Exploring the Role of Landscape Water Conservation and Efficiency in Meeting Colorado's Water Gap: Expected Benefits of Landscape Water Conservation Best Management Practices

2015 Update to GreenCO Literature Review

Prepared for
GreenCO

GreenCO
Green Industries of Colorado

Prepared by
Wright Water Engineers, Inc.
Northern Colorado Water Conservancy District
Aquacraft, Inc.

WWE WRIGHT WATER ENGINEERS, INC.
Northern Water
Aquacraft inc WATER ENGINEERING & MANAGEMENT

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Report Preparation

This report was prepared under funding provided by the Green Industries of Colorado (GreenCO) with project management provided by Brenda O'Brien, GreenCO Water Projects & BMP Outreach Manager, and Kristen Fefes, Executive Director of the Associated Landscape Contractors of Colorado (and GreenCO Board representative).

Report authors and reviewers include:

Jane Clary, Wright Water Engineers, Inc.
Patricia Flood, P.E., Wright Water Engineers, Inc.
Adam Kremers, P.E., Wright Water Engineers, Inc.
Bill DeOreo, P.E., Aquacraft Engineering
Mark Crookston, P.E., Northern Colorado Water Conservancy District
Brent Mecham, Irrigation Association (reviewer)

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Executive Summary

Colorado is facing a projected water supply gap that may exceed 500,000 acre-feet (AF) by 2050. A multi-faceted strategy is needed to meet to this gap, and urban landscape water conservation is part of the solution. From 2002-2008, GreenCO worked to develop a scientifically-based set of 39 best management practices (BMPs) for the Green Industry, summarizing practices that conserve (require less) water, increase irrigation efficiency, protect water quality, and support healthy, sustainable landscapes. Represented examples of these BMPs include: Xeriscape, water budgeting, soil amendment/ground preparation, various irrigation efficiency practices (e.g., design, installation, maintenance, technology), and landscape design and maintenance practices. While most agree that landscape water conservation opportunities are plentiful in urban landscapes, the magnitude of water savings achievable through various BMPs is not currently quantified in a manner that is consistently transferable or readily integrated into local watering guidelines, rules and regulations, Water Conservation Plans, Basin Implementation Plans, the State Water Plan, or various legislative House and Senate Bill initiatives.

To help convey the quantitative benefits of landscape BMPs, both within the industry and for water providers, GreenCO has undertaken two efforts to identify and synthesize data useful for quantifying water savings for BMPs. The first effort included a landscape water conservation literature review in 2009, which was funded by the Colorado Water Conservation Board. Because water savings in the literature were reported using a variety of methods and varying levels of site-related characteristics (metadata), additional work was recommended to "normalize" these data sets (i.e., translate to a common metric) for purposes of developing quantitative savings estimates. In 2015, GreenCO undertook a second effort to extract key data from the 2009 literature review studies and review additional literature to better quantify the benefits of landscape water conservation BMPs, as summarized in this report.

The original intent of this effort was to extract new landscape water conservation savings from the literature and normalize the varied findings reported in the literature to support quantitative estimates for various landscape BMPs. One of the challenges associated with interpretation and synthesis of landscape water conservation studies conducted for multiple purposes in various geographic locations and hydrologic conditions (e.g., wet year, dry year) is that the measures of performance are often not directly transferable. For example, a 50% savings of water during a wet year on the Front Range would overestimate the savings that would be expected during a dry year on the West Slope. In order to increase the transferability and comparability of study findings, additional steps must be taken to normalize study findings. Although such techniques to normalize data are available, adequate metadata (information about the study conditions) are needed to accomplish this task. Because the literature review indicated that limited empirical data were available, an expanded multipronged approach was developed to further the understanding of the potential water savings associated with various BMPs and to develop a better understanding of the role of landscape water conservation BMPs in meeting the state's water gap. These three complementary approaches were used:

1. Compile and normalize the findings of existing empirical data in the literature.

2. Complete engineering calculations to estimate net irrigation requirements for various landscape scenarios using a spreadsheet tool based on the Dual Kc Method described in the Food and Agricultural Organization Handbook 56 (FAO 56). This analysis was used to better quantify how landscape water needs change as BMP-related variables such as plant type, irrigation method and soil characteristics are altered.

3. Conduct macro-scale modeling for the South Platte Basin to estimate potential water demand reductions achievable under several outdoor water use scenarios. This effort was conducted by Aquacraft Engineering, utilizing an approach similar to the one used in the Water Research Foundation-sponsored Water Residential End Uses of Water Study 2 (REUWS2).

Although each of these exercises was primarily oriented to Front Range settings, similar exercises could be conducted for other basins in Colorado. All three of these exercises could continue to be refined based on new data, or other hypothetical scenarios.

Summary of Findings

As a result of the expanded literature review and modeling efforts, key findings supported by the analysis in this report include:

1. Both empirical data and modeling efforts demonstrate that landscape water conservation BMPs can provide significant water demand reductions, without sacrificing attractive, sustainable landscapes. The absolute magnitude of these reductions varies based on site-specific landscape conditions, climate and behavioral change. The primary practices evaluated in this report relate to Xeriscape, including (but not limited to) plant selection, irrigation practice and technology, soil amendment (to a limited extent), and improvements to irrigation systems in response to irrigation audits.

2. Simply reducing over-irrigation remains a significant opportunity for water savings. This practice can be implemented without costly retrofits of landscapes, although upgrades to irrigation systems and use of advanced irrigation technology will certainly support this objective. Water budgeting is a fundamental tool that can be used to educate property owners and landscape contractors about the irrigation requirements needed to maintain healthy landscapes. When targeting reduction in over-irrigation, recent studies by Denver Water and others show that many service areas include multiple irrigation user types: those who under-irrigate, those who practice sustainable irrigation practices and those who over-irrigate. Efforts to reduce over-irrigation and planning-level reduction targets should be targeted to the subset of customers who are over-irrigating. Modeling conducted by Aquacraft for this report shows that reducing over-irrigation by 20% for single family residential units and 10% for multi-family residential units could save nearly 86,560 AF of water in the South Platte Basin over a 40-year period.

3. Based on the expanded literature review, study characteristics and water savings data were extracted and compiled in a consistent format to facilitate normalization of expected water savings for various landscape BMPs. The lack of consistency in reporting of data in the literature significantly constrained this exercise. Nonetheless, quantitative ranges of savings in gallons per square foot (gpsf) were calculated for the Front Range for the following general practice groups:

    a. Conversion of Cool-Season Turf (e.g., Kentucky bluegrass) to Plants with Lower Irrigation Requirements: Converting cool-season turf areas to shrubs, ground covers and perennials is estimated to save 2.0 to 5.5 gpsf of landscape area. These savings increase to 5.9-11.5 gpsf if the replacement is with low-water xeric plants. Portions of lawns where such conversions may be particularly beneficial include steep slopes, narrow strips that are difficult to irrigate, and other areas where cool-season turf is difficult to efficiently maintain or is not providing aesthetic or functional benefits.

    b. Irrigation Efficiency Audits: Performing irrigation efficiency audits is estimated to save 1.3 to 3.3 gpsf when irrigation efficiency is improved in response to irrigation audits.

    c. Irrigation System Technology and Retrofits: Study designs vary substantially, making generalizations difficult. Examples of reported savings include 4.8 gpsf for replacing old irrigation systems and 3.3 gpsf for weather based irrigation controllers. Some studies have shown increases in irrigation use when manual watering is converted to automated irrigation or when advanced weather-based controllers are implemented. (In such cases, the baseline landscape conditions represent under-watering and the irrigation level is raised to meet the irrigation requirement of the plants.)

   Estimates were also calculated for Grand Junction, with the magnitude of savings (gpsf) generally greater on the West Slope due to higher ET (evapotranspiration) rates and lower precipitation.

4. A spreadsheet model (based on the Dual Kc Method described in FAO 56) was used to calculate the net irrigation requirements of various landscape scenarios, with results compared to two irrigated cool-season turf landscape scenarios. Key findings from this modeling exercise included:

    a. The lowest overall irrigation requirement achieved was for deep-rooted xeric plants, irrigated infrequently using drip irrigation, followed by more shallow rooted xeric ground covers. The ground cover scenario represents approximately 50 to 60 percent savings relative to the baseline turf scenarios. Deep-rooted xeric plants provided an additional 10 percent reduction in water requirement relative to more shallow rooted (6 inches) xeric plants. The root depth could be affected by choice of xeric plants, as well as by soil type.

b. For annuals, use of drip irrigation rather than spray irrigation resulted in approximately 10 percent less water requirement.

c. Warm-season turfgrass (e.g., Buffalograss) had lower water requirements than the other cool-season turfgrass scenarios except with regard to the scenario that represented use of soil amendment and irrigation management using a more advanced “manage allowable depletion” (MAD) approach for cool-season turfgrass. This analysis suggests that an aggressively managed cool-season turfgrass with proper soil amendment may achieve water savings comparable to or greater than warm-season turfgrass, depending on the management strategy implemented. This is an important finding because GreenCO and Colorado State University Turf Program both recommend that turf selection should be based on the desired functional, recreational and aesthetic benefits, in addition to considering maintenance and water requirements. For example, cool-season turfgrass is desirable for certain landscape purposes, such as for high use areas, whereas warm-season Buffalograss has lower traffic tolerance and may be more suitable for low-traffic areas.

d. For cool-season turfgrass (e.g., Kentucky bluegrass) management scenarios, the lowest water use resulted for the scenario represented by soil amendment and aggressively managed irrigation using a MAD approach, which typically requires advanced irrigation technology. (This is the same cool-season turf scenario described in c., above.) This scenario reduced the irrigation requirement by nearly 50% relative to the baseline turf scenarios under an average water year. This scenario approaches the water savings achieved by drip-irrigated annuals and is similar to warm-season turf. In summary, the irrigation management practice at a site is a critical factor in the irrigation requirement. This may represent a significant opportunity for savings on large landscapes or highly managed commercial landscapes, even if this is not directly transferable to the average homeowner.

5. The Dual Kc modeled results compare relatively well to the normalized empirical data from the literature with regard to plant selection, as shown in these examples for the Front Range:

   a. Xeriscape/Plant Selection--replacement of cool-season turf areas with shrubs, ground covers and perennials: Literature = 2.0 to 5.5 gpsf and Dual Kc Model =3.7 to 5.4 gpsf (average year).

   b. Xeriscape/Plant Selection--replacement of cool-season turf areas with xeric groundcovers and deep-rooted xeric plants: Literature = 5.9 to 11.5 gpsf and Dual Kc Model =8.5 to 12 gpsf (average year).

These results assume that portions of lawns replaced with plants with lower water requirements would be irrigated appropriately (according to hydrozones).

Study designs and site conditions were too variable to make this comparison for irrigation technology.

6. At a basin-scale, Aquacraft's modeling exercise demonstrated that landscape water conservation and efficiency measures can help to significantly reduce the water gap in Colorado. Three landscape-related conditions were evaluated that considered reductions in over-irrigation and effective irrigated area (scenarios including 10% and 25% reductions in irrigated area). Model results for the South Platte Basin indicate that reductions in over-irrigation and reducing effective irrigated landscape areas can play a significant role in filling the projected 2050 water gap, without eliminating or reducing the aesthetic quality of Colorado landscapes. Of the three landscape-related conservation scenarios evaluated, reduction in over-irrigation provided the most significant water savings, with essentially no impact to landscape quality (since this scenario simply reduces water waste). With regard to reduced effective irrigated area, there are multiple combinations of plant types that can be selected to achieve a 10 to 25 percent effective irrigated area reduction on individual landscape parcels, without drastically changing the character of Colorado's landscaped areas. However, implementing this type of change at a basin or state-wide scale would be challenging. The feasibility of implementation of the modeled scenarios would require additional input from water providers.

Recommendations

Many of the recommendations from GreenCO's 2009 Literature Review remain valid, with some additional recommendations emerging as a result of this 2015 study. These recommendations apply to state-led efforts, water providers and the Green Industry, with recommended actions including:

1. Support well-designed monitoring efforts that can be used to better quantify the expected benefits of landscape BMPs and that can be used to support modeling efforts based on empirically-derived relationships (real-world data). Overall, this analysis indicates that there are significant data gaps for empirical studies related to landscape water conservation, particularly studies that provide adequate metadata to normalize data sets to support broader planning objectives. Empirical studies are important because they can incorporate behavioral aspects of water conservation in a manner that agronomic models and theoretical calculations do not. Empirical studies can be used to develop better estimates of uncertainty in demand models and should continue to be conducted and funded.

2. Develop a set of standardized monitoring and reporting protocols for large-scale and site-specific landscape water conservation studies to increase transferability of study findings through better metadata reporting.

3. Assess interest in a statewide database to store conservation studies that follows a standard format noted in #2 above. Such a database would need to be kept as simple as possible to encourage participation and use. It may also be worthwhile to discuss pursuing

funding at a national scale from EPA and professional organizations, following a model similar to that used for stormwater BMPs (www.bmpdatabase.org).

4. Support efforts to implement separate metering of indoor and outdoor water use to refine estimates of outdoor water demand. Denver Water and others are implementing this practice in certain areas.

5. Analyze and evaluate House Bill 10-1051 data sets to develop a realistic baseline of outdoor water demand. Although residential single-family water demands have been characterized in several large-scale studies nationally and in Colorado, data for the multi-family properties and irrigation-only accounts is far less reliable and could be improved by obtaining better information on the multi-family sector and irrigated urban landscape areas.

6. Organize a large, systematic study of residential water use and landscape irrigation based on sampling from all of the large water providers in targeted basins such as the South Platte, similar to the end use studies in the Aquacraft models. This would be a major undertaking, but the work would provide a wealth of details on the parameters needed to make accurate predictions of water use, and would greatly improve the accuracy of the predictive tools. This would allow water demand projections and potential savings to be made in a more explicit and mathematically satisfying manner.

Conclusion

As Colorado works to meet the projected water gaps identified in the State Water Plan, the findings above should be considered in the development of sound water policy. This study further confirms that there are significant opportunities for landscape water conservation through the use and adoption of Best Management Practices, and it is possible to reduce outdoor water use and still enjoy the environmental and aesthetic benefits that the urban landscape provides.

1 Introduction and Purpose

Colorado is facing a projected water supply gap that may exceed 500,000 acre-feet (AF) by 2050 (CWCB 2015). A multi-faceted strategy is needed to meet this gap, and urban landscape water conservation is part of the solution. While most agree that landscape water conservation opportunities are plentiful, the magnitude of water conservation achievable through various practices is not currently quantified in a manner that is consistently transferable or readily integrated into local watering guidelines, rules and regulations, Water Conservation Plans, Basin Implementation Plans, the State Water Plan, or various legislative House and Senate Bill initiatives. The need for better quantitative landscape water conservation information for best management practices (BMPs) is evident. In 2009, GreenCO completed a review of landscape water conservation literature and provided a series of recommended steps needed to maximize use of this information in water conservation planning (WWE 2009). In 2010, Colorado WaterWise integrated GreenCO's work into the *Guidebook of Best Practices for Municipal Water Conservation* (Aquacraft 2010). Since then, various initiatives by local water providers, municipalities, Basin Roundtable efforts and the State Water Plan have continued moving forward, generally referencing potential water conservation opportunities associated with landscaping, but not scientifically quantifying the benefits of specific practices in detail.

To support GreenCO's efforts to further quantify the benefits of landscape water conservation BMPs, an expanded literature review has been completed, taking the next steps beyond GreenCO's 2009 literature review. Initially, the intention of this report was to extract new landscape water conservation savings (demand reduction) from the literature and normalize the varied findings reported in the literature to support quantitative estimates for various landscape BMPs. However, the limited available empirical data indicated that additional analysis approaches were needed to better address GreenCO's objectives. As a result, three approaches have been used in this report to further the understanding of the potential water savings associated with various BMPs, as well as develop a better understanding of the role of landscape water conservation BMPs in meeting the state's water gap. These approaches include: 1) compiling and normalizing the findings of existing empirical data in the literature, 2) conducting engineering calculations to better quantify how landscape water needs change as BMP-related variables are altered (better quantifying theoretical irrigation requirements), and 3) macro-scale modeling conducted for the South Platte Basin to estimate potential water demand reductions achievable under several outdoor water use scenarios.

This report is also intended to be useful in working toward the objectives of Colorado Senate Bill 14-07, which include:

1. Identification and quantification of the best practices to limit municipal outdoor water consumption that can be used, including by local governments, water suppliers, homeowners, real estate developers and landscaping contractors; and

2. Proposed legislation, if appropriate, to facilitate the implementation of those practices that are both reasonable and likely to result in measureable conservation of municipal water for outdoor purposes.

2 Colorado Water Plan: Role of Landscape Water Conservation

Concurrent to preparation of this report, the Colorado Water Conservation Board (CWCB) released the second draft of the Colorado Water Plan for public comment. The Colorado Water Plan identifies a >500,000 acre-foot (AF) water gap between municipal water supply and demand by 2050. The estimated gap is based on work completed through the State Water Supply Initiative (SWSI) in 2010, incorporating the efforts of the Basin Roundtables throughout the state.

The Water Plan identifies water challenges including the growing water supply gap, agricultural dry-up concerns, environmental concerns, effects of climate change, inefficient regulatory processes and increasing funding needs. The Water Plan is focused on "achieving the right balance of water resource management strategies" and "recognizes that water is important for all sectors and regions in Colorado and greatly affects livelihoods." The goals of the Water Plan are to "defend Colorado's compact entitlements, improve the regulatory processes, and explore financial incentives all while honoring Colorado's water values and ensuring that the state's most valuable resource is protected and available for generations to come."

The Water Plan covers many topics pertaining to water management in Colorado and establishes actions to address water challenges. Approaches advocated in the plan include advancing conservation, reuse, alternative agricultural transfers, and multi-purpose and collaborative projects. Water conservation is included as a key part of the solution to meet water demands. As quoted from SWSI 2010, Chapter 5 of the Water Plan states:

> "If water conservation is to be part of Colorado's future water supply portfolio, it must be supported and funded like other supply initiatives. To obtain the savings forecast in this report, the strategies described must be rigorously implemented at the state, regional, local, and customer level. Water is saved by municipal customers, but customers can be aided in the effort. State polices that promote conservation-oriented rates, water loss control measures, water efficient landscape and building standards, improved plumbing codes, and education and outreach set the stage for regional and local conservation program measures that target high demand customers and ensure new customers join the water system at a high level of efficiency."

The total potential savings from active water conservation in SWSI 2010 range from 160,000 to 461,000 acre-feet statewide in 2050. These savings are in addition to passive conservation savings estimated at 154,000 acre-feet as a result of natural replacement of fixtures and appliances. Active conservation savings depend on whether strategies are implemented at low, medium or high penetration levels and focus on reduction in residential indoor use, non-residential indoor use, landscape water use and utility water loss control. Landscape related efforts include: 1) targeted audits for high demand landscape customers, 2) landscape transformation of some high water requirement turf to low water requirement plantings and 3) irrigation efficiency improvements. Percentage reductions in water demand achieved through these actions at various penetration levels are targeted at 15% (low), 22-25% (medium) and 27-35% (high). The Water Plan also recognizes that additional technical analysis is needed to better inform the statewide discussion related to savings achieved through conservation.

Chapter 6 of the Water Plan focuses on conservation and is of particular relevance to the Green Industry. Seven key actions related to conservation identified by the Interbasin Compact Committee (IBCC) are summarized in Table 1.

Table 1. Draft Colorado Water Plan: Interbasin Compact Committee Potential Future Action Summary (Table 6.3.1-1 in Draft Water Plan)

Table 6.3.1-1: IBCC Potential Future Actions Summary
1. Improve Tracking and Quantification of Conservation
2. Establish a Statewide Conservation Goal with Intermittent Benchmarks a. Develop general political support for a statewide conservation goal b. Develop statewide agreement tying conservation to new supply development and agricultural transfers c. Support local entities in their efforts to outline and report their own approaches to help achieve the statewide goal. d. Explore best approach to implementation of standards to achieve goal e. Develop and implement conservation standards
3. Continue to Support Local Implementation of Best Practices a. Continue implementation of state conservation programs b. Encourage use of levels framework and best practices guidebook
4. Promote Enabling Conditions for Use of Conserved Water a. Maintain and develop storage and infrastructure for the use of conserved water b. Promote incentives for the use of conserved water c. Identify and, where possible, resolve legal and administrative barriers to the use of conserved water d. Identify and explore barriers to sharing conserved water
5. Develop New Incentives for Conservation a. Explore funding options in support of the Water Efficiency Grant Program b. Develop professional education and certification programs c. Develop new eligibility requirements for state grants and loans that include certain conservation levels or indications of commitment to conservation d. Develop conservation standards for communities planning to use agricultural transfers or new supplies for future water needs e. Develop incentives that incorporate the following concepts: encourage a base level of conservation; assess issues, benefits, and drawbacks of the current definition of "covered entities;" conservation water markets; small community support; permitting incentives
6. Explore Legislative Concepts and Develop Support a. Explore legislative options and support for indoor plumbing code standards b. Explore legislative options and support for outdoor water efficiency standards c. Engage in outreach and education efforts to explain the need for legislation; develop political support
7. Implement Education and Outreach Efforts a. Track public attitudes through baseline and ongoing surveys b. Develop statewide messaging and use focus groups to refine and guide implementation c. Develop decision-maker outreach strategies d. Pursue a coordinated media campaign

Conservation-related actions identified in Chapter 6 of the Water Plan are based on the Interbasin Compact Committee's (IBCC's) "No and Low Regrets Action Plan," the work of the Water Conservation Technical Advisory Group and the basin roundtables, and utility water conservation plans. Thirteen actions are identified in the Water Plan (paraphrased):

1. **Adopt conservation incentives**. Over the next two years, the CWCB will adopt policies stating that in order to achieve a state endorsement and financial assistance for water management projects, water providers must conduct comprehensive integrated water resource planning geared toward implementing the water conservation best practices at the "high" customer participation levels.

2. **Support foundational activities for all water providers**. The CWCB will continue to provide funding, technical support, and training workshops to assist water providers with managing their water systems better through techniques such as: water budgets, smart metering, comprehensive water loss management programs, savings tracking and estimating tools, and improved data collection on customer water uses.

3. **Recommend WaterSense specifications for outdoor irrigation technology**. Through a stakeholder process, the Department of Natural Resources (DNR) will work with the General Assembly to consider adopting WaterSense specifications for outdoor technology at the retail level.

4. **Explore incentives for outdoor water conservation measures**. As part of a broader funding strategy being developed over the next year, the CWCB will work with stakeholders to explore a tax credit program to incentivize retrofitting higher water-use landscapes with lower water-use landscapes and more efficient irrigation systems.

5. **Adopt a stretch goal**. Reduce projected 2050 demands by 400,000 acre feet through active conservation savings. Based on stakeholder work, the CWCB will adopt a "stretch goal" to encourage demand-side innovation that places Colorado at the conservation forefront in a thoughtful way that recognizes and addresses the impacts conservation carries. The CWCB will support a stakeholder process that examines various options, including options for local providers to establish targets consistent with the IBCC identified stretch goal, while giving appropriate credit for recent strides made in demand reduction.

6. **Water conservation education and outreach**. The CWCB will develop an education and outreach strategy that includes water conservation topics.

7. **Support local water smart ordinances**. Over the next two years, the CWCB will provide trainings that support local regulatory efforts that shape how new construction interacts with water use to accomplish local water conservation goals. For example, local jurisdictions could craft landscape and irrigation ordinances, tap fees that reflect actual water uses, education or certification of landscape professionals, green infrastructure ordinances, and more stringent green construction codes that include higher efficiency fixtures and appliances and water-wise landscapes.

8. **Evaluation of barriers to green building and infrastructure**. CWCB and Colorado Department of Public Health and Environment (CDPHE) will work together to determine which state agencies govern green infrastructure and buildings, identify barriers, and work with the appropriate agencies to adapt regulations to allow for graywater, green infrastructure, and other aspects of green developments.

9. **Strengthen Partnerships**. The CWCB will create or renew partnerships between the CWCB and [selected] groups to reach water conservation goals. These include: local water providers and local governments, intra-state government, the Green Industry, home building/construction, non-governmental organizations, academia and others.

10. **Explore expanding conservation funding**. Increase annual funding for the Water Efficiency Grant Program to $2,000,000 per year. In addition, the CWCB's loaning ability should be expanded to encompass conservation actions.

11. **Market for conserved consumptive use water**. The CWCB will investigate legal and administrative barriers to the use or sharing of conserved consumptive use water through a stakeholder process. If barriers can be addressed through acceptable legislative modification, the DNR will work with the Water Resources Review Committee to propose legislative action.

12. **Develop an alternative process for smaller entities to create water conservation plans and report water use data to the CWCB**. The CWCB will provide technical and financial support on this and will work to formalize this process into the CWCB Municipal Water Efficiency Guidance document.

13. **Continue implementation of state conservation programs.** This action includes several activities conducted by the CWCB related to water conservation plans and water efficiency grants.

Most of these actions generally align with GreenCO's strategic initiatives related to landscape water conservation (most notably actions 2-4 and 6-9). The on-going need for quantitative data and improved demand and conservation projects is emphasized in the Water Plan.

3 GreenCO's Landscape Water Conservation Efforts

GreenCO is both a stakeholder and a partner to help promote outdoor water conservation and efficiency, as well as overall protection of water resources. Green Industry professionals include those who grow and sell plants and equipment, those who design, install and maintain irrigation systems and landscapes, and those involved with managing golf courses and parks. GreenCO is committed to water conservation and industry-wide best management practices as a sustainable business model. Over the past 15 years, GreenCO has been working to raise the bar for water conservation and sustainable landscaping practices, particularly through development of BMPs and an industry-wide training program. The 2008 GreenCO BMPs are summarized below, along with a summary of GreenCO's 2009 literature review to provide an initial summary of the water conservation benefits of landscape BMPs.


Green Industry
Best Management Practices (BMPs)
for the Conservation and Protection
of Water Resources in Colorado:
Moving Toward Sustainability

Prepared for
The Green Industries of Colorado (GreenCO)
5290 E. Yale Circle, Suite 204
Denver, CO 80222

Prepared by
Wright Water Engineers, Inc.
2490 West 26th Avenue, Suite 100A
Denver, CO 80211

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3.1 2008 GreenCO Landscape BMPs

In 2008, the Colorado Water Conservation Board (CWCB) provided a grant to the Green Industries of Colorado (GreenCO) to update its landscape best management practices (BMP) manual titled "Green Industry Best Management Practices for the Conservation and Protection of Water Resources in Colorado – Moving Towards Sustainability." This manual provides information on 39 BMPs (see Table 2) that support landscape water conservation objectives; however, water conservation benefits of these practices are not quantified in the BMP Manual.

Table 2. Summary of GreenCO BMPs

General Category	GreenCO BMP Name	Brief BMP Description
Sustainability	Sustainable Landscaping	This BMP introduces basic sustainability and energy conservation concepts that Green Industry professionals can consider integrating into their professional practice.
Xeriscape	Xeriscape	Implement the seven basic landscape principles of Xeriscape: planning and design, soil improvement, zoning of plants, practical turf areas, efficient irrigation, mulching and maintenance.
Water Budgeting	Water Budgeting	Calculate the water needs of irrigated landscapes based on plant types, land area and irrigation system efficiency. Use the calculated water budget to apply water according to the needs of the plants and manage irrigation.
Design	Landscape Design	Plan and design landscaping comprehensively to conserve water and protect water quality.
Landscape Installation: General	Landscape Installation/Erosion and Sediment Control	Minimize erosion and control sediment leaving the construction site during landscape installation.
Soils	Soil Amendment/ Ground Preparation	Evaluate soil and improve, if necessary, to promote efficient water usage and healthy plants.
Trees	Tree Protection	Identify trees suitable for preservation and implement measures to protect these trees during construction activities.
Trees	Tree Placement in Urban Landscapes	Trees must be placed in the urban landscape so that adequate soil and space for root growth are provided for the long-term growth and health of the tree.
Trees	Tree Planting	Properly plant trees, shrubs and other woody plants to promote the long-term health of the tree.
Irrigation	Irrigation Efficiency	Properly design, install and maintain irrigation systems to ensure uniform and efficient distribution of water, thereby conserving water and protecting water resources.
Irrigation	Irrigation System Design	Design the irrigation system for the efficient and uniform distribution of water.
Irrigation	Irrigation System Installation	Install the irrigation system according to the irrigation design specifications, which should be in accordance with manufacturers' specifications, local code requirements and sound principles of efficient and uniform water distribution.
Irrigation	Irrigation System Maintenance	Maintain the irrigation system for optimum performance, ensuring efficient and uniform distribution of water. Modify the irrigation system as needed to provide supplemental water for maintaining healthy plants without wasting water.
Irrigation	Irrigation Efficiency Audits	Auditing existing irrigation systems to identify needed improvements is a key tool in reducing landscape water waste and improving irrigation efficiency.
Irrigation	Irrigation Technology and Scheduling	Irrigation systems can be equipped with a variety of water conserving devices such as soil moisture sensors, rain sensors and shutoff devices, weather stations, high wind shutoff devices, freeze protection devices, and advanced, automated, "Smart" control systems that incorporate evapotranspiration (ET) conditions.
Irrigation	Irrigation Using Nonpotable Sources	Nonpotable water may be used for irrigation purposes as a method to conserve potable or higher quality water sources for human consumption (drinking water).

General Category	GreenCO BMP Name	Brief BMP Description
Maintenance: General	Landscape Maintenance	Practice landscape maintenance appropriate for the site including practices such as pruning, weeding, mulching, fertilization and attention to the irrigation system.
Maintenance: Trees	Tree and Other Woody Plant Care	Properly plant and maintain prune or trim trees, shrubs and other woody plants to maximize the plants' health.
Maintenance: Herb. Plants	Herbaceous Plant Care	Properly plant and maintain herbaceous plants to maximize plant health and conserve water.
Maintenance: Turf	Turf Management	Plan, properly install and maintain practical turf areas.
Maintenance	Fertilizer Application	Properly apply fertilizers, based on the specific needs of plants, particularly as identified by appropriate soil or plant tissue tests.
Maintenance	Pesticide and Herbicide Application	Apply pesticides and herbicides at minimal levels in accordance with the label and targeted to specific disease and weed problems.
Maintenance	Pesticide, Fertilizer and Other Chemical Storage, Handling and Disposal	Pesticides, herbicides, fertilizers, fuel and other maintenance chemicals must be properly applied, stored, handled and disposed of to prevent contamination of surface water and groundwater.
Maintenance	Lawn Aeration	Aerate lawns to reduce thatch, thereby improving nutrient and water uptake, reducing runoff and reducing compaction.
Maintenance	Lawn Waste Disposal/Composting	Dispose of yard waste to minimize adverse impacts to the environment by keeping waste out of storm drains. Recycle and compost organic materials whenever possible.
Maintenance	Mowing	Mow lawns to the proper height and at the proper frequency to maintain turfgrass health, thereby minimizing the need for pesticide and fertilizer application and reducing water usage.
Maintenance	Mulching	Use organic mulches to reduce water loss through evaporation, to reduce soil loss due to exposure to wind and runoff, to suppress weeds, and to provide a more uniform soil temperature.
Maintenance	Drought and General Water Conservation Practices for Landscapes	Manage landscapes using the most water-efficient techniques during drought conditions.
Snow	Snow Removal	Snow removal practices should be conducted in a manner that minimizes adverse impacts to vegetation, soils and water quality.
Production	Production Practices for Nurseries, Greenhouses, and Sod Growers	Nurseries, greenhouses and other growers should implement a variety of source, structural, cultural and managerial controls to minimize pollution of water resources. Irrigation practices that minimize off-site transport of pollutants also typically conserve water.
Production	Water Management Practices for Nurseries, Greenhouses, Sod Growers and Holding Yards	Manage production and holding areas to promote the efficient use of water.
Retail	Retail Practices for Nurseries, Greenhouses and Garden Centers	Retail businesses should operate in a manner to maintain the health of plants, to conserve water and to promote water conservation and water resource protection to the general public.

