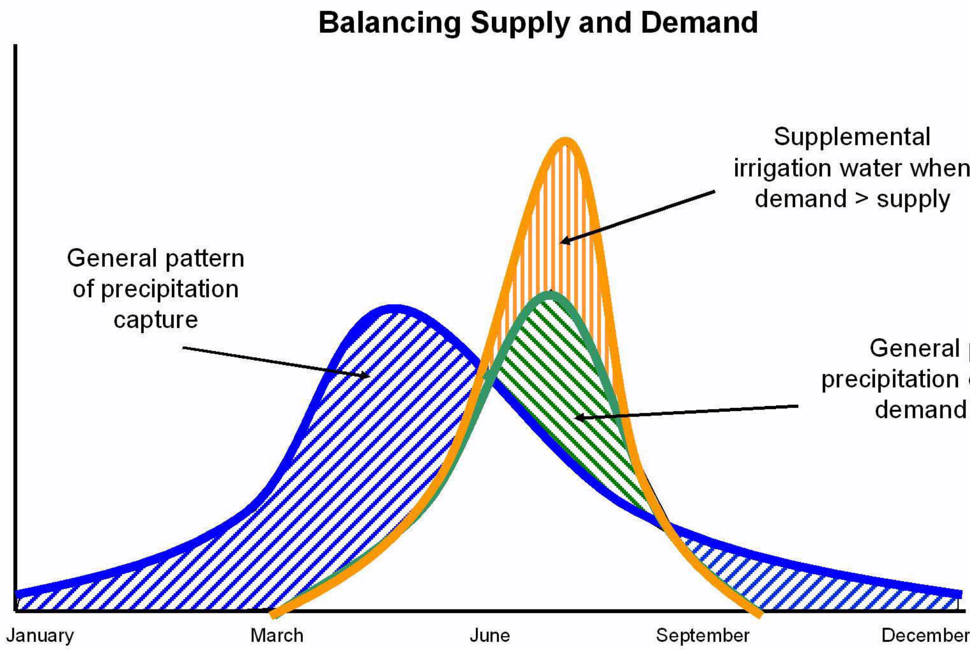


Figure 14. Concepts of Balancing Supply and Demand

To show how rainwater harvesting and outdoor water demand management practices can be paired to provide a holistic approach to sustainable water management in Douglas County, three general examples were considered:

- New Residential Development – precipitation collected from rooftops only,
- Existing Domestic Well Users – precipitation collected from rooftops only,
- Existing Commercial Non-Tributary Well User – precipitation collected from rooftops and other impervious areas.

Using the algorithms presented in Chapters 5 and 6, monthly water budgets were developed to compute the supply from precipitation, and outdoor water demands for landscaping irrigation. The algorithms presented in Chapter 4 were then used to estimate augmentation requirements under each scenario. A study period of 1993 through 2003, representing average, wet, and dry conditions, was selected. Precipitation data from the Kassler NOAA climate station were used to estimate the supply from precipitation. Outdoor water demands were estimated using temperature and frost dates from the Kassler NOAA climate station and wind speeds, vapor pressure, and solar radiation data from the Ft. Lupton CoAgMet climate station, the closest CoAgMet climate station with this type of data. The results provided below are based on these monthly water budget analyses.

7.1 New Residential Development

The benefits of pairing rainwater harvesting with traditional, moderate, and water wise conservation scenarios, as identified in Section 5.2.2, for a new residential development were considered (**Table 12**). For this example, a 1,500 square foot roof capture area with a 5,000-gallon cistern and 85% capture efficiency was considered. Irrigated areas and associated outdoor water demands for traditional landscaping, moderate conservation, and water wise conservation were based on information presented in Chapter 6. An example of the calculations under a moderate conservation scenario are provided in Appendix I.

Table 12. Precipitation and Outdoor Water Demand Management with New Residential Development

One Single Family Residential Equivalent (SFE)								
Demand Scenario	Irrigated Area	Outdoor Water Demand		Cistern Supply [(a)]		Supplemental Irrigation Supply	Supply From Precipitation	Savings from Traditional Landscaping
	(Sq. Feet)	(Acre-Feet)	(Gallons)	(Acre-Feet)	(Gallons)	(Acre-Feet)	(%)	(%)
	[1]	[2]	[3]	[4]	[5]	[6]	[7] [(d)]	[8] [(d)]
Traditional Landscaping	3,500	0.347 [(c)]	113,000	0	0	0.347	0%	---
Traditional Landscaping & Cisterns [(b)]	3,500	0.347	113,000	0.042	13,800	0.305	12%	12%
Moderate Conservation	2,500	0.164	53,600	0	0	0.164	0%	53%
Moderate Conservation & Cisterns [(b)]	2,500	0.164	53,600	0.042	13,800	0.122	26%	65%
Water Wise	1,500	0.082	26,600	0	0	0.082	0%	76%
Water Wise & Cisterns [(b)]	1,500	0.082	26,600	0.041	13,200	0.041	50%	88%

(a) Cistern supply varies depending on timing of precipitation supply and irrigation demand.
(b) 5,000 gallon cistern
(c) The Traditional Landscaping scenario equates to 32 gallons per square foot per year water demand, which is higher than the 20 gallons per square foot per year identified in other outdoor water demands studies by The City of Boulder and Colorado State University.
(d) A lower Traditional Landscaping water demand will increase the percentage of supply identified in column 7 and reduce the savings identified in column 8.

As previously mentioned, this study considers rainwater harvesting and outdoor water demand management practices individually as stand alone concepts, and then explores the added benefit of combining the two. For the new residential example described above, the average annual water savings are as follows:

- Outdoor water demand management practices alone, as compared to traditional landscaping practices, can produce an average water savings of approximately 53% (0.183 acre-feet per SFE) and 76% (0.265 acre-feet per SFE) under moderate conservation and water wise practices, respectively (Table 12, columns 2 and 8).
- Rainwater harvesting has the potential of supplying approximately 0.04 acre-feet or 12% of the traditional landscape demand, approximately 26% of moderate conservation demand, and approximately 50% of the demand with water wise practices (Table 12, column 7).
- Combining outdoor water management with rainwater harvesting, as compared to traditional landscaping water demand without cisterns (0.35 acre-feet per year), has potential potable water savings of 65% (0.23 acre-feet per year) for the moderate conservation scenario, and 88% (0.31 acre-feet per year) for the water wise scenario (Table 12, column 8).

Precipitation and outdoor water demand management offer an opportunity for substantial water savings, particularly when considered on a larger scale. For example, the numbers provided in Table 12 could be incorporated with Douglas County growth projections to estimate the full potential savings if rainwater harvesting and outdoor water demand management were incorporated in all new developments throughout Douglas County.

To illustrate potential savings on a larger scale, the same examples presented in Table 12 are shown in Table 13. For a new development of 1,000 homes, without precipitation or outdoor water demand management, the new development would require approximately 350 acre-feet to meet average outdoor demands with traditional landscaping (column 2). Adding rainwater harvesting could provide 40 acre-feet of supply, reducing the demand to 310 acre-feet (columns 2 and 4). Even without the rainwater harvesting component, water savings are estimated to be approximately 190 acre-feet with moderate conservation and 310 acre-feet with water wise practices (column 4).

Pairing rainwater harvesting and moderate landscape conservation, the same development that required 350 acre-feet of supply with traditional demands would require only 120 acre-feet with moderate conservation and only 40 acre-feet with water wise practices (column 2). For these examples, the cost savings in water supply acquired for outdoor demands are estimated to be approximately $5.1 million and $6.8 million, respectively (column 6).

Table 13. Precipitation and Outdoor Water Demand Management on a Development Scale

1,000 Single Family Residential Equivalents (SFE)						
Demand Scenario	Outdoor Water Supply Required [(a)]		Water Rights Cost [(c,d)]	Savings from Traditional Landscape (1,000 SFE's)		
	1 SFE	1,000 SFE's				
	(Acre-Feet)	(Acre-Feet)	($ Millions)	(Acre-Feet)	(%)	($ Millions)
	[1]	[2]	[3]	[4] [(f)]	[5] [(f)]	[6] [(f)]
Traditional Landscaping	0.35 [(e)]	350	$7.70	0	---	$0.00
Traditional Landscaping & Cisterns [(b)]	0.31	310	$6.80	40	12%	$0.90
Moderate Conservation	0.16	160	$3.50	190	53%	$4.20
Moderate Conservation & Cisterns [(b)]	0.12	120	$2.60	230	65%	$5.10
Water Wise	0.08	80	$1.80	270	76%	$5.90
Water Wise & Cisterns [(b)]	0.04	40	$0.90	310	88%	$6.80

(a) Cistern supply varies depending on timing of precipitation supply and outdoor water demand.
(b) 5,000 gallon cistern
(c) Cost based on $15,000 to acquire and $7,000 for storage to provide a firm yield of water at a total cost of $22,000 per acre-foot.
(d) Includes cost for augmentation that protects downstream water rights per this study.
(e) The Traditional Landscaping scenario equates to 32 gallons per square foot per year water demand, which is higher than the 20 gallons per square foot per year identified in other outdoor water demands studies by The City of Boulder and Colorado State University.
(f) A lower Traditional Landscaping water demand will reduce the savings identified in columns 4, 5, and 6.