General Category	GreenCO BMP Name	Brief BMP Description
Large Landscapes	Park, Golf Course and Other Large Landscape Design and Management	Large landscaped areas such as parks and golf courses should be well designed and properly managed to be an environmental amenity and to minimize runoff to waterbodies.
Drainage	Landscape Features in Low Impact Development	Properly design, install and maintain landscape features serving stormwater runoff water quality treatment and volume reduction functions. Low Impact Development (LID) designs seek to approximate pre-development runoff hydrology by allowing storm runoff to infiltrate into the landscape rather than routing urban runoff directly into the storm sewer.
Drainage	Revegetation of Drainageways	Establishment of a robust cover of vegetation is critical to the proper functioning of engineered drainage structures.
Drainage	Riparian Buffer Preservation	Preserve wide, undisturbed natural riparian areas along streams.
Education	Employee Education	Educate industry employees on water quality and water conservation practices.
Education	Public Education	Model and teach water conservation and water pollution prevention to the general public and consumers of green industry products.
Education	Regulatory Awareness	Green industry professionals should be aware of relevant federal, state and local regulations and comply with their requirements.

3.2 2009 GreenCO Literature Review: Summary of Findings

In 2009, the Colorado Water Conservation Board (CWCB) provided a grant to GreenCO to complete a literature review ("2009 GreenCO Literature Review"). The goals of the 2009 GreenCO Literature Review (WWE 2009) included:

- Identify literature potentially useful in quantifying the water conservation benefits associated with various landscape BMPs.
- Assess usefulness of literature in developing a range of quantitative estimates for various practices under a given set of conditions.
- Summarize findings in a manner that is transferable to future Colorado Water Conservation Board (CWCB), GreenCO and local water provider projects.
- Determine whether available literature provides a reasonable basis for estimating water conservation benefits of various landscape practices and, if so, identify next steps in this process.

This project was intended as a fundamental step needed to bridge the gap between identified landscape water conservation BMPs (GreenCO and WWE 2008) and quantification of the benefits of these practices. This project provided a common base of information for use in future projects by CWCB, water utilities and GreenCO, as well as identified information gaps that should be included in future efforts and research.

The 2009 project approach included review of a variety of literature sources that described and identified landscape water conservation practices, with expected benefits of such practices quantified or estimated to various extents under varying site conditions. The first step in this project was to identify literature sources likely to provide quantitative water conservation data. "Literature" potentially includes the following information sources:

- Published academic research in peer-reviewed journals (e.g., American Water Works Association [AWWA] Journal, Colorado State University Extension) or text books.
- Published reports sponsored by independent organizations (e.g., U.S. Bureau of Reclamation, Irrigation Association, Northern Colorado Water Conservancy District, Western Resource Advocates, Center for ReSource Conservation).
- Published or unpublished data compiled and analyzed by water providers (in-state and out-of-state) and Green Industry professionals. Priority was given to water providers within Colorado, followed by those in semi-arid or arid neighboring states (e.g., New Mexico, Arizona, Utah, Nevada, California).
- Other "grey" literature including periodicals (e.g., Water Efficiency) and general website searches.

The key conclusions from the 2009 GreenCO Literature Review included:

1. A wide range of literature confirms that landscape water conservation can play a meaningful role in demand management to stretch limited water supplies. Specific practices documented with an initial base of information include: Xeriscape, irrigation audits, and irrigation technology. Much more information is currently available in several other states than in Colorado. The tabulated information [in Attachment 2 of the 2009 Literature Review], although imperfect, provides an additional resource for utilities developing conservation estimates for planning purposes. Statewide water supply planning efforts would be well-served to continue sponsoring and promoting studies <u>within</u> Colorado. Locally based studies are important due to both climate and social values influencing behavior.
2. A limitation of the compilation of data in the [2009] literature review is that it requires further processing to normalize the data in a manner that can be applied to utility or statewide landscape conservation projections. An important follow-up step to make the most use of this literature review would be to review site-specific studies reporting landscape savings in more detail, according to an established set of minimum reporting parameters that would enable some normalization of the data. More refined estimates of water conservation savings could potentially be developed from this process. It is clear from the available literature that expected savings would vary according to the distribution of users with existing high, moderate and low water usage categories within a service area.

3. Many of the literature sources reported cost data in terms of water savings, cost of implementation and return on investment. [This information is informally noted on the reporting forms in Attachment 3 of the 2009] literature review.] Further compilation and processing of this information is needed for it to be effectively used.

4. Information developed in other states in terms of volumes or percent savings is less transferable than their general conclusions confirming that water savings occurred when certain practices were implemented. For example, percent savings associated with replacing turf with desert landscaping, as is done in Arizona, Nevada and other arid states, are not directly transferable to the Front Range of Colorado, where landscaping associated with a plains ecosystem is more consistent with the natural environment. On the other hand, more arid portions of Colorado may be able to draw more directly upon experiences in such states. Rainfall, temperature and other climatological data could be further examined to normalize data from other arid and semi-arid locations. On a related note, significant climatic differences within Colorado reinforce the importance of the basin roundtable approach to statewide water supply planning (e.g., Denver has nearly twice the annual precipitation of Grand Junction and Alamosa; therefore, a one-size fits-all approach with regard to expected landscape water conservation is unlikely).

5. Estimating the magnitude of water savings through landscape conservation/efficiency measures is highly dependent on site-specific factors, some of which are physically based and others which are behaviorally based. Some literature exists documenting the relationship of both types of factors into predictive models to estimate water conservation. Additional research is needed in these areas. This relates directly to the SWSI II debate regarding extent of penetration of conservation measures.

6. Development of a standard set of reporting and performance assessment protocols for landscape water conservation studies would enable collection of more meaningful data useful at a statewide level. These reporting protocols may need to be developed at both the macro (utility-wide) and micro (site-specific) scales. These protocols could also be used for reporting associated with Water Conservation Plans submitted to CWCB by covered entities. If such protocols were developed and accepted, development of a landscape conservation practice database could be developed that would be extremely valuable to developing a more refined assessment of landscape BMP performance.

7. Additional exploration of water conservation data tracked by Colorado utilities is needed and is a significant limitation of this literature review. Although data relating rebate programs to water savings was pursued from several water providers, this information was not successfully obtained. For covered entities, it would be expected that this information would be available under measurement and verification tasks specified in Water Conservation Plans. It is unclear whether: 1) the information exists,

but was not able to be provided within the short turn-around time of this project, 2) the information is being tracked, but water utilities are reluctant to release it due to billing privacy and other issues, or 3) the information is not being systematically tracked. This issue warrants further follow-up and discussion with the Colorado WaterWise Council members to develop a better understanding of these issues. Tracking this information should be "low-hanging fruit" in terms of assessing effectiveness of water conservation efforts in Colorado. Additional efforts to assess the type and extent of data potentially obtainable from Colorado utilities could be accomplished by additional follow-up interviews and possibly through review and assessment of the approved Water Conservation Plans.

8. Opportunities to fund studies of landscape water conservation practices should continue to be pursued in Colorado. Criteria for study designs should be developed to enable transferability of data to other utilities. Example studies from this literature review serving as a starting place include: YardX (Medina and Gumper 2004), California WBIC (Mayer et al. 2009), Kenney et al. (2008), Mecham and Boyd (2004), etc.

9. With regard to monitoring and evaluation needs for specific landscape conservation BMPs, it would be beneficial to monitor the following practices, following experimental design principles leading to statistically meaningful results:

    a. Continued monitoring of Xeriscape, particularly over the long-term. Follow-up with the YardX sites would be a logical starting point. (Sidenote: When the term Xeriscape is used, it is intended to reflect implementation of all seven principles, not simply "turf replacement.") There may be opportunity to conduct some neighborhood-based studies where similar demographics are present, but significant variation in landscape practices (e.g., Xeriscape retrofits) is present.

    b. Effectiveness of real-time water use technology that enhances customer knowledge and decision making related to water use. The Aurora Water Smart reader study is one such example. [Other technologies are also available.] These types of studies may be particularly beneficial in developing a better understanding of the behavioral/social component of water conservation.

    c. Weather-based irrigation controllers in Colorado (e.g., a Colorado-based "WBIC" study).

    d. Test plots of turf under various soil preparation scenarios (if it is confirmed that such research has not already been completed at CSU).

    e. Overall irrigation system retrofit performance (e.g., more examples similar to those developed by Keesen and Denver Parks and Recreation). This goes beyond ET controllers, which alone cannot correct existing irrigation system deficiencies. A starting point would be to document case studies already existing within utilities.

f. Effectiveness of landscape contractor education programs (e.g., Castle Rock model) and public education programs.

g. Continued socioeconomic/behavioral research with regard to landscape conservation practices and values is important, since this information affects the durability of landscape conservation savings and market penetration estimates. Several of the existing literature sources provide initial insights that could be further processed and evaluated, as a starting point.

h. Refinement of understanding of water usage patterns associated with varied irrigation approaches (e.g., hose, drip, automated) (recommended by Kenney et al. 2009).

10. Explore enhanced multi-disciplinary/interdepartmental dialogue to determine how landscape water conservation objectives may support other community goals related to sustainability, stormwater management and wastewater management. Although this is a somewhat vague recommendation, there appears to be untapped opportunity for better integration between multiple water disciplines. For example, communities pursuing Low Impact Development [Green Infrastructure] strategies or encouraging LEED certified developments may have synergistic opportunities providing multiple community benefits of reduced water use or water waste (runoff). For example, where preservation of natural areas/riparian buffers, preservation of undisturbed soils and mature trees, and use of bioretention (rain gardens) for stormwater management are objectives, these practices can positively reduce landscape irrigation requirements.

The 2009 report also included five recommended actions. This 2015 literature review addresses Recommendation #2.

1. Convene an advisory committee comprised of utilities and Green Industry representatives to review and refine the findings of this initial literature review and prioritize areas in need of follow-up.

2. Further process the data collected in this initial literature review into a more standardized format, normalizing data, if possible. Concurrently, provide additional follow-up in several areas of the literature review: 1) available utility landscape water conservation data, 2) horticultural literature sources, particularly related to turf and soils, and 3) more in-depth review of conservation-related conference proceedings over the past decade. (Although many studies were identified during the course of this literature review, more are known to be available, but excluded due to scope limitations.)

3. Develop a set of standardized monitoring and reporting protocols for large-scale and site-specific landscape water conservation studies.

4. Assess interest in a statewide database to store conservation studies (following a

standard format from #3 above). Such a database would need to be kept as simple as possible to encourage participation and use. It may also be worthwhile to discuss pursuing funding at a national scale from EPA and professional organizations, following a model similar to that used for stormwater BMPs.

5. Develop a pilot-scale GIS-based tool to better integrate landscape water conservation and land use/demographics. Potential benefits include targeting of rebate programs in areas of high water use, assessment of effectiveness of various conservation measures at the neighborhood scale and eventual development of a statewide model that could be useful for longer range planning.

Many of the conclusions and recommendations of the GreenCO (2009) literature review were affirmed in similar conclusions in a recent literature review by Alliance for Water Efficiency (2015).

4 2015 Update to Literature Review

This 2015 update to the 2009 GreenCO literature review include two general components: 1) updates to guidebooks, planning documents and key references, and 2) site-specific studies (or literature reviews by others) that quantify water savings resulting for landscape BMP implementation.

4.1 General Guidance and Planning Reports Released After 2009

Since 2009, several key guidance documents have been completed in Colorado that warrant brief summaries, in addition to the draft Colorado Water Plan (discussed in Section 2). These include the Colorado Best Practices Guidebook, the Municipal Water Efficiency Plan, and SWSI Conservation Levels Analysis. Additionally, House Bill 10-1051 provides a potential source of key information related to water demands, although this information is not yet publically available. Lastly, the Irrigation Association updated its handbook *Irrigation*, in 2011, providing up-to-date guidance on landscape irrigation practices that informed a 2014 update of the Irrigation Association's Landscape Irrigation Best Management Practices (IA and ASIC 2014). (Note: The descriptions provided in this section are very brief and are intended to provide a quick overview of information that may be pertinent to GreenCO's efforts related to landscape water conservation.)

4.1.1 Colorado Best Practices Guidebook

In 2010, Colorado WaterWise and Aquacraft completed the Colorado Best Practices Guidebook, which summarized best practices for both indoor and outdoor water conservation and efficiency for municipal and industrial water users. The landscaping portion of the guidebook incorporated GreenCO's work to date on landscape water conservation BMPs (GreenCO and WWE 2008; WWE and GreenCO 2009). In particular, Best Practice 9 focused on Water Efficient Design, Installation, and Maintenance for New and Existing Landscapes. With regard to landscape water conservation savings projections associated with Best Practice 9, the guidebook states:

- Range of Likely Water Savings: "Varies"
- "Water savings achievable…not well quantified. For some landscapes, on the order of 30-50%, but for others no net change or increase."

4.1.2 Municipal Water Efficiency Plan

In 2012, AMEC completed the Municipal Water Efficiency Plan for the CWCB. Municipal water efficiency landscape components included in this plan are summarized in Table 3. Most of the topics addressed in the Water Efficiency Plan were included in some form in the 2008 GreenCO BMP Manual.

Table 3. Municipal Water Efficiency Plan Landscape Components

Low Water Use Landscapes	Landscape Design/Installation Rules and Regulations
Drought Resistant Vegetation	Rules and Regulations for Landscape Design/Installation (BP 9)
Removal of Phreatophytes	Landscaper Training and Certification (BP8)
Irrigation Efficiency Evaluations/Outdoor Water Audits	Irrigation System Installer Training and Certification (BP 8)
Outdoor Irrigation Controllers	Soil Amendment Requirements (BP 9)
Irrigation Scheduling/Timing	Turf Restrictions (BP 9)
Rain Sensors	Irrigation Equipment Requirements
Residential Outdoor Meter Installations	Outdoor Water Audits/Irrigation Efficiency Regulations (BP10)
Xeriscape	Outdoor Green Building Construction (BP 8,9)
Other Low Water Use Landscapes	
Irrigation Equipment Retrofits	

4.1.3 SWSI Conservation Levels Analysis

In 2010, the Great Western Institute completed the SWSI Conservation Levels Analysis (2010), which identified potential opportunities for meeting "the 20% Gap" and states: "The majority of providers with water conservation plans have yet to implement meaningful water conservation programs." The overall goal of this SWSI Conservation Levels Analysis project was to re-assess the water conservation classification "levels" developed and used in SWSI I to estimate future water demand reductions associated with passive and active water conservation savings. The analysis included these tasks:

1. Collect and analyze data from past CWCB projects (including the Drought and Water Supply Assessment (DWSA) of 2004, the Colorado Drought and Water Supply Update (CDWSU) of 2007, and SWSI I and II) and from those Water Conservation Plans currently approved and on file with the OWCDP;

2. Analyze SWSI I water conservation level evaluations; and

3. Develop a new framework for evaluating and characterizing ongoing water conservation conducted by Colorado's water utilities and special districts.

Analyses were also performed to estimate the likely range of municipal water demand reductions expected as a result of current and future passive water conservation. Analyses of active conservation savings were beyond the scope of Great Western's analysis.

There are many findings presented in SWSI Conservation Levels Analysis, and the new framework for evaluating and characterizing ongoing water conservation is of particular interest. The framework includes measures and programs in the following four categories:

1. <u>Foundational Measures and Programs</u>: The foundational measures and programs are those that all water utilities and districts should have in place to support their operations by maintaining positive cash flow, limiting system wide leaks, and tracking those data that will allow the organization to understand and predict trends in customer water use. These measures include: 1) Leak Detection, 2) Tracking (e.g., through better metering and billing practices) and 3) Rates (e.g., inclining block rate structures).

2. <u>Ongoing Water Use Measures and Programs</u>—the three levels include:

- Level 1: Water demand reductions by the water utility at its own facilities.
- Level 2: Collect information characterizing customer water use – focusing on the utility's largest water users.
- Level 3: Commit resources to assist customers in their water demand management (e.g., customer rebate and incentive programs, as well as different types of technical support for targeted groups and populations).

3. <u>Ordinances and Regulations</u>—the three levels include:

- Level 1: Water waste ordinances, cooling tower single use prohibitions.
- Level 2: New construction controls related to obtaining water taps (e.g., landscaper certification requirements, soil amendment requirements, irrigated turf restrictions, indoor fixture and appliance requirements, etc.).
- Level 3: Existing construction controls related to point of sales compliance (through bank loan programs).

4. <u>Educational Efforts</u>—the three levels include:

- Level 1: Bill stuffers, mass mailings, web pages, Xeriscape demonstration gardens.

- Level 2: Water fairs, interactive websites, K-12 teacher and classroom education. programs.
- Level 3: Focus groups, customer surveys, citizen advisory boards.

Additionally, the report provides quantitative passive savings estimates by basin for 2030 and 2050. These passive savings estimates are important because they help to bracket the remaining gap that will need to be filled by other means (such as urban landscape water conservation and other active conservation practices). The statewide estimate for passive savings by 2050 ranged from 125,000 to 212,000 AF. The largest potential savings estimate is for the South Platte Basin, with passive savings estimates ranging from 86,000 to 146,000 by 2050 (Great Western 2010).

4.1.4 Colorado House Bill 10-1051 and Municipal Water Use Data

In 2010, the Colorado General Assembly adopted House Bill 10-1051 which requires covered entities (retail water providers who sell 2,000 acre feet or more of water annually) to report, on an annual basis, water use and conservation data to be used for statewide water supply planning. The bill directed the CWCB to adopt guidelines regarding the reporting of water use and conservation data by covered entities (Guidelines), and to report to the legislature regarding the Guidelines. The reporting Guidelines include clear descriptions of customer categories, uses, and measurements; how the Guidelines will be implemented; and how data will be reported to the Board. The first data submittal requirement was June 30, 2014. The guidelines (CWCB 2011) state:

> All water use and conservation data reporting under these Guidelines will become public record and will be available to the public through the CWCB website. The reporting under Section 37-60-126(4.5), C.R.S. does not take the place of local conservation planning or plans that must be submitted per Section 37-60-126(2), C.R.S. These data will be used for general statewide water supply planning per Section 37-60-126(4.5(a), C.R.S. These Guidelines shall be reviewed and updated as necessary.

Although data can be submitted through an on-line portal, data cannot currently be retrieved from this portal (http://www.cowaterefficiency.com/unauthenticated_home). The submitted water use information is intended to be publically available and was requested from CWCB to support this project; however, the data were not yet in form suitable for public release in accordance a stipulation in the bill that does not allow for release of reports from individual water providers (Personal Communication with Kevin Reidy, CWCB, May 6, 2015). (Note: Once data become publically available, it may be feasible to update some of the information in this report using this information, particularly with regard to model scenarios in Section 8.)

4.1.5 Irrigation, 6th Edition and IA 2014 Landscape Irrigation BMPs

The Irrigation Association completed a major update to its book, *Irrigation*, releasing the sixth edition in 2011 (Stetson and Mecham 2011). This 1089-page reference provides 30 chapters with in-depth information on irrigation-related topics. Selected chapters of interest for purposes of urban landscape water conservation and the Green Industry include:

- Irrigation Planning, Site Evaluation and Design
- Irrigation Water Requirements
- Irrigation Scheduling
- Performance Audits
- Sprinkler Fundamentals
- Microirrigation System Fundamentals
- Conservation and Environmental Protection
- Residential and Commercial Irrigation Systems
- Greenhouse and Nursery Irrigation Requirements
- Landscape Applications of Micro-irrigation
- Golf Course Irrigation Systems
- Turf and Landscape Irrigation Installation

In 2014, the Irrigation Association and the American Society of Irrigation Consultants updated their manual titled *Landscape Irrigation Best Management Practices*. These BMPs are intended to help key stakeholders (policy makers, water purveyors, designers, installation and maintenance contractors, and consumers) develop and implement appropriate codes and standards for effective water stewardship in the landscape. The manual includes three landscape irrigation BMPs: BMP 1: Design the Irrigation System for Water Use Efficiency, BMP 2: Install the Irrigation System to Meet the Design Criteria, and BMP 3: Manage Landscape Water Resources. The manual also includes three practice guidelines (PGs): PG 1: Practice Guidelines for Designing an Irrigation System, PG 2: Practice Guideline for Installing an Irrigation System, and PG 3: Practice Guideline for Landscape Water Management. (Note: A previous version of this manual was used to develop the 2008 GreenCO BMPs related to irrigation.)

4.2 Recent Studies and Literature Reviews Characterizing Landscape Water Demand and Effectiveness of Landscape BMPs

Since completion of the 2009 GreenCO Literature Review, new monitoring studies and planning documents have been completed. Several of the key larger-scale studies are summarized below, with additional studies summarized in Appendix A.

4.2.1 Alliance for Water Efficiency (AWE) 2015 Literature Review

In 2014, the Alliance for Water Efficiency published the *AWE Outdoor Water Savings Research Initiative, Phase 1 – Analysis of Published Research* (Mayer et al. 2014). This report provided a review, analysis, and synthesis of published and pending research on outdoor water use and water savings. Table 4 summarizes the ranges of landscape water conservation savings identified in the AWE literature review.

Some of the key findings from the literature review included (quoted directly from Mayer et al. 2015):

- Outdoor water savings are achievable and can be significant. Numerous recent studies documented outdoor water savings from specific measures such as conservation oriented rates, xeriscape, or soil moisture sensors that reduced outdoor water use by 15 to 65% or more. The research shows that successful approaches to reducing outdoor water use are available and are in fact being implemented across the U.S.

- Quantifying water savings from outdoor programs and measures is challenging. Remarkably few studies quantify water savings from measures such as xeriscape or landscape contractor training and certification. Many studies that originally sought to measure water savings instead report "hypothetical" or modeled savings results because of data collection problems or climate variability.

- Reporting of outdoor water savings in research varies and there is a lack of geographic and climate variability in the research. Many studies report savings as a percentage, but the basis of the percentage is not consistent across all studies. Some studies reported savings in gallons per square foot of landscape impacted. Much of the urban landscape outdoor water savings research to date of real significance has been conducted in Florida, California, and Nevada. Except for Florida, outdoor water savings research east of the Mississippi is hard to come by.

- Cost savings are rarely documented. Water savings are documented in some good studies, but cost savings – from either the customer perspective or the utility perspective are documented in very few of the studies. If cost savings are documented, it is almost always based on water reductions only. Very few studies consider the time and maintenance costs associated with a landscape and how these may be impacted by the efficiency program.

- Standardized approaches and methods for measuring and evaluating outdoor water efficiency programs are needed. Work has begun on establishing conservation metrics, and robust methods for measuring changes in water use are available. Developing standardized approaches and performance indicators, similar to what has been accomplished for water loss control, could be highly beneficial for water utilities in measuring their progress.

The report also provides recommendations for research needs and concludes that practices with the most well developed performance information include: 1) Impact of water budget-based rates, and 2) Irrigation control technology including weather-based controllers and soil moisture sensors.

Table 4. AWE 2015 Literature Review Findings

Measure	Lower Bound of Water Savings	Higher Bound of Water Savings	Best Available Estimate of Water Savings*
Water budget-based rates	10 %	20%	18% (Barenklau et. al. 2013)
Mandatory drought irrigation restrictions	18%	56%	Varies by severity of restriction. More severe = more savings.
Voluntary drought irrigation restrictions	4%	12%	Varies.
Customized mailed home water use reports		5%	5% (Mitchell et. al. 2013)
Conservation education programs	2%	12%	Varies.
Florida-Friendly Landscaping	50%	76%	50% (Boyer, et. al. 2014)
Xeriscape rebates (NM)		33%	Varies (Price, et. al. 2014)
Xeriscape conversion (NV)	34 gpsf	60+ gpsf	55.8 gpsf savings (Sovocool, et. al. 2005)
Urban densification (MA)		5%	5% (Runfola, et. al.)
Natural and manufactured shade (Israel)		50%	50% (Shashua-Bar, et. al. 2009)
Soil moisture sensor-based control (FL)	24%	92%	65% (Haley, et. al. 2012)
Residential weather-based control (CA)	6%	9.4%	9.4% (MWDOC 2011)
Commercial weather-based control (CA)	8%	27.5%	27.5% (MWDOC 2011)
ET signal-based control (FL)	23%	34%	Varies. (Davis, et. al. 2014)
Rain switch and pause (FL)	25%	41%	Varies. (Rutland et. al. 2012)
Weather-based control (NM)	34%	54%	Varies. (Al-Ajlouni, et. al. 2012)
Weather-based control (NV)	4.6%	68%	Varies. (Devitt, et. al. 2008)
Rotating sprinkler heads	0 or negative	31% (hypothetical)	Unknown

*Some savings estimates did not differentiate between indoor and outdoor reductions, but in all cases the primary focus was on outdoor.

4.2.2 WRF Residential End Uses of Water Study 2 (REUWS 2)

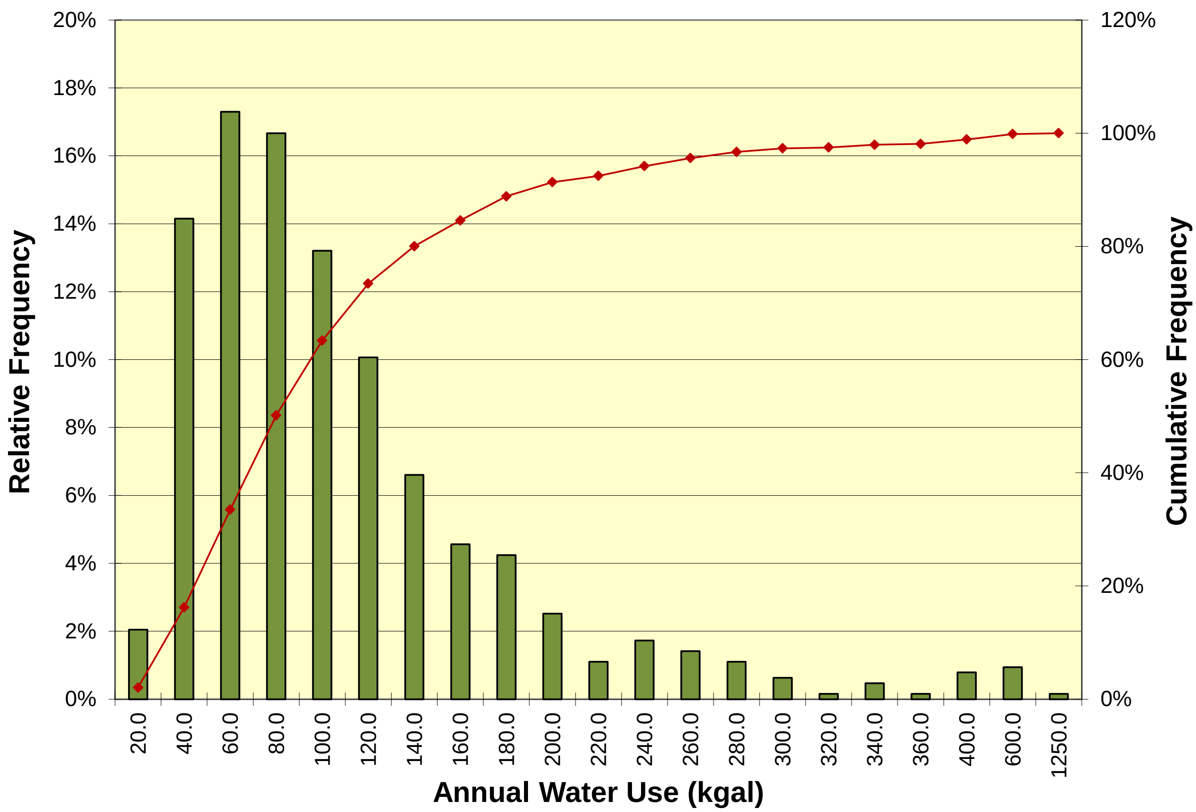
From 2008 to 2015, Aquacraft et al. (2015, under review) conducted the Single Family Residential End Uses of Water Study Update ("REUWS2) for the Water Research Foundation.[1] The study was based on water data logging for nine sites around the country from 2008-2012, some of which included the same communities in REUWS1 (1996-97). Fort Collins and Denver participated in

[1] Findings summarized in this section were extracted from "Some Key Results from REUW2, Single Family Residential End Uses of Water Study Update, Water Research Foundation Project 4309 "Water Smart Innovations Conference, Las Vegas, NV, 10/9/2014 presented by DeOreo et al.)

REUWS2. Denver and Boulder participated in REUWS1. Additionally, 16 sites participated in a survey, including the Colorado communities of Colorado Springs and Aurora. The study evaluated both indoor and outdoor water uses; however, the summary below focuses only on outdoor use.

One of the key findings from this study that is useful in terms of targeting landscape water conservation opportunities is that landscape water use tends to be log-normally distributed, as summarized in Figure 1. This means that opportunities for water conservation are not evenly distributed across water service areas, with significant opportunities for water conservation (or improved efficiency) concentrated among a relatively small percentage of the service population.

Figure 1. Lognormal Distribution of Water Use in REUWS2

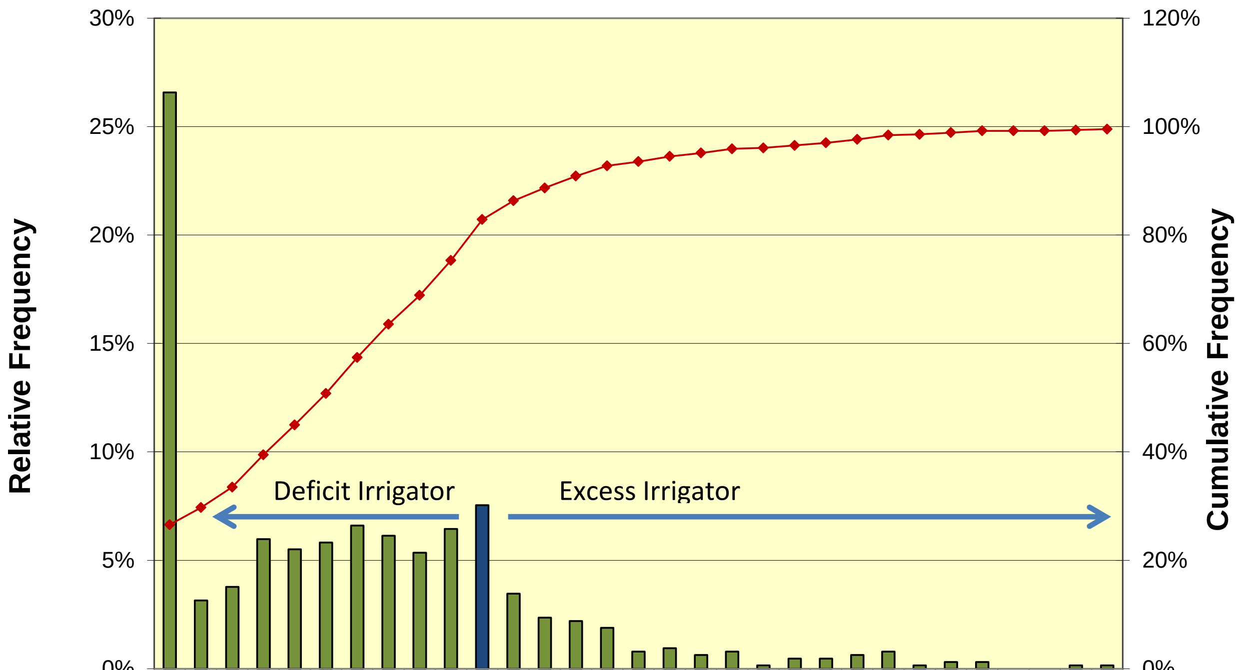


The study also documented the wide range of outdoor water use for the communities participating in the study, as shown in Table 5. This range in outdoor water use illustrates one of the challenges in normalizing irrigation water use from studies in different parts of the country. This study showed that the percentage of outdoor water use in Denver was 65 percent of single family residential household water use and in Fort Collins was 57 percent. Additional analysis of the outdoor water use also showed the lognormal pattern of water use, with many irrigators under-irrigating (deficit irrigation) and a relatively low percentage significantly over-irrigating, but representing a significant opportunity for water savings (Figure 2). Key factors predicting outdoor water use included: the amount of irrigated area, net evapotranspiration (ET), cost of water, in-ground sprinklers (versus hand-watering), and occurrence of excess irrigation. A water demand model based on these factors considered two outdoor conservation scenarios, with results included in Figure 2, suggesting that an approximately 20 to 50 percent reduction in outdoor water use may be attainable through a combination of reducing irrigated area, increasing the price of water and reducing over-irrigation. (In Section 8, a similar modeling exercise has been conducted for the South Platte Basin using this model, but without varying the pricing component.)

Table 5. Range of Outdoor Water Use in REUWS2

Site	Average Annual Water Use (kgal)	Average Outdoor Water Use (kgal)	% Outdoor
Clayton	57.5	19.2	33
Denver	119.4	77.0	65
Fort Collins	98.3	55.9	57
Peel	76.6	24.1	31
San Antonio	103.9	62.0	60
Scottsdale	175.1	120.4	69
Tacoma	68.6	27.0	39
Toho	83.2	33.1	40
Waterloo	55.5	13.0	23
Grand Total	**95.5**	**50.5**	**53**

Figure 2. Distribution of Deficit Irrigators vs. Over-Irrigators in REUWS2



	-100	-90	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200
% of Houses	27%	3%	4%	6%	6%	6%	7%	6%	5%	6%	8%	3%	2%	2%	2%	1%	1%	1%	1%	0%	0%	0%	1%	1%	0%	0%	0%	0%	0%	0%	0%
Cum %	27%	30%	33%	39%	45%	51%	57%	64%	69%	75%	83%	86%	89%	91%	93%	94%	94%	95%	96%	96%	97%	97%	98%	98%	99%	99%	99%	99%	99%	99%	100

Table 6. Summary of Outdoor Conservation Model Scenarios from REUWS2

Conservation Scenario	Resulting Savings
Modest conservation scenario: • 10% reduction in irrigated area • 10% increase in price for outdoor water • 15% reduction in occurrence of over-irrigation	18% reduction in outdoor water use (~10kgal/year)
Aggressive conservation scenario: • 25% reduction in irrigated area • 25% increase in cost for outdoor water • 90% reduction in occurrence of over-irrigation	47% reduction in outdoor use (~25 kgal/yr)

4.2.3 Denver Water Residential Landscape Water Demands Study

Concurrent to this literature review, Denver Water has been conducting an internal analysis of residential water demands in its service area. Initial findings from this study are available in "Risks of Overgeneralization" prepared by Mitch Horrie, Phil Segura, and Mark Cassalia of Denver Water, as presented at the American Water Works Association Annual Conference and Exposition (ACE) in 2015.

Denver Water serves approximately 25% of the state's population with about 2% of the state's available water. One of the primary objectives of their evaluation is to determine whether the approximately 20% reduction in residential water demand that occurred following the 2002 drought is expected to be a relatively permanent "sustainable" reduction, or whether this reduction will eventually rebound to previous demand levels. The analysis has included both quantitative analysis of demand patterns (including GIS analysis of residential landscapes) and analysis of behavioral patterns through use of a survey to determine level of satisfaction with their landscapes and motivating factors in conserving water. Examples of topics covered in survey questions included: changes to landscape and water use, who maintains the landscape, presence/absence of in-ground sprinklers, level of satisfaction with the landscape, demographic information, and other questions. Some of the initial findings from this study (which is not yet published or finalized), include:

- Although the population has grown more than 40% in the last 40 years, demand is at about the same level as it was 40 years ago. Single family residential is the largest customer class by number of accounts and by volume served. Outdoor water use is approximately 50% of single family residential demand (Figure 3). Approximately 70% of single family residential customers decreased outdoor water use since 2000/2001 (Figure 4). Customers are using about 10,000 AF less per year outdoors.

- The 20% reduction in demand since the 2001/2002 drought should not be generalized across all customers. Instead, some customers have dramatically reduced water use, some are using water at a "sustainable" level, and other subgroups are overwatering. The "sustainable" group is applying water at a moderate level and is maintaining their landscapes. The group that is under-watering includes a combination of very low water landscapes and landscapes that have been "abandoned." The abandoned landscapes are considered "at risk" for rebounding water demands. The distribution of water use varies across the service area, as shown in Figure 5.

- The initial analysis suggests that an additional 4,000 acre-feet in potential savings from reducing water waste could be achieved through focusing on areas with inefficient water use. The potential rebound of water demand was lower than expected, but is initially estimated at approximately 3,400 acre-feet.

Figure 3. Single Family Water Use in Denver Water's Service Area

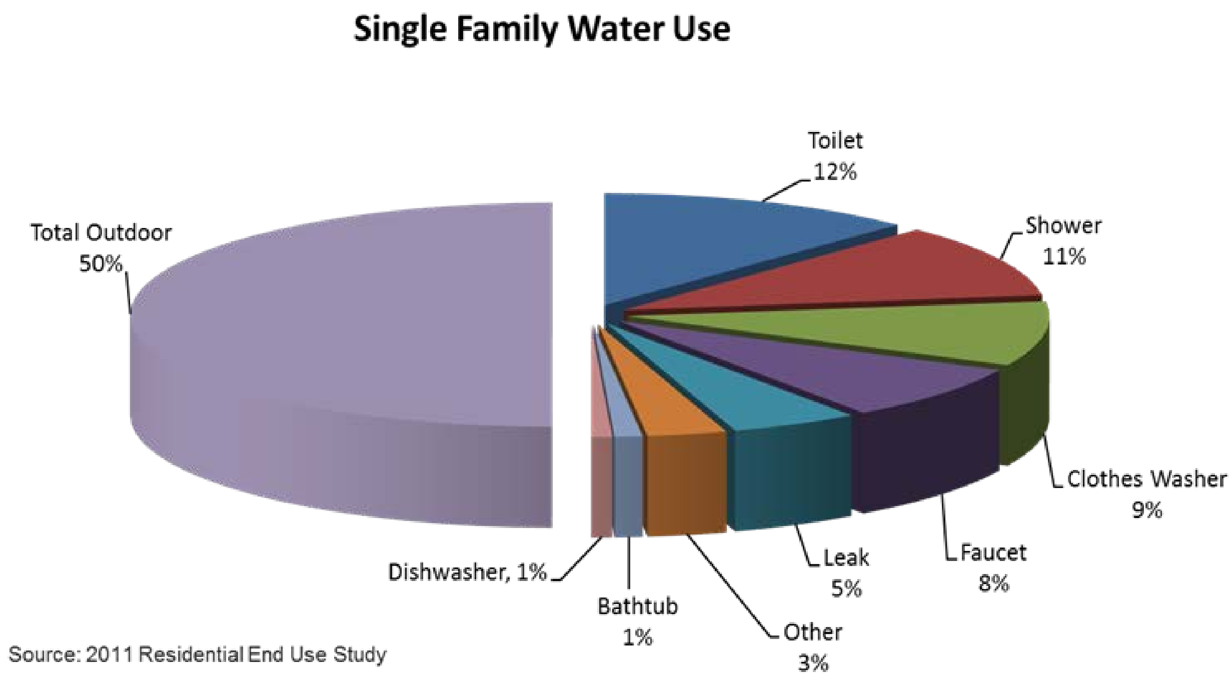


Figure 4. Changes in Single Family Outdoor Water Use in Denver Water's Service Area (2000/2001 vs. 2010/2011)

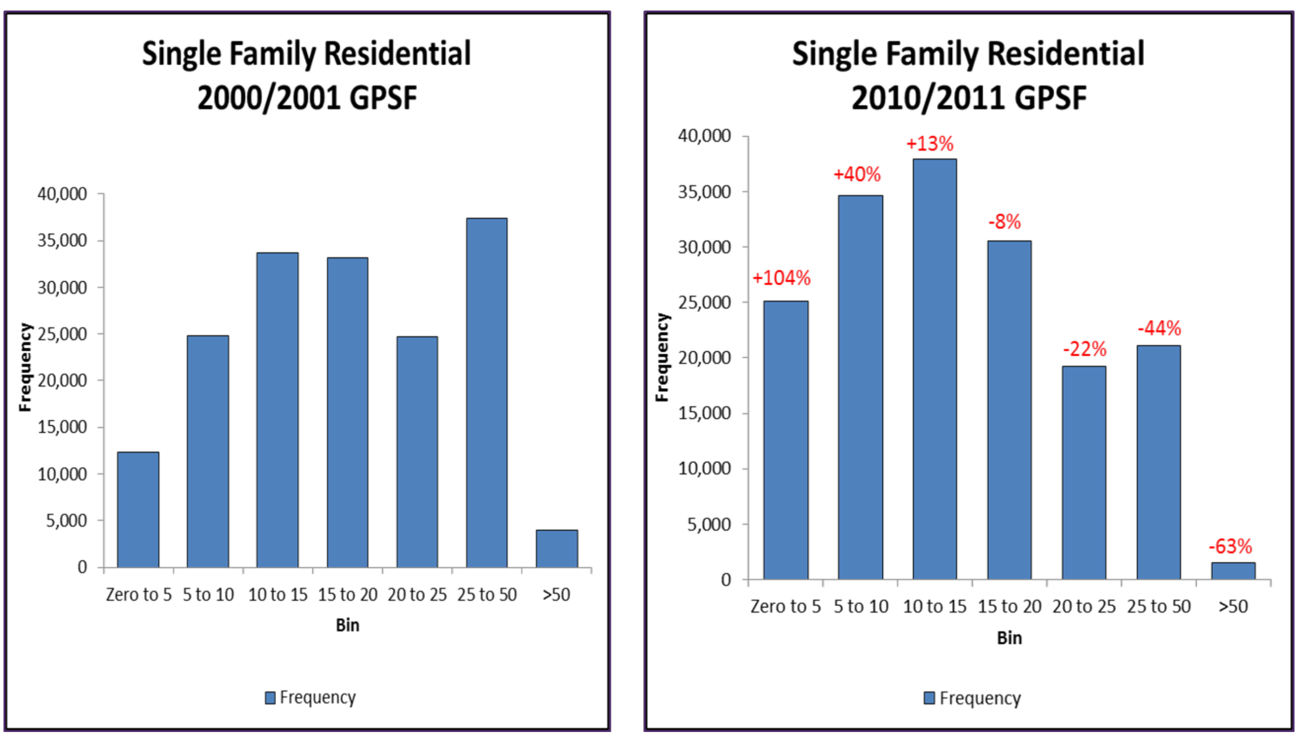
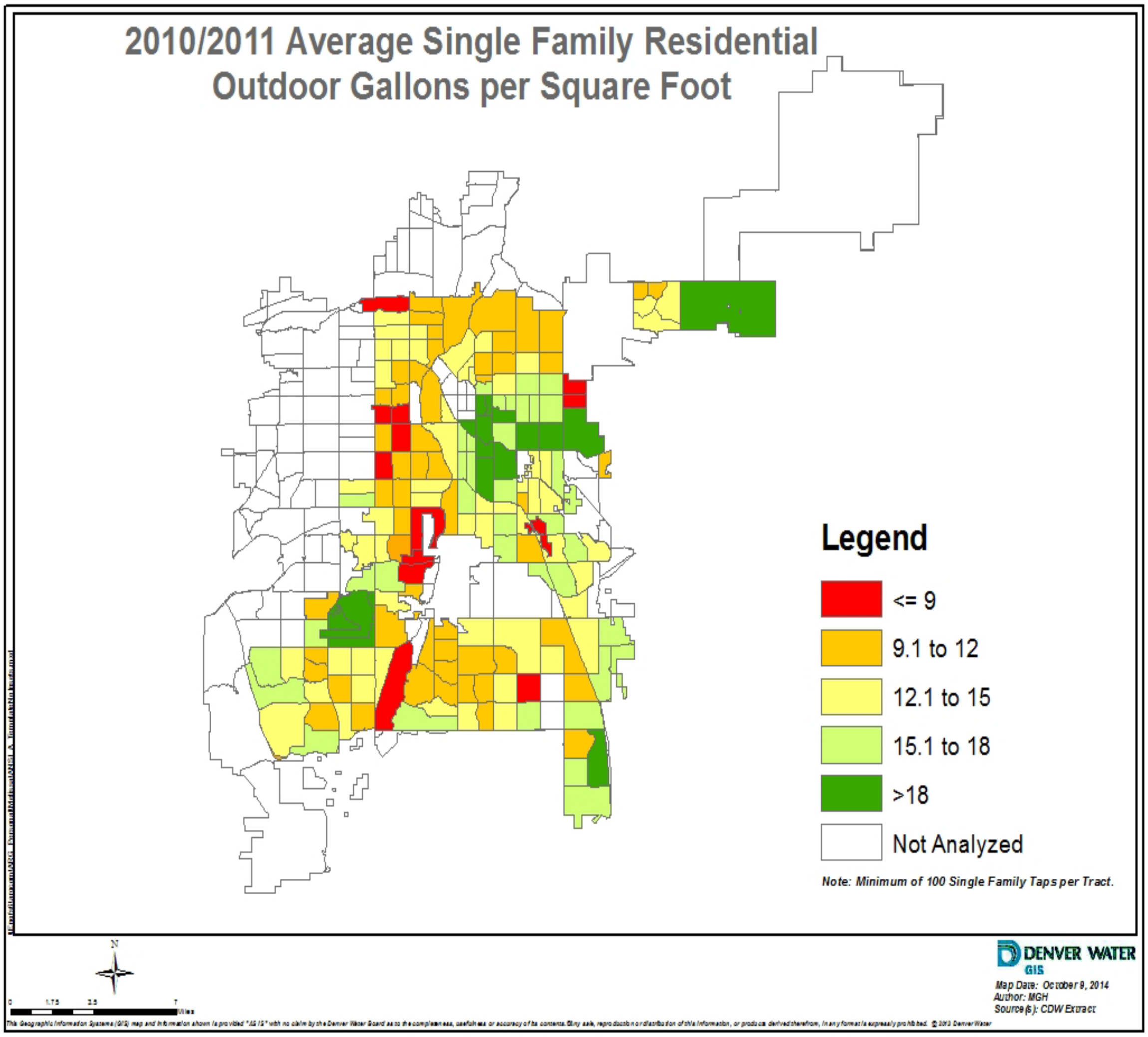


Figure 5. Distribution of Outdoor Water Use in Denver Water Service Area (2010/2011)



4.2.4 Center for ReSource Conservation Studies

The Center for ReSource Conservation, formerly the Boulder Energy Conservation Center (BECC), was founded in 1976 by a group of community-minded citizens seeking ways to help reduce dependence on non-renewable resources. The Center for ReSource Conservation's Water Division coordinates a suite of programs designed to help people irrigate efficiently and implement water-wise landscaping. The Water-Wise Landscape Seminars, Garden in a Box Xeriscape Program, Slow the Flow Outdoor Sprinkler Consultation Program and Slow the Flow Indoor Water Consultation Program are complementary services, each of which provides local residents with tools they need to use water more efficiently. CRC's water programs are also designed to help utilities meet water conservation goals. In 2014, CRC served 25 communities with these four conservation programs.

In 2014, the Center for ReSource Conservation completed a multi-year study (2005-2013) focused on the "Slow the Flow" program findings titled "Water Conservation Impact Assessment 2013 Final Report" (CRC 2014b). The Slow the Flow program has conducted nearly 16,000 irrigation audits, primarily on irrigated turf lawns. The primary finding of the study was that the average Slow the Flow participant saved 4.8 kgal of water in the first year following the audit and continued to save water for up to five years beyond the audit. The study also identified that some uncertainty remains regarding the sustainability of these savings over time.

4.2.5 Northern Colorado Water Conservancy District

Northern Colorado Water Conservancy District (Northern Water) has been conducting significant landscape water research at its Conservation Gardens in Berthoud, CO, including monitoring landscape plots under varying conditions, evaluating irrigation technology, collecting weather data collecting for ET calculations, and conducting modeling using the Dual Kc Method, as discussed later in this report (Section 7). As a result, Northern Water has prepared a series of landscape fact sheets with monthly water budgets for native plant gardens, prairie landscape, yucca garden, "Southwest" landscape and a "Keep It Simple Landscape." These fact sheets go beyond rules of thumb for irrigation water requirements and provide more detailed information on expected savings for various landscape types, and provide information on soil preparation, irrigation intervals and equipment, and calculations regarding managed allowable depletion (MAD) that the plants can tolerate. An emphasis of Northern Water's guidance materials is that water conservation is more than "a plant type" and that water conservation results from a combination of practices, similar to the principles underlying GreenCO's BMPs.

4.2.6 City of Westminster Residential Water Demand Study

In 2011, Aquacraft completed the City of Westminster Residential Water Demand study to closely examine water use and water use patterns of the city, particularly for single-family residential customers, for the purpose of informing demand forecasting and water conservation planning efforts. The study included both indoor and outdoor components. A summary of findings for outdoor components related to landscape irrigation included:

- Single-family residential irrigators in Westminster adjust their irrigation patterns in response to changes in weather.

- The study sample of households in Westminster applied substantially less water than was theoretically required for a turfgrass landscape (e.g., approximately 68-73% of the expected requirement). These results suggest that outdoor water conservation efforts in Westminster should be targeted at the relatively small percentage (12.9%) of customers who are applying more than 100% of the theoretical requirement.

- Real potential for increased outdoor use exists in Westminster, particularly among customers who are currently manually irrigating but who could install an automatic irrigation system in the future.

- There is not great potential to further reduce single-family residential outdoor water demands in Westminster. In this study group, the excess irrigation measured in 2010 only accounted for 3% of all outdoor demand. In other words, if the 12.9% of the study sample that applied more than 100% of the theoretical irrigation requirement (TIR) in 2010 reduced their use to exactly 100% of the TIR, the savings would only amount to a 3% reduction in outdoor use.

- By contrast, the level of under-irrigation in this sample of households is much more significant. If all households that applied less than the TIR in 2010 were to increase their irrigation application rate to match the TIR, outdoor use would be approximately 35% higher. It appears that the level of under-irrigation in Westminster is much more significant than the level of excess irrigation. The potential to increase outdoor demands, particularly among those currently manually irrigating, is far more significant than the potential for reducing outdoor demands.

- Single-family residential outdoor irrigation in Westminster has been at a relatively low average rate over the past 10 years, indicating that relatively few customers in Westminster over-irrigate. The City should be aware that outdoor use in Westminster could increase due to: 1) conversions of landscapes that are currently manually irrigated to automatic irrigation, 2) changes in customer preferences regarding plants and landscape materials, and 3) hotter and drier climate conditions.

4.2.7 California Weather Based Irrigation Controller Studies

In the 2009 GreenCO Literature Review, initial findings from the California Single Family Water Efficiency Study (Aquacraft 2011) were included in the literature review. Since then, another larger-scale study has been completed "Evaluation of Water Savings from Weather Based Irrigation Contollers in Santa Clarity Valley for the Castaic Lake Water Agency" (AquaCraft 2015). The report provides empirical information about the performance of WBICs for water conservation through an examination of actual water use for over 1000 WBIC sites in the Santa Clarita Valley of California.

Considerable effort was expended to get the best possible estimates of the theoretical irrigation requirements (TIRs) for each of the test homes. This was done to allow the analysis to take into effect the ratios of the actual irrigation applications to the TIR values (the application ratios) for the homes prior to receiving WBICs, which were referred to as the antecedent application ratios. Homes with higher application ratios would be expected to show the greatest decrease in landscape water use, and homes with the lower application ratios would be expected to show an increase in water use, given how WBICs are intended to work. Aquacraft (2015)'s conclusions from the study included:

- The WBICs performed generally as expected and brought the application ratios of the group closer to 1.0, which is what they are designed to do.

- However, because more than half of the lots were under-irrigating prior to receiving the devices, the program resulted in an overall increase in outdoor water use. On the other hand, when the performance of just the lots that were over-irrigating was investigated, a significant reduction in outdoor use was observed. Overall, however, there was a slight net increase in the weather-adjusted outdoor water use of the Test group compared to the Control group.

- The conclusion of the study was that, when considering retrofits, WBIC programs must be directed only at customers that are known to be over-irrigating, and that general rebate or give-away programs are likely to have the unintended consequence of increasing the landscape water use of the population. When used for new homes, however, with landscapes designed for low water application from the start, WBICs should be a useful tool. The danger comes when they are installed on existing landscapes that have been historically under irrigated. It is this situation in which they can lead to an increase in water use.

5 Quantifying Landscape Water Conservation Savings

In order to begin to quantify potential savings from landscape water conservation practices statewide and for individual water providers, it is necessary to develop a baseline water demand for outdoor water use. This is a challenging task for the following reasons:

- Most outdoor water use is not metered separately from indoor water use. (*Estimates of outdoor use are typically estimated by subtracting the average monthly winter baseline use from monthly summer monthly use*.)
- A consolidated database of outdoor water use with supporting metadata is not available statewide.
- A long period of record is needed to develop a reasonably accurate estimate of outdoor water use, encompassing both “wet” and “dry” years.

As a result, there are significant data gaps at a statewide level. Nonetheless, there are a variety of techniques that can be used to better quantify the potential benefits of landscape conservation, provided that constraints of these estimates are recognized. A limited discussion of the factors to consider when summarizing and transferring landscape water conservation data is provided in this section, along with techniques that can be used to develop such estimates.

5.1 Factors to Consider When Summarizing and Transferring Landscape Water Conservation Data

In order to develop and apply landscape water conservation savings estimates in longer term planning, several factors need to be taken into consideration when using data collected in site-specific studies. WWE and GreenCO (2009) identified these key considerations:

1. **Quality, scope and location of the study.** Studies based on statistically valid sample sizes and study designs should be given preference, as would Colorado-based studies. Other estimates of water savings may be useful as general benchmarks or “reality

checks." An example would be the U.S. EPA benchmarks included in EPA (1998). Presumably, these estimates have an underlying data source, but there is not enough information to translate how applicable those benchmarks are for a particular utility. Additionally, as noted by Heaney et al. (1998) and many others, irrigation water use varies widely across the United States from little use to being the dominant use.

2. **Demographics/User Profile**. Multiple studies have shown that expected savings are contingent on "the starting point." As an example, Kenney et al. (2009) found that comparison of data during pre-drought and drought conditions varied according to general water user type. High water users saved roughly 15%, mid-level water users saved 5-7% and low water users saved 1-2%. In order to apply savings data, it is important to understand the demographic base of the literature (e.g., were the participants randomly selected or targeted at high water users?) This phenomenon is one of the reasons that weather-based irrigation controllers show increased water usage in some cases: if the property owner was already a low-water user or under-irrigator, there is not much room for savings (Mayer et al. 2009). Similarly, Heaney et al. (1998) and CDM (2007) noted the relationship between housing density and irrigable area per capita. In the late 1990s, lower density housing was the trend, but more recent trends associated with Green Building programs such as LEED are promoting densification and redevelopment within cities. Additionally, people vary in how they use water outdoors, whereas indoor water use is more constant.

3. **Performance Benchmarks**.[2] The studies reviewed in both 2009 and 2015 assess the performance of the BMPs using three basic approaches, affecting transferability of findings:

   - Volume Saved
   - Percent Savings
   - Percent (or Volume) Above or Below Water Budget

   In order to use these varied performance measures to develop estimates in Colorado, results need to be standardized according to a single metric or set of metrics. From a technical perspective, the most meaningful is calculation of volume of water per landscaped area compared to a target water budget. (This was the approach used by Mecham and Boyd 2004.) Nonetheless, percent savings is the most common value reported in the literature. These are some significant data transferability issues with percent savings because it begs the question: "percent of what?" For example,

[2] An additional factor that should be considered when reviewing quantitative savings data is whether the landscape quality is being maintained. For example, it is possible to save water by abandoning the care of this landscape, but this type of savings is at risk for water demand rebound, as described by Denver Water (Section 4.2.3) and does not represent a desirable outcome for landscapes in urban communities.

implementation of a weather-based irrigation controller on a property that already applies minimal irrigation will show a low percent savings [*or an increase*], whereas installation of the same controller on a property originally over-irrigating will show a high percent savings. The more meaningful measure would be percent of properties meeting a water budget. In terms of CWCB's desire to forecast percent savings attributable to landscape water conservation, it may be more desirable to estimate the current landscape water budget and compare it to a target landscape water budget. As examples, Denver Parks and Recreation has used 30 inches as a comparison benchmark, and the Water-Efficient Landscape Design Model Ordinance (Department Office of Smart Growth of the Colorado Department of Local Affairs 2004) recommends 15 gallons per square foot [*24 inches*].

4. **Market Penetration**. Closely related to the demographic information described above, the reasonably attainable market penetration for conservation practices is a challenging variable to define, particularly at a statewide level. Relatively little information on market penetration estimates was discussed in the literature reviewed, although some case studies provide numbers of participants in various programs. Other arid/semi-arid states may also have better developed market penetration information that could be pursued.

5.2 AWWA M52 (Service Area Planning)

As a general starting point, the American Water Works Association (2006) guidance manual titled *Water Conservation Programs: A Planning Manual, Manual of Water Supply Practices M52* was reviewed for water savings estimates for various landscape practices. While specific numeric estimates were provided for many forms of indoor and commercial conservation/efficiency measures, the only landscape irrigation measure with a quantitative estimate provided was evapotranspiration (ET) irrigation controllers, with an estimated water savings of 18-22%. Other landscape water conservation/efficiency practices with savings identified as "varies" in terms of end-use reductions, included these practices: drip systems, micro-spray systems, hose timers, trigger shut-off valves on hoses, irrigation system moisture sensors, rainwater tanks, native plants and mulch. "Varies" was defined as "depending on the amount of water used outside and interaction with other outdoor measures." Public education, inclusive of overall general household water use, was estimated to provide a 1-5% reduction in end-use.

In terms of calculating water savings, AWWA (2006) notes that baseline water use must first be determined for the targeted group of users. Water savings will depend on 1) reduction in water use as a result of implementing the measure; and 2) the degree of coverage that the measure can achieve (i.e., market penetration). The general formula to estimate how effective a specific efficiency measure is in a given year is:

$$E = R \times C \times V$$

Where:

E = estimated reduction in water use (million gallons/year)

R = percent reduction in water use as a result of the measure if all customers implemented the practice (entered as a fraction of 1)

C = percent coverage of the measure of the group water users (entered as a fraction of 1)

V = volume of water use without the water-efficiency measure in million gallons/year

Based on the literature review conducted, for some landscape BMPs, the "R" (technical) part of the equation can be calculated, but the "C" (behavioral) part of the equation is much more challenging. AWWA (2006) notes that for mandatory measures, the C factor is considered 100%, whereas for voluntary measures, the C factor is much lower. Most landscape water conservation practices in Colorado are voluntary under non-drought conditions, with a few exceptions such as soil amendment and penalties for blatant water waste in some jurisdictions. AWWA notes that the experience of other utilities may be useful in developing C factor estimates. This literature review may be helpful in developing estimates for the "R" factors.

5.3 EPA's WaterSense Water Budget Tool (Lot Scale Planning Estimates)

On its WaterSense website (http://www.epa.gov/watersense/), EPA reports that in the U.S., "…30 percent is devoted to outdoor water use. In the hot summer months, or in dry climates, a household's outdoor water use can be as high as 70 percent." EPA includes landscape BMP types similar to those recommended by GreenCO in its outdoor program. EPA's WaterSense program for outdoor water use includes these general components:

- Design a water-smart landscape (based on a water budget).
- Apply proper irrigation (rate and timing), with emphasis on WaterSense labeled controllers when in-ground irrigation system are in place.
- Utilize irrigation professionals certified by a WaterSense labeled program to install, maintain, or audit the irrigation system to ensure it is operating efficiently while using less water.

To support water-smart landscape design, EPA provides a spreadsheet-based Water Budget Tool, accessible at: http://www.epa.gov/watersense/water_budget/. This tool can be used for general information, as well as to calculate the water budget for the "WaterSense New Home Specification," which defines the criteria a home must meet in order to earn the WaterSense label. To meet the specification's Landscape Design Criteria, the builder must design the landscaped area using the WaterSense Water Budget Tool. The builder is required to submit a copy of the completed Excel tool or a copy of the Water Budget Tool Report generated by the

Web-based version of the tool as part of the inspection package.

The tool, available both online and as a Microsoft Excel spreadsheet format on the WaterSense website, guides the user through the water budget calculation in three parts. First, the tool calculates the amount of water a standard landscape would require and the amount of water the designed landscape is allowed in order to be considered water-efficient. Next, the tool calculates how much water the designed landscape requires based on climate, plant type, and irrigation system design. Lastly, it determines whether the designed landscape meets EPA's criteria (EPA 2014). This tool is similar to the water budget calculator accessible on GreenCO's website.

5.4 FAO Irrigation and Drainage Paper 56: Crop Evapotranspiration (Agricultural Engineering Calculations)

Water budgets for landscapes can be developed by engineering calculations that typically draw upon techniques described in Food and Agricultural Organization of the United States (FAO) Irrigation and Drainage Paper No. 56 (FAO-56). FAO 56 is technical guidance for calculating crop water requirements that relies on the Penman Montieth equation to calculate reference ET (ETo), which is then multiplied by one or more coefficients to determine crop irrigation needs. FAO 56 describes two methods: 1) single crop coefficient method (Kc) or 2) dual crop coefficient method (Kcb +Ke). To date, GreenCO (GreenCO and WWE 2008) and most simple water budget approaches such as the EPA Water Budget Calculator utilize the single crop coefficient (Kc) method, which is described briefly below.[3] For purposes of this report, additional calculations have been completed using the dual crop coefficient method (Kcb) to allow further exploration of how various landscape BMPs may affect landscape water requirements.

5.4.1 FAO-56 Single Crop Coefficient Method (Kc)

As described in FAO 56 (Allen et al. 2005), ET for a crop (ETc) is determined by the crop coefficient approach whereby the effect of the various weather conditions are incorporated into ETo and the crop characteristics into the Kc coefficient:

$$ETc = (Kc)\ ETo$$

The effect of both crop transpiration and soil evaporation are integrated into a single crop coefficient. The Kc coefficient incorporates crop characteristics and averaged effects of evaporation from the soil. For normal irrigation planning and management purposes, for the development of basic irrigation schedules, and for most hydrologic water balance studies, average crop coefficients are relevant and more convenient than the Kc computed on a daily time step using a separate crop and soil coefficient (the Dual Kc method). Only when values for Kc are needed on a daily basis for specific fields of crops and for specific years, must a separate

[3] Descriptions extracted from FAO 56 have been directly quoted.

transpiration and evaporation coefficient (Kcb + Ke) be considered. The calculation procedure for crop evapotranspiration, ETc, consists of:

1. Identifying the crop growth stages, determining their lengths, and selecting the corresponding Kc coefficients;

2. Adjusting the selected Kc coefficients for frequency of wetting or climatic conditions during the stage;

3. Constructing the crop coefficient curve (allowing one to determine Kc values for any period during the growing period); and

4. Calculating ETc as the product of ETo and Kc.

5.4.2 FAO-56 Dual Crop Coefficient Method (Kcb + Ke)

The dual Kc method divides Kc into two separate coefficients, one for crop transpiration (i.e., the basal crop coefficient (Kcb)), and one for soil evaporation (Ke):

$$ETc = (Kcb + Ke)\ ETo$$

The dual crop coefficient approach is more complicated and more computationally intensive than the single crop coefficient approach (Kc). The procedure is conducted on a daily basis and is intended for applications using computers. FAO describes the calculation procedure for crop evapotranspiration, ETc, as involving these steps:

1. Identifying the lengths of crop growth stages, and selecting the corresponding Kcb coefficients;

2. Adjusting the selected Kcb coefficients for climatic conditions during the stage;

3. Constructing the basal crop coefficient curve (allowing one to determine Kcb values for any period during the growing period);

4. Determining daily Ke values for surface evaporation; and

5. Calculating ETc as the product of ETo and (Kcb + Ke).

Allen et al. (2005) describe the dual crop coefficient method and developed a series of spreadsheet tools to execute these calculations. Northern Water has adapted these spreadsheets for use in calculating various water demand scenarios in Colorado, as discussed later in this report (see Section 7).

6 Summary of Outdoor Demand Reduction Based on Normalized Data Sets in the Literature: Lot Scale

In the 2009 Literature Review, general summaries of studies potentially useful for quantifying the benefits of landscape water conservation were tabulated; however, "normalizing" these studies to common metrics was beyond the scope of the literature review. For this 2015 update of the literature review, WWE conducted a more detailed review of the 2009 studies to identify studies potentially suitable for developing a better quantitative understanding of the benefits of various landscape water conservation practices. Additionally, WWE included studies in the AWE (2015) literature review that were suitable for this purpose, along with some additional studies not included in the AWE literature review. The resulting subset of studies is provided in Appendix A, which provides the underlying basis for estimates of water savings discussed later in this report. To develop Appendix A, a basic subset of key metadata to be extracted from each study was summarized in Table 7. Ideally, additional metadata would also be extracted and was considered in development of this table; however, this basic subset was settled upon due to inconsistent reporting of other parameters in the literature.

Appendix A includes 43 studies reviewed for this report (narrowed from the much broader 2009 GreenCO literature review and the AWE (2015) literature review) along with five general reference documents. Five of the reports were from the 2009 literature review and 38 of the documents were "new" studies obtained as part of this literature review effort. Of the 38 "new" studies, 32 were conducted from 2010 to the present and six were from 2009 or earlier. In summary, the 2015 literature review effort resulted in identification of significant new literature. Unfortunately, the list of 38 studies was significantly narrowed down to approximately 14 studies that had adequate information to develop quantitative landscape water conservation estimates. Of these, eight studies had enough data to normalize the studies to Front Range conditions and the other six studies were conducted under conditions too different from the Front Range to consider for this analysis.