7.1.1 Augmentation Requirements for New Residential Development

Under current law, 100% of the precipitation captured would need to be augmented (returned to the stream), as presented in Sections 3 and 4. However, our scientific literature review shows that on average, only 3% of precipitation falling over undeveloped areas returns to the stream. Therefore, an average of 97% of the historical precipitation could be used in a rainwater harvesting system without injuring other water rights.

Due to inefficiencies in capturing precipitation, we estimated that on average, only 85% of the water falling over the roof area would be captured with cisterns. If 97% of the historical precipitation can be used without injuring other water rights but only 85% can be captured with cisterns, it is possible that all of the captured water could be used without injuring other water rights.

What happens to the other 15% of the precipitation that is not captured? A portion may return to the stream system or it may be consumed by rooftop evaporation and other losses. To be conservative to the stream system and other existing water rights, we are recommending augmentation requirements be based on a percentage of the total precipitation that fell over the rooftop areas rather than the 85% that was actually captured and used.

As previously described in Section 4.4, prior to development, the historical average annual precipitation of 17.5 inches that fell over a development of 1,000 homes with 1,500 square foot rooftops was equivalent to 50 acre-feet. On average, only 2 acre-feet (3%) returned to the stream system via surface and groundwater return flows. The difference of 48 acre-feet was consumed by native vegetation and never returned to the stream system. Therefore, we estimate the average annual augmentation requirement from this development should be 2 acre-feet per year in order to protect existing water rights. However, current law requires the full 50 acre-feet to be replaced.

7.2 Existing Domestic Well Users

7.2.1 Non-Tributary

With the exception of a 2% relinquishment to the stream system, non-tributary water is fully consumable. When the wastewater from indoor uses is treated with an individual sewage disposal system, it is typically estimated to be only 10% consumptive, with the remaining 90% returning to the stream system. The portion that is not consumed and not relinquished can be used as a reusable "credit" to offset stream depletions associated with other uses. Note that outdoor uses are not typically considered to be 100% consumptive and therefore also result in a return flow credit. However, for simplicity, the example provided for this study considers reusable credits associated with indoor uses only.

The benefits of adding rainwater harvesting to an existing domestic non-tributary well user with traditional landscaping were considered. For this example, a 1,500 square foot roof area with a 5,000-gallon cistern and maximum 85% capture efficiency was considered. The associated demands are shown below in **Table 14**. With 10% consumption and 2% relinquishment, this well user would have a reusable credit of 88% or approximately 86,000 gallons. This credit far exceeds the amount captured with the cistern as well as the total amount that historically fell over the 1,500 square foot roof area. There are sufficient return flow credits associated with the indoor use of non-tributary water to offset the augmentation requirement, even if 100% of the water falling over the capture area had to be replaced. Even with current Colorado water law, rainwater harvesting could be a viable option for domestic non-tributary well users. Rainwater harvesting is in alignment with the goals outlined in the Douglas County 2020 Comprehensive Master Plan and under this example, would save an average of 13,800 gallons per year pumping. Pairing rainwater harvesting with outdoor water demand management would have even greater potential of reducing pumping.

Table 14. Augmentation Requirements for a Domestic Non-Tributary Well User (Gallons per Year)

Outdoor Use	
Outdoor Demand	113,000
Average Precipitation	16,000
Precipitation Captured (max 85%)	13,800
Supplemental Supply	99,200
Indoor Use Credits	
Indoor Demand (0.3 AF)	97,800
Reusable Credits (88%)	86,064
Augmentation Requirement (Current Law)	
Depletions (100% of Precip)	16,000
Return Flow Credits (88%)	86,064
Augmentation Requirement	0

7.2.2 Tributary

Douglas County residents relying on or seeking a water supply from a tributary aquifer likely have or may be able to apply for an "exempt" well permit. According the Colorado Department of Water Resources, exempt well permits for Household Use Only Wells are issued for ordinary household uses in one single family dwelling on tracts of land that are less than 35 acres. These permits do not allow for any outdoor water use or livestock watering. Generally, this type of permit is issued to individuals in a rural setting who own a lot in a subdivision that was created prior to June 1, 1972. These types of users are likely located in the foothills on the west side of Douglas County.

For these specific water users, rainwater harvesting could provide a physical water supply for outdoor uses, as well as a potential supply for fire storage. To legally divert, store, and use the precipitation would require an augmentation plan. Currently, the Upper South Platte Water Conservancy District has applied for a "blanket" augmentation plan (Case No. 02CW389) to cover these types of small depletions for users within its boundaries such as the foothills area of Douglas County. The algorithms presented in this report could serve as the basis for determining the augmentation requirements. **Table 15** compares estimated augmentation requirements for a domestic tributary well user under current law versus replacements needed to protect existing water rights.

Table 15. Augmentation Requirements for a Domestic Tributary Well User (Gallons per Year)

Augmentation Requirement	Current Law (100% of Precip)	Protect Existing Water Rights
Depletions	16,000	480

7.3 EXISTING COMMERCIAL NON-TRIBUTARY WELL USER

Irrigated and impervious acreage and water use information associated with the Castle Pines North administration building were used to consider the benefits of adding rainwater harvesting to an existing commercial non-tributary well user with traditional landscaping. While the administration building may actually be more representative of a public facility than a true commercial user (due to a slightly higher irrigated area to impervious area ratio), it is sufficient for demonstrating the concept of capturing precipitation from both a rooftop and other impervious areas.

As previously mentioned, with the exception of a 2% relinquishment to the aquifer, non-tributary water is fully consumable. With commercial users, the wastewater from indoor uses is typically treated at a central wastewater treatment plant. In this case, the indoor use is typically considered to be only 5% consumptive, with the remaining 95% returning to the stream system. The portion that is not consumed can be used as a reusable "credit" to offset stream depletions associated with other uses. As with the domestic example provided above, return flow credits associated with outdoor uses were not considered for this example.

The following estimates were used for this example:

- Cistern capacity of 70,000 gallons with an maximum 85% capture efficiency,
- Impervious capture area of 0.60 acres (including rooftop, parking lot, and sidewalks),
- Irrigated area of 0.586 acres (92% bluegrass, 8% traditional plantings), and
- Traditional landscaping application efficiencies.

Under these conditions, this commercial well user would have an average outdoor demand of approximately 540,000 gallons per year (**Table 16**). It is estimated that rainwater harvesting with cisterns could supply approximately 237,400 gallons (44%) of this demand. Note that the amount of precipitation that historically fell over the impervious areas is approximately 286,700 gallons, but with a maximum capture efficiency of 85% and cistern capacity of 70,000 gallons, only 237,400 gallons are captured.

The indoor demand for this user is estimated to be 48,000 gallons per year. With 5% consumption and 2% relinquishment, this well user would have a reusable credit of approximately 44,640 gallons. In this case, the available credit is less than the amount captured with the cistern. While rainwater harvesting would save an average of 237,400 gallons per year pumping, it would result in a net augmentation requirement of approximately 242,060 gallons from indoor uses under current law. It is likely that under a more typical commercial use, where the irrigated area to impervious area ratio is lower, the results of this analysis would be more similar to the case of the domestic non-tributary well user where the reusable return flow credits would exceed the augmentation requirements even under current law.