Challenges encountered in developing transferable (or normalized) water conservation estimates from these studies included:

- Reporting of percent savings without other key metadata or quantitative data.
- Volume of water savings reported without associated irrigated area.
- Allocating water savings among multiple conservation practices at sites where more than one BMP was implemented.
- Incomplete or unclear documentation of the type of "ET" referenced in the study (e.g., ET_o, $ET_{actual,}$ ET_{net}).
- Inadequate metadata to support a normalized quantitative estimate of ET.
- Factors associated with the study that were too different from Colorado to be considered

for use in Colorado, such as studies from humid areas with year-round irrigation. (Decisions related to transferability were made on a case-by-case basis, based largely on best professional judgment; however, a more formal decision process could be developed for future updates of this analysis.)

In an attempt to more fully understand the ET values cited in various studies, the EPA WaterSense budget tool was used as a comparison for ET values at a particular zip code location. The WaterSense tool's data set is based upon data from 1961-1990 extracted from the International Water Management Institute (IWMI) water and climate atlas (www.iwmi.cgiar.org/WAtlas/Default.aspx). The IWMI Atlas based upon the latitude and longitudinal location provides average Penman-Monteith reference ET rates in millimeters per day (mm/day) for each month and the average precipitation by month in mm/day. When the ET rate provided in the literature reference was unclear, the IWMI rate was checked and the IWMI rate was used if the ET data were missing from the literature source.

Dziegielewski and Kiefer (2010) note that to normalize data collected in different locations, key parameters are the precipitation and the maximum average temperature during the growing season. These two factors are both incorporated into the ET_{net}. Thus, for purposes of this report, the ratio of ET_{net} for two locations was used to normalize data from climate types similar to the Colorado Front Range. This approach is considered reasonable for studies in similar climate regions (e.g., arid or semi-arid areas), but it is not expected to be appropriate for normalizing data from very different climates such as Colorado and Florida.

Despite the limited number of studies identified as useful at the conclusion of the updated literature review effort, three categories of practices had several studies useful for developing some initial quantitative estimates of landscape water conservation practices including: 1) irrigation technology (Table 8), 2) water use/efficiency audits (Table 9), and 3) plant-related practices pertaining to xeriscape or turf conversion to plants with lower water use requirements (Table 10). These tables provide ranges of water savings in inches and in gallons per square foot normalized to Colorado Front Range and Grand Junction. These calculations could be completed for other parts of the state, as well.

Key observations from this exercise include:

- Xeriscape/plant selection: Savings range from 2.0 to 5.5 gpsf for replacement of lawn areas with shrubs, ground covers and perennials (2.2 to 6.0 gpsf estimated for Grand Junction). These savings increase to 5.9-11.5 gpsf if the replacement is low-water xeric plants (6.4-14.0 gpsf for Grand Junction).

- Irrigation efficiency audits: Savings range from 1.3 to 3.3 gpsf for improving irrigation efficiency in response to irrigation audits (1.4 to 3.7 gpsf for Grand Junction).

- Irrigation system technology and retrofits: Study designs vary substantially making generalizations difficult. Examples of reported savings for replaced of old irrigation system would be 4.8 gpsf (5.3 gpsf Grand Junction), and 3.3 gpsf (3.7 gpsf Grand Junction) for weather based irrigation controllers. Some studies have shown increases in irrigation use when manual watering is converted to automated irrigation or when advanced controllers are implemented. In these cases, landscapes are being under-watered and the irrigation level is raised to the irrigation requirement of the plants.

- Replacement of older irrigation systems with modern irrigation systems represents a significant water savings opportunity, although the actual savings achieved will be site-specific.

- Converting manual (i.e., hand watering, hose and sprinkler) irrigation systems to automated systems typically results in an increase in water use. This is expected to be due to significant under-watering of landscapes that occurs with manual watering due to the additional effort required to irrigate these landscapes.

- Although not fully captured in the tables below, a common observation in multiple recent studies is that the benefits of advanced weather-based irrigation controllers are greatest when targeted to properties that are over-irrigating (Aquacraft [2015], Boyer [2015], DeOreo [2014], Dziegielewski [2014], Aquacraft [2011], Mayer [2010] and Aquacraft [2009]). Under-irrigating (deficit irrigation) is common; therefore, broad distribution of advanced controllers may actually increase water use to meet the agronomic needs of the plants for those practicing deficit-irrigation.

Overall, this analysis indicates that there are significant data gaps for empirical studies related to landscape water conservation, particularly data that provide adequate metadata to normalize data sets in a manner that allows estimates to be used for general estimates in Colorado. Empirical studies are important because they can incorporate behavioral aspects of water conservation in a manner that agronomic models (theoretical calculations) do not. Empirical studies can be used to develop better estimates of uncertainty in demand models and should continue to be conducted (and funded).

Table 7. Tabulated Metadata Used to Develop Quantitative Landscape Water Conservation Estimates from Literature

Parameter	**Description**
Study ID	Study ID
Yr	Year study conducted
Literature Source	Literature source
BMP Category	A = Water Use/Irrigation Efficiency Audits P = Plant Selection, Turf Management, Xeriscape IT = Irrigation Technology. IT subcategories included: WBIC - Weather Based Irrigation Controllers, SMS - Soil Moisture Sensor, RS - Rain Shutoff
Location	City, State
Study Period	Year(s) study conducted
Sample Size	Number of sites included in the study
SF, MF, Residential, CII, Public, Test Plot	Land Use Type: Single Family (SF) of Multi-family (MF) Residential, Commercial/Industrial/Institutional (CII), Public Property (Public), Test Plot
Annual Precipitation (in)	Annual precipitation in inches
ET_o inches & gpsf	Grass reference ET, precipitation not deducted and no landscape coefficient yet applied. Quantitative values provided in both inches and gallons per square foot (gpsf)
ET_{net} inches & gpsf	$ET_{net} = ET_L$ - Effective Precip. Where: $ET_L = ET_o \times K_L$ Where: K_L = landscape coefficient = $K_v K_d K_{mc} K_{sm}$ Where: ET_L = ET level to sustain healthy, attractive landscape (prior to deducting precipitation).
Plant Coeff K_L	Landscape coefficient used to adjust ETo.
Annual Water Application (in)	Annual water application rate in inches = actual irrigation applied
Water Savings (-Water Increase) inches & gpsf	Water savings (or increase) identified in (or calculated from) study, reported in inches and gpsf.
Water Savings Normalized to Front Range inches & gpsf	To normalize water savings, the ratio of Front Range ET_o to ET_o at the study area was applied to develop an estimate of the water savings if the study had been conducted on the Front Range and for Grand Junction. (A similar ratio approach could be used for other parts of Colorado.)
Comments	Other metadata pertinent to the study.

Table 8. Normalized Outdoor Water Savings Resulting from Irrigation Technology BMPs

IRRIGATION TECHNOLOGY	Water Savings + (-Increase)		ET_{net}	Normalize to Front Range Water Savings + (-Increase)		Normalize to Grand Junction Water Savings + (-Increase)	
	inches	gpsf	inches	inches	gpsf	inches	gpsf
Replacement of Irrigation System							
Denver Parks and Recreation (2009)	15.3	9.5					
Attribute 1/2 to irrigation system replacement	7.7	4.8	30.2	7.7	4.8	8.4	5.3
Manual to Sprinkler Irrigation							
Aquacraft (2011) Westminster, CO	-9.9	-6.2	30.2	-9.9	-6.2	-10.9	-6.8
Automatic Timer with Rain-Shutoff							
Grabow (2013) Raleigh, NC 2007-08 growing seasons	1.3	0.8					
Weather Based Irrigation Controller							
Kopp (2014), Apr-Oct 2013, Salt Lake City Metro Area	6.5	4.1	36.6	5.4	3.3	5.9	3.7
Aquacraft (2009)							
Costal	-0.1	-0.1					
Intermediate	3.5	2.2					
Inland	-0.5	-0.3					
Grabow (2013) Raleigh, NC 2007-08 growing seasons	-1.3	-0.8					
Davis and Dukes, FL (2014)	6.1	3.8					
Haley and Dukes, FL (2012)	5.0	3.1					
Average				5.4	3.3	5.9	3.7
Soil Moisture Sensors							
Grabow (2013) Raleigh, NC 2007-08 growing seasons							
SMS1 1-set point	8.1	5					
SMS2 - 2 set points	5.5	3.4					

Irrigation Technology BMP Data Transferable to Colorado	Front Range Average water savings+ (increase (-)		Grand Junction Average water savings+ (increase (-)	
	inches	gpsf	inches	gpsf
Replacement of Irrigation System	7.7	4.8	8.4	5.3
Manual to Sprinkler Irrigation System	-9.9	-6.2	-10.9	-6.8
Automatic with Rain Shutoff	-	-	-	-
Weather- Based Irrigation Controller	5.4	3.3	5.9	3.7

Table 9. Normalized Outdoor Water Savings Resulting from Plant Selection/Xeriscape BMPs

PLANT SELECTION, TURF MANAGEMENT & XERISCAPE	Water Savings + (-Increase)		ET_{net} inches	Normalize to Front Range Water Savings + (-Increase)		Normalize to Grand Junction Water Savings + (-Increase)	
	inches	gpsf		inches	gpsf	inches	gpsf
Turf Conversion to Shrubs, groundcover & perennials							
Northern Colorado WCD, shrubs, groundcover, & perennials vs. turf	5.2	3.2	30.2	5.2	3.2	5.7	3.6
Denver Parks and Recreation (2009)	15.3	9.5					
Attribute 1/2 to Turf Conversion and 1/2 to irrigation system replacement	7.7	4.8	30.2	7.7	4.8	8.4	5.3
Rosenberg (2011), 8 years Salt Lake City Metro Area	6.9	4.3	36.6	5.7	3.5	6.3	3.9
Sun, Kopp, and Kjelgren (2012), UT, Savings compared to Turf (Mesic) years							
Turf Xeric - MAD = 33%	3.5	2.2	33.3	3.2	2.0	3.5	2.2
Woody - MAD = 67%	9.7	6.0		8.8	5.5	9.7	6.0
Average Water Savings				**6.1**	**3.8**	**6.7**	**4.2**
Range				**3.2 - 8.8**	**2.0 - 5.5**	**3.5 - 9.7**	**2.2 - 6.0**
Turf Conversion to Xeric Landscape							
Sun, Kopp, and Kjelgren (2012), UT, Savings compared to Turf (Mesic) years							
Perennial - MAD = 50%	20.4	12.7	33.3	18.5	11.5	22.5	14.0
Northern Colorado WCD, hybrid bluegrass and Southwest plants	9.5	5.9	30.2	9.5	5.9	10.5	6.5
Sovocol (2005) NV - Conversion Turf to Xeric Landscape	62.4	38.9	90.0				
Average Water Savings				**14.0**	**8.7**	**16.5**	**10.3**
Range				**9.5-18.5**	**5.9-11.5**	**10.5-22.5**	**6.5-14.0**

Table 10. Normalized Outdoor Water Savings Resulting from Irrigation Efficiency Audits

WATER USE & IRRIGATION EFFICIENCY AUDITS	Water Savings + (-Increase)		ET_{net} inches	Normalize to Front Range Water Savings + (-Increase)		Normalize to Grand Jct. Water Savings + (-Increase)	
	inches	gpsf	inches	inches	gpsf	inches	gpsf
Center for ReSource Conservation Water Conservation Impact Assessment 2013 Final Report [*for 2007-2011*] (2014a)	2.1	1.3	30.2	2.1	1.3	2.3	1.4
Center for ReSource Conservation, Slow the Flow Impact Analysis Addendum [*for 2013 program*] (2014b)	3.6	2.2	30.2	3.6	2.2	3.9	2.4
Kopp et al., UT (2014)	6.5	4.1	36.6	5.4	3.3	5.9	3.7
Boyer, Mackenzie & Dukes, FL (2015)	5.0	3.1					
Average	4.3	2.7		3.7	2.3	4.0	2.5
Range	2.1 to 6.5	1.3 to 4.1		2.1 to 5.4	1.3 to 3.3	2.3 to 5.9	1.4 to 3.7

7 Calculated Outdoor Water Savings Based on Dual Kc Method (FAO-56): Lot Scale

Due to the limited availability of empirical data in the literature for landscape water conservation BMPs, a modeling approach using the Dual Kc Method has been conducted for various landscape scenarios.[4]

7.1 Overview of Dual Kc Method (FAO-56) Variables

For purposes of this report, a Dual Kc Method spreadsheet tool originally developed by Allen et al. (2005) was adapted by Northern Water to model various landscape irrigation requirement scenarios to support this report. The spreadsheet tool calculates baseline water requirement and theoretical irrigation requirement based on modification of inputs for selected variables, along with static assumptions for a portion of these variables in order to manage the number of permutations of outputs. The spreadsheet tool allows variation of 12 variables. A list of assumption for these variables includes:

Variables Kept Constant

1. Slope: Selected "0 to 3% surface slope."
2. Exposure: Selected "Full Sun."
3. Irrigation Period Start Date: April 15: Selected same irrigation water available date in the spring of each year.
4. Irrigation Period Stop Date: October 31: Selected same irrigation stop date in the fall of each year.
5. Average Plant Height: Selected a standardized plant height for each of the 10 plant choices.

Variables Modified

6. Soil texture (9 choices): For purposes of these scenarios, only two choices were considered: silty clay soil or loam. Silty clay soil would be a typical soil type in much of the urbanized portion of the Front Range. The loam option was used as a general surrogate to represent potential benefits of soil amendment.
7. Plants (10 choices): The subset of plant choices considered in these scenarios included:
    - Cool season turf. The most common example on the Front Range is Kentucky bluegrass. Kentucky bluegrass is used as the "baseline" plant selection since it is used as the basis

[4] Mark Crookston, Northern Water, executed the model scenarios included in this section.

for ETo (*Note: ETo is adjusted by a crop coefficient [0.9] to account for a 3-inch mowing height in urban landscapes*).

- Warm season turf. Representative examples include blue grama and buffalograss. Blue grama and buffalograss are warm-season, perennial, native grasses found throughout the Great Plains. These are the major native grass species of the shortgrass prairie. Blue grama is typically the dominant species on sandy soils, with buffalograss dominating the heavier clay soils. Both are drought tolerant and do not require supplemental irrigation once established. However, better quality will be achieved if irrigation is provided to prevent summer dormancy (Koski 2005, www.csuturf.colostate.edu).
- Mixture of trees, shrubs and ground cover.
- Annuals.
- Ground Cover (XGC).
- Xeric deep-rooted plants (XDeep): Although these are entered into the spreadsheet tool as ground cover, the deeper rooting depth of 12 inches is intended to represent other types of xeric plants.

8. Landscape density (Kd, value can change for all but trees and turf): The landscape density is defined as the collective leaf area of all plants in the landscape area. The higher the density factor, Kd, the greater the amount of transpiration and water requirement by the landscape. Irrigation density factors for this analysis were assumed based on *Irrigation*, 6th Edition. Trees, bermuda, fescue, cool season turf, warm season turf are assumed to have a Kd = 1. A mixture of trees, shrubs, and ground cover is set at 0.95. Ground cover is set at 0.85, and annuals and XGC Deep are set at 0.7.

9. Managed Allowable Stress (4 choices): Managed Allowable Stress is based on the concept of Managed Allowable Depletion (MAD). The MAD is the maximum amount of water in the soil that is available to the landscape before an irrigation event occurs. Usually 50% is a reasonable value to use for a MAD target for most landscapes. Perennials are generally 60%. These model scenarios ranged from 46-85% MAD at the time of irrigation, indicating that the landscapes are able to go longer without another watering event, with the ability to draw more water from the soil zone. As soon as the soil profile empties, then the model fills the soil reservoir again, providing a full amount of total available water for the landscape. See Table 5.12 in *Irrigation*, 6th Edition, which provides recommendations of managed allowable stress by plant type. Generally, plants with deeper roots can withstand a greater amount of stress.

10. Effective root zone depth (value can change): The amount of water that a landscape is able to extract from the root zone depends on the maximum effective root zone depth per plant type. Ranges of root zone depth depend on plant type. A relatively shallow root zone per plant type may indicate over-watering or poor soil quality. A deeper root zone per plant type

can be achieved by providing soil amendments or irrigating more efficiently (i.e., MAD interval). Annuals and ground cover have the most shallow range of root zone depths compared with deeper rooted trees and shrubs.

11. Irrigation method (3 choices): The subset of irrigation methods selected for these scenarios include drip or sprinkler. (The third choice is subsurface irrigation.)

12. Irrigation interval (9 choices): Irrigation intervals considered in these model scenarios included:

    - MWF: This is a fixed 3-day interval (Monday-Wednesday-Friday) intended to mimic "circle-diamond-square" watering patterns, but allows a user to skip watering days (allows managed stress).

    - Monthly Adj.: This is a fixed 3-day interval intended to mimic "circle-diamond-square" watering patterns, with the user always watering on these days, but it assumes the irrigator adjusts the water needs monthly (e.g., more water applied in July than in April).

    - MAD: This is a "managed allowable depletion" watering schedule which would represent the most efficient irrigation pattern. This typically would require use of advanced weather-based irrigation controllers to achieve.

    - Wed: This is fixed once per week watering (e.g., Wednesday) for xeric plants.

In addition to these variables, weather station data by geographic location are uploaded separately for each geographic area considered. For purposes of this report, Berthoud, Boulder and Fort Lupton were selected as example locations. These sites were selected because Northern Water has installed weather stations enabling calculation of ET at these locations and has at least eight years of data for each station. Berthoud and Boulder have similar climate conditions, with Fort Lupton having higher ET and slightly less precipitation.

7.2 Landscape Water Use Scenarios Evaluated

Many combinations of variables are possible using the spreadsheet tool; however, Table 9 summarizes the combinations of assumptions used for a manageable number of model runs. Twelve sets of assumptions were considered for the three geographic locations, resulting in 36 scenarios; however, these variables could be modified in the future to evaluate alternative assumptions as well. These scenarios are also described narratively. The first six scenarios are related to turfgrass (shown by a "T" prefix), and the second group of six scenarios is for other plant types. Two of the turfgrass scenarios are presented as alternative baseline conditions. Each landscape scenario is limited to a single plant type (with the exception of the tree/shrub/groundcover mixture ["Mix"]); however, the irrigation requirement for an overall landscape with several hydrozones can be calculated by summing the irrigation requirement for each hyrozone in a landscape, weighted by the landscape area.

Table 11. Landscape Scenario Inputs Used in Dual Kc Method (FAO 56) Calculations

	Turf Scenarios					
Landscape	T-Base 1	T-Base 2	T-MAD	T-Soil	T-Soil&MAD	T-Warm
Planting	Cool Season Turf	Cool Season Turf	Cool Season Turf	Cool Season Turf	Cool Season Turf	Warm Season Turf
Irrigation Method	SPRINKLER	SPRINKLER	SPRINKLER	SPRINKLER	SPRINKLER	SPRINKLER
Irrigation Turn-On	April 15th	April 15th	April 15th	April 15th	April 15th	April 15th
Irrigation Turn-Off	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st
Irrigation Interval	Month Adj	MWF	MAD	MWF	MAD	MWF
Max Eff Root Zone (in)	7.35	7.35	12	7.35	12	9.8
MAD Target (%)	50	50	69	65	80	85
Soil	Silty clay soil	Silty clay soil	Silty clay soil	Loam	Loam	Silty clay soil
Other Plant Type Scenarios						
Landscape	Mix-Spk	Mix-Drip	Ann-Spk	Ann-Drip	X-GC	X-Deep
Planting	Mixture of Trees, Shrubs & Ground Cover	Mixture of Trees, Shrubs & Ground Cover	Annuals (flowers)	Annuals (flowers)	Ground Cover	Ground Cover
Irrigation Method	SPRINKLER	DRIP	SPRINKLER	DRIP	DRIP	DRIP
Irrigation Turn-On	April 15th	April 15th	April 15th	April 15th	April 15th	April 15th
Irrigation Turn-Off	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st
Irrigation Interval	Every 3 days	Every 3 days	MWF	MWF	Wed	Wed
Max Eff Root Zone (in)	18	18	4.5	6	6	12
MAD Target (%)	90	90	64	65	70	90
Soil	Silty clay soil	Silty clay soil	Silty clay soil	Silty clay soil	Silty clay soil	Silty clay soil

The purpose and narrative description of each of the scenarios in Table 11, with comments related to GreenCO BMPs, includes:

1. T-Base1: This scenario represents cool-season turfgrass, irrigated by a sprinkler system on a Monday-Wednesday-Friday fixed schedule, with the owner adjusting the irrigation application rate on a monthly basis (i.e., no irrigation days are skipped, regardless of the soil moisture level). This scenario is considered to represent the "typical irrigator."

2. T-Base2: This scenario is identical to T-Base1, except the owner could skip irrigation days based on MAD (adequate soil moisture on some of the days). This is a less conservative baseline value and represents an "efficient irrigator" within the constraints of a fixed interval irrigation approach specified by the water provider.

3. T-MAD: This scenario is identical to T-Base1 and T-Base2 with the exception that irrigation is applied based on managed allowable depletion (MAD). This represents the level of irrigation management achievable if an advanced irrigation controller is properly programmed and operated. This scenario represents a typical Front Range lawn that is managed aggressively to only apply irrigation that the plants truly require. Although it is unrealistic to assume that all irrigated landscapes would implement a MAD approach, larger landscaped areas, highly managed landscapes, multi-family landscapes and a portion of the general population could be expected to implement this approach.

4. T-Soil: This scenario is identical to T-Base2, but allows deeper effective rooting depth associated with a loam soil type. This scenario is entered as a surrogate to illustrate the potential benefits of soil amendment in turf landscapes.

5. T-Soil-MAD: This scenario is similar to T-Base2 and T-Soil, but allows deeper effective rooting depth associated with a loam soil type and irrigation intervals based on MAD. This scenario illustrates the potential benefits of soil amendment in turf landscapes combined with irrigation intervals based on MAD. This scenario is expected to approximate a turf lawn managed under relatively optimum conditions in terms of water efficiency, typically using advanced irrigation controllers.

6. T-Warm: This scenario changes the turf type to a warm-season turf (e.g., blue grama, buffalograss) under the T-Base2 conditions, which are based on the Monday-Wednesday-Friday irrigation schedule, but allowing skipped irrigation days.

7. Mix-Sprk: This scenario includes a mixture of trees, shrubs and groundcover irrigated by sprinkler irrigation every three days in a silty clay soil, with some MAD allowance in terms of skipping irrigation days. This plant type would be expected to represent a component of both Xeriscape landscape designs, as well as many traditional landscapes. Many existing landscapes water trees, shrubs and groundcover using sprinkler systems, as indicated by "Sprk."

8. Mix-Drip: This scenario is identical to Mix-Sprk, but uses a more water-efficient drip irrigation system.

9. Ann-Sprk: This scenario includes annual plants irrigated by sprinklers on a fixed MWF schedule in a silty clay soil, with some MAD allowance in terms of skipping irrigation days. This plant type would be expected to represent a component of both Xeriscape landscape designs, as well as many traditional landscapes.

10. Ann-Drip: This scenario is identical to Ann-Sprk, but uses a more water-efficient drip irrigation system.

11. XGC: This scenario includes xeric ground covers in a silty clay soil that are drip-irrigated once per week (fixed day). This plant type would be expected to be included as a hydrozone in many Xeriscape designs, as a lower-water use portion of the landscape.

12. XDeep: This scenario includes xeric plants with deeper root zones (12 inches) in a silty clay soil that are drip-irrigated once per week (fixed day). This plant type would be expected to be included as a hydrozone in many Xeriscape designs, as a lower-water use portion of the landscape. The deeper root zone is intended to represent taller, non-groundcover xeric plants.

7.3 Results of Analysis for Landscape Scenarios

The quantitative results of the Dual Kc analysis for each of the 12 scenarios for the three geographic areas are summarized in Tables 10 and 11 in terms of reduced irrigation water required relative to Baseline 1 and Baseline 2. Table 12 provides results in inches of irrigation water applied and Table 13 provides the same relative results, but in terms of gallons per square foot (gpsf). Appendix B provides detailed spreadsheets supporting these summary tables. Additionally, wet, dry and average year conditions are provided as well. The dry condition results may be helpful in understanding water needs during drought conditions.

Table 12. Comparison of Landscape Scenarios to Baseline Landscape with Water Savings (inches)

Landscape	T-Base 1	T-Base 2	T-MAD	T-Soil	T-Soil&MAD	T-Warm	Mix-Spk	Mix-Drip	Ann-Spk	Ann-Drip	X-GC	X-Deep
Planting	Cool Season Turf	Cool Season Turf	Cool Season Turf	Cool Season Turf	Cool Season Turf	Warm Season Turf	Mixture of Trees, Shrubs & Ground Cover	Mixture of Trees, Shrubs & Ground Cover	Annuals (flowers)	Annuals (flowers)	Ground Cover	Ground Cover
Irrigation Method	SPRINKLER	SPRINKLER	SPRINKLER	SPRINKLER	SPRINKLER	SPRINKLER	SPRINKLER	DRIP	SPRINKLER	DRIP	DRIP	DRIP
Irrigation Turn-On	April 15th	April 15th	April 15th	April 15th	April 15th	April 15th	April 15th	April 15th	April 15th	April 15th	April 15th	April 15th
Irrigation Turn-Off	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st
Irrigation Interval	Month Adj	MWF	MAD	MWF	MAD	MWF	Every 3 days	Every 3 days	MWF	MWF	Wed	Wed
Max Eff Root Zone (in)	7.35	7.35	12	7.35	12	9.8	18	18	4.5	6	6	12
MAD Target (%)	50	50	69	65	80	85	90	90	64	65	70	90
Soil	Silty clay soil	Silty clay soil	Silty clay soil	Loam	Loam	Silty clay soil	Silty clay soil	Silty clay soil	Silty clay soil	Silty clay soil	Silty clay soil	Silty clay soil
BERTHOUD												
WATER SAVINGS (Values in inches)												
Avg Year	Water Savings v. Typical Irrigator	2.6	9.2	7.6	15.4	14.8	11.1	11.6	11.8	15.2	16.2	19.2
Dry Year		0	5.9	4.2	11.1	11.6	5.7	6.5	9.8	13.4	15.4	15.8
Wet Year		3.6	8.1	8.3	15.0	12.3	12.8	12.7	9.6	12.4	16.0	19.0
Avg Year		Water Savings v. Efficient Irrigator	6.6	5.0	12.8	12.2	8.5	9.0	9.2	12.6	13.6	16.6
Dry Year			5.9	4.3	11.1	11.7	5.7	6.6	9.8	13.5	15.5	15.9
Wet Year			4.5	4.7	11.3	8.6	9.2	9.0	6.0	8.8	12.3	15.4
BOULDER												
WATER SAVINGS (Values in inches)												
Avg Year	Water Savings v. Typical Irrigator	2.4	9.2	6.9	15.4	13.6	10.2	10.8	11.1	14.7	15.1	18.8
Dry Year		0.7	7.9	5.2	15.4	10.7	7.5	7.7	9.6	12.8	15.7	18.7
Wet Year		4.1	8.3	6.9	16.1	11.9	9.9	10.1	9.9	13.5	14.6	16.7
Avg Year		Water Savings v. Efficient Irrigator	6.7	4.5	13.0	11.1	7.8	8.4	8.7	12.3	12.7	16.3
Dry Year			7.2	4.5	14.7	10.0	6.8	7.0	8.9	12.1	15.1	18.1
Wet Year			4.2	2.9	12.0	7.9	5.9	6.1	5.9	9.5	10.6	12.7
FORT LUPTON												
WATER SAVINGS (Values in inches)												
Avg Year	Water Savings v. Typical Irrigator	4.4	9.9	8.2	16.3	15.1	10.8	11.1	13.9	17.2	18.8	21.2
Dry Year		0.8	7.0	5.2	14.9	13.4	6.6	6.9	11.3	15.5	19.5	20.2
Wet Year		3.5	7.7	6.0	14.1	12.0	10.2	10.2	10.6	13.1	17.8	19.7
Avg Year		Water Savings v. Efficient Irrigator	5.5	3.8	11.9	10.8	6.5	6.7	9.6	12.9	14.4	16.8
Dry Year			6.2	4.4	14.1	12.6	5.8	6.1	10.5	14.7	18.7	19.4
Wet Year			4.2	2.5	10.7	8.6	6.7	6.8	7.2	9.7	14.3	16.2
WATER SAVINGS (Values in gpsf)												
Avg Year	Water Savings v. Typical Irrigator	2.7	6.1	5.1	10.1	9.4	6.7	6.9	8.7	10.7	11.7	13.2
Dry Year		1	4.4	3.2	9.3	8.4	4.1	4.3	7.0	9.7	12.2	12.6
Wet Year		2.2	4.8	3.7	8.8	7.5	6.4	6.4	6.6	8.2	11.1	12.3
Avg Year		Water Savings v. Efficient Irrigator	3.4	2.4	7.4	6.7	4.0	4.2	6.0	8.0	9.0	10.5
Dry Year			3.9	2.7	8.8	7.9	3.6	3.8	6.5	9.2	11.7	12.1
Wet Year			2.6	1.6	6.6	5.4	4.2	4.2	4.5	6.0	8.9	10.1

Savings Range:

>15 inches	10-15 inches	5-10 inches	<5 inches

Table 13. Comparison of Landscape Scenarios to Baseline Landscape with Water Savings (gpsf)

Landscape	T-Base 1	T-Base 2	T-MAD	T-Soil	T-Soil&MAD	T-Warm	Mix-Spk	Mix-Drip	Ann-Spk	Ann-Drip	X-GC	X-Deep
Planting	Cool Season Turf	Cool Season Turf	Cool Season Turf	Cool Season Turf	Cool Season Turf	Warm Season Turf	Mixture of Trees, Shrubs & Ground Cover	Mixture of Trees, Shrubs & Ground Cover	Annuals (flowers)	Annuals (flowers)	Ground Cover	Ground Cover
Irrigation Method	SPRINKLER	SPRINKLER	SPRINKLER	SPRINKLER	SPRINKLER	SPRINKLER	SPRINKLER	DRIP	SPRINKLER	DRIP	DRIP	DRIP
Irrigation Turn-On	April 15th	April 15th	April 15th	April 15th	April 15th	April 15th	April 15th	April 15th	April 15th	April 15th	April 15th	April 15th
Irrigation Turn-Off	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st
Irrigation Interval	Month Adj	MWF	MAD	MWF	MAD	MWF	Every 3 days	Every 3 days	MWF	MWF	Wed	Wed
Max Eff Root Zone (in)	7.35	7.35	12	7.35	12	9.8	18	18	4.5	6	6	12
MAD Target (%)	50	50	69	65	80	85	90	90	64	65	70	90
Soil	Silty clay soil	Silty clay soil	Silty clay soil	Loam	Loam	Silty clay soil	Silty clay soil	Silty clay soil	Silty clay soil	Silty clay soil	Silty clay soil	Silty clay soil
BERTHOUD												
WATER SAVINGS (Values in gpsf)												
Avg Year	Water Savings v. Typical Irrigator	1.6	5.7	4.8	9.6	9.2	6.9	7.2	7.4	9.5	10.1	12.0
Dry Year		0	3.7	2.6	6.9	7.3	3.5	4.1	6.1	8.4	9.6	9.8
Wet Year		2.3	5.1	5.2	9.3	7.6	8.0	7.9	6.0	7.7	10.0	11.8
Avg Year		Water Savings v. Efficient Irrigator	4.1	3.1	8.0	7.6	5.3	5.6	5.7	7.9	8.5	10.3
Dry Year			3.7	2.7	6.9	7.3	3.6	4.1	6.1	8.4	9.6	9.9
Wet Year			2.8	2.9	7.1	5.4	5.7	5.6	3.7	5.5	7.7	9.6
BOULDER												
WATER SAVINGS (Values in gpsf)												
Avg Year	Water Savings v. Typical Irrigator	1.5	5.7	4.3	9.6	8.5	6.4	6.7	6.9	9.2	9.4	11.7
Dry Year		0.4	4.9	3.2	9.6	6.6	4.7	4.8	6.0	8.0	9.8	11.7
Wet Year		2.5	5.2	4.3	10.0	7.4	6.2	6.3	6.2	8.4	9.1	10.4
Avg Year		Water Savings v. Efficient Irrigator	4.2	2.8	8.1	6.9	4.8	5.2	5.4	7.6	7.9	10.2
Dry Year			4.5	2.8	9.2	6.2	4.3	4.4	5.5	7.5	9.4	11.3
Wet Year			2.6	1.8	7.5	4.9	3.7	3.8	3.7	5.9	6.6	7.9
FORT LUPTON												
WATER SAVINGS (Values in gpsf)												
Avg Year	Water Savings v. Typical Irrigator	2.7	6.1	5.1	10.1	9.4	6.7	6.9	8.7	10.7	11.7	13.2
Dry Year		1	4.4	3.2	9.3	8.4	4.1	4.3	7.0	9.7	12.2	12.6
Wet Year		2.2	4.8	3.7	8.8	7.5	6.4	6.4	6.6	8.2	11.1	12.3
Avg Year		Water Savings v. Efficient Irrigator	3.4	2.4	7.4	6.7	4.0	4.2	6.0	8.0	9.0	10.5
Dry Year			3.9	2.7	8.8	7.9	3.6	3.8	6.5	9.2	11.7	12.1
Wet Year			2.6	1.6	6.6	5.4	4.2	4.2	4.5	6.0	8.9	10.1

Savings Range:

>10 gpsf	5-10 gpsf	<5 gpsf

There are many observations that can be drawn from this exercise. For simplicity, a subset of these observations believed to be of most interest includes:

- During dry years, less water savings are achievable than during average or wet years, regardless of the landscape scenario. Although this is "obvious" since less precipitation is available to meet plant water needs in dry years, this concept may be overlooked when planning for the "average" year. Planning for a range of dry to wet conditions is important.