Table 16. Augmentation Requirements for a Commercial Non-Tributary Well User (Gallons per Year)

Outdoor Use	
Outdoor Demand	540,000
Average Precipitation	286,700
Precipitation Capture (max 85%)	237,400
Supplemental Supply	302,600
Indoor Use Credits	
Indoor Demand	48,000
Return Flow Credits (93%)	44,640
Augmentation Requirement (Current Law)	
Depletions (100% of Precip)	286,700
Reusable Credits	44,640
Augmentation Requirement	242,060

8.0 AUGMENTION PLANS

8.1 CURRENT AUGMENTATION REQUIREMENTS

A plan for augmentation is statutorily defined as "a detailed program . . . to increase the supply of water available for beneficial use in a division or portion thereof by the development of new or alternate means or points of diversion, by a pooling of water resources, by water exchange projects, by providing substitute supplies of water, by the development of new sources of water, or by any other appropriate means. *'Plan for Augmentation' does not include the salvage of tributary waters by the eradication of phreatophytes, nor does it include the use of tributary water collected from land surfaces that have been made impermeable, thereby increasing the runoff but not adding to the existing supply of tributary water.*" C.R.S. § 37-92-103(9). Because no credit is allowed for the eradication of phreatophytes or the collection of precipitation off impermeable surfaces, such as rooftops, all rainwater or snowmelt collected is considered to be tributary to the stream and must be replaced with another source of water.

In the 1,000-unit new home development example discussed above, an augmentation plan for rooftop capture of precipitation with subsequent storage in cisterns and application to beneficial use would require the following elements:

- Appropriation of new, conditional water right that would represent the diversion of water through capture of precipitation;
- Identification of structures to be augmented, i.e., structures capturing precipitation;
- Measurement and/or calculation of all precipitation captured;
- Identification of sufficient water to be used to replace presumed depletions to the stream such as non-tributary groundwater return flows, reservoir releases, or the addition to the stream of changed surface water rights;

- Timing analysis of when precipitation would reach stream and protective term and condition mimicking timing;
- Calculation of lawn irrigation return flows generated by irrigating with water collected in cisterns in order to offset augmentation requirements. NOTE: if an applicant did not want to undertake this analysis, or wanted to do so later, 100% of captured precipitation would have to be replaced;
- Accounting forms acceptable to Division Engineer to track augmentation requirements; and
- A way to curtail or shut off precipitation capture mechanisms if adequate replacement not being made.

Despite water quality and storm water management benefits, under today's law, there is no incentive to invest in precipitation harvesting and management, which require additional infrastructure, because water supply requirements are not reduced.

8.2 Augmentation Requirements if Colorado Allowed Use of Rainwater Harvesting

For augmentation plans involving the capture and beneficial use of precipitation to function as an actual component of the water supply, changes in the law are necessary. Ultimately, water users meeting certain criteria established by the legislature to maintain a system of balance and control would need to be allowed to:

- Capture precipitation from impermeable surfaces for storage and later use,
- Quantify how much of that precipitation had never historically reached the stream because it had been consumed by native vegetation or sublimation, and
- Reduce their augmentation requirement by that historical ET amount.

Many of the elements of an augmentation plan that allowed credit for historic water consumption by native plants would be similar to those outlined above in Section 8.1. However, in addition to those elements outlined above, an applicant would have to quantify the percentage of precipitation consumed by vegetation, and therefore not available to the stream, versus the percentage of precipitation that did accrue to the stream via surface flows and/or groundwater flows. An applicant for an augmentation plan involving precipitation harvesting would also have to provide evidence of the timing of the augmentation requirements.

Besides the additional elements of proof involved, the main difference between an augmentation plan under current legal standards and an augmentation plan that allowed an applicant to calculate and take credit for actual, historic patterns of precipitation accrual to streams, is that the later enables the water user to utilize on-site precipitation as a real component of their water supply system. Water users, pursuant to balancing and control standards established by the legislature, would be able to capture and use rain or snowfall on-site, thereby reducing the amount of water they would otherwise need to acquire and introduce to that same site.

9.0 STUDY CONCLUSIONS AND RECOMMENDATIONS

This study investigates a holistic approach to balancing sustainable/renewable water supplies with outdoor water demands in the design of water supply systems in the study area of northwest Douglas County. The study was conducted at a feasibility level, investigating the pairing of one specific component of rainwater harvesting (use of cisterns) with outdoor water demand management.

While rainwater harvesting is being practiced and encouraged in Colorado's neighboring states, it presents unique challenges in Colorado due, in part, to Colorado's water law. Through conducting a detailed literature review and applying generally accepted algorithms, the results from this study show that the limitations currently posed by Colorado's water law on use of precipitation are overly conservative with respect to protecting the stream system for existing water rights.

Combining rainwater harvesting with outdoor water demand management provides the greatest potential for saving water, however, the results from this study are presented such that the recommended algorithms and findings related to each practice can be utilized to investigate benefits associated with either practice individually or paired together. These concepts can be used to find innovative solutions under various water supply situations. Although this study focuses on the water supply needs in northwest Douglas County, the methodologies presented herein are applicable throughout the county and to much extent, throughout the state.

9.1 STUDY CONCLUSIONS

9.1.1 Precipitation as a Potential Water Supply

- The annual precipitation in northwest Douglas County ranges from 10.68 inches to 28.11 inches, with an average of 17.5 inches per year.
- Based on the lowest record amount for the period 1950 through 2004, the estimated "sustainable" yield from precipitation in northwest Douglas County is over 10 inches.

9.1.2 Legal Right to Use Precipitation

- Current law in Colorado requires 100% of any precipitation captured for later use to be replaced to the stream system in quantity, time, and place.
- There are two statutory exceptions (for streambed reservoirs and gravel pit ponds) which allow "credit" to be taken for the portion of the precipitation that did not historically reach the stream system, due to evapotranspiration (ET) and sublimation.
- For the two statutory exceptions, the Division of Water Resources generally accepts an ET credit of 70% of the total precipitation and will accept higher ET credits when supported by appropriate engineering documentation.
- For rainwater harvesting to become a viable component of water supply planning, legislation would need to be enacted defining the circumstances under which precipitation capture, including appropriate credit for historic patterns of native vegetation ET, could be implemented, taking into consideration adequate balancing and control mechanisms to protect other valuable state resources.

9.1.3 Precipitation Water Budget under Pre-Developed Conditions

To expand the ability to use ET Credits beyond the two statuary exceptions (for streambed reservoirs and gravel pit ponds), an algorithm is needed to quantify the portion of the total precipitation that falls over an undeveloped site but does not reach the stream system, and therefore could be used in new ways without injuring existing water rights).

- Of the total precipitation that falls on undeveloped lands, a portion runs off the land as surface water runoff, a portion is used to satisfy native vegetation ET and sublimation requirements, and the remainder deep percolates to the groundwater aquifer (i.e., groundwater recharge). This relationship is described by the following equation:

$$\textbf{Total Precipitation} = \textbf{Runoff} + \textbf{Native Vegetation ET \& Sublimation} + \textbf{Deep Percolation} + \textbf{Change in Soil Moisture} \qquad (1)$$

- Research was conducted of various scientific methods to calculate variables in equation (1). We conclude that application of the following equations reasonably reflects the destination of precipitation on undeveloped lands.

  Runoff – The Soil Conservation Service (SCS) Curve Number Method was selected to estimate daily runoff from an undeveloped site.
  - Application of the SCS Curve Number methodology for the study area shows that for the period of 1950 through 2004, the average annual runoff is equivalent to 2% of the annual precipitation (0.03 acre-feet per acre). The maximum runoff in a wet year (1969) was 12% (0.28 acre-feet per acre) and the minimum runoff in a dry year (1956) was 0%.

  Native Vegetation ET & Sublimation – During the growing season, the modified Blaney-Criddle method, with an elevation adjustment, was selected to estimate the monthly ET from native vegetation (based on potential consumptive use of pasture grass). During the non-growing season, up to 38% of the total monthly precipitation was made available to recharge the soil moisture reservoir; the remainder was considered to be runoff, evaporation, or sublimation.
  - The combined growing season and non-growing season study area results show that for the period of 1950 through 2004, the average ET and sublimation is equivalent to 97% of the total precipitation (1.4 acre-feet per acre). The maximum ET and sublimation in a wet year (1969) was 85% (2.0 acre-feet per acre) and the minimum ET and sublimation in a dry year (1956) was 100% (0.89 acre-feet per acre).

  Deep Percolation – A monthly water balance approach was used to estimate deep percolation as total precipitation less the sum of runoff and native vegetation ET and sublimation.
  - Study area results show that for the period 1950 through 2004, the average deep percolation is equivalent to 1% of the total precipitation (0.01 acre-feet per acre). The maximum deep percolation in a wet year (1969) was 3% (0.07 acre-feet per acre) and the minimum deep percolation in a dry year (1956) was 0%.