- As would be expected, the lowest overall irrigation requirement achieved was for the X-Deep scenario, representing deep-rooted xeric plants irrigated by drip irrigation once per week. This scenario represents approximately 50 to 60 percent savings relative to the baseline turf scenarios. Deep-rooted (12 inches) xeric plants provided an additionally 10 percent reduction in water requirement relative to more shallow rooted (6 inches) xeric plants. The root depth could be affected by choice of xeric plants, as well as by soil type.

- For annuals, use of drip irrigation over spray irrigation resulted in approximately 10 percent less water requirement. This water savings between irrigation types was less evident for trees/shrubs/groundcover. A likely explanation relates to the deeper effective root zone of the trees/shrubs/groundcover scenario relative to the much shallower root zone for annuals.

- Warm season turfgrass had lower water requirements than the other cool season turfgrass scenarios except with regard to the "T-Soil&MAD" scenario for cool season turfgrass. This suggests that an aggressively managed cool season turfgrass with proper soil amendment may achieve water savings comparable to or greater then warm season turfgrass, depending on the management strategy implemented. This is an important finding because GreenCO (2008) and CSU (Koski 2008) both recommend that turf selection should be based on the desired functional, recreational and aesthetic benefits, in addition to considering maintenance and water requirements. (If the "wrong" turf type is selected for a particular use, then it may be end up being replaced later.) For example, cool season turfgrass is desirable for certain landscape purposes, such as for high use areas, whereas warm season buffalograss has lower traffic tolerance and may be more suitable for low-traffic areas.[5]

- For cool season turfgrass management scenarios, the lowest water use results for cool season turfgrass planted in loamy soil and aggressively managed using a MAD approach with advanced irrigation technology. This scenario reduced the irrigation requirement by approximately 50% relative to the baseline turf scenarios under an average water year. During average and wet years, this scenario approaches the water savings achieved by drip-irrigated groundcovers and is similar to warm season turf and annual plants watered by drip irrigation. In summary, the irrigation management practice at a site is a critical factor

[5] Warm season grass managed using MAD was not a scenario in this analysis but could be evaluated in future analyses.

in the irrigation requirement. This may represent a significant opportunity for savings on large landscapes, even if this is not directly transferable to the average homeowner.

- As shown in Table 14, the two xeric plant scenarios provide more than 15 inches of water savings relative to Baseline 1, regardless of the water-year type. The relative order of irrigation water requirement for the scenarios evaluated from highest to lowest varies to some extent, depending on the water year type.

Table 14. Water Savings Achieved Relative to Baseline-1 Turf in Berthoud, CO under Average, Dry and Wet Weather Conditions

Landscape Category	Water Savings (inches) Relative to Baseline-1 in Berthoud, CO		
	Avg Year	Dry Year	Wet Year
T-Base 1 (Net Irrig. Requirement in Inches)	*30.3*	*31.1*	*29*
Expected Irrigation Savings (inches) Relative to T-Base 1			
T-Base 2	2.6	-0.1	3.6
T-Soil	7.6	4.2	8.3
T-MAD	9.2	5.9	8.1
Mix-Spk	11.1	5.7	12.8
Mix-Drip	11.6	6.5	12.7
Ann-Spk	11.8	9.8	9.6
T-Warm	14.8	11.6	12.3
Ann-Drip	15.2	13.4	12.4
T-Soil&MAD	15.4	11.1	15.0
X-GC	16.2	15.4	16.0
X-Deep	19.2	15.8	19.0
Color-Coding Legend:			
Red: <5 inches			
Orange: 5-10 inches			
Blue: >10 to <15 inches			
Green: 15 inches or greater			

There are many other observations that can be drawn from Northern Water's analysis completed in support of this report. Overall, this analysis indicates that there are multiple approaches to reduce outdoor water demands based on landscape design and maintenance practices. In particular, there are significant opportunities to reduce the irrigation requirement for turf through aggressive management using weather data and MAD strategies.

8 Analysis of Potential Water Savings from Residential and Irrigation Accounts in the South Platte Basin through 2050: Basin Scale

To provide an initial estimate of the role that landscape water conservation practices may play in meeting the state's 2050 water gap, a basin-scale modeling exercise was completed for the South Platte Basin by Aquacraft, as described in this section.

8.1 Introduction

There are currently approximately 3.5 million people living in the South Platte River basin. This number is expected to reach up to 6.6 million people by 2050.[6] If the population grows as anticipated during this period, then there are significant implications for demands for raw water. According to the South Platte Basin Implementation Plan (SP BIP), demands for municipal and industrial (M&I) water are expected to grow from ~650,000 AF/Yr to approximately 1,150,000 AF/Yr under the low to high growth rate scenarios.[7] In the approach used by the SP BIP, M&I water includes residential, commercial, industrial, irrigation and losses.

In preparation of the SP BIP, water demands were generated by multiplying the number of people living in the area (the driver) by the average per capita demand. In this method, per capita demands are estimated as the ratio of the total water produced (gpd) to the total population (capita) to generate gallons per capita per day (gpcd). Water savings from various conservation programs are then expressed in terms of reductions in per capita use, and new demand estimates are generated. This approach has the benefit of simplicity, but it is difficult to determine how accurate any reduction in per capita use predicted as the result of a specific conservation program (either passive or active) might be since there is no clear mathematical relationship between the cause and effect to rely upon. For example, it is difficult to determine how replacement of old toilets and clothes washers will affect total per capita use for a given system, given the fact that there are so many components to overall water use that need to be taken into consideration.

A more precise way to assess the impacts of growth and other conditions is to use explicit demand models that deal with the demands in a disaggregated manner. Residential and irrigation demands can be modelled based on the values of key parameters that have been found to best predict demands based on empirical data. For example, indoor residential demands are highly dependent on the number of people per household and the efficiency class of the fixtures and appliances present. The values of these parameters can be adjusted to capture the effects of changes in household size and efficiency of the fixtures and appliances present in the home. By doing this, the household water demands for domestic (indoor) uses in gallons per household per day (gphd)

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[6] See Table 2.1 of the South Platte Basin Implementation Plan (BIP).

[7] See Table 2.3 of the South Platte BIP. The estimate of 1,150,000 is the average of the three water demand estimates (low, medium and high) presented in the table. None of these include passive savings. The estimated supply is 736,000 AF (from Table 2-13), so the gross gap is ~414,000 AF. This is the amount that needs to be filled from passive and active conservation.

can be explicitly predicted. The total demands for each category of housing can be estimated in this way for each year of a specific study period. Both total demands and per capita demands can be determined.

The same approach can be used for outdoor (landscape) uses, which are highly influenced by factors such as irrigated area, local net evapotranspiration (ET), the presence of an in-ground sprinkler system and irrigation habits of the occupants (such as whether they typically over-irrigate their landscapes). Allowances can be made for water use by irrigation-only accounts, and an estimate of total water use for residential and irrigation accounts can be prepared over a selected study period, and under a range of conservation scenarios with each based on a unique set of assumptions regarding the factors that affect water use, and how these change over time.

Aquacraft has been studying residential water demands since 1993, beginning with the first end use analysis of residential water use in the Heatherwood neighborhood of Boulder, Colorado. Since then, Aquacraft has conducted end-use analysis on over 4000 homes, most of which have included surveys and landscape analysis. These homes have been highly diverse in terms of their geography, occupancy, levels of efficiency and extent and type of landscape uses. This has provided a large and broad database from which to develop mathematical models of the end uses of water in residences and of water use for landscape irrigation.

To support GreenCO's understanding of potential water savings associated with landscape-related demands under various scenarios, Aquacraft used these models to generate estimates of residential and irrigation demands for the South Platte population over a 40 year time period, which provides estimates out to 2050.[8] Demands have been estimated for indoor and outdoor uses under a range of conservation scenarios. This has provided estimates of the conservation saving potential that are available to bridge gaps between demands and supplies over the planning period, and to identify from where these savings might originate, and the degree to which the savings appear to be achievable without causing undue hardships to the residents of Colorado. This report explains how this was done, and provides summaries of the demands and savings estimates generated by the process.

8.2 Description of the Residential Demand Model

Aquacraft has extracted data from several key end use studies and combined them into a single model of indoor and outdoor water use that focuses on the most available and useful parameters as inputs. Individual models were created for each indoor end use (including leakage). The models also dealt with outdoor (landscape) use based on variables found to best predict landscape use. The outputs for the models were gallons per day per household for each end use and thousands of gallons per year per household for landscape uses. Monthly and annual estimates were prorated from the daily and annual demands output by the model.

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[8]Due to the limited scope of this report, only the South Platte Basin was analyzed; however, this analysis could be expanded to other basins in the future, if desired by GreenCO and/or the CWCB.

The seven studies listed in Table 15 were used to develop models of water use specifically for this application. The data available included: water agency, billing data, end use data developed from flow trace analysis, weather information, and survey data provided by the households. A total of 3659 homes are included in the dataset. All data were entered into a statistical program (SPSS) and analyses were performed to examine the relationships between household end uses and a range of variables. Variables were chosen to maximize both the predictive ability of the models and the practicality of obtaining the needed data. Table 15 shows the end use studies from which the data were derived to construct the household demand models.

Table 15. Studies Used for Development of Water Use Models

Study Name
EPA New Home Study (Standard and High Efficiency)
California Single Family Water Use Efficiency Study
EPA Retrofit Study
Albuquerque Baseline & Retrofit Study
Residential End Uses of Water Study Update (2015)
Residential End Uses of Water Study (1999)
Westminster SF Home Baseline Study (2011)

A list of variables that were found to be useful for predicting indoor end uses of water is shown in Table 16, and the variables used for creation of the landscape (outdoor) model are shown in Table 17. These variables were used to create models of the individual uses of water: toilets, showers, clothes washers, faucets, leaks, dishwashers, baths and other indoor uses. The output from these models was gallons per day of household use for the indoor models and kgal of annual use for the landscape model.

The models of indoor and landscape water use were used to create a spreadsheet-based predictive tool for making projections of indoor and outdoor water demands for residential customers. The demands are estimated on an annual basis for the following categories of customers: single family existing, single family new, multi-family existing, multi-family new, and landscape irrigation accounts. Allowances can also be made for Industrial, Commercial and Institutional (ICI) demands, which are estimated based on the historic fraction of residential demands that they comprise.

The model works by increasing or decreasing the values of the individual predictive variables on an annual basis in a way that simulates changes in the population for that variable. The user specifies the starting value of each parameter, the annual change (either + or -), and an upper and lower limit that variable will be allowed. Each year these values are updated (within the specified limits) and the demands are recalculated. The output for each category is placed in tables of monthly demands, which are then summarized on an annual basis. Allowances are made for real losses and treatment and storage losses.

The starting values for the parameters were based on information obtained from the recent Residential End Uses of Water Update Study (REUWS2). Two of the logging sites for that study, Denver and Fort Collins, are located in the South Platte basin, so data on the parameters was available from the logging and survey data collected for that study. Data for the demand projections were also obtained from the U.S. Census for housing and population information.

Annual changes in the values were selected to simulate various water conservation programs. These annual changes to the parameter values, in combination with the limits, allowed gradual changes in variables such as the percent of homes with high efficiency toilets or clothes washers to be simulated. Changes in water price, irrigated area, or the percent of homes over-irrigating could also be simulated. In this manner, household and landscape water demands can be explicitly estimated based on changes to parameters that have been demonstrated to affect each end-use rather than having to rely on estimates based on percent changes or gross changes to average per capita use, which are difficult to explain from empirical data.

Table 16. Variables Used for Modelling Indoor Household Water Demands

	Indoor Variable	**Description of Variable**
1	Capita	Number of people per home
2	Adults	Number of adults per home
3	Toilet_Class (-1,0,1)	L=>2.0 gpf (-1), E=1.4-2.0 gpf (0), H=<1.3 gpf (+1)
4	CW_Class (-1,0,1) (Clothes Washer)	L=>30 gpl (-1), E=20-30 gpl (0), H=<20 gpl (+1)
5	Non_Adults_+1	ln of <21 yr olds + 1
6	Shower_Class (-1,0,1)	L=>3 gpm (-1), E=2-3 gpm (0), H=<2 gpm (+1)
7	Shower_Duration	Ln of durations (Avg=8.0 min)
8	% with Outdoor_Spa	0 = no spa; 100% = spa
9	% with swim_pool	0 = no pool, 100% = pool
10	% with HW_OnDemand (Hot Water)	0 = no on demand, 100% = on demand
11	Indoor_Use_Excluding Leaks	Ln of indoor use w/o leaks (calculated)
12	% with Softening	0= no; 100% = yes
13	% with IndoorSpa	0 = no spa; 100% = spa
14	Employed_Adults	Ln of employed Adults
15	Adults_Home_in_day	integer
16	Baths_per_week_survey	Estimated value from surveys
17	Income_Percentile	Avg Income as percentile of all study homes
18	% with Disposal	0= no; 100% = yes
19	DW_Class (Dishwasher)	L=>10 gpl (-1), E=6-10 gpl (0), H=<6 gpl (+1)
20	% of Pop with Active Leak Control	% of population with active leak cntrl.
21	% of Pop with toilet recycle Systems	% of pop. With toilet recycle systems

L = Low; E = Efficient; H = High; gpf = gallons per flush; Ln = natural logarithm

Table 17. Variables Used for Developing Landscape Model

	Outdoor Variable	Description of Variable
1	Intercept	Constant term
2	Irrigated Area (sf)	Average irrigated area per household
3	Net ET (inches)	Average Annual Net ET
4	Ave Cost at 25 kgal ($/kgal)	Avg $/kgal for water + ww at 25 kgal consumption
5	% of HHs w/In-ground sprinklers	
6	% HHs Over-irrigating	% of households that are applying more than the theoretical irrigation requirements for their landscapes

HH = Households

8.3 Population and Housing

According to the U.S. Census, the total population of the counties located in the South Platte basin as of 2011 was 3,524,704 people. These individuals resided in a total of 1,343,997 occupied housing units, of which 72% were single family households and 28% were in multi-family residences. According to the demographics used for the SP BIP, the population of the basin is expected grow to somewhere around 6.6 million people by 2050. The two parameters that are of key importance to the demand models used for this analysis are the number of single family and multi-family households and the average numbers of occupants. As mentioned above, these population projections are in line with the projections contained in the SP BIP. The population and housing projections derived from the Census data and used for the projections in this report are shown in Table 18.

Table 18. Housing and Population Data Use for Projections

South Platte Basin	Start Yr: 2010	Yr 40 (2050)
SF HH (2011)	966,230	1,736,623
SF Capita	2.74	2.75
SF Population	2,648,147	4,775,712
MF HH	377,767	678,937
MF Capita	2.32	2.32
MF Population	876,531	1,581,923
Total Population	3,524,680	6,357,635

The projection for single family and multi-family household growth are shown in Figures 6 and 7, respectively. These were developed by inserting the starting numbers of housing units and an initial growth rate of 2.5% for each category. An exponential decay factor was used to simulate a gradual deceleration of growth over time as the population growth faces resistance from the environment. This factor was adjusted so that the growth in population and housing reasonably matched the growth scenario of the SP BIP. The average population forecast from the BIP was 6.6 million people, and the population projection from this analysis was 6.36 million.

Figure 6. Projection of SF Households Used for Water Demand Projections

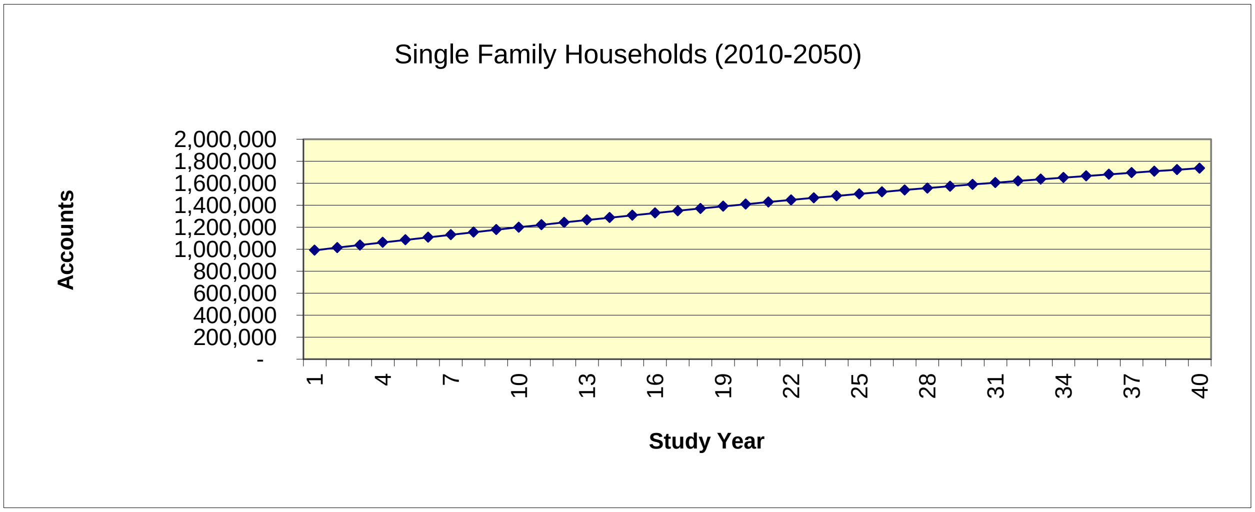
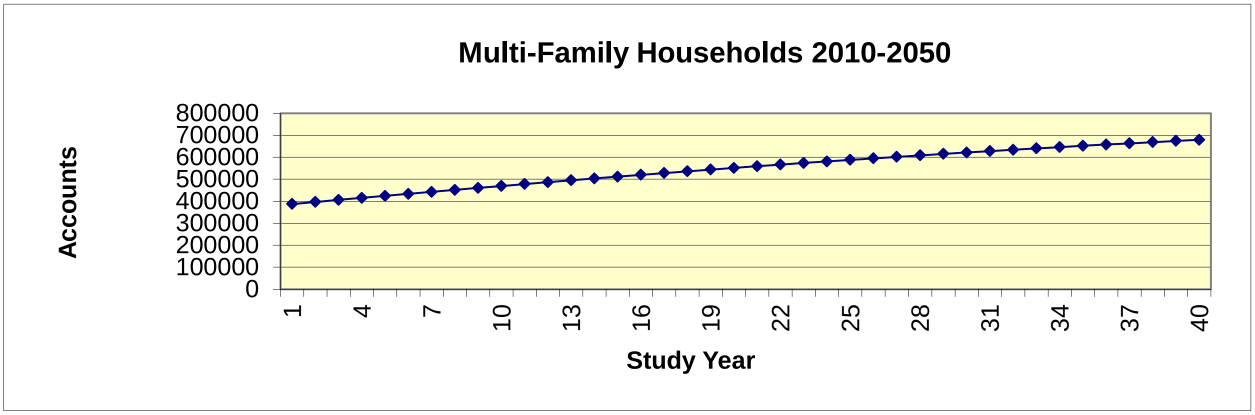
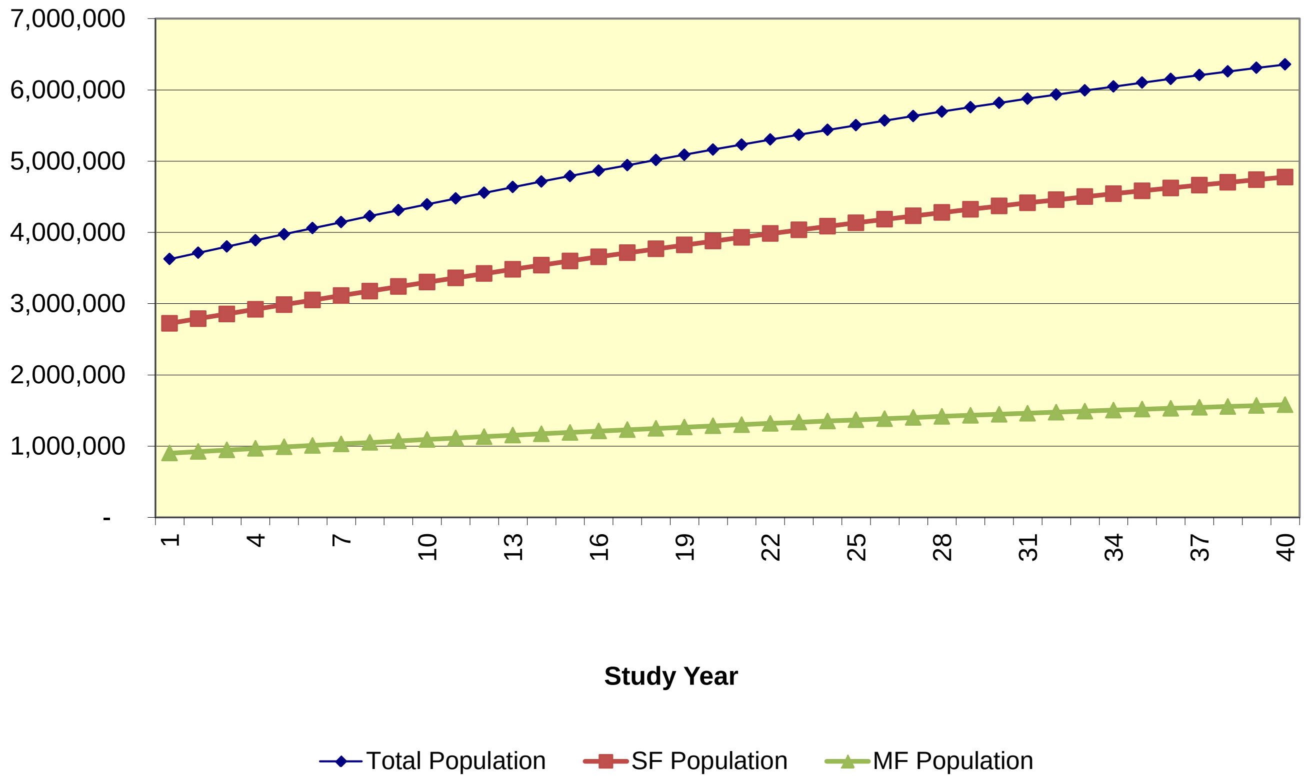


Figure 7. Projection of Multi-family Households Used for Demand Projection



The population for the Basin over the 40 year planning period is shown in Figure 8. These projections assume that the same mix of housing between SF and MF that was present in 2010 would prevail over the planning period. This assumption could easily be changed by altering the growth rates for the two categories to shift more of the new population into multi-family housing. For the present analysis, the assumption was that the future mix would remain the same as the current mix.

Figure 8. Population Projection for South Platte Basin: 2010-2050



8.4 Baseline Water Demands

In order to determine how well the Aquacraft model conforms to the general projections made by the SP BIP, the model was run over a 40 year period with parameters set to simply extrapolate the existing conditions estimated for the current population based on the REUWS2 results. The key parameters used are shown in Table 19. Parameters shown in Table 16, but not shown in Table 19, were left unchanged.

Table 19. Values Used for Baseline Analysis for Single Family Households

Parameter for Existing and New Single Family Households	Starting Value
People per home	2.75
Average efficiency class of toilets	-0.54 -1 = low >2.0 gpf, 0 = medium 1.4-2.0 gpf, 1=high <2.4 gpf
Average efficiency class of clothes washers	-0.24 -1 = low >30 gpl, 0= medium 20-30 gpl, 1= high< 20 gpl
Average efficiency class of showers	0.45 -1=low >3 ppm, 0=medium 2-3 gpm, 1=high <2 gpm
Average efficiency class of dishwashers	0 -1 = low >10 gpl, 0=medium 6-10 gpl, 1=high <6 gpl
% of Population with active leak control	0
% of Population using recycled water for toilet flushing	0
Average irrigated area	6500 sf
Average net ET	32 inches
Average cost of water at the 25 kgal consumption level	5.81
% of households with in-ground irrigation systems	53%
% of Households over-irrigating	30% (existing), 50% new
Parameters for New Single Family Homes	

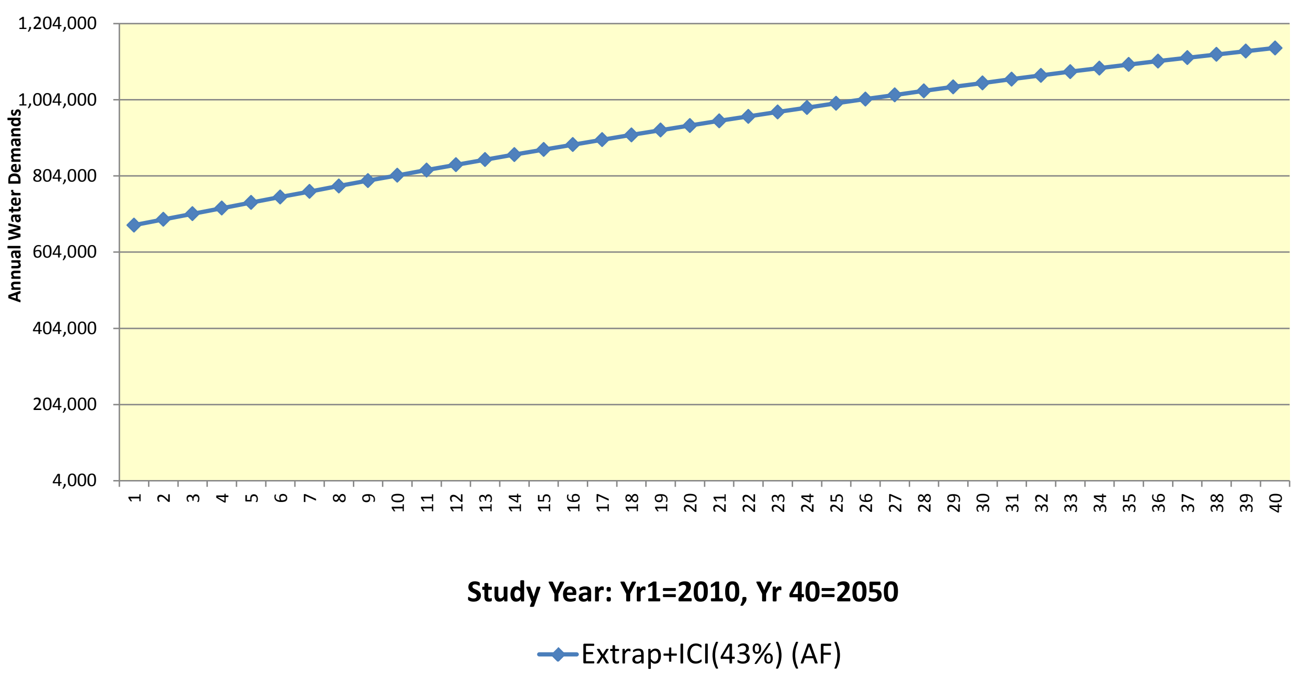
Table 20. Values Used for Baseline Analysis for Multi-family Households

Parameter for Existing and New Multi-Family Households	Starting Value
People per home	2.33
Average efficiency class of toilets	-0.50 -1 = low >2.0 gpf, 0 = medium 1.4-2.0 gpf, 1=high <2.4 gpf
Average efficiency class of clothes washers	-0.50 -1 = low >30 gpl, 0= medium 20-30 gpl, 1= high< 20 gpl
Average efficiency class of showers	0.0 -1=low >3 ppm, 0=medium 2-3 gpm, 1=high <2 gpm
Average efficiency class of dishwashers	0 -1 = low >10 gpl, 0=medium 6-10 gpl, 1=high <6 gpl
% of Population with active leak control	0
% of Population using recycled water for toilet flushing	0
Average irrigated area per account	40,000 sf
Average net ET	32 inches
Average cost of water at the 25 kgal consumption level	5.81
% of households with in-ground irrigation systems	100%
% of Households over-irrigating	20% (existing)

Using these parameters, the model was run for a 40 year period in which the numbers of households followed the growth curves shown in Figures 6 and 7, the parameters for the new households were kept the same as that of the existing households. In addition to the residential demands, the model included allowances for irrigation-only accounts and ICI accounts. Since data are not available to permit explicit modelling of these account types, the billed consumption reports submitted by the 26 agencies that participated in the REUWS2 study were used to set the percent of water for irrigation and for ICI to the same proportion of residential use that prevailed in the REUWS2 participants. For irrigation-only accounts, this was 10%, and for ICI accounts, the proportion was 50%. The average percent of billed deliveries for the 26 agencies was 6% for irrigation and 62% for residential (SF+MF), so the irrigation use amounted to 10% of the residential consumption. Similarly, the deliveries for ICI accounts amounted to 32% of total deliveries, compared to 62% for residential. So, the ICI allowance was set to 50% (initially). This was reduced to 43% so that the total deliveries for the model matched the estimated deliveries from the SP BIP demands discussed earlier in this report. Using these parameters, the demand model projected total M&I demands, including losses, irrigation and ICI demands that are shown in Figure 9. These start at 675,000 AF and grow to 1,140,000 AF in 2050 (year 40 of the study period). These demands do not include passive savings. According to the SP BIP, the total water supplies available to the South Platte Basin are 736,000 AF, which implies a total gap between demands and supplies of 404,000 AF of water.[9]

The purpose of this model scenario was simply to show that the model predictions for total M&I demand matched the predictions of the SP BIP. ICI demands were not included in the runs that estimated savings from residential and irrigation accounts. The reason for this is that the ICI demands were pegged at a specific percentage of residential demands (43%). This meant that as residential demands dropped in response to conservation programs, the ICI demands would fall proportionally. While it is reasonable to assume that ICI demands will drop as residential demands fall, there is no reason to expect them to fall in a constant proportion. Therefore, to avoid possibly over-estimating savings from ICI account, ICI savings were not included in the model runs that were used for prediction of savings. The setting aside of ICI demands had no bearing on the outcome of the study; however, since our objective was to obtain estimates of the savings available from the residential and irrigation accounts. (Savings from ICI customers could be the subject of a separate study.)

Figure 9. Projected Total M&I Water Demands (Baseline Condition) using Extrapolation from Existing Conditions and No Passive Conservation



[9]The SP BIP estimated that the M&I demands with passive savings to be exactly 10% of the gross demands; suggesting that the passive savings were estimated as a simple percent of the gross demands.

8.5 Predicted Savings for Four Scenarios

Working for the Baseline water demand calculated in Section 8.4, four water conservation scenarios were calculated. These scenarios included:

- Scenario 1: Savings from Passive Changes (Indoor)
- Scenario 2: Reducing Rates of Over Irrigation
- Scenario 3: Reducing Effective Irrigated Areas by 10%
- Scenario 4: Reducing Effective Irrigated Areas by 25%

8.5.1 Scenario 1: Savings from Passive Changes

Rather than assume that passive savings can be estimated as a flat percentage of gross demands, the demand model was run to simulate passive savings as the first scenario studied. By definition, passive savings are those reductions in residential water demands that are expected to occur due to changes in building codes and standards and are expected to occur irrespective of any actions on the part of the water agency. In this case, passive savings are assumed to be derived from the changes outlined in Table 21. For this study, no other indoor residential conservation programs were studied since the focus of this investigation was on the potential savings from landscape uses, after passive savings were taken into account.