- To maintain the water supply that existing water rights have relied upon, if precipitation is captured and used, the historical runoff and deep percolation amounts would need to be replaced in quantity, time, and place. The runoff and water budget analysis shows that for the period of 1950 through 2004, the average annual return flow to the stream was 3% (2% from runoff and 1% from deep percolation). The maximum return flow to the stream in a wet year (1969) was 15% (12% from runoff and 3% from deep percolation) and the minimum return flow in a dry year (1956) was 0%. This means that for previously undeveloped areas within the study area of northwest Douglas County, on average, only 3% of the annual precipitation historically returned to the stream system via surface water and groundwater return flows.

- We conclude that current law is very conservative in protecting existing water supplies: for every acre-foot of precipitation captured, one acre-foot of replacement water must be acquired and returned to the stream. Our scientific literature review shows that for new developments, where runoff from impervious areas is not already part of the water supply to existing water rights, the average leverage potential of rainwater harvesting is on the order of 28 fold. In other words, for every acre-foot of replacement water available, one could capture and use 28 acre-feet of precipitation on the average without injury to the water supply of existing water rights.

9.1.4 Outdoor Water Demand Management

- There are a multitude of factors that affect outdoor water demands. The literary review and interviews identified five main coefficients that combine to evaluate a holistic approach to outdoor water demand: 1) irrigated area, 2) landscaping, 3) system performance, 4) water management, and 5) provider commitment and public acceptance. These factors are combined into an algorithm as defined by equations 10, 11, and 12, to calculate the total outdoor water demand.

$$\textbf{Outdoor Water Demand} = \textbf{Turf Demand} + \textbf{Planting Demand} \qquad \textbf{(10)}$$

$$\textbf{Turf Demand} = \frac{\textbf{[(Ref ET X Turf Coeff)} - \textbf{Water Management]}}{\textbf{System Performance}} \;\textbf{X}\; \textbf{Irr Acres} \qquad \textbf{(11)}$$

$$\textbf{Planting Demand} = \frac{\textbf{[(Ref ET X Planting Coeff)} - \textbf{Water Management]}}{\textbf{System Performance}} \;\textbf{X}\; \textbf{Irr Acres} \qquad \textbf{(12)}$$

- Reducing the irrigated area of landscaping (turf and plants) can save 57% of the outdoor water demand of a traditional northwest Douglas County water demand.
- Changing turf and plantings to more water conservative options can reduce outdoor water demand by 34% while still maintaining the "look" of a traditional outdoor water demand lot.
- Irrigation system performance, like installing a subsurface drip irrigation system and maintaining it in excellent condition, can save 52% more water than a spray irrigation system that is poorly maintained.
- Using water controlling technology allows for water management savings of 34% over a standard irrigation controller.

- Provider commitment and public acceptance is the filter the other water management coefficients must pass through before true water savings can be realized. The report presents several areas to consider when analyzing the effectiveness of the provider's commitment and the public's acceptance.
- Using Douglas County total water demand criteria and a traditional landscaping plan, a lot density of 3.8 units per acre is achieved.

9.1.5 Rainwater Harvesting

This study focuses on the use of local (residential) cisterns to store and regulate precipitation to meet outdoor demands. In certain situations, other storage options such as regional cisterns, regional infiltration ponds, or modified detention/retention facilities may prove to be more advantageous from a management, maintenance, and cost perspective.

- **Water Quality** – Gutter leaf screens, first flush devices, cistern liners, and sand filter traps can be incorporated with cisterns to maintain good water quality.
- **Capture Efficiency** – Precipitation capture efficiencies were cited ranging from 75 percent to 95 percent, depending on the system design and capacity; an average of 85 percent was used for the examples in this study.
- **Cistern Sizing** – The literature suggests using a water budget approach for system sizing, where the monthly supply is compared to the monthly demand. Ultimately, sizing comes down to an economic decision: whether to install a larger, more costly cistern to capture the maximum possible amount or to install a smaller, less expensive cistern and capture only a portion of the available precipitation.
  - For a typical residence with a 1,500 square foot capture area and an 85% capture efficiency, a 5,000-gallon cistern results in around 10,000 to 16,000 gallons of precipitation captured (depending on the landscape demand and the rate at which precipitation is withdrawn from storage) over an average season, almost 85% of the total precipitation.
- **Costs** – Costs to install rainwater harvesting systems depend on the type of system, degree of filtration, and distance between the storage container and the place of use.
  - The storage vessel is typically the most expensive component in the system. Research indicates a 1,000-gallon capacity cistern costs around $5.50 to $6.50 per gallon installed, while a 5,000-gallon capacity cistern costs around $2.00 to $2.40 per gallon.
- **Useful Life** – The storage tanks have an average life of around 30 years, while the pumping equipment has a life of approximately 5years.

9.1.6 Combining Rainwater Harvesting with Outdoor Water Demand Management

Potential water savings from implementing rainwater harvesting and outdoor water demand management were considered for new residential users and existing well users.

New Residential – The base residential outdoor water demand was estimated at 0.35 acre-feet per year for a traditional landscaped yard, and precipitation capture was based on a 1,500 square foot roof capture area with a 5,000-gallon cistern. The outdoor water demand may vary based on the local water provider's criteria. Potential water savings from implementing rainwater harvesting and outdoor water demand management for moderate and water wise conservation scenarios are summarized below:

- Outdoor water demand management practices alone, as compared to traditional landscaping practices, can produce an average savings in water of approximately 53% (0.19 acre-feet per residence) under a moderate conservation scenario and 76% (0.27 acre-feet per residence) for a water wise scenario.
- Rainwater harvesting has the potential of supplying approximately 12% (0.04 acre-feet per residence) of the traditional landscaping demand, approximately 26% of a moderate conservation scenario demand, and approximately 50% of a water wise scenario demand.
- Combining outdoor water management with rainwater harvesting, as compared to traditional landscaping demand without cisterns (0.35 acre-feet per year), has potential potable water savings of 65% (0.23 acre-feet per year) for a moderate conservation scenario and 88% (0.31 acre-feet per year) for a water wise conservation scenarios.
- The study example shows traditional landscape demands are on the order of 0.35 acre-feet per residence – a water supply of 350 acre-feet is needed for a 1,000-home development. Based on an estimated total cost to purchase water rights and provide regulatory storage at $22,000 per acre-foot, implementation of rainwater harvesting and outdoor water demand management to a 1,000-home development represents the following savings in water supply acquisitions:
  - A moderate conservation scenario requires approximately 120 acre-feet, a 230 acre-foot savings, which represents about $5.1 million dollars in savings.
  - A water wise scenario requires approximately 40 acre-feet, a 310 acre-foot savings, which represents about $6.8 million dollars in savings.

Existing Well Users – Results of implementing rainwater harvesting and outdoor water demand management to existing well users show the following:

- For well users in areas determined to be non-tributary, every gallon of precipitation captured and used for outdoor landscape irrigation is one less gallon pumped from the non-tributary aquifer. For a typical single family home with a 1,500 square foot roof capture area and a 5,000-gallon cistern, this represents about 13,800 gallons per year savings. For 1,000 wells, this represents about 42 acre-feet per year less pumping.
- Even under current Colorado law, rainwater harvesting could be a viable option for non-tributary well users because of reusable return flow credits from indoor uses. Typical return flow credits from indoor use are estimated to average 86,000 gallons per year, while

augmentation requirements for rainwater harvesting would approximate 16,000 gallons per year under current law.

- For domestic exempt well users currently limited to indoor use only, rainwater harvesting represents a potential water supply for fire storage and outdoor water uses. An augmentation plan would be required to replace captured precipitation; either 100% under current law (16,000 gallons/year), or something far less if precipitation ET credits were allowed (approximately 500 gallons/year).

9.1.7 Augmentation Plans

- Under current law, it is possible for a water user to capture precipitation for beneficial use. However, 100% of the precipitation captured would have to be replaced to the stream. This full replacement requirement makes utilizing precipitation capture impracticable in most situations, with the possible exception of non-tributary well users.
- If legislation was passed that allowed, in certain circumstances, the capture of precipitation, the calculation of the amount of such precipitation that had historically accrued to the stream, and for credit to be assigned for that amount of precipitation that did not historically accrue to the stream, rainwater harvesting could become a viable component of sustainable water supply planning, particularly in areas such as Douglas County where renewable surface supplies are very limited.

9.2 Recommendations

1. We recommend that statutory law be crafted to allow precipitation capture and use with augmentation requirements based on maintaining the amount, timing, and location of historical runoff and deep percolation, which is the water supply for existing water rights. The law would require a water court application for an augmentation plan to provide a forum to allow existing water right owners to evaluate the details of the augmentation plan and impose terms and conditions to protect the historical yield of their water rights.

    - Colorado's current law is constraining the ability of its citizens to use available water resources in the state by requiring 100% of captured precipitation to be augmented, even though studies show a large percent does not contribute to the stream or aquifer system.
    - Colorado currently has two statutory laws that recognize not all precipitation contributes to stream flows and allows the use of historically consumed precipitation by native vegetation to offset evaporation augmentation requirements for streambed reservoirs and gravel pit ponds.

2. We recommend the water budget algorithms presented in Chapter 4 be the basis for determining the augmentation requirements for a water court application to capture and use precipitation, where:

    - Total daily precipitation is based on the nearest active representative climate station.
    - Runoff is determined on a daily basis using the SCS Curve Number Method.

- Native vegetation ET and sublimation is determined on a monthly basis, using the Modified Blaney-Criddle Method for the growing season and findings from the Greb study for the non-growing season.
- Deep percolation is determined on a monthly basis as the residual in the water balance equation: Deep Percolation = Total Precipitation – Runoff – Native Vegetation ET/Sublimation.
- Delayed ground water return flows are determined using an appropriate groundwater model such as the Glover Method for alluvial areas with a groundwater table and MODFLOW for areas outside the stream alluvium.

Other more detailed methods may also be appropriate where data are available.

3. Policy makers may want to consider first authorizing a pilot project to verify and/or calibrate the calculated results from the recommended algorithms above. The pilot project could be used to work out many of the detail issues that may arise in a water court application to use rainwater harvesting. Variables such as rainfall intensity versus runoff and winter consumption are two potentially contentious issues that may be raised in a water court application. A pilot project would also provide an opportunity to evaluate how cisterns or other rainwater collection systems are constructed and operated.

4. We recommend Douglas County and other counties/municipalities consider approval of the algorithms in Chapter 5 for computing outdoor water demands, under various water conservation alternatives, in determining water supply requirements for new developments. For Douglas County, we recommend this be an approved methodology in the appeal process to using the standard minimum of 0.75 acre-feet per year per residence.

    - Decision makers at the County may want to first consider authorizing a pilot project be conducted to verify and/or calibrate the calculated results from the recommended algorithm in Chapter 5.
    - Alternatively, a safety factor, such as 10% to 20%, could be applied to calculated outdoor water demands, with residential data collected to verify and/or calibrate the calculated results from the recommended algorithm for future developments.

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Appendices

Appendix A – Summary of Previous Case Law

Southeastern Colorado Water Conservancy Dist. v. Shelton Farms, Inc., 529 P.2d 1321 (1974)

Facts

Shelton owned about five hundred acres of land on the Arkansas River. He cleared two land areas of phreatophytes and filled in a third marshy area; by doing this he claimed that approximately four hundred and forty-two acre-feet of water per year was now available for beneficial use. Shelton's plan was to use the water salvaged from phreatophyte eradication to augment his water rights for eight previously decreed wells. The lower court awarded Shelton 181.72 acre-feet of water, free from the call of the river in recognition of his activities that saved water that otherwise would have been taken from the river by the plants or evaporation.

The companion appellee to this case, Colorado-New Mexico Land, Co., Inc., received a similar award of 181 acre-feet of water free from the call of the river. The facts in this case differ only because there was no plan for augmentation.

Appellees claimed their actions provided maximum utilization of water, protected vested water rights, and encouraged conservation and waste reduction. They also argued that their actions did not injure any other water rights because the water they claimed was unavailable for use anyway.

Objectors asserted the decrees violated Colorado's appropriation doctrine of "first in time, first in right." Further, existing case law in Colorado limits the doctrine of 'free from call' to waters which are truly developed and were never part of the river system.

Holdings

- In Colorado, one who adds to an existing water supply is entitled to a decree affirming the use of such water. Strong evidence is required to prove the addition of the water. The court distinguishes between "developed" and "salvaged" water. The former is new water not previously part of the river system, that is, it is imported or nontributary water. The latter is tributary water made available for beneficial use through elimination of waste. Only developed water can be made the basis of a right independent of the priority system.

- Court agreed with objectors and ruled that the waters salvaged by the removal of phreatophytes were subject to call by prior appropriators. The phreatophytes were water thieves (they grew up after the most senior water rights were appropriated and had been stealing water from the river for decades) and the thirsty men cannot step into their shoes.

- Can't substitute priority doctrine with lack of injury doctrine.

- Court acknowledges this is a legislative issue. **"No one on any river would be adverse to a schematic and integrated system of developing this kind of water supply with control and balancing considerations. But to create such a scheme is the work of the legislature..."** (1327)

1975 Statutory Amendment

In 1975, shortly after *Shelton Farms*, the General Assembly revised the definition of "plan for augmentation" to affirm that neither the salvage of tributary waters by eradicating phreatophytes nor the increase of runoff by making land surfaces impermeable provides an increased supply of water that may be utilized to support a plan for augmentation. C.R.S. §37-92-103(9).

R.J.A. v. Water Users Ass'n of Dist No.6, 690 P.2d 823 (1984)

Facts

R.J.A. operates a summer resort business on property south of Estes Park, CO. The land originally included a twenty-seven-acre peat moss marsh which was approximately three thousand years old and comprised the headwaters of Tahosa Creek.

R.J.A. removed the peat moss, drained the marsh and converted it to a meadow. RJA then sought a developed water right outside of the priority system based on reducing the consumptive use of water formerly lost to evaporation in the marsh. R.J.A. argued that because peat bog pre-existed all water rights, there was not a water "thief" issue as there was in Shelton.

Holdings

- Lower Court's ruling denying claim for a water right was upheld.
- Reduction of consumptive use of tributary water cannot provide basis for a water right that is independent of the system of priorities on the stream.
- Court comes to same conclusion reached under *Shelton Farms*: that under prior case law no person has been granted a water right free from the call of the river for water which has always been tributary to a stream.
- Emphasis on environmental balancing: "the waters of Colorado belong to the people, but so does the land. There must be a balancing effect, and the elements of water and land must be used in harmony to the maximum feasible use of both."
- **Court reemphasized a legislative scheme that provides control and balance:** "The water rights sought here are based upon alterations of long existing physical characteristics of the land. Alteration of natural conditions and vegetation in order to save water carries with it the potential for adverse effects on soil and bank stabilization, soil productivity, wildlife habitat, fisheries production, water quality, watershed protection and the hydrologic cycle. Whether to recognize such rights, and thus to encourage innovative ways of reducing historical consumptive uses by modifying conditions found in nature, is a question fraught with important public policy considerations. As such, the question is especially suited for resolution through the legislative process." (828).

Giffen v. State, 690 P.2d 1244 (1984)

Facts

The applicant sought approval from the water court for a plan for augmentation that included a proposed developed water right. The applicant based his claim to a developed water right on a proposal to reduce water lost to the atmosphere by replacing trees on his property with less water-consumptive grasses. He again relied upon "old" vegetation to eliminate the water thief argument. The applicant's plan would have resulted in a net gain to the stream, so there was no injury to other water rights. The water court granted the objectors' motion for summary judgment and denied the applicant's request.

Holdings

- For reasons given in *R.J.A., Inc.*, reduction of consumptive use of tributary water cannot provide the basis for a water right that is independent of the system of priorities. Such reductions cannot be considered "development of new sources of water" as part of a plan for augmentation pursuant to C.R.S. § 37-92-103(9).
- Contrary to applicant's assertion, the water saved is clearly tributary ground water under the relevant statutes. Tributary ground water consists of "that water in the unconsolidated alluvial aquifer of sand, gravel, and any other sedimentary materials, and all other waters [under the surface] hydraulically connected thereto which can influence the rate or direction of movement of the water in that alluvial aquifer or natural stream." C.R.S. § 37-92-103(11).
- Applicant's argument that trees are not phreatophytes and that the legislature impliedly condoned removal of non-phreatophytes failed (court concluded that the legislature did not provide that a reduction in a consumptive use of tributary water by the removal of non-phreatophytic vegetation could have been a basis for a developed water right outside of the priority system).