Table 21. Changes to Baseline Case to Model Passive Savings

Parameter	Category	Passive Change
Toilets	SF Existing	Gradual retrofit to HET standards in 40 years, with maximum penetration at 90% of existing SF households.
	SF New	All new SF households come in at HET standards.
	MF Existing	Retrofit all existing MF units to HET in 40 years
	MF New	All new MF units come in with HET toilets.
Clothes Washers	SF Existing	Retrofit to high efficiency standard (<20 gpl) over 40 years in 90% of homes.
	SF New	All new homes come in at high efficiency status.
	MF Existing	Replacement of all units to high efficiency standard over 40 years.
	MF New	All new MF units come in at high efficiency.
Showers	SF Existing	Upgrade to high efficiency over 40 years in 90% of homes.
	SF New	All new SF units come in at high efficiency.
	MF Existing	Replacement of all showers to high efficiency over 40 years.
	MF New	All new MF units come in with high efficiency showers.
Dishwashers	SF Existing	Replacement of dishwashers to high efficiency units in 90% of homes over 40 year period.
	SF New	All new SF units come in with high efficiency dishwashers.
	MF Existing	Replacement of all dishwashers to high efficiency over 40 years.

8.5.2 Scenario 2: Effects of Reducing Rates of Over Irrigation

After analyzing the impacts of passive conservation, the next option studied was to reduce the percentages of households that were over-irrigating. The model of landscape water use showed a strong relationship between the average landscape water use and the percentage of households that were applying more than their theoretical irrigation requirements (TIR). In the baseline and passive cases, the percentage of SF homes that were over-irrigating was 30% and the rate of over-irrigation in the multi-family properties was 20%. In the reduced excess irrigation case, these rates were assumed to be brought down to 10% at 1% per year. In this case, there was no change to the irrigated areas or types of irrigation systems employed. The only change was that by whatever means necessary, the percentage of customers that were applying more than their theoretical requirements was reduced from 30% to 10% for single family homes and 20% to 10% for multi-family homes. This simulated the savings that can be obtained through better irrigation management BMPs rather than changes to plant materials or reduced effective irrigated areas.

8.5.3 Scenarios 3 and 4: Effects of Reducing Irrigated Areas

The third option studied was to reduce the average irrigated areas of the customers by 10% over the 40 year study period. This meant that the average irrigated areas of the SF homes dropped from 6529 to 5876 sf at 1% per year. The new SF homes were assumed to be limited to no more than 5000 sf of irrigated area. The existing multi-family properties reduced their irrigated area by 10% from 40,000 sf to 36,000 sf at 1% per year, and the new multi-family properties were assumed to have no more than 36,000 sf of irrigated area.

A fourth option was included, which was to reduce irrigated area by 25% for existing and new residences. The difficulty of reduction of the average irrigated areas should not be under-estimated. Many homes may already be well under the average area, and not able to reduce their areas easily. Reductions of 10% are thought to be challenging, and reduction of 25% for the average service area would be a difficult task. (*On selected individual parcels, accomplishing this reduction may not be overly difficult, but this margin of demand reduction may not exist on all properties throughout a service area. Thus, additional analysis would be needed to further evaluate feasibility*.)

Reduction of irrigated area does not necessarily mean that 10% and 25% of landscaped areas are eliminated. While a gross reduction in irrigated areas could be accomplished, an equally valid approach would be to alter the landscapes by use of a greater proportion of low-water plants to have a lower overall irrigation requirement equivalent to a 10 to 25% irrigated landscape area reduction.

8.5.4 Results

The results of the baseline plus four conservation scenarios are shown in the following figures and tables. (Baseline is labelled as “Extrap” in the figures.) Figure 10 shows a graph of annual residential and irrigation demands that are projected for the baseline case and each conservation scenario. Figure 11 shows the estimated savings relative to the baseline case for each scenario.

Table 22 provides the estimated total M&I and Residential/Irrigation demands for each of the 40 years in the study period and the savings from the passive case (Scenario 1), the case with less excess irrigation (Scenario 2) and the two cases with reduced effective irrigated areas (Scenarios 3 and 4). The figures show that the largest savings are expected to come from the passive replacement of the existing toilets, clothes washer, showers and dishwashers over the next 40 years with new, high efficiency devices. As shown in Table 22, the savings in year 40 from the passive case (177,745 AF) are expected to equal 16% of the gross M&I demands (1,150,020 AF) and 22% of the gross residential and irrigation demands (819,622 AF).

The three additional conservation programs all involve changes only to landscape water use rather than any additional changes to indoor uses from leak control or recycling of gray water for toilet flushing. If the percentage of the residential and irrigation properties that are over-irrigating could be brought down to no more than 10%, then another 87,000 AF of additional water could be saved. These additional savings could be increased to 115,000 AF if effective irrigated areas could be reduced by 10%, and the savings could be brought up to 146,000 AF with a reduction of 25% in irrigated areas. As noted earlier, these irrigated area reductions are not necessarily removal of irrigated landscape area, but could be accomplished by changing the water use intensity of the landscape to mimic the water savings from an equivalent area reduction. For purposes of this report, all of these savings are projected to occur from only the residential and irrigation accounts, and do not include any savings from ICI uses, which are certainly available, but have not been quantified here.

According to the SP BIP, the gross water supply gap equals 414,000 AF. This is the difference between the gross demands and the supplies without taking passive conservation savings into account. By this analysis, the available savings from the options evaluated for this report, as shown in Table 23, could equal from between 43% to 78% of this gap, without accounting for additional active indoor controls and additional savings from ICI uses, where substantial water savings are also expected to be available.

Figure 10. Projected Residential and Irrigation Water Demands and Four Conservation Scenarios

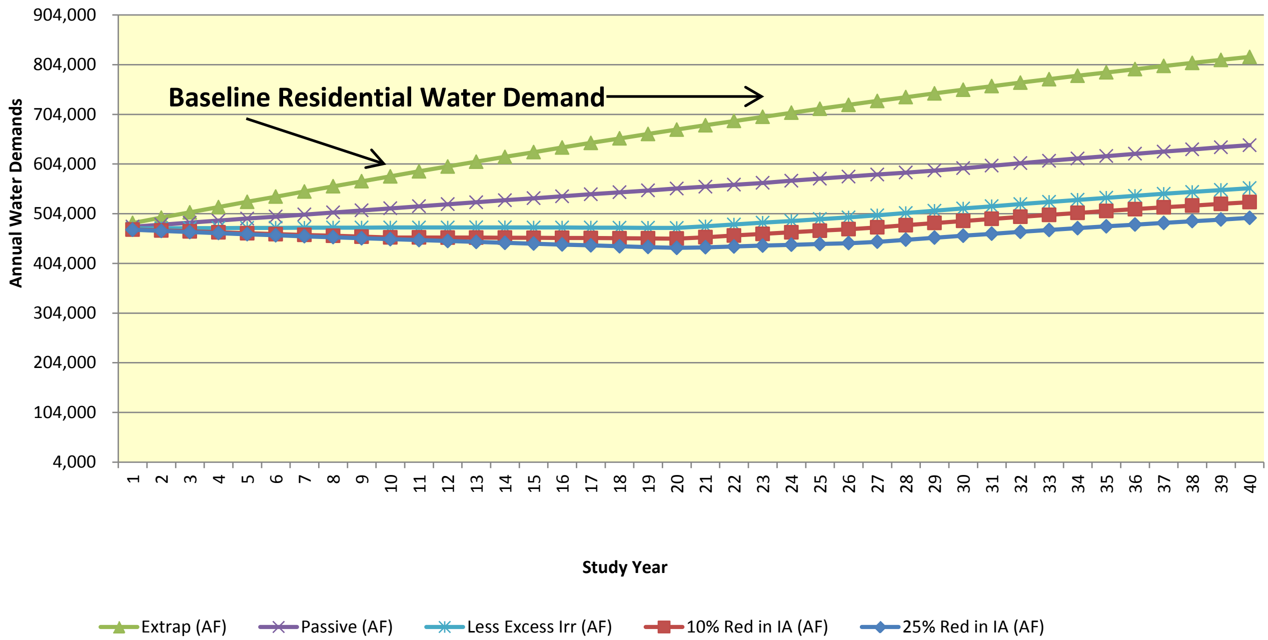


Figure 11. Projected Cumulative Annual Savings (AF) Relative to Baseline for Four Scenarios

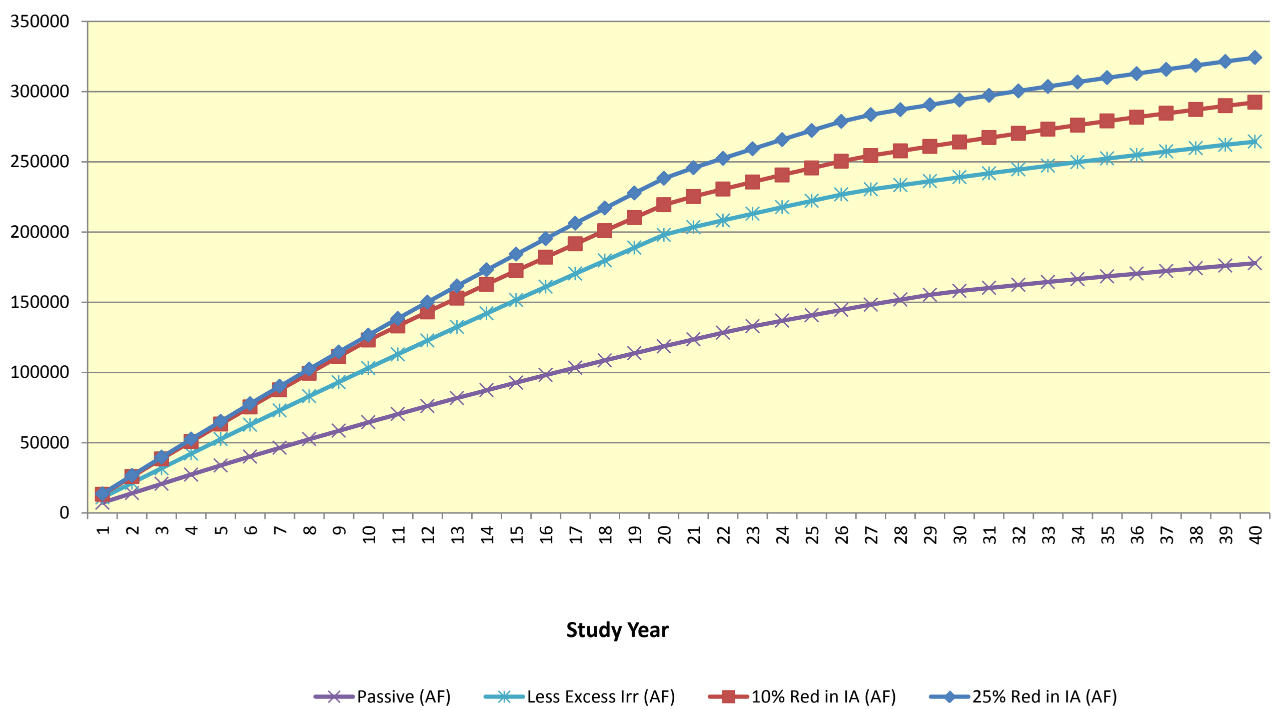


Table 22. Projected Total and Incremental Water Savings from Three Water Conservation Scenarios

	Baseline M&I Demands	**Baseline Res. & Irrig. Demands**	**Total Savings Relative to Baseline Case**			
Year			Passive (AF)	Passive + Less Excess Irrigation on No More than 10% of Landscapes (AF)	Passive + Less Excess + Reduce Irrigated Area by 10% (AF)	Passive + Less Excess + 25% Reduction in Irrigated Area
2011	674,909	485,229	7265	10854	13128	13556
2012	689,885	495,996	14025	21327	25808	26648
2013	704,771	506,698	20684	31751	38374	39611
2014	719,557	517,329	27243	42124	50824	52444
2015	734,234	527,881	33700	52442	63156	65144
2016	748,793	538,348	40057	62703	75369	77710
2017	763,226	548,724	46312	72904	87461	90142
2018	777,525	559,005	52467	83033	99431	102432
2019	791,682	569,183	58521	93095	111276	114584
2020	805,691	579,255	64475	103086	122997	126595
2021	819,545	589,216	70328	112925	133058	138392
2022	833,239	599,061	76082	122691	143027	150049
2023	846,768	608,787	81737	132380	152905	161564
2024	860,125	618,391	87292	141991	162689	172938
2025	873,307	627,868	92749	151520	172378	184169
2026	886,310	637,216	98108	160967	181970	195256
2027	899,129	646,433	103370	170329	191463	206199
2028	911,762	655,515	108535	179605	200855	216997
2029	924,206	664,461	113604	188791	210145	227650
2030	936,457	673,270	118579	197887	219332	238157
2031	948,515	681,939	123459	203386	225220	245624
2032	960,377	690,467	128246	208217	230435	252418
2033	972,042	698,854	132832	212958	235553	259117
2034	983,508	707,097	136787	217609	240575	265721
2035	994,775	715,198	140665	222171	245501	272230
2036	1,005,842	723,154	144466	226644	250332	278606
2037	1,016,709	730,967	148192	230326	254365	283503
2038	1,027,375	738,636	151843	233266	257649	287014
2039	1,037,841	746,160	155264	236151	260872	290460
2040	1,048,108	753,542	157994	238980	264034	293839
2041	1,058,175	760,780	160159	241755	267134	297153
2042	1,068,045	767,875	162281	244475	270173	300402
2043	1,077,717	774,829	164360	247141	273151	303586
2044	1,087,193	781,642	166397	249753	276069	306705
2045	1,096,474	788,315	168393	252311	278927	309761
2046	1,105,562	794,849	170346	254816	281726	312752
2047	1,114,459	801,245	172259	257268	284466	315681
2048	1,123,166	807,505	174131	259668	287147	318547
2049	1,131,686	813,630	175963	262016	289770	321352
2050	1,150,020	819,622	177754	264313	292337	324095

8.6 Summary of Savings

Table 23 shows a summary of the projected South Platte gap and the potential savings that the Aquacraft analysis indicates could be met from passive savings and three progressively more aggressive landscape programs. These do not include savings from ICI uses or savings from more advanced domestic conservation programs such as leak control and recycling. It is interesting to note that over 40% of the gap could be met with the passive replacement of interior retrofits, and strict building codes that require all new residences to use the best available fixtures and appliances. While not included here, the model shows that if 50% of new residences were required to employ active leak detection devices and use recycled gray water for toilet flushing an additional 25,000 AF of water could be saved over the 40 year planning period (these estimated savings are not included in Table 23).

Table 23 also shows that of the three landscape programs, the biggest savings are expected to be derived from better management of irrigation and reductions in the percentage of homes that are over-irrigating, rather than from reductions in irrigated areas. However, the additional savings from reductions in effective irrigated areas are also substantial. The combination of the passive indoor savings and the three landscape programs examined in this report could amount to 78% of the anticipated gap in M&I supplies, and this is without accounting for active indoor conservation, ICI conservation and more aggressive landscape-targeted programs.

Table 23. Summary of Total Water Savings from Residential and Irrigation Accounts in the South Platte Basin

	Water Demand & Gap	
Total Available Supply	736,000 AF	
Gross M&I Demands	1,150,000 AF	
Total Gap	(414,000) AF	
	Incremental Savings	**Cumulative Savings (AF)**
Passive Savings	177,751 AF	177,751 (43% of gap)
Saving from reduction in Excess Irrigation	86,558 AF	264,313 (64% of gap)
Savings from 10% Reduction in Irrigated Area	28,024 AF	292,334 (71% of gap)
Savings from 25% Reduction in Irrigated Area	59,782 AF	324,095 (78% of gap)

The SP BIP estimates landscape savings as a percentage reduction in landscape use.[10] These savings ranged from a low of 15% of landscape use in the Low Strategy to a high of 35% reduction in the High Strategy. In order to allow a comparison in percent reductions in landscape use for the three scenarios investigated in this report, the water savings were determined for just the landscape use and are shown in Table 24. This table shows that in order to achieve the savings

[10] See Table 5.2 on page 84 of the Second Draft of the SP BIP.

hoped for in the High Strategy, of 35%, will require the types of changes included in our most aggressive program, namely that no more than 10% of the properties are applying more than their theoretical irrigation requirements, and that the average effective irrigated areas be reduced by 25%. Our medium case, where effective irrigated areas are reduced by an average of 10%, is equivalent to the Medium Strategy of the SP BIP.

Table 24. Summary in Landscape Water Use and Savings (AF/%)

Case	SF Existing	SF New	MF Existing	MF New	Irrig. Only	Total Landscape Water Use
Passive	203420	99362	5294	2469	55425	365970
-Excess Irrigation	150216	73374	4549	2220	47851	278210
Savings	53204 (26%)	25988 (26%)	745 (14%)	249 (10%)	7576 (14%)	87760 (24%)
-10% Effective Irrigated Area	139756	61120	4232	1103	45436	251647
Savings	63664 (31%)	38240 (39%)	1062 (20%)	1366 (55%)	9989 (18%)	114321 (31%)
-25% Effective Irrigated Area	121678	52458	3735	973	42699	221543
Savings	81742 (40%)	46904 (47%)	1559 (29%)	1496 (61%)	12726 (23%)	147427 (40%)

Source: these figures were derived from the monthly demands tables for landscape uses in year 2050 by scenario.

8.7 Relationship of Landscape Demand Reduction Scenarios to Landscape BMPs

The landscape programs investigated in this report are not explicitly tied to any particular landscape BMP, but there is clearly a relationship between achieving the water savings associated with the landscape programs included in the models and the BMPs. The BMPs not only provide the tools to achieve the conservation goals, but also allow savings to be achieved in a way that minimizes negative impacts on the urban environment. The scenarios can be related to the following GreenCO BMPs:

- Reducing over-irrigation can be achieved through implementation of irrigation-related practices that include design, construction and maintenance of irrigation systems, use of advanced irrigation technology, and through the use of water budgets (in combination with education and real time information on water use) so that water is applied according to the needs of the plants in the landscape and so that landscape managers have knowledge of current water use on which to base intelligent operation of their systems. Xeriscape, including use of hydrozones, is also important so that each individual components of the landscape is watered according to its needs, rather than to the highest water using plant in the landscape.

- Reducing effective irrigated area can be accomplished by either changing the balance of the plants in the landscape or by replacing landscape with hardscape or mulched areas (e.g., unvegetated garden paths, outdoor eating areas, etc.) Although hardscape can be an attractive component of urban landscapes, this option should be used sparingly because pervious, living landscape surfaces provide multiple environmental benefits related to stormwater infiltration, reduction in urban heat island effects, aesthetic benefits, atmospheric carbon cycling, and habitat for insects and wildlife. Rebalancing landscape plant mixes to achieve the 10 percent and 25 percent reductions used in the model can be accomplished by designing landscapes using a water budget. A water budget target of 10 to 25 percent reduction relative to turf could be achieved on individual landscapes in many different ways, with a few examples shown below:
    - Irrigated Area at 18 gpsf – (18 x 10%) = Effective Irrigated Area 16.2 gpsf
    - Irrigated Area at 18 gpsf – (18 x 25%) = Effective Irrigated Area 13.5 gpsf

As discussed previously in this report, demand reduction achieved (or achievable) depends on the baseline water use for a site. For the purposes of the example in Table 25, it is assumed that the effective reduction in irrigated landscape is being accomplished by replacing plants with high water requirements with lower water requirements, based on ET. In keeping with Appendix E of the GreenCO BMP Manual (2008), high water use plants are estimated to need 15-20 gpsf. A value of 18 gpsf (29 inches) was used as the starting point for purposes of the calculations in Table 25. (A higher value could also be used (e.g., 20 gpsf [32 inches]).

Table 25. Representative Options to Achieve Effective Irrigated Area Reduction Targets

High Use Plant (gpsf)	% Area	Medium Water Use Plant (gpsf)	% Area	Low Water Use Plant (gpsf)	% Area	Total (gpsf)	Target: 16. 2 gpsf	Target 13.5 gpsf
18	40%	10	30%	5	30%	11.70	✓	✓
18	50%	10	25%	5	25%	12.75	✓	✓
18	50%	10	25%	5	25%	12.75	✓	✓
18	50%	10	25%	5	25%	12.75	✓	✓
18	50%	10	25%	5	25%	12.75	✓	✓
18	50%	10	25%	5	25%	12.75	✓	✓
18	65%	10	0%	5	35%	13.45	✓	✓
18	60%	10	30%	5	10%	14.30	✓	
18	66%	10	17%	5	17%	14.43	✓	
18	75%	10	0%	5	25%	14.75	✓	
18	60%	10	40%	5	0%	14.80	✓	
18	70%	10	20%	5	10%	15.10	✓	
18	70%	10	25%	5	5%	15.35	✓	
18	67%	10	33%	5	0%	15.36	✓	
18	70%	10	30%	5	0%	15.60	✓	

8.8 Suggestions for Improving Predictions

The water demand projections in this report are based on empirically derived relationships between the explanatory variables shown in Table 19 and water use. These values were based on survey information obtained as part of REUWS2 with emphasis on Denver and Fort Collins, but including results from all 26 of the participating agencies across the U.S. and Canada that participated in that study. Data for the new homes was obtained primarily from the EPA New Home Study and various retrofit studies conducted by Aquacraft since 2000. Data for the multi-family properties and irrigation-only accounts is far less reliable and could be improved by obtaining better information on the multi-family sector and the areas of irrigated landscape served in the communities of the South Platte Basin. Much of this information could come from the self-reported information required by the Colorado legislature in House Bill 10-1051. Ultimately, however, the most beneficial action would be to organize a large, systematic study of residential water use and landscape irrigation based on sampling from all of the large water providers in the basin, similar to the end use studies on which the models have been based upon. This would be a major undertaking, but the work would provide a wealth of details on the parameters needed to make accurate predictions of water use, and would greatly improve the accuracy of the predictive tools such as the model used for this analysis. This would allow water demand projections to be made in a more explicit and mathematically satisfying manner.

9 Summary and Conclusions

To support GreenCO's efforts to further quantify the benefits of landscape water conservation BMPs, an expanded literature review has been completed, taking the next steps beyond GreenCO's 2009 literature review. Initially, the intention of the report was to extract new landscape water conservation savings (demand reduction) from the literature and normalize the varied findings reported in the literature. However, the limited available empirical data indicated that additional analysis approaches were needed to better address GreenCO's objectives. As a result, three approaches have been used in this report to further the understanding of the potential role of landscape water conservation BMPs. These include: 1) compiling and normalizing the findings of existing empirical data in the literature, 2) conducting engineering calculations to better quantify how landscape water needs change as BMP-related variables are altered (better quantifying theoretical irrigation needs), and 3) macro-scale modeling conducted for the South Platte Basin to estimate the potential water demand reductions. Although each of these exercises was primarily oriented to Front Range settings, similar exercises could be conducted for other basins in Colorado. This decision was made to manage the scope of this report and because the largest water gap is present on the Front Range. All three of these exercises could continue to be refined based on new data, or other hypothetical scenarios. Key findings from this analysis include:

1. Both empirical data and modeling efforts demonstrate that landscape water conservation BMPs can provide significant water demand reductions, without sacrificing attractive landscapes. The absolute magnitude of these reductions varies based on site-specific landscape conditions, climate and behavioral change. The primary practices evaluated in

this report relate to Xeriscape (including, but not limited to, plant selection), irrigation practice and technology, soil amendment (to a limited extent) and improvements to irrigation systems in response to irrigation audits.

2. Simply reducing over-irrigation remains a significant opportunity for water savings. This practice can be implemented without costly retrofits of landscapes, although upgrades to irrigation systems and use of advanced irrigation technology can certainly support this objective. Water budgeting is a fundamental tool that can be used to educate property owners and landscape contractors about the irrigation requirements needed to maintain healthy landscapes. When targeting reduction in over-irrigation, recent studies (e.g., Denver Water [2015], Aquacraft [2015]) have shown that many service areas include multiple irrigation user types: those who under-irrigate, those who practice sustainable irrigation practices and those who over-irrigate. Efforts to reduce over-irrigation and planning-level reduction targets should to be targeted to the subset of customers who are over-irrigating. Modeling conducted by Aquacraft for this report shows that reducing over-irrigation by 20% for single family residential units and 10% for multi-family residential units could save nearly 86,560 AF of water in the South Platte Basin over a 40-year period.

3. Improved consistency and standardization of reporting protocols for landscape water conservation/efficiency studies would improve the overall opportunity to synthesize and quantify water savings associated with various practices. This lack of consistency constrained the number of studies suitable for developing quantitative water savings associated with various practices. Nonetheless, quantitative ranges of savings in gallons per square foot (gpsf) were calculated for the Front Range for the following general practice groups:

    a. Conversion of Cool-Season Turf (e.g. Kentucky bluegrass) to Plants with Lower Irrigation Requirements: Converting cool-season turf areas to shrubs, ground covers and perennials is estimated to save 2.0 to 5.5 gpsf of landscape area. These savings increase to 5.9-11.5 gpsf if the replacement is with low-water xeric plants. Portions of lawns where such conversions may be particularly beneficial include steep slopes, narrow strips that are difficult to irrigate, and other areas where cool-season turf is difficult to efficiently maintain or is not providing aesthetic or functional benefits.

    b. Irrigation Efficiency Audits: Performing irrigation efficiency audits is estimated to save 1.3 to 3.3 gpsf when irrigation efficiency is improved in response to irrigation audits.

    c. Irrigation System Technology and Retrofits: Study designs vary substantially, making generalizations difficult. Examples of reported savings include 4.8 gpsf for replacing old irrigation systems and 3.3 gpsf for weather based irrigation controllers. Some studies have shown increases in irrigation use when manual watering is converted to automated irrigation or when advanced weather-based controllers are implemented. (In such cases, the baseline landscape conditions represent under-watering and the irrigation level is raised to meet the irrigation requirement of the plants.)

Estimates were also calculated for Grand Junction, with the magnitude of savings (gpsf) generally greater on the West Slope due to higher ET (evapotranspiration) rates and lower precipitation.

4. A spreadsheet model (based on the Dual Kc Method described in FAO 56) was used to calculate the net irrigation requirements of various landscape scenarios, with results compared to two irrigated cool-season turf landscape scenarios. Key findings from this modeling exercise included:

    a. The lowest overall irrigation requirement achieved was for deep-rooted xeric plants, irrigated infrequently using drip irrigation, followed by more shallow rooted xeric ground covers. The ground cover scenario represents approximately 50 to 60 percent savings relative to the baseline turf scenarios. Deep-rooted xeric plants provided an additional 10 percent reduction in water requirement relative to more shallow rooted (6 inches) xeric plants. The root depth could be affected by choice of xeric plants, as well as by soil type.

    b. For annuals, use of drip irrigation rather than spray irrigation resulted in approximately 10 percent less water requirement.

    c. Warm-season turfgrass (e.g., Buffalograss) had lower water requirements than the other cool-season turfgrass scenarios except with regard to the scenario that represented use of soil amendment and irrigation management using a more advanced "manage allowable depletion" (MAD) approach for cool-season turfgrass. This analysis suggests that an aggressively managed cool-season turfgrass with proper soil amendment may achieve water savings comparable to or greater than warm-season turfgrass, depending on the management strategy implemented. This is an important finding because GreenCO and Colorado State University Turf Program both recommend that turf selection should be based on the desired functional, recreational and aesthetic benefits, in addition to considering maintenance and water requirements. For example, cool-season turfgrass is desirable for certain landscape purposes, such as for high use areas, whereas warm-season Buffalograss has lower traffic tolerance and may be more suitable for low-traffic areas.

    d. For cool-season turfgrass (e.g., Kentucky bluegrass) management scenarios, the lowest water use resulted for the scenario represented by soil amendment and aggressively managed irrigation using a MAD approach, which typically requires advanced irrigation technology. (This is the same cool-season turf scenario described in c., above.) This scenario reduced the irrigation requirement by nearly 50% relative to the baseline turf scenarios under an average water year. This scenario approaches the water savings achieved by drip-irrigated annuals and is similar to warm-season turf. In summary, the irrigation management practice at a site is a critical factor in the irrigation requirement. This may represent a significant opportunity for savings on large landscapes or highly managed commercial landscapes, even if this is not directly transferable to the average homeowner.

5. The Dual Kc modeled results compare relatively well to the normalized empirical data from the literature with regard to plant selection, as shown in these examples for the Front Range:

    a. Xeriscape/Plant Selection--replacement of cool-season turf areas with shrubs, ground covers and perennials: Literature = 2.0 to 5.5 gpsf and Dual Kc Model =3.7 to 5.4 gpsf (average year).

    b. Xeriscape/Plant Selection--replacement of cool-season turf areas with xeric groundcovers and deep-rooted xeric plants: Literature = 5.9 to 11.5 gpsf and Dual Kc Model =8.5 to 12 gpsf (average year).

    These results assume that portions of lawns replaced with plants with lower water requirements would be irrigated appropriately (according to hydrozones).

    Study designs and site conditions were too variable to make this comparison for irrigation technology.

6. At a basin-scale, Aquacraft's modeling exercise demonstrated that landscape water conservation and efficiency measures can help to significantly reduce the water gap in Colorado. Three landscape-related conditions were evaluated that considered reductions in over-irrigation and effective irrigated area (scenarios including 10% and 25% reductions in irrigated area). Model results for the South Platte Basin indicate that reductions in over-irrigation and reducing effective irrigated landscape areas can play a significant role in filling the projected 2050 water gap, without eliminating or reducing the aesthetic quality of Colorado landscapes. Of the three landscape-related conservation scenarios evaluated, reduction in over-irrigation provided the most significant water savings, with essentially no impact to landscape quality (since this scenario simply reduces water waste). With regard to reduced effective irrigated area, there are multiple combinations of plant types that can be selected to achieve a 10 to 25 percent effective irrigated area reduction on individual landscape parcels, without drastically changing the character of Colorado's landscaped areas. However, implementing this type of change at a basin or state-wide scale would be challenging. The feasibility of implementation of the modeled scenarios would require additional input from water providers.

10 Recommendations

Many of the recommendations from GreenCO's 2009 Literature Review remain valid, with some additional recommendations emerging as a result of this 2015 study. These recommendations apply to state-led efforts, water providers and the Green Industry, with recommended actions including:

1. Support well-designed monitoring efforts that can be used to better quantify the expected benefits of landscape BMPs and that can be used to support modeling efforts based on empirically-derived relationships (real-world data). Overall, this analysis indicates that there are significant data gaps for empirical studies related to landscape water conservation, particularly studies that provide adequate metadata to normalize data sets to support broader planning objectives. Empirical studies are important because they can incorporate behavioral aspects of water conservation in a manner that agronomic models and theoretical calculations do not. Empirical studies can be used to develop better estimates of uncertainty in demand models and should continue to be conducted and funded.

2. Develop a set of standardized monitoring and reporting protocols for large-scale and site-specific landscape water conservation studies to increase transferability of study findings through better metadata reporting.

3. Assess interest in a statewide database to store conservation studies that follows a standard format noted in #2 above. Such a database would need to be kept as simple as possible to encourage participation and use. It may also be worthwhile to discuss pursuing funding at a national scale from EPA and professional organizations, following a model similar to that used for stormwater BMPs (www.bmpdatabase.org).

4. Support efforts to implement separate metering of indoor and outdoor water use to refine estimates of outdoor water demand. Denver Water and others are implementing this practice in certain areas.

5. Analyze and evaluate House Bill 10-1051 data sets to develop a realistic baseline of outdoor water demand. Although residential single-family water demands have been characterized in several large-scale studies nationally and in Colorado, data for the multi-family properties and irrigation-only accounts is far less reliable and could be improved by obtaining better information on the multi-family sector and irrigated urban landscape areas.

6. Organize a large, systematic study of residential water use and landscape irrigation based on sampling from all of the large water providers in targeted basins such as the South Platte, similar to the end use studies in the Aquacraft models. This would be a major undertaking, but the work would provide a wealth of details on the parameters needed to make accurate predictions of water use, and would greatly improve the accuracy of the predictive tools. This would allow water demand projections and potential savings to be made in a more explicit and mathematically satisfying manner.

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Attachment 1.