State Engineer v. Castle Meadows, Inc., 856 P.2d 496 (1993)

Facts

The issue in these consolidated cases was whether other water rights will be injured by post-withdrawal stream depletions that will result from the applicants' pumping of not nontributary Denver aquifer groundwater. Castle Meadows obtained a decree in April of 1987, enabling it to make annual withdrawals of 2,990 acre-feet of not nontributary groundwater through its Denver aquifer wells provided Castle Meadows obtained judicial approval of an augmentation plan ensuring replacement of four percent of the amounts withdrawn annually pursuant to C.R.S. §37-90-137(9)(c).

In October of 1986, Castle Meadows filed an application in the district court seeking approval of such a plan. The district court determined the plan was sufficient and in December of 1988, entered a final judgment and decree entitling Castle Meadows to withdraw 2,990 acre-feet of Denver aquifer groundwater annually. However, this augmentation plan extended only to those years that water is actually pumped from the wells. Although, the court found that Castle Meadows withdrawals will have some continuing depletive effect on the tributary stream system after one hundred years, it did not require that water be replaced after withdrawals from the wells cease.

The State Engineer appealed contending that Castle Meadows' plan for augmentation did not satisfy §37-90-137 because it requires compensation be made for depletions accruing to a stream after ground water withdrawals cease. The case was remanded to consider whether pumping will cause injury. The water court found there would be post pumping depletions to the stream, but that those depletions would not be injurious because they would be offset by increased runoff attributable to urbanization (i.e., more impermeable surfaces and different plants).

Similarly, in the second case, Castle Pines sought an augmentation plan to replace depletions associated with pumping not nontributary Denver basin groundwater. The water court found that post-pumping depletions would be offset of the amounts of increased runoff attributable to urbanization. Thus, Castle Pines was not required to augment the stream system after withdrawals cease and it would satisfy its statutory obligation by replacing four percent of its annual withdrawals during the years in which water is withdrawn through the wells.

Applicants did not dispute that statute prevents use of runoff as a source of supply water for an augmentation plan. Rather, applicants say it was a factor in determining the overall impact of their pumping. The runoff was likened to a return flow that reduces the consumptive use of the withdrawn water and must be taken into account in assessing whether senior water rights will be injured.

Holdings

- Court said district court erred when it considered urban runoff as a factor in making determination that applicants need not include means of compensating for post-withdrawal stream depletions.

- It would contravene the purpose of the 1975 amendment to §37-92-103(9) to allow stream depletions to be offset by these anticipated increases in runoff with the result of circumventing the applicant's obligations to compensate holders of water rights for injuries that would otherwise occur.

- In C.R.S. § 37-92-102(1)(a), the legislature declared it is the policy of this state to integrate the appropriation, use, and administration of underground water tributary to a stream with the use of surface water in such a way as to maximize the beneficial use of all of the waters of this state. However, case law and the General Assembly have recognized that the countervailing interest of protection of vested rights must be given effect. Therefore, the goal of maximizing the use of our waters must sometimes yield to that interest and be implemented to ensure that water resources are utilized in harmony with the protection of other valuable state resources.

- Emphasis on legislative amendment of §37-92-103(9) prohibiting the removal of phreatophytes from constituting an augmentation plan. The fact that this amendment also prevents runoff water collected from land surfaces that have been made impermeable from serving as a source of augmentation means the legislature intended the analogous result of removing the incentive for persons to attempt to increase water supplies by replacing natural land conditions with impermeable surfaces.

Appendix B.1 – Monthly Precipitation Records for Kassler NOAA Climate Station (1950 through 2004)

```
Time Series Identifier  = 4452.NOAA.Precip.Month
Description             = KASSLER
Data source             = NOAA
Data type               = Precip
Data interval           = Month
Data units              = IN
Period                  = 1950-01 to 2004-12
Orig./Avail. period     = 1948-08 to 2006-03

Comments:
Station and time series information from HydroBase determined at time of query:
Time series identifier         = 4452.NOAA.Precip.Month
Description                    = KASSLER
Data source                    = NOAA
Data type                      = Precip
Data interval                  = Month
Data units                     = IN
HydroBase query period         = Query All
HydroBase available period     = 1948 to 2006
Located in water div, district = 1, 8
Located in county, state       = JEFFERSON, CO
Located in HUC                 = 10190002
Latitude, longitude            =   39.483334, -105.099998
Drainage area                  = NA
Non-natural contributing area  = NA
Elevation                      = 5586.94 FT
```

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1950	0.91	0.95	0.80	3.46	4.08	1.12	0.83	0.35	0.84	0.32	1.60	0.11	15.37
1951	0.84	1.25	1.82	1.43	2.10	1.81	2.49	1.90	0.69	1.66	1.02	0.14	17.15
1952	0.00	0.47	1.77	3.49	3.84	0.04	0.93	0.92	0.18	0.09	1.18	0.45	13.36
1953	0.47	1.16	1.51	1.86	2.92	1.16	2.08	0.94	0.10	0.35	0.51	1.51	14.57
1954	0.35	0.50	1.03	0.95	1.12	0.25	2.76	1.19	1.82	0.14	0.89	0.58	11.58
1955	0.22	1.02	1.25	1.27	6.27	1.45	2.48	3.35	0.89	0.46	0.36	0.18	19.20
1956	0.44	0.93	0.99	0.95	2.03	0.35	1.36	1.60	0.00	0.58	0.89	0.56	10.68
1957	0.40	0.58	0.96	4.10	5.46	2.28	1.47	0.89	0.93	2.22	1.14	0.16	20.59
1958	0.69	0.69	1.59	2.29	3.19	1.94	2.86	0.85	1.54	0.56	0.68	0.40	17.28
1959	1.35	1.01	2.81	1.89	3.10	1.39	0.60	0.93	2.66	2.93	0.71	0.56	19.94
1960	0.59	2.57	0.83	1.48	2.70	0.55	0.53	0.38	0.50	3.33	0.40	1.66	15.52
1961	0.27	1.15	2.01	1.23	3.41	1.46	2.66	1.73	5.15	0.84	1.41	0.26	21.58
1962	1.17	1.00	0.62	2.82	0.73	1.97	0.94	0.64	0.59	0.05	0.92	0.26	11.71
1963	0.72	0.36	1.24	0.04	0.97	2.71	0.51	2.39	1.59	0.66	0.74	0.97	12.90
1964	0.36	1.36	1.78	0.93	2.33	1.26	0.49	1.68	0.87	0.13	0.99	0.67	12.85
1965	0.85	1.18	2.00	2.30	1.27	4.05	3.94	2.61	2.95	0.42	0.43	0.64	22.64
1966	0.30	1.27	0.57	1.54	0.62	1.65	1.84	1.09	1.67	1.95	0.67	0.12	13.29