Tabulated Quantitative Landscape Water Savings Estimates from Expanded Literature Review (2015)

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Quantification of Expected Benefits of Landscape Conservation BMPs

General Categories of BMP:

IT Irrigation Technology
- WBIC - Weather Based Irrigation Controllers
- SMS - Soil Moisture Sensor
- RS - Rain Shutoff
- TIM - Timer

A Water Use/Irrigation Efficiency Audits

P Plant Selection, Turf Management, Xeriscape

ET_o grass reference ET, inches (gpsf), precipitation not deducted and no landscape coefficient

ET_L ET_L = ETo x K_L , landscape ET based on minimum ET level to sustain healthy, attractive landscape. Precipitation not deducted

K_L landscape coefficient where $K_L = K_v K_d K_{mc} K_{sm}$

ET_{act} ET_L less effective precipitation

Yr	Literature Source	BMP Category		Location	Study Period	Sample Size	SF, MF, Residential, CII, Public, Test Plot	Annual Precipitation inches	ET_o[1] inches (gpsf)	ET_{act} inches (gpsf)	Plant Coeff K_L	Annual Water Application inches	Water Savings (-Water Increase)	Normalize to Front Range	Comments
2015	Alliance for Water Efficiency, Mayer, P., Lander, P. and Glenn, D. (2015). Outdoor Water Savings Research Initiative Phase 1 - Analysis of Published Research. January.	General												Summary	Summary of Published Research
2015	Glenn, Diana T., Endter-Wada, J; Kjelgren, R.; Neale, C. (2015). Tools for evaluating and monitoring effectiveness of urban landscape water conservation interventions and programs. Landscape and Urban Planning 139:82-93. (March).	A	Water Check Audit & irrigation recommenda-tions	Logan, UT	2002-2007	144 "Reliable" No residential mobility, given correct irr. scheduling, etc. 105 in year 2005	SF	17.72	50.7" (31.6 gpsf)	35.5" Range 33.7-37.9" (22.1 gpsf) (Range 21.0-23.6 gpsf)	NA			Not Transferrable	Provide a needed set of common assessment methods and monitoring results.
2013	Endter-Wada, J., D.T. Glenn, C.S. Lewis, R.K. Kjelgren, and C.M.U. Neale. (2013). Water User Dimensions of Meter Implementation on Secondary Pressurized Irrigation Systems. Research Report for Weber Basin Water Conservancy District and the US Bureau of Reclamation. April.	A	Metered Irrigation Water Use	Ogden, UT	2012	869	Residential CII		56.8" (35.4 gpsf)		0.8 turf and 0.5 trees and shrubs			Not Transferrable	Applied a 70% irrigation efficiency to the landscape ET to calculate the estimated "Water Need," the figure in the denominator of the Landscape Irrigation Requirement (LIR). 20% LIRs<1, 60% between LIR of 1 - 2.
2015	Aquacraft, Inc. (2015). Evaluation of Water Savings from Weather Based Irrigation Controllers in Santa Clara Valley. Submitted to Castaic Water Agency, Santa Clarita, CA. January 23.	IT	WBIC	Santa Clarita, CA	2007-2014	892 Paired Group Analysis	SF	NA	68" (42.4 gpsf)	NA	0.8 turf to 0.3 xeric		Net increase of 400 CCF = 2,992 gallons per home	Not Transferrable	For Retrofits aim WBIC at Over-irrigators. Use on under-irrigated properties tends to increase water use.
2015	Boyer, Mackenzie, and Dukes, Michael. (2015). "Wat-er" They Irrigating: Characterizing Irrigation of Individual Residential Water Customers. World Environmental and Water Resources Congress 2015: Floods, Droughts, and Ecosystems. ASCE Conference May 17-21, 2015. pp. 2058-2066.	A	Behavior of individual residential water customers	Southwest Florida Water Management District. Northwest Hillsborough County, member of regional water supply authority, Tampa Bay Water	12 years water billing records (1998-2010); monthly water use analyses 2006-2008	N/A	SF	46"	59.2" (36.9 gpsf)	26.7"	see: M.J. Boyer's paper - Irrigation Conservation of Florida-Friendly Landscaping Based on Water Billing Data.	Occasional 6.1", Low 23.9", Medium 32.8", High 37.3"	Potential savings 5" for the low, medium and high irrigating groups and 24.5" for high-irrigating groups	Not Normalized to Front Range due to climate difference	Design standard of 300 gal/acct/day) is not representative of actual water use of customers. Careful to implement conservation measures that eliminate excess irrigation, while allowing under-irrigators to continue their practice, and reduce water consumption without compromising landscape quality.
2015	Colorado Water Conservation Board (2015). Colorado's Water Plan - Second Draft. Chapter 5 Water Demand, Chapter 6 Water Supply Demand for the Future. July 2.	General		State of Colorado	NA	NA	Residential and Non-residential	Varies	NA	NA	NA		Strategy - % reduction Low - 15% Medium 22-25% High 27-35%	Not Transferable	Conservation measures: Targeted audits for high demand landscape customers, Landscape transformation of some high water requirement turf to low water requirement plantings, Irrigation efficiency improvements. "Stretch Goal": reduce year 2050 demand by 400,000 AF statewide.
2015	Northern Colorado Water Conservancy District (2015). Landscape Watering Needs / Keep-It-Simple (KIS) Landscape. April 28.	P	Irrigation Demand Bluegrass Turf	Berthoud, CO	2004-2014	NA	Irrigation Plots	15.2	54.8" (34.2 gpsf)		0.52 - 0.90	Average Turf 22.1" (13.8 gpsf) Shrubs 16.9" (10.5 gpsf)	Shrubs, groundcover, perennial vs. turf 5.2" (3.2 gpsf)	Shrubs, groundcover, perennial vs. turf 5.2" (3.2 gpsf)	The maximum water demand (17.1 gpsf for turf) exceeded the average year demand by over 5" (~3.4 gpsf). Management allowable depletion (MAD) 0.71 for bluegrass and 0.8 for other plants.
2015	Northern Colorado Water Conservancy District (2015). Landscape Watering Needs / Native Plant Garden. May 5.	P	Alkaligrass, a cool season turf	Berthoud, CO	2004-2014	NA	Irrigation Plots	15.2	54.8" (34.2 gpsf)		0.52 - 0.90				Management allowable depletion (MAD) 0.57 for alkaligrass and 0.8 for other plants
2015	Northern Colorado Water Conservancy District (2015). Landscape Watering Needs / Prairie Landscape. May 5.	P	Mix of warm season grasses	Berthoud, CO	2004-2014		Irrigation Plots	15.2	54.8" (34.2 gpsf)		0.86		Warm season grass savings of ~ 5.1" (3.2 gpsf) as compared to cool season grass		Blue grama-buffalograss mixture, green up late in spring and goes dormant earlier in fall. Management allowable depletion (MAD) 0.8 for Prairie landscape with warm season grasses.

Yr	Literature Source	BMP Category		Location	Study Period	Sample Size	SF, MF, Residential, CII, Public, Test Plot	Annual Precipitation inches	ET_o[1] inches (gpsf)	ET_{act} inches (gpsf)	Plant Coeff K_L	Annual Water Application inches	Water Savings (-Water Increase)	Normalize to Front Range	Comments
2015	Northern Colorado Water Conservancy District (2015). Landscape Watering Needs / Southwest Landscape. May 5.	P	Texas Hybrid bluegrass and Southwest shrubs, groundcover & perennials	Berthoud, CO	2004-2014		Irrigation Plots	15.2	54.8" (34.2 gpsf)		0.35 to 0.90		Southwest shrub, groundcover & perennial mixture savings of 9.5" (5.9 gpsf) as compared to a Native mixture	9.5" (5.9 gpsf)	Management allowable depletion (MAD) 0.71 for Texas hybrid bluegrass and 0.9 for SoWest shrubs, ground cover and perennials. Passive water harvesting - planting higher water requirement plants lower to benefit from runoff
2015	Northern Colorado Water Conservancy District (2015). Landscape Watering Needs / Yucca Garden. May 5.	P	Buffalograss, warm season turf and xeric plantings	Berthoud, CO	2004-2014		Irrigation Plots	15.2	54.8" (34.2 gpsf)		0.35-0.86		Combination buffalo grass and Xeric planting mixture savings of 5.1" (3.2 gpsf) for turf and 9.5" (5.9 gpsf) as compared to a Bluegrass and native planting mixture	9.5" (5.9 gpsf)	Management allowable depletion (MAD) 0.8 for buffalograss and 0.9 for Yucca and hardy ornamental grasses/shrubs
2015	Northern Water Landscape Water Conservation Resources and Training (Retrieved 2015). "Smart Irrigation Technology,"	IT	SM, WBIC, Rain Shutoff	General Information, not site specific										Not Transferrable	Smart Controller Demonstration Project. Factors to consider in placement of sensors, rooting depth and type of soil, slopes cycle/soak
2015	Northern Water Landscape Water Conservation Resources and Training (Retrieved 2015). "Northern Water Turf Grass Water Conservation Studies."	IT P	Turf	Berthoud, CO	2010-Current	11 turf species and grass mixes	Irrigation Plots	15.2	54.8" (34.2 gpsf)					Not Transferrable	Lysimeter study with crop coefficients to be developed. Soil preparation at two levels of amendments, 3 and 6 cy/1000 sf;, two types of compost plant waste and animal waste; tilling at two levels 6" and 15". Spray and subsurface drip irrigation (SDI) systems to be compared.
2014	Bijoor, Neeta S., Pataki, D.E., Haver, D., and Famiglietti, J.S. (2014). A comparative study of the water budget of lawns under three management scenarios," Urban Ecologist DOI 10.1007/s11252-014-0361-4. Published online: May 15.	IT P	Turf species and Irrigation Control	Irvine , CA	July 2008 - July 2009	3 simulated residences with differing turf and irrigation control	SF	14.4" Study period 8.42"	50.2" (31.3 gpsf)	NA	NA	Typical landscape water 113 inches (70 gpsf)		Not Transferrable	The conclusion of the study was that the utilization of smart controllers is more important than the choice of turf species. A water balance analyses is available only for the Typical landscape and the water scheduling was heavy (10 minutes every day for about half of the study period. For this reason, water saving between the Alternatives and the Typical Landscaped appear overstated.
2014	Center for ReSource Conservation. (2014). Putting Conservation into Action, Slow the Flow Impact Analysis Addendum to 2014 Annual Report.	A	Audit quantification, irrigation retrofits, xeriscaping, indoor retrofits, education	Colorado Front Range	Audits conducted in 2013	996 single family properties for Slow the Flow audits	SF	Varies~15-18"	56.2" (35.0 gpsf)	18.1" to 25.4"	0.8	see report.	Audit/consultation savings estimate: Mean Landscape Area: 1.9 gpsf Median Landscape Area: 2.6 gpsf	3.6" (2.2 gpsf)	Multiple programs are employed, including for outdoor water use, water-wise landscape seminars, xeriscape programs, outdoor sprinkler consultations, and retrofit installations or recommendations. Savings reported for audits for single family residences.
2014	Center for ReSource Conservation. (2014). Water Conservation Impact Assessment 2013 Final Report. January 20.	A	Comparison Pre- & Post-Audit	Colorado Front Range	2005-2013 (2 yrs pre-audit, up to 5 yrs post-audit)	2054 SF initial, 80 in yr 5	SF	Varies~15-18"	56.2" (35.0 gpsf)	2005-13 Range 18.1 - 25.4" (11.3 - 15.8 gpsf)	0.8	see report.	4.8 kgal per participant Mean Landscape: 1.2 gpsf Median Landscape: 1.5 gpsf	2.1" (1.3 gpsf)	Slow the Flow (STF) participants tended to have higher water use than the general population. Water use of general populations follows ET pattern. Educational component of the audit suggested as being a more important factor in water savings than sprinkler system improvements.
2014	Clary, Jane, and O'Brien, B. (2014). Quantification and Expected Benefits of Landscape Water Conservation. Presented at Colorado WaterWise. October.	General	Goals for Grant	Colorado										Not Transferrable	The powerpoint notes that further study is needed to quantify expected water savings in Colorado and outlines a plan and information relating to the need for quantification. Includes: summary of Senate Bill 14-017, and public education pamphlets.
2014	Crookston, Mark A., Northern Water (2014). Deficit Irrigation for Water Conservation. Powerpoint. Retrieved May, 2015.	IT	Water Budget, Irrigation Controllers	Berthoud, CO	2014								No Quantification	Not Transferrable	Testing of Rain Shut-off devices and summary of Smart Controllers. Summarizes Managed Stress Factors, Management Allowed Depletion (MAD), net irrigation depth citing Irrigation Association, 6th Edition.
2014	Davis, S.L. and Dukes, M.D. (2014). Irrigation of Residential Landscapes Using the Toro Intelli-Sense Controller in Southwest Florida. ASCE J. Irrig. Drain Eng.	IT	WBIC	Apollo Beach, Riverview, & Valrico, Hillsborough County, FL	2009-2010 Historical Period 2001-2008	21 in ET Group 15 in Comparison Group		47.6" (29.7 gpsf) for 2 yr period 51.4" (32 gpsf) for 9 yr period	59.2" (36.9 gpsf) 58.4" (36.4 gsl/sf) for 2 yr study period 56.0" (34.9 gsl/sf) for 9 yr period		0.45 (Dec-Feb) to 0.9 (May)	ET Group 18.0" (11.2 gpsf) Comparison Group 24.1" (15.0 gpsf)	6.1" (3.8 gpsf)	Not Normalized to Front Range due to climate difference	Irrigation savings not as significant as identified in other studies due to participants who did not necessarily irrigate more than the TIR. ET controllers decreased water use compared to historic use. Control participants also reduced water use as compared to historic use, thought due perhaps to contact with researchers. Landscape use quite varied but follows same pattern.

Yr	Literature Source	BMP Category		Location	Study Period	Sample Size	SF, MF, Residential, CII, Public, Test Plot	Annual Precipitation inches	ET_o[1] inches (gpsf)	ET_{act} inches (gpsf)	Plant Coeff K_L	Annual Water Application inches	Water Savings (-Water Increase)	Normalize to Front Range	Comments
2014	DeOreo, W. (2014). Some Key Findings of the 2014 REUWS Update Study. WRF Project #4309. Presented at Water Research Foundation (WRF) Sustainable Water Management Conference, Denver, CO, March 31, 2014.	B	Baseline Data	Level 1 and Level 2 participants, Water Providers in US and Canada	2008-2012 $REUWS_2$ 1996-1997 $REUWS_1$	NA	SF	Varies	Varies		NA	NA	20% Savings remains	Not Transferrable	Small number of big users raise mean water use. At least a 20% potential for irrigation use savings remains. Consider water budgets to put high premium on high consumption. Water use per household rather than per capita to scale results.
2014	DeOreo, W. (2014). Some Key Results from REUWS2 Single Family Residential End Uses of Water Study Update, WRF Project #4309 Presented at WaterSmart Innovations, Las Vegas, NV, October 4.	A	Baseline Data	Level 1 and Level 2 participants, Water Providers in US and Canada, including Denver and Ft. Collins, CO in Level 1; Cities of Aurora and Colorado Springs in Level 2 Survey	2008-2012 $REUWS_2$ 1996-1997 $REUWS_1$	838	SF	Varies	56.2" (35.0 gpsf)		NA	Average Outdoor Use Denver 77.0 kgal Ft. Collins 55.9 kgal	Avg. 33.9 kgal/hh; Median 27.6 kgal/hh Caution that many factors and does not represent a trend		Modest Outdoor conservation scenario: 10% reduction in irrigated area; 10% increase in price for outdoor water; 25% reduction in over-irrigation; 18% reduction in use (~10 kgal)
2014	Dziegielewski, B., (2014). "End-Use Based Benchmarking of Residential Water Use." WRF 4309-Residential End Use Study Update REUWS2. Presented at WaterSmart Innovations, Las Vegas, NV, October 4.	A	Baseline Data	Level 1 and Level 2 participants, Water Providers in US and Canada	2008-2012 $REUWS_2$	Denver - 95 Ft. Collins 88 All 838	SF		56.2" (35.0 gpsf)		k_s = species factor k_{mc} = microclimate factor k_d = density factor			Text	Irrigators below TIR assumed to be "efficient" Outdoor savings potential 16% Benchmark usage in gal per household Baseline Data Majority of irrigators efficient
2014	U.S. Environmental Protection Agency. (2014). WaterSense Budget Approach, Version 1.02. July.	A	Water Budget Tool	USA	1961-1990 (Weather Data); Current study		SF	Effective Rainfall - 50%		Landscape Water Allowance (LWA) - 70% of baseline amount of water if landscaped area is covered by well-maintained expanse of average-height green grass	k_L = landscape coefficient k_s = species factor k_{mc} = microclimate factor k_d = density factor	LWA		Text	User enters zip code, Water Budget Finder displays peak watering month, associated Et_o and associated rainfall. Peak watering month = when ET_o exceeds precip by greatest amount. Baseline and LWA are calculated to provide design specifications
2014	Irrigation Association and American Society of Irrigation Consultants. (2014). Landscape Irrigation Best Management Practices. May.	General	Outline of BMPs										No Quantification	Not Transferrable	BMPs for: 1) design, 2) installation, and 3) management
2014	Kopp, K., Endter-Wada, J., Johnson, P., Kjelgren, R. and Rupp, L. (2014). Conserving Water Without Reducing Quality of Life. Utah State University Center for Water Efficient Landscaping.	A	Baseline Use WBIC Recommended Plants	Salt Lake City Metro Area, UT	4/1/2013 to 10/31/2013	1369 - Baseline Not given for WBIC	SF	17.0	57.3" (35.7 gpsf)	NA			WBIC Minimum savings 6.5" (4.1 gpsf)	5.3" (3.4 gpsf)	2013 Irrigation Season, LIR = 2.01 with range from 0.44 tp 6.43 Weber Basin Water Conservancy District, Secondary Meters for irrigation with detailed report on historic use and projected ET need.
2013	Baerenklau, K., K.A. Schwabe, and A. Dinar. (2013). Do Increasing Block Rate Water Budgets Reduce Residential Water Demand? A Case Study in Southern California. University of California, Riverside. Riverside, CA. Water Science and Policy Center Working Paper 01-0913. September.	A	Water Budget and Water Rates	Southern CA	2003-2012	13565 SF households	SF	12" to 16"	56.9" (35.5 gpsf)		NA	NA	18%	Not Transferrable	The study found that a simple (3 or 4 tier) IBR water budget can increase water savings up to 18%, but it takes some times (in this case 3 years) for that level of savings to be reached. Education may be able to speed up the process.
2013	Grabow, G.L., I.E. Ghali, R.L. Huffman, G.L. Miller, D. Bowman, and A. Vasanth. (2013). Water Application Efficiency and Adequacy of ET-Based and Soil Moisture- Based Irrigation Controllers for Turfgrass Irrigation. Journal of Irrigation and Drainage Engineering, 139:113-123.	IT	SMS1(1 set pt.), SMS2 (2 set pts), ET (WBIC), and Timer Irrigation (set monthly to match hist. ET) Controllers with Rain shutoffs	Raleigh, NC	2007-2009 Growing periods (April-Sept)	40 parcels, 4x4m (13.1x13.1=172.1 sf)	NA	2007 - 10.9" 2008 - 24.8" 2009 - 15.8" Long term Average 16.7"	47" (29.3 gpsf) Net ET 2007 - 20.0" 2008 - 18.1" 2009 - 17.9" 2007 - 12.5 gpsf 2008- 11.3 gpsf 2009 - 11.2 gpsf	Long term 23.7" (14.8 gpsf)	0.8	Average of 2007-2008 SMS1 - 11" (6.9 gpsf) SMS2 - 13.5" (8.4 gpsf) TIM - 17.8" 11.1 gpsf ET - 20.3" (12.7 gpsf)	SMS1 - 8.1" (5.0 gpsf) SMS2 - 5.5" (3.4 gpsf) TIM - 1.3" 0.8 gpsf ET - -1.2" (-0.8 gpsf)	Not Normalized to Front Range due to climate difference	• SMS systems applied least water with best efficiency • ET systems applied most water, lowest efficiency, but best turf quality • Irrigation adequacy best for the SMS2 & ET systems • SMS1 averaged the least water applied, but had poorest turf quality • Most effective irrigation was achieved with SMS2 • SMS1 applied 39% less water than TIM (but poor adequacy) • TIM application below ETo. • ET applied 11% more than TIM.
2012	Al-Ajlouni, M.G., D.M. Vanleeuwen, and R. St. Hilaire. 2012. Performance of weather-based residential irrigation controllers in a desert environment. Journal of American Water Works Association, 104(12):E608-E621.	IT	WBIC	NM: Chihuahuan Desert	1.) 12/15/09 - 1/31/10 2.) 4/1/10 - 3/31/11	18 field plots 3.7m x 3.7m 12.1' x 12.1' 147.3 sf	Res.	15.60	45.3" (28.2 gpsf)	NA	1.) 0.76 for December and February 2.) June - August = 0.88 and September - May = 0.76	Irritrol 69.9" (45.1 gpsf); Rainbird 114.5" (73.5 gpsf)	34% (Rainbird ET Manager) and 54% (Irritrol SmartDial) as compared with manual controller	Not Transferrable	Two experiments were performed, and are delineated as 1.) 5 controllers, 1 manual and 2.) Smart Dial (Irritrol) divided all irrigation events into cycles to allow soak time

Yr	Literature Source	BMP Category		Location	Study Period	Sample Size	SF, MF, Residential, CII, Public, Test Plot	Annual Precipitation inches	ET_o[1] inches (gpsf)	ET_{act} inches (gpsf)	Plant Coeff K_L	Annual Water Application inches	Water Savings (-Water Increase)	Normalize to Front Range	Comments
2012	Cardenas-Lailhacar, B. and M.D. Dukes. (2012). Soil Moisture Sensor Landscape Irrigation Controllers: A Review of Multi-Study Results and Future Implications. Transactions of the ASABE Vol. 55(2): 581-590.	IT	SMS	Gainesville, Citra, and Palm Harbor (Pinellas Co.), FL	Varies with location, 2004 - 2008	Gainesville 56 plots Citra 36 plots Palm Harbor 58 homes	Test plots SF	Gainesville Citra Palm Harbor 49.6"	Gainesville 55.0" (34.3 gpsf) Palm Harbor 58.6" (36.5 gpsf)					Not Transferrable	Thresholds settings on SMS important in relation to turf quality on sandy soils with field capacities of 7 to 11%. Irrigation frequency of 7 days/week with control by SMS could provide water savings because with frequent rain, often no irrigation event.
2012	Denver Water Conservation Group. (2012). Which 'Hoods Use Only What They Need? Map.	A	Water Use	Denver		Denver Water service area	SF	15.81"						Not Transferrable	Map of Denver Water service area showing "Which 'Hoods Use Only What They Need?" A - Cameltastic; B - Water Saver; C - Water Neutral; D - Water Addict; F - Drowning
2012	Haley, M.B. and M.D. Dukes. (2012). Validation of Landscape Irrigation Reduction with Soil Moisture Sensor Irrigation Controllers. Journal of Irrigation Drainage Engineering, 138:135-144.	IT	Comparison Auto timers with SMS, RS with Education, & RS	Palm Harbor, Pinellas County, Southwest Florida	Nov 2006 - Dec 2008 26 months	58 homes	SF	26 month period - 41.1" Historical - 49.6"	58.6" (36.5 gpsf)	24.8" (630 mm)	$K_{c\ turf}$ Jan-Dec 0.45 ranging to May 0.9	SMS - 10.9 RS w/ ED - 17.0 RS - 26.5 TIM - 30.2	5.)" 3.1 (gpsf)	Not Normalized to Front Range due to climate difference	The objective of the study was to determine if documented savings of SMS-based controllers under research conditions could be validated in actual homeowner landscape use. Water use and turf quality evaluated. SMS had significantly less (1/3 to 1/2) irrigation events with a water savings of 65% concurred with previous plot studies. No significant difference in turf quality. All treatments under-irrigated in spring relative to Theoretical Irrigation Requirement (TIR).
2012	Sun, H., K. Kopp, and R. Kjelgren. (2012). Water-efficient Urban landscapes: Integrating Different Water Use Categorizations and Plant Types. HortScience, 47(2):254-263. February.	P	Water Use Efficiency for Plants	Utah Botanical Center, Kaysville, Utah	Planted 2004 Study 2009-2010	(3 landscapes x 3 replicates) 9 large drainage lysimeter plots, 600 sf ea.	Irrigation Plots	17.0" Long term Growing seasons 2009 - 7.24" 2010 - 8.46"	56.1" (35.0 gpsf) Years 2009-2010 33.3" 20.8 gpsf		woody plants (0.3 to 0.9) perennials (0.2 to 0.5) turf species (0.5 to 1.2)	Turf Conventional 2009 - 22.8" 2010 - 26.3"	Turf 3.5" (2.2 gpsf) Woody 9.7" (6.0 gpsf) Perennial 20.4" (12.7 gpsf)	Turf 3.2" (2.0 gpsf) Woody 8.8" (5.5 gpsf) Perennial 18.4" (11.5 gpsf)	Plant canopy cover, rather than plant material water use categorization, is controlling factor in woody plant and perennial water use. Under-watering during stressed conditions, plant material plays a larger role in water use. Mild water stress promotes water uptake deeper in the root zone, particularly for drought-adapted plants.
2011	Aquacraft, Inc. (2011) California Single Family Water Use Efficiency Study. Sponsored by the California Department of Water Resources. Managed by the Irvine Ranch Water District. July 20.	A	Baseline Data	Irvine Ranch, CA	2005-2010	735 homes in indoor analysis 87% of homes irrigating 639 homes	SF		51.6" (32.2 gpsf) Mean ETo Pre-Install 47.63"Post-Install 49.6"	Mean Pre-Install 34.9" Post Install 36.8"	0.8			Increase	Water savings potential with the 15% of customers who are over-irrigating
2011	Aquacraft, Inc. (2011). City of Westminster Residential Water Demand Study.	IT	Automatic v. Manual Irrigation Systems	Westminster, CO	2000-2010	70 49 Automatic 21 Manual	SF	NA	56.2" (35.0 gpsf) Average 2000-2010 ETnet 29.4" (18.3 gpsf)	29.1	NA	Manual - 12.7" (7.9 gpsf) Automatic - 22.6" (14.1 gpsf) All - 19.8" (12.3 gpsf)	Manual vs Automatic 9.9" (6.2 gpsf)	Manual vs Automatic 9.9" (6.2 gpsf)	Most Irrigators using less than ETo. Over-irrigators excess if reduced to TIR would reduce demand only 3%. Manual irrigators use much less water and there may be conversion to automatic sprinklers in future. City cautioned that if under-irrigators begin irrigating at TIR, demand would go up 35%.
2011	Farag, F. A., Neale, C. M. U., Kjelgren, R. K., & Endter-Wada, J. (2011). Quantifying urban landscape water conservation potential using high resolution remote sensing and GIS. Photogrammetric Engineering and Remote Sensing: 77(11), 1113-1122. November.	A	Remote Sensing and GIS	Cities of Layton & West Jordan (Salt Lake City suburbs) and Logan, UT	Logan 1997-2000 W. Jordan & Logan 1998-2000	Layton ~6.56 mi^2 up to 2,862 parcels W. Jordan Validate Layton water use Logan % turf shaded by tree canopy	ALL	May-Sep 12.3"	Salt Lake City 57.3" (35.7 gpsf) Logan 50.7" ((31.6 gpsf)	39.4" 24.6 gpsf	0.8 for cool season turf grass 0.5 for trees and shrubs	NA	NA	Not Transferrable	• Commercial-industrial & institutional (CII) users were applying water in excess in greater amounts. • Small % of users accounted for most of the excess irrigation. • Overall accuracy of 89% (In remote method to ground truth) • Lower correlation in ground truth measurements with digital imagery in residential than in commercial.
2011	Irrigation Association, Edited by Stetson, LaVerne E. and Mecham, Brent Q. (2011). Irrigation, Sixth Edition, Falls Church, VA.	General											Not Quantified.	Not Transferrable	Reference for Terms and BMPs
2011	Kopp, K., & Gunnell, J. (2011). Practical Turfgrass Areas. In H. Kratsch, Water-Efficient Landscaping in the Intermountain West: A Professional and Do-It-Yourself Guide (pp. 58-70). Logan: Utah State University Press.	P	Turf Techniques	Northern Utah					50.7" (31.6 gpsf)					Not Transferable	The chapter outlines different techniques to save water, labor, and hydrocarbon emissions through turfgrass management. No specific values are listed. Recommendations include: irrigation times, turfgrass placement, species selection, irrigation frequency, maintenance, and proper fertilization.
2011	Rosenberg, D., K. Kopp, et al. (2011). Value Landscape Engineering: Identifying Costs, Water Use, and Impacts to Support Landscape Choice. Journal of the American Water Resources Association.	P	Value Landscape Engineering (VLE) Model for Landscape Options	Salt Lake City Metropolitan Area, Utah	3 Landscape Types Observed for 8 years and compared to VLE Model	3 Landscapes	Irrigation Plots	16.1	57.3" (35.7 gpsf)		0.8 (cool-season grass), 0.6 (warm-season grass)		Traditional Landscape17.6 gpsf, Perennial Landscape 13.3 gpsf, Average savings 4.3 gpsf	Traditional to Perennial 4.3 gal.sf	Application of a computer VLE model to predict water, financial, and carbon impact of certain changes in a landscape. Model can be found at http://vle.cuwcd.com. Replacing turf saved water but at higher life cycle cost. Intense management increased water use and expenditures.

Yr	Literature Source	BMP Category		Location	Study Period	Sample Size	SF, MF, Residential, CII, Public, Test Plot	Annual Precipitation inches	ET_o[1] inches (gpsf)	ET_{act} inches (gpsf)	Plant Coeff K_L	Annual Water Application inches	Water Savings (-Water Increase)	Normalize to Front Range	Comments
2010	Dziegielewski, B., and J.C. Kiefer. (2010) "Water Conservation Measurement Metrics." American Water Works Association Water Conservation Division Subcommittee Report. June.	A	Water Efficiency Metrics and Benchmarks	Various US locations	2008	7 Water utilities	SF,MF,Other	See Summary range from 8.3 - 44.8"	NA	NA	0.8		NA	Equation given to Normalize data based on a Outdoor Conservation Index (OCI)	Paper provides metrics for seven water utilities including indoor and outdoor water use. Retail water sales by sector by account are given for SF, MF and Other. Precipitation during growing season and Max average temperature during growing season are noted as key parameters to normalize data in similar areas. For cross utility normalization, a Outdoor Conservation Index equation is given.
2010	Mayer, P., DeOreo, W. (2010). "Improving urban irrigation efficiency by capitalizing on the conservation potential of weather-based "smart" controllers." Journal AWWA 102:2. September.	IT	Smart Controllers	Southern CA (Metropolitan Water District of Southern CA) and Northern CA (East Bay Municipal Utility District)	multi-year, years not given	3,112 smart controllers at 2,294 sites	SF, MF, Comm, and Other nonresidential		So. CA 50.2" (31.3 gpsf) No. CA 44.8" (27.9 gpsf)		0.8	TIR ≤ 1, 19.9" TIR ≥ 1, 85"	TIR < 1, 24.1" TIR > 1, 77.6"		Water use increased for customers under-irrigating and decreased for over-irrigators by 7.8%.
2009	Aquacraft, Inc, National Research Center, Inc, and Dr. Peter J. Bickel. (2009). Evaluation of California Weather-Based "Smart" Irrigation Controller Programs.	IT	WBIC	CA Sites Coastal 655, Intermediate 1,444, Inland 195	2 years (varies)	2294 sites 14 WBIC brands	All Types	Varies	Varies by Zone, 18 zones with average annual ET range from 33" to 71.8"	NA	0.8	Pre-Install = 50.4", Post-Install = 50.4"; (Pre-Install 32.7, Post-Install 31.4)	Combined Coastal, Inland & Intermediate Average Savings 2.1" ((1.3 gpsf) Range -0.5 to 3.5" ((0.3 to 2.2 gpsf)	Not Normalized to Front Range due to climate difference	56.7% of sites had a statistically significant reduction in weather-normalized application ratio (actual application to TIR), but 41.8% had an increase. Concludes that WBIC effective for those who are overwatering prior to installation and not effective for those underwatering prior to installation. HydroPoint/Toro/Irritrol did not achieve water savings in this analysis, but the technology performed better over time (yrs 2 and 3 = increase, in further study of 384 sites). Only Accurate WeatherSet (33.2%) and ET Water (6.2%) achieved significant water savings.
2009	Denver Parks and Recreation. (2009). Martin Luther King Jr. Boulevard Post-Construction Analysis. Fact Sheet provided by Jill Wuertz. June. Denver, CO.	IT P	Water Use and Turf Conversion	Denver MLK Boulevard	2001-2008	7 medians on MLK Boulevard	Civic	15.81"	56.2" (35.0 gpsf)		NA	Pre-Const = 44.4" (27.7 gpsf) Post-Const = 29.1" (18.1 gpsf)	15.3" (9.5 gpsf)	15.3" (9.5 gpsf)	Turf Conversion and Replacement of Irrigation System. Irrigated Landscape reduced by 21 %.
2009	Shashua-Bar, L., D. Pearlmutter, and E. Erell. (2009). The cooling efficiency of urban landscape strategies in a hot dry climate. Landscape and Urban Planning, 92:179-186. January.	P	Shade	Sde-Boqer campus in arid Negev Highlands region of southern Israel	July - August 2007	6 different landscape strategies							Trees over grass effect, but quantity not transferrable	Not Transferrable	Four Landscape areas of interest: trees & bare ground; trees & grass; exposed grass; and grass under trees. Conclusions: Combination of shade trees over grass most effective for cooling. Shading grass by trees increased the cooling effect and reduced water consumption. Trees by far the most efficient means of reducing outdoor temperature relative to grass. Adding grass added only slightly more cooling with greater water consumption.
2006	Hurd, B. (2006). Water Conservation and Residential Landscapes: Household Preferences, Household Choices. Journal of Agricultural and Resource Economics, 31(2):173-192. August.	P	Landscape type and behavior/social attitudes toward landscape and water use	Albuquerque, Las Cruces, Santa Fe, NM	2004	423 homeowners	SF						Not Quantified.	Not Transferrable.	Analysis of landscape choices - actual (homeowner's existing) and preferred. Choices sensitive to: water cost, level of public education, and awareness of conservation responsibility.
2005	Gutzler, D.S. and J.S. Nims. (2005). Interannual Variability of Water Demand and Summer Climate in Albuquerque, New Mexico. Journal of Applied Meteorology, 44:1777-1787. December.	B	Climate correlation on water use	Albuquerque, NM	1980-2001 1985 beginning conservation program	City of Albuquerque	NA	9.39"	70.7"(44.1 gpsf)	NA	NA	NA	41 gpcd savings pre- and post-conservation program	Not Transferrable.	Showed that conservation measures, such as educational efforts, direct incentives for consumption reduction, and price increases implemented in 1995 did decrease water per capita demand. (Fig. 2) Also showed that precipitation or forecasts of precipitation reduced residential seasonal daily water consumption. Water use negatively correlated with precipitation and positively correlated with temperature.
2005	Sovocol, K.A. (2005). Xeriscape Conversion Study, Las Vegas, NV: Southern Nevada Water Authority.	P	Xeriscape	Clark County, NV	1995-2001	Xeric (XS) - 472 Comparison Control - 288 Turf(TS) - 253 Comparison Control - 179	SF	4.5	90" 56.1 gpsf		0.33 for Xeric	XS - 27.6" (17.2 gpsf) TS - 117.2" (73 gpsf)	89.6" (55.8 gpsf)	Not Normalized to Front Range due to climate difference	285 of 381 homes saved water following conversion to xeriscape. Turf exceeded ET every month except March. Xeric well below ET year round. "Rule-of-thumb" - xeric landscapes require about a third of the ET as needed for turf. Xeric conversion water use decreased immediately and remained stable.