1967	0.72	0.65	0.58	3.70	4.22	4.06	2.45	1.32	1.56	1.91	1.25	1.41	23.83
1968	0.48	1.28	1.00	2.45	1.66	0.32	1.44	1.61	1.02	1.47	1.23	0.49	14.45
1969	0.31	0.36	1.47	0.64	9.64	3.51	1.76	1.64	0.25	6.49	1.04	1.00	28.11
1970	0.28	0.12	3.26	1.38	1.82	2.37	1.76	0.42	2.59	1.54	2.33	0.03	17.90
1971	0.39	1.45	0.90	4.56	2.76	0.79	1.07	0.82	3.31	0.67	0.43	0.38	17.53
1972	0.76	0.74	0.92	1.92	1.92	1.97	1.20	1.86	0.79	0.41	3.48	1.14	17.11
1973	1.44	0.13	2.23	4.23	7.96	0.39	1.57	0.10	3.12	1.31	0.63	2.00	25.11
1974	1.46	1.07	1.28	1.87	0.24	1.86	0.83	0.33	1.38	1.95	1.13	0.91	14.31
1975	0.42	0.61	0.82	1.70	3.38	2.46	0.82	1.87	1.09	0.73	2.31	0.15	16.36
1976	0.53	0.09	1.63	1.56	1.19	1.15	5.05	1.87	2.90	1.57	0.22	0.76	18.52
1977	0.15	0.51	0.71	2.66	0.58	1.68	4.31	1.75	0.07	0.60	0.88	0.38	14.28
1978	0.32	0.56	1.94	2.46	4.22	0.98	0.46	0.21	0.38	1.80	0.38	1.40	15.11
1979	0.84	0.39	3.27	1.91	4.45	2.72	0.66	2.75	0.63	1.39	1.79	1.20	22.00
1980	0.54	0.40	1.44	2.06	3.65	0.00	2.01	1.57	1.23	0.17	1.04	0.04	14.15
1981	0.02	0.59	2.25	0.72	3.55	0.84	1.81	1.13	0.58	1.51	0.49	0.85	14.34
1982	0.30	0.32	0.54	0.56	3.77	2.06	1.06	3.44	2.38	1.26	0.38	1.05	17.12
1983	0.19	0.17	5.64	2.30	3.60	3.82	2.21	1.48	0.22	0.08	3.24	0.87	23.82
1984	0.28	1.18	2.17	2.61	0.82	0.79	2.53	4.86	0.91	5.98	0.54	0.34	23.01
1985	0.52	0.87	1.06	2.70	1.56	1.54	2.37	0.62	2.87	0.44	1.98	0.72	17.25
1986	0.32	0.66	0.80	3.39	2.70	1.60	0.52	0.37	0.70	2.24	1.81	1.43	16.54
1987	1.65	1.80	1.39	1.52	4.85	2.51	0.90	2.29	0.31	1.99	2.43	2.14	23.78
1988	0.35	0.77	1.15	1.10	3.80	1.23	0.88	2.52	1.41	0.07	0.62	1.05	14.95
1989	0.75	0.47	0.74	1.49	2.92	2.92	1.50	1.10	2.19	1.24	0.05	0.97	16.34
1990	0.52	0.38	3.12	1.63	1.65	0.53	2.71	1.13	1.45	0.97	1.40	0.17	15.66
1991	0.77	0.10	0.37	1.58	3.76	2.86	2.74	1.81	0.71	0.99	3.37	0.00	19.06
1992	0.97	0.02	3.35	0.52	1.82	1.61	0.87	3.22	0.05	0.25	1.98	1.08	15.74
1993	0.34	0.77	1.20	2.71	2.20	2.13	0.56	1.01	2.68	2.77	1.44	0.36	18.17
1994	0.42	0.70	2.06	2.57	1.79	2.06	0.76	0.45	1.23	1.06	1.69	0.42	15.21
1995	0.39	0.61	1.99	4.73	5.50	2.70	0.72	1.40	2.69	0.50	0.87	0.16	22.26
1996	1.17	0.20	1.66	1.22	3.32	1.01	0.80	2.08	3.67	0.76	0.87	0.24	17.00
1997	0.37	1.30	0.69	3.77	0.74	2.21	1.59	3.35	2.82	3.27	1.53	1.16	22.80
1998	0.36	0.07	2.70	3.29	0.61	1.67	2.75	1.61	0.52	0.99	1.46	0.66	16.69
1999	0.35	0.32	0.44	6.10	2.79	1.15	1.54	3.88	0.90	0.77	0.48	1.48	20.20
2000	0.80	0.21	1.78	1.49	3.27	1.44	1.04	3.02	2.48	0.52	0.96	0.45	17.46
2001	0.38	0.74	0.64	1.46	3.88	1.21	0.99	2.21	1.66	0.23	1.12	0.64	15.16
2002	0.69	0.13	1.00	0.10	1.79	1.38	3.07	0.75	1.27	1.30	0.31	0.07	11.86
2003	0.18	1.16	7.52	1.38	1.06	1.94	0.41	1.20	0.44	0.36	0.44	0.67	16.76
2004	0.80	1.09	1.01	4.64	1.07	5.54	1.65	2.64	0.86	1.66	1.91	0.63	23.50

Notes:
Years shown are calendar years.
Annual values and statistics are computed only on non-missing data.
NC indicates that a value is not computed because of missing data or the data value itself is missing.

Appendix B.2 – Monthly Runoff Estimates in Inches, Summarized from Daily Runoff Analysis

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1950	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.03**
1951	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
1952	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.01**
1953	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
1954	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
1955	0.00	0.00	0.00	0.00	0.80	0.00	0.03	0.01	0.00	0.00	0.00	0.00	**0.85**
1956	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
1957	0.00	0.00	0.00	0.16	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.26**
1958	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
1959	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.03	0.09	0.00	0.00	**0.13**
1960	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	**0.06**
1961	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	**0.07**
1962	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
1963	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	**0.03**
1964	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
1965	0.00	0.00	0.00	0.00	0.00	0.06	0.06	0.03	0.00	0.00	0.00	0.00	**0.15**
1966	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	**0.03**
1967	0.00	0.00	0.00	0.30	0.03	0.02	0.00	0.00	0.00	0.00	0.00	0.00	**0.36**
1968	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
1969	0.00	0.00	0.00	0.00	3.30	0.00	0.00	0.00	0.00	0.02	0.09	0.00	**3.41**
1970	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.03	0.00	0.01	0.00	**0.06**
1971	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	**0.10**
1972	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	**0.04**
1973	0.00	0.00	0.00	0.00	0.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.48**
1974	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
1975	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	**0.01**
1976	0.00	0.00	0.00	0.00	0.00	0.00	0.26	0.00	0.00	0.00	0.00	0.00	**0.26**
1977	0.00	0.00	0.00	0.00	0.00	0.00	1.05	0.00	0.00	0.00	0.00	0.00	**1.05**
1978	0.00	0.00	0.00	0.00	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.14**
1979	0.00	0.00	0.08	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	**0.16**
1980	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
1981	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
1982	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.07	0.00	0.00	0.00	0.00	**0.08**
1983	0.00	0.00	0.98	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.03	0.00	**1.03**
1984	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	**0.07**
1985	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
1986	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.17**
1987	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.19	**0.39**
1988	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.01	0.00	0.00	0.00	0.00	**0.11**
1989	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
1990	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
1991	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	**0.30**
1992	0.00	0.00	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.14**
1993	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
1994	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
1995	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.16**
1996	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.01**
1997	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.26	0.00	0.00	**0.26**
1998	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
1999	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.00	0.00	0.00	0.00	**0.18**
2000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
2001	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
2002	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
2003	0.00	0.00	3.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**3.97**
2004	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.04	0.00	0.00	0.00	0.00	**0.14**

Appendix C – Summary of Monthly Water Budget Under Pre-Developed Conditions

Total Precipitation	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total
Study Period Average	Average	10.6	14.8	31.6	39.5	52.7	34.3	30.6	30.8	27.0	24.7	21.8	12.9	331.5
Min Year	1956	8.4	17.8	18.9	18.2	38.8	6.7	26.0	30.6	0.0	11.1	17.0	10.7	204.3
Max Year	1969	5.9	6.9	28.1	12.2	184.4	67.1	33.7	31.4	4.8	124.2	19.9	19.1	537.8

Runoff	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total
Study Period Average	Average	0.0	0.0	1.9	0.3	1.7	0.1	0.5	0.1	0.1	0.2	0.1	0.1	5.2
Min Year	1956	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Max Year	1969	0.0	0.0	0.0	0.0	63.2	0.0	0.0	0.0	0.0	0.4	1.7	0.0	65.3

Potential Native Vegetation CU	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total
Study Period Average	Average	0.0	0.0	0.0	37.9	78.1	117.4	147.3	126.9	81.0	41.6	0.0	0.0	630.2
Min Year	1956	0.0	0.0	0.0	43.8	95.3	147.6	146.5	127.4	94.6	55.3	0.0	0.0	710.5
Max Year	1969	0.0	0.0	0.0	53.5	86.5	95.0	151.7	136.4	90.4	15.4	0.0	0.0	629.0

Actual Native Vegetation CU	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total
Study Period Average	Average	0.0	0.0	0.0	35.9	66.3	55.6	35.0	30.8	26.3	18.9	0.0	0.0	268.8
Min Year	1956	0.0	0.0	0.0	39.3	38.8	6.7	26.0	30.6	0.0	11.1	0.0	0.0	152.5
Max Year	1969	0.0	0.0	0.0	40.3	86.5	95.0	40.5	31.4	4.8	15.4	0.0	0.0	313.9

Winter Evaporation/Sublimation	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total
Study Period Average	Average	6.6	9.2	17.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.4	7.9	54.7
Min Year	1956	5.2	11.0	11.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.6	6.6	45.2
Max Year	1969	3.7	4.3	17.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.6	11.9	47.9

Unlagged Deep Percolation	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total
Study Period Average	Average	0.0	0.1	0.6	0.6	1.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	2.7
Min Year	1956	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Max Year	1969	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	7.6	7.3	15.6

Augmentation Requirement = Runoff + Lagged Deep Percolation	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total
Study Period Average	Average	0.2	0.2	2.2	0.5	2.0	0.3	0.8	0.3	0.3	0.4	0.4	0.3	7.9
Min Year	1956	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Max Year	1969	1.3	1.3	1.3	1.3	64.5	1.3	1.3	1.3	1.3	1.7	3.0	1.3	80.9

Change in Soil Moisture	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total
Study Period Average	Average	4.01	5.53	11.38	2.63	-16.42	-21.37	-4.96	0.00	0.67	5.61	8.14	4.77	0.00
Min Year	1956	3.20	6.76	7.20	-21.08	0.00	0.00	0.00	0.00	0.00	0.00	6.47	4.07	6.62
Max Year	1969	2.25	2.62	10.69	-28.06	34.69	-27.89	-6.80	0.00	0.00	107.58	0.00	0.00	95.07

Notes: 230 acres = 1,000 (sq-ft) / 43,560 (sq-ft/acre) * 10,000 single family homes
All Values in Acre-Feet
Change in Soil Moisture = 0 for overall period; individual years may vary

Appendix D – Irrigated Area Calculation

D.1 Lot Size Review

This appendix includes development information for the Highlands Ranch, Roxborough Park, Roxborough Village, and The Meadows from the Douglas County demographer, Ms. Nancy Gedeon. These communities are all located in the northwest portion of Douglas County. The communities' density serve as a way to bound the lot density of 5 units per acre used for the study area. A summary of the densities are below.

Table D.1 – Community Density

Community	Density (units per acre)
Highlands Ranch	5.39
Roxborough Park	2.91
Roxborough Village	5.79
The Meadows	6.61

D.2 Irrigated Area Calculation

The lot area calculation for the study lot size of 5 units per area is included in this appendix. The lot area is calculated as a gross area and a net area. The net area is gross lot area reduced by 20% for roads. The calculation also calculates the irrigated area of the lot assuming 50% of the net lot area is available for landscaping.

Appendix E – Landscape Water Usage Estimates

E.1 Landscape Estimate Water Usage

Attached is the cover sheet and Appendix E from Green Industry Best Management Practices, May 2004. Appendix E provides a water usage estimate for plants based on a survey from horticulturists from around the Rocky Mountain Region. The landscape is divided into plant type and water usage. The categories for the landscape and water usage are summarized below.

Table E.1 – Planting Water Usage

Estimated Water Usage	Percentage of Reference ET
Very Low	<25%
Low	25-50%
Medium	50-75%
High	>75%

Table E.2 – Landscape Choices

1	Annual
2	Perennial
3	Tree
4	Vine
5	Ground Cover
6	Shrub
7	Turf

Appendix F – Water Demand Calculation

F.1 Water Demand Calculation

The water coefficients identified in Section 5.1 are summarized on the attached calculation. The base scenario for the Water Demand Calculation Algorithm is included to calculate the total water demand of 0.35 acre-feet per year for the base scenario. The coefficients for the base scenario and the algorithm equation are below.

Table F.1 – Traditional Landscape Outdoor Water Demand Scenario

	Coefficient	Sub Coefficient	Coefficient Description
1	Irrigated Area	Turf Irrigated Area	2,000 square feet
		Planting Irrigated Area	1,500 square feet
2	Landscaping	Turf	Bluegrass with Reference ET of 90%
		Planting	Traditional with Reference ET of 70%
3	System Performance	Application Method	Spray with an efficiency of 75%
		Operations Method	Good with an efficiency of 80%
4	Water Management	Technology	None used

F.2 Water Demand Calculation Algorithm

$$\textbf{Total Landscape Demand} = \textbf{Turf Demand + Plantings Demand}$$

$$\textbf{Turf Demand} = \frac{\textbf{[(Reference ET X Turf Coefficient) – Water Management]}}{\textbf{System Performance}}$$

$$\textbf{Planting Demand} = \frac{\textbf{[(Reference ET X Planting Coefficient) – Water Management]}}{\textbf{System Performance}}$$

Appendix G – Water Demand Sensitivity Analysis

G.1 Sensitivity Analysis of Water Demand Coefficients

This appendix identifies the sensitivity analysis for the water demand coefficients. The base scenario presented in Appendix C is used for the starting point of the analysis. An individual coefficient was varied while the remaining coefficients were held constant. Below is a summary of the water savings by coefficient.

Irrigated Area – A 57% reduction in water demand, from 0.35 acre-feet per year (ac-ft/yr) to 0.15 ac-ft/yr, when the landscape area was reduced. The turf area ranged from 2,000 square feet (sf) to 1,000 sf. The planting area ranged from 1,500 sf to 500 sf.

Landscaping – A 34% reduction in water demand, from 0.35 ac-ft/yr to 0.23 ac-ft/yr, when the landscape choices were reduced from bluegrass turf and traditional plantings to fescue turf and native plantings. The turf choices were bluegrass, fescue, and buffalograss. The planting categories were traditional, moderate, and native water usage. A 48% reduction in water demand is obtained from bluegrass turf and traditional plantings to buffalograss turf and native plantings. There is some question on whether this options would be marketable, so it was not considered.

System Performance – A 52% reduction in the water demand, from 0.46 ac-ft/yr to 0.22 ac-ft/yr, when the water application method was varied using spray, rotor, and subsurface drip irrigation. The water usage was highly influenced by the efficiency of the operation and maintenance excellent, good, or poor of the irrigation system.

Water Management – A 34% reduction in the water demand, from 0.35 ac-ft/yr to 0.23 ac-ft/yr, when the water management was used to adjust the water supply for the effective precipitation. Technology is used to adjust the watering cycles of the irrigation system using active, passive, or no technology.

Appendix H – Douglas County Water Demand Calculation

H.1 Douglas County Base Scenario

The attached slide and calculation (Attachment H) determine the outdoor water demand and lot size using the Douglas County water demand criteria of 0.75 acre-feet per year and the Water Demand Calculation Algorithm.

Appendix I.1 – Water Use Scenarios

I.1 Water Use Scenarios

The attached slide and calculations (Attachment I) determine the outdoor water demand using the Water Demand Calculation Algorithm.

Appendix I.2 – Moderate Conservation Example for New Residential Development

Total Precipitation	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total
Study Period Average	Average	1.4	1.6	5.7	7.5	7.0	4.9	3.7	5.5	5.3	3.3	2.9	1.6	50.5
Dry Year	2002	2.0	0.4	2.9	0.3	5.1	4.0	8.8	2.2	3.6	3.7	0.9	0.2	34.0
Wet Year	1999	1.0	0.9	1.3	17.5	8.0	3.3	4.4	11.1	2.6	2.2	1.4	4.2	58.0

Precipitation Captured	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total
Study Period Average	Average	1.2	1.4	4.2	6.4	6.0	4.2	3.2	4.6	4.5	2.8	2.5	1.4	42.3
Dry Year	2002	1.7	0.3	2.4	0.2	4.4	3.4	7.5	1.8	3.1	3.2	0.8	0.2	28.9
Wet Year	1999	0.9	0.8	1.1	14.9	6.8	2.8	3.8	9.5	2.2	1.9	1.2	3.6	49.3

Total Landscape Demand	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total
Study Period Average	Average	0.0	0.0	0.0	19.3	22.2	28.2	31.3	26.1	20.9	16.4	0.0	0.0	164.4
Dry Year	2002	0.0	0.0	0.0	25.6	21.9	30.7	30.9	25.9	20.3	13.7	0.0	0.0	169.0
Wet Year	1999	0.0	0.0	0.0	14.5	22.4	26.5	28.8	22.2	17.2	16.1	0.0	0.0	147.7

Total Landscape Demand Met by Precipitation	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total
Study Period Average	Average	0.0	0.0	0.0	14.0	7.4	5.3	3.2	4.7	4.6	2.2	0.0	0.0	41.4
Dry Year	2002	0.0	0.0	0.0	9.0	4.4	3.4	7.5	1.8	3.1	2.8	0.0	0.0	31.9
Wet Year	1999	0.0	0.0	0.0	14.5	15.1	2.8	3.1	10.1	2.2	1.9	0.0	0.0	49.7

Deficit Needing to be Made Up	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total
Study Period Average	Average	0.0	0.0	0.0	5.3	14.8	22.8	28.1	21.5	16.3	14.2	0.0	0.0	123.0
Dry Year	2002	0.0	0.0	0.0	16.7	17.5	27.3	23.4	24.1	17.2	10.9	0.0	0.0	137.1
Wet Year	1999	0.0	0.0	0.0	0.0	7.3	23.7	25.7	12.1	15.0	14.3	0.0	0.0	98.0

Notes: Moderate - 1500 sf of Low Maintenance Grass and 1000 sf of Low Maintenance Landscaping - 1,000 single family homes
All Values in Acre-Feet

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