Appendix A. 2015 GreenCO Literature Review Data Sets with Extracted Metadata

Yr	Literature Source	BMP Category		Location	Study Period	Sample Size	SF, MF, Residential, CII, Public, Test Plot	Annual Precipitation inches	ET_o[1] inches (gpsf)	ET_{act} inches (gpsf)	Plant Coeff K_L	Annual Water Application inches	Water Savings (-Water Increase)	Normalize to Front Range	Comments
2004	Bargar, J., D.F. Culbert, and E. Holzworth. (2004). "Landscape Irrigation as a Water Conservation Practice." Proceedings, Florida State Horticultural Society (2004) 117:249-253.	IT A	Irrigation audit, irrigation operation recommen-dations	Florida: Indian River County's Orchard Island Golf and Beach Resort	1999-2003	293 sites	SF, MF & golf course	51.51	73.2" (45.6 gpsf)	14.7" (9.1 gpsf)	NA	14.4" to 45.2" (9.0 to 28.1 gal.sf)	57% for one year	Not Transferrable	• 2 irrigations maximum per week recommended • Irrigation rates had never been adjusted from those typical for newly established plant materials. • Sprinklers were sometimes obstructed. This problem was addressed with height adjustment or pruning of shrubs or grass. • Need for regular education and evaluation are necessary to maintain change and reduction in water usage.
2004	Kenney, D., R.A. Klein, and M.P. Clark. (2004). Use and Effectiveness of Municipal Water Restrictions During Drought in Colorado. Journal of the American Water Resources Association. 40(1):77-87.2. February.	A	Water Savings through Restrictions in Drought	Front Range CO	May - Aug 2002 Compared to 2000-2001	8 water providers	All users	17" Average 10.2" year 2002	56.2" (35.0 gpsf)				Per capita savings data not transferrable.	Not Transferrable	Water savings by utility and by per capita. 4 conclusions: 1) Mandatory restrictions effective. 2) Voluntary restrictions of limited value. 3) Greatest savings found with most aggressive and mandatory restrictions. 4) Every Provider able to reduce per capita use.
2004	Medina, Jonnie G., and Julia Gumper, (2004) YARDX: Yield And Reliability Demonstrated in Xeriscape: Final Report. Metro Water Conservation, Incorporated, Littleton, CO, p. 140. December.	P		Front Range CO Cities: Fort Collins Greeley Arvada Wheat Ridge Denver	1997-2002	Nine utilities and 357 SF non-rental customers 7 field demonstrations	SF	15" in Denver and Fort Collins 17.5" in Colorado Springs		~30" (18.7 gpsf)	NA	NA	30% Savings Treatment vs. Control, but no water application rate given.	Not Transferrable	
2001	Mecham, Brent Q. "Distribution uniformity results comparing catch-can tests and soil moisture sensor measurements in turfgrass irrigation." Proceedings, Irrigation Association's 2001 International Irrigation Show (2001): 133-139.	IT	Distribution Uniformity											Not Transferrable	Soil Moisture (measured by SMS) and can be significantly higher than that indicated by Catch Can Test. Measuring sprinkler system uniformity can be used as a "report card," but should not be used to determine the amount of water needed because it does not take into account the soil properties redistributing irrigation water.
1995	Bamezai, A. (1995). Application of Difference-in-Difference Techniques to the Evaluation of Drought-Tainted Water Conservation Programs. Evaluation Review, 19(5):559-582.	A	Audits, other Factors on reporting water savings	San Diego, CA	1988-1993 predrought, drought, and post audit	1350 participants and 420 control group	SF	NA	ET not given in report. (33" to 39"based on CIMIS ET Zones)	NA	NA	NA	2.2%-13.6% through various methods (audit) in a drought	Text	The study identified common forms of error in evaluation of water consumption, specifically self-selection, measurement error, and nonstationary outcome. For example, after a meter retrofit increase to 8.7% (31.3 gal/HH). • No detected patterns related with home ownership. Automatic irrigation = greatest outdoor water consumption, followed by drip irrigation and manually controlled sprinkler systems, all compared to watering with a hose. Auditing participants appears to have made a difference.

Attachment 2.

Theoretical Irrigation Requirements Calculated Using FAO 56 Dual Kc Method for Various Landscape Conditions

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Irrigation Savings Summaries Calculated Using FAO 56 Dual Kc Method

Landscape	T-Base 1	T-Base 2	T-MAD	T-Soil	T-Soil&MAD	T-Warm	Mix-Spk	Mix-Drip	Ann-Spk	Ann-Drip	X-GC	X-Deep
Planting	Cool Season Turf	Cool Season Turf	Cool Season Turf	Cool Season Turf	Cool Season Turf	Warm Season Turf	Mixture of Trees, Shrubs & Ground Cover	Mixture of Trees, Shrubs & Ground Cover	Annuals (flowers)	Annuals (flowers)	Ground Cover	Ground Cover
Irrigation Method	SPRINKLER	SPRINKLER	SPRINKLER	SPRINKLER	SPRINKLER	SPRINKLER	SPRINKLER	DRIP	SPRINKLER	DRIP	DRIP	DRIP
Irrigation Turn-On	April 15th	April 15th	April 15th	April 15th	April 15th	April 15th	April 15th	April 15th	April 15th	April 15th	April 15th	April 15th
Irrigation Turn-Off	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st
Irrigation Interval	Month Adj	MWF	MAD	MWF	MAD	MWF	Every 3 days	Every 3 days	MWF	MWF	Wed	Wed
Max Eff Root Zone (in)	7.35	7.35	12	7.35	12	9.8	18	18	4.5	6	6	12
MAD Target (%)	50	50	69	65	80	85	90	90	64	65	70	90
Soil	Silty clay soil	Silty clay soil	Silty clay soil	Loam	Loam	Silty clay soil	Silty clay soil	Silty clay soil	Silty clay soil	Silty clay soil	Silty clay soil	Silty clay soil

BERTHOUD

WATER SAVINGS (Values in inches)

Avg Year	Water Savings v. Typical Irrigator	2.6	9.2	7.6	15.4	14.8	11.1	11.6	11.8	15.2	16.2	19.2
Dry Year		0	5.9	4.2	11.1	11.6	5.7	6.5	9.8	13.4	15.4	15.8
Wet Year		3.6	8.1	8.3	15.0	12.3	12.8	12.7	9.6	12.4	16.0	19.0
Avg Year		Water Savings v. Efficient Irrigator	6.6	5.0	12.8	12.2	8.5	9.0	9.2	12.6	13.6	16.6
Dry Year			5.9	4.3	11.1	11.7	5.7	6.6	9.8	13.5	15.5	15.9
Wet Year			4.5	4.7	11.3	8.6	9.2	9.0	6.0	8.8	12.3	15.4

WATER SAVINGS (Values in gpsf)

Avg Year	Water Savings v. Typical Irrigator	1.6	5.7	4.8	9.6	9.2	6.9	7.2	7.4	9.5	10.1	12.0
Dry Year		0	3.7	2.6	6.9	7.3	3.5	4.1	6.1	8.4	9.6	9.8
Wet Year		2.3	5.1	5.2	9.3	7.6	8.0	7.9	6.0	7.7	10.0	11.8
Avg Year		Water Savings v. Efficient Irrigator	4.1	3.1	8.0	7.6	5.3	5.6	5.7	7.9	8.5	10.3
Dry Year			3.7	2.7	6.9	7.3	3.6	4.1	6.1	8.4	9.6	9.9
Wet Year			2.8	2.9	7.1	5.4	5.7	5.6	3.7	5.5	7.7	9.6

BOULDER

WATER SAVINGS (Values in inches)

Avg Year	Water Savings v. Typical Irrigator	2.4	9.2	6.9	15.4	13.6	10.2	10.8	11.1	14.7	15.1	18.8
Dry Year		0.7	7.9	5.2	15.4	10.7	7.5	7.7	9.6	12.8	15.7	18.7
Wet Year		4.1	8.3	6.9	16.1	11.9	9.9	10.1	9.9	13.5	14.6	16.7
Avg Year		Water Savings v. Efficient Irrigator	6.7	4.5	13.0	11.1	7.8	8.4	8.7	12.3	12.7	16.3
Dry Year			7.2	4.5	14.7	10.0	6.8	7.0	8.9	12.1	15.1	18.1
Wet Year			4.2	2.9	12.0	7.9	5.9	6.1	5.9	9.5	10.6	12.7

WATER SAVINGS (Values in gpsf)

Avg Year	Water Savings v. Typical Irrigator	1.5	5.7	4.3	9.6	8.5	6.4	6.7	6.9	9.2	9.4	11.7
Dry Year		0.4	4.9	3.2	9.6	6.6	4.7	4.8	6.0	8.0	9.8	11.7
Wet Year		2.5	5.2	4.3	10.0	7.4	6.2	6.3	6.2	8.4	9.1	10.4
Avg Year		Water Savings v. Efficient Irrigator	4.2	2.8	8.1	6.9	4.8	5.2	5.4	7.6	7.9	10.2
Dry Year			4.5	2.8	9.2	6.2	4.3	4.4	5.5	7.5	9.4	11.3
Wet Year			2.6	1.8	7.5	4.9	3.7	3.8	3.7	5.9	6.6	7.9

FORT LUPTON

WATER SAVINGS (Values in inches)

Avg Year	Water Savings v. Typical Irrigator	4.4	9.9	8.2	16.3	15.1	10.8	11.1	13.9	17.2	18.8	21.2
Dry Year		0.8	7.0	5.2	14.9	13.4	6.6	6.9	11.3	15.5	19.5	20.2
Wet Year		3.5	7.7	6.0	14.1	12.0	10.2	10.2	10.6	13.1	17.8	19.7
Avg Year		Water Savings v. Efficient Irrigator	5.5	3.8	11.9	10.8	6.5	6.7	9.6	12.9	14.4	16.8
Dry Year			6.2	4.4	14.1	12.6	5.8	6.1	10.5	14.7	18.7	19.4
Wet Year			4.2	2.5	10.7	8.6	6.7	6.8	7.2	9.7	14.3	16.2

WATER SAVINGS (Values in gpsf)

Avg Year	Water Savings v. Typical Irrigator	2.7	6.1	5.1	10.1	9.4	6.7	6.9	8.7	10.7	11.7	13.2
Dry Year		1	4.4	3.2	9.3	8.4	4.1	4.3	7.0	9.7	12.2	12.6
Wet Year		2.2	4.8	3.7	8.8	7.5	6.4	6.4	6.6	8.2	11.1	12.3
Avg Year		Water Savings v. Efficient Irrigator	3.4	2.4	7.4	6.7	4.0	4.2	6.0	8.0	9.0	10.5
Dry Year			3.9	2.7	8.8	7.9	3.6	3.8	6.5	9.2	11.7	12.1
Wet Year			2.6	1.6	6.6	5.4	4.2	4.2	4.5	6.0	8.9	10.1

Savings Range:

>15 inches	10-15 inches	5-10 inches	<5 inches
>10 gpsf	5-10 gpsf	<5 gpsf	

Theoretical Irrigation Requirement Summaries Calculated Using FAO-56 Dual Kc Method

Station	FtLupton	ftl	
Precipitation in inches	Avg 2006-2014	Dry 2012	Wet 2014
	13.1	8.9	17.0

Landscape	T-Base 1	T-Base 2	T-MAD	T-Soil	T-Soil&MAD	T-Warm
	L	C	F	H	I	K
	15	15	15	15	15	15
Planting	Cool Season Turf	Cool Season Turf	Cool Season Turf	Cool Season Turf	Cool Season Turf	Warm Season Turf
Irrigation Method	SPRINKLER	SPRINKLER	SPRINKLER	SPRINKLER	SPRINKLER	SPRINKLER
Irrigation Turn-On	April 15th	April 15th	April 15th	April 15th	April 15th	April 15th
Irrigation Turn-Off	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st
Irrigation Interval	Month Adj	MWF	MAD	MWF	MAD	MWF
Max Eff Root Zone (in)	7.35	7.35	12	7.35	12	9.8
MAD Target (%)	51	51	69	64	79	84
Soil	Silty clay soil	Silty clay soil	Silty clay soil	Loam	Loam	Silty clay soil
Values in inches						
All Years Avg Eto = 50.64 in						
Prec	13.1	13.1	13.1	13.1	13.1	13.1
Eto	50.6	50.6	50.6	50.6	50.6	50.6
ETc actual	41.1	37.8	33.6	34.4	27.7	28.3
Irrig Net	33.7	29.4	23.9	25.5	17.4	18.6
No. Irrig Events	73.3	47.3	19.9	34.7	12.4	17.2
Kc effective	0.8	0.7	0.7	0.7	0.5	0.6
Water Savings - Typical		4.4	9.9	8.2	16.3	15.1
Water Savings - Efficient			5.5	3.8	11.9	10.8
Dry Year Avg Eto = 56.7 in						
Prec	8.9	8.9	8.9	8.9	8.9	8.9
Eto	56.7	56.7	56.7	56.7	56.7	56.7
ETc actual	41.9	41.1	35.6	37.3	28.7	29.8
Irrig Net	35.2	34.4	28.1	30.0	20.2	21.8
No. Irrig Events	76.0	55.0	23.0	40.0	14.0	19.0
Kc effective	0.7	0.7	0.6	0.7	0.5	0.5
Water Savings - Typical		0.8	7.0	5.2	14.9	13.4
Water Savings - Efficient			6.2	4.4	14.1	12.6
Wet Year Avg Eto = 48.95 in						
Prec	17.0	17.0	17.0	17.0	17.0	17.0
Eto	49.0	49.0	49.0	49.0	49.0	49.0
ETc actual	42.1	39.0	34.4	36.3	28.6	31.0
Irrig Net	32.1	28.7	24.4	26.2	18.0	20.1
No. Irrig Events	68.0	47.0	21.0	36.0	14.0	19.0
Kc effective	0.9	0.8	0.7	0.7	0.6	0.6
Water Savings - Typical		3.5	7.7	6.0	14.1	12.0
Water Savings - Efficient			4.2	2.5	10.7	8.6

Landscape	Mix-Spk	Mix-Drip	Ann-Spk	Ann-Drip	X-GC	X-Deep
	B	A	E	G	D	J
	15	15	15	15	15	15
Planting	Mixture of Trees, Shrubs & Ground Cover	Mixture of Trees, Shrubs & Ground Cover	Annuals (flowers)	Annuals (flowers)	Ground Cover	Ground Cover
Irrigation Method	SPRINKLER	DRIP	SPRINKLER	DRIP	DRIP	DRIP
Irrigation Turn-On	April 15th	April 15th	April 15th	April 15th	April 15th	April 15th
Irrigation Turn-Off	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st
Irrigation Interval	Every 3 days	Every 3 days	MWF	MWF	Wed	Wed
Max Eff Root Zone (in)	18	18	4.5	6	6	12
MAD Target (%)	90	90	62	64	70	90
Soil	Silty clay soil	Silty clay soil	Silty clay soil	Silty clay soil	Silty clay soil	Silty clay soil
Values in inches						
All Years Avg Eto = 50.64 in						
Prec	13.1	13.1	13.1	13.1	13.1	13.1
Eto	50.6	50.6	50.6	50.6	50.6	50.6
ETc actual	33.2	32.6	28.7	25.4	24.5	23.6
Irrig Net	22.9	22.6	19.8	16.5	15.0	12.5
No. Irrig Events	11.6	11.3	42.6	29.4	22.7	9.0
Kc effective	0.7	0.6	0.6	0.5	0.5	0.5
Water Savings - Typical	10.8	11.1	13.9	17.2	18.8	21.2
Water Savings - Efficient	6.5	6.7	9.6	12.9	14.4	16.8
Dry Year Avg Eto = 56.7 in						
Prec	8.9	8.9	8.9	8.9	8.9	8.9
Eto	56.7	56.7	56.7	56.7	56.7	56.7
ETc actual	36.8	36.5	31.1	26.9	23.7	23.4
Irrig Net	28.6	28.3	23.9	19.6	15.6	15.0
No. Irrig Events	14.0	14.0	50.0	34.0	23.0	11.0
Kc effective	0.6	0.6	0.5	0.5	0.4	0.4
Water Savings - Typical	6.6	6.9	11.3	15.5	19.5	20.2
Water Savings - Efficient	5.8	6.1	10.5	14.7	18.7	19.4
Wet Year Avg Eto = 48.95 in						
Prec	17.0	17.0	17.0	17.0	17.0	17.0
Eto	49.0	49.0	49.0	49.0	49.0	49.0
ETc actual	32.8	32.5	32.1	28.8	24.9	24.0
Irrig Net	21.9	21.9	21.5	19.0	14.3	12.4
No. Irrig Events	11.0	11.0	46.0	34.0	22.0	9.0
Kc effective	0.7	0.7	0.7	0.6	0.5	0.5
Water Savings - Typical	10.2	10.2	10.6	13.1	17.8	19.7
Water Savings - Efficient	6.7	6.8	7.2	9.7	14.3	16.2

Theoretical Irrigation Requirement Summaries Calculated Using FAO-56 Dual Kc Method

Landscape	T-Base 1	T-Base 2	T-MAD	T-Soil	T-Soil&MAD	T-Warm	Mix-Spk	Mix-Drip	Ann-Spk	Ann-Drip	X-GC	X-Deep
Planting	Cool Season Turf	Cool Season Turf	Cool Season Turf	Cool Season Turf	Cool Season Turf	Warm Season Turf	Mixture of Trees, Shrubs & Ground Cover	Mixture of Trees, Shrubs & Ground Cover	Annuals (flowers)	Annuals (flowers)	Ground Cover	Ground Cover
Irrigation Method	SPRINKLER	SPRINKLER	SPRINKLER	SPRINKLER	SPRINKLER	SPRINKLER	SPRINKLER	DRIP	SPRINKLER	DRIP	DRIP	DRIP
Soil	Silty clay soil	Silty clay soil	Silty clay soil	Loam	Loam	Silty clay soil	Silty clay soil	Silty clay soil	Silty clay soil	Silty clay soil	Silty clay soil	Silty clay soil
Fort Lupton Values in gal/sf												
All Years **Avg Eto = 31.57 gal**												
Prec	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2
Eto	31.6	31.6	31.6	31.6	31.6	31.6	31.6	31.6	31.6	31.6	31.6	31.6
ETc actual	25.6	23.6	20.9	21.5	17.3	17.6	20.7	20.3	17.9	15.8	15.3	14.7
Irrig Net	21.0	18.3	14.9	15.9	10.9	11.6	14.3	14.1	12.3	10.3	9.3	7.8
No. Irrig Events	73.3	47.3	19.9	34.7	12.4	17.2	11.6	11.3	42.6	29.4	22.7	9.0
Kc effective	0.8	0.7	0.7	0.7	0.5	0.6	0.7	0.6	0.6	0.5	0.5	0.5
Water Savings - Typical		2.7	6.1	5.1	10.1	9.4	6.7	6.9	8.7	10.7	11.7	13.2
Water Savings - Efficient			3.4	2.4	7.4	6.7	4.0	4.2	6.0	8.0	9.0	10.5
Dry Year **Avg Eto = 35.34 gal**												
Prec	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6
Eto	35.3	35.3	35.3	35.3	35.3	35.3	35.3	35.3	35.3	35.3	35.3	35.3
ETc actual	26.1	25.6	22.2	23.3	17.9	18.6	22.9	22.7	19.4	16.8	14.7	14.6
Irrig Net	21.9	21.4	17.5	18.7	12.6	13.6	17.8	17.6	14.9	12.2	9.7	9.3
No. Irrig Events	76.0	55.0	23.0	40.0	14.0	19.0	14.0	14.0	50.0	34.0	23.0	11.0
Kc effective	0.7	0.7	0.6	0.7	0.5	0.5	0.6	0.6	0.5	0.5	0.4	0.4
Water Savings - Typical		0.5	4.4	3.2	9.3	8.4	4.1	4.3	7.0	9.7	12.2	12.6
Water Savings - Efficient			3.9	2.7	8.8	7.9	3.6	3.8	6.5	9.2	11.7	12.1
Wet Year **Avg Eto = 30.51 gal**												
Prec	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6
Eto	30.5	30.5	30.5	30.5	30.5	30.5	30.5	30.5	30.5	30.5	30.5	30.5
ETc actual	26.2	24.3	21.5	22.6	17.8	19.3	20.4	20.2	20.0	18.0	15.5	14.9
Irrig Net	20.0	17.9	15.2	16.3	11.2	12.5	13.7	13.7	13.4	11.8	8.9	7.7
No. Irrig Events	68.0	47.0	21.0	36.0	14.0	19.0	11.0	11.0	46.0	34.0	22.0	9.0
Kc effective	0.9	0.8	0.7	0.7	0.6	0.6	0.7	0.7	0.7	0.6	0.5	0.5
Water Savings - Typical		2.2	4.8	3.7	8.8	7.5	6.4	6.4	6.6	8.2	11.1	12.3
Water Savings - Efficient			2.6	1.6	6.6	5.4	4.2	4.2	4.5	6.0	8.9	10.1

Theoretical Irrigation Requirement Summaries Calculated Using FAO-56 Dual Kc Method

Station	Boulder	bou	
	Avg 2002-2014	Dry 2002	Wet 2013
Precipitation in inches	15.9	12.0	27.2

Landscape	T-Base 1	T-Base 2	T-MAD	T-Soil	T-Soil&MAD	T-Warm	Mix-Spk	Mix-Drip	Ann-Spk	Ann-Drip	X-GC	X-Deep
	L	C	F	H	I	K	B	A	E	G	D	J
	15	15	15	15	15	15	15	15	15	15	15	15
Planting	Cool Season Turf	Cool Season Turf	Cool Season Turf	Cool Season Turf	Cool Season Turf	Warm Season Turf	Mixture of Trees, Shrubs & Ground Cover	Mixture of Trees, Shrubs & Ground Cover	Annuals (flowers)	Annuals (flowers)	Ground Cover	Ground Cover
Irrigation Method	SPRINKLER	SPRINKLER	SPRINKLER	SPRINKLER	SPRINKLER	SPRINKLER	SPRINKLER	DRIP	SPRINKLER	DRIP	DRIP	DRIP
Irrigation Turn-On	April 15th	April 15th	April 15th	April 15th	April 15th	April 15th	April 15th	April 15th	April 15th	April 15th	April 15th	April 15th
Irrigation Turn-Off	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st
Irrigation Interval	Month Adj	MWF	MAD	MWF	MAD	MWF	Every 3 days	Every 3 days	MWF	MWF	Wed	Wed
Max Eff Root Zone (in)	7.35	7.35	12	7.35	12	9.8	18	18	4.5	6	6	12
MAD Target (%)	50	50	70	65	80	85	90	90	64	65	70	90
Soil	Silty clay soil	Silty clay soil	Silty clay soil	Loam	Loam	Silty clay soil	Silty clay soil	Silty clay soil	Silty clay soil	Silty clay soil	Silty clay soil	Silty clay soil
Values in inches												
All Years Avg Eto = 47.91 in												
Prec	15.9	15.9	15.9	15.9	15.9	15.9	15.9	15.9	15.9	15.9	15.9	15.9
Eto	47.9	47.9	47.9	47.9	47.9	47.9	47.9	47.9	47.9	47.9	47.9	47.9
ETc actual	38.7	36.7	32.1	32.8	26.6	27.5	31.8	31.2	28.0	24.6	24.9	23.2
Irrig Net	29.7	27.3	20.6	22.8	14.3	16.1	19.5	18.9	18.6	15.0	14.6	10.9
No. Irrig Events	73.2	44.9	17.2	31.0	10.2	14.8	9.8	9.7	39.8	26.8	22.6	8.0
Kc effective	0.8	0.8	0.7	0.7	0.6	0.6	0.7	0.7	0.6	0.5	0.5	0.5
Water Savings - Typical		2.4	9.2	6.9	15.4	13.6	10.2	10.8	11.1	14.7	15.1	18.8
Water Savings - Efficient			6.7	4.5	13.0	11.1	7.8	8.4	8.7	12.3	12.7	16.3
Dry Year Avg Eto = 52.1 in												
Prec	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
Eto	52.1	52.1	52.1	52.1	52.1	52.1	52.1	52.1	52.1	52.1	52.1	52.1
ETc actual	38.6	37.6	32.5	33.3	25.7	28.2	32.7	31.1	28.3	24.9	23.4	21.9
Irrig Net	30.7	30.0	22.8	25.5	15.3	20.0	23.2	23.0	21.1	17.9	14.9	11.9
No. Irrig Events	76.0	48.0	19.0	34.0	11.0	18.0	12.0	12.0	45.0	32.0	22.0	9.0
Kc effective	0.7	0.7	0.6	0.6	0.5	0.5	0.6	0.6	0.5	0.5	0.5	0.4
Water Savings - Typical		0.7	7.9	5.2	15.4	10.7	7.5	7.7	9.6	12.8	15.7	18.7
Water Savings - Efficient			7.2	4.5	14.7	10.0	6.8	7.0	8.9	12.1	15.1	18.1
Wet Year Avg Eto = 44.48 in												
Prec	27.2	27.2	27.2	27.2	27.2	27.2	27.2	27.2	27.2	27.2	27.2	27.2
Eto	44.5	44.5	44.5	44.5	44.5	44.5	44.5	44.5	44.5	44.5	44.5	44.5
ETc actual	38.5	35.0	31.6	32.1	25.5	28.8	31.5	31.0	29.6	26.0	24.8	23.9
Irrig Net	27.7	23.6	19.4	20.7	11.5	15.7	17.7	17.5	17.7	14.1	13.0	10.9
No. Irrig Events	66.0	38.0	16.0	28.0	8.0	15.0	9.0	9.0	38.0	27.0	20.0	8.0
Kc effective	0.9	0.8	0.7	0.7	0.6	0.6	0.7	0.7	0.7	0.6	0.6	0.5
Water Savings - Typical		4.1	8.3	6.9	16.1	11.9	9.9	10.1	9.9	13.5	14.6	16.7
Water Savings - Efficient			4.2	2.9	12.0	7.9	5.9	6.1	5.9	9.5	10.6	12.7

Theoretical Irrigation Requirement Summaries Calculated Using FAO-56 Dual Kc Method

Landscape	T-Base 1	T-Base 2	T-MAD	T-Soil	T-Soil&MAD	T-Warm	Mix-Spk	Mix-Drip	Ann-Spk	Ann-Drip	X-GC	X-Deep
Planting	Cool Season Turf	Cool Season Turf	Cool Season Turf	Cool Season Turf	Cool Season Turf	Warm Season Turf	Mixture of Trees, Shrubs & Ground Cover	Mixture of Trees, Shrubs & Ground Cover	Annuals (flowers)	Annuals (flowers)	Ground Cover	Ground Cover
Irrigation Method	SPRINKLER	SPRINKLER	SPRINKLER	SPRINKLER	SPRINKLER	SPRINKLER	SPRINKLER	DRIP	SPRINKLER	DRIP	DRIP	DRIP
Soil	Silty clay soil	Silty clay soil	Silty clay soil	Loam	Loam	Silty clay soil	Silty clay soil	Silty clay soil	Silty clay soil	Silty clay soil	Silty clay soil	Silty clay soil
Boulder Values in gal/sf												
All Years **Avg Eto = 29.87 gal**												
Prec	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9
Eto	29.9	29.9	29.9	29.9	29.9	29.9	29.9	29.9	29.9	29.9	29.9	29.9
ETc actual	24.1	22.9	20.0	20.4	16.6	17.2	19.8	19.4	17.4	15.3	15.5	14.5
Irrig Net	18.5	17.0	12.8	14.2	8.9	10.1	12.2	11.8	11.6	9.4	9.1	6.8
No. Irrig Events	73.2	44.9	17.2	31.0	10.2	14.8	9.8	9.7	39.8	26.8	22.6	8.0
Kc effective	0.8	0.8	0.7	0.7	0.6	0.6	0.7	0.7	0.6	0.5	0.5	0.5
Water Savings - Typical		1.5	5.7	4.3	9.6	8.5	6.4	6.7	6.9	9.2	9.4	11.7
Water Savings - Efficient			4.2	2.8	8.1	6.9	4.8	5.2	5.4	7.6	7.9	10.2
Dry Year **Avg Eto = 32.48 gal**												
Prec	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Eto	32.5	32.5	32.5	32.5	32.5	32.5	32.5	32.5	32.5	32.5	32.5	32.5
ETc actual	24.1	23.5	20.2	20.8	16.0	17.6	20.4	19.4	17.6	15.5	14.6	13.7
Irrig Net	19.1	18.7	14.2	15.9	9.5	12.5	14.5	14.4	13.2	11.2	9.3	7.4
No. Irrig Events	76.0	48.0	19.0	34.0	11.0	18.0	12.0	12.0	45.0	32.0	22.0	9.0
Kc effective	0.7	0.7	0.6	0.6	0.5	0.5	0.6	0.6	0.5	0.5	0.5	0.4
Water Savings - Typical		0.4	4.9	3.2	9.6	6.6	4.7	4.8	6.0	8.0	9.8	11.7
Water Savings - Efficient			4.5	2.8	9.2	6.2	4.3	4.4	5.5	7.5	9.4	11.3
Wet Year **Avg Eto = 27.73 gal**												
Prec	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0
Eto	27.7	27.7	27.7	27.7	27.7	27.7	27.7	27.7	27.7	27.7	27.7	27.7
ETc actual	24.0	21.8	19.7	20.0	15.9	17.9	19.6	19.3	18.4	16.2	15.5	14.9
Irrig Net	17.2	14.7	12.1	12.9	7.2	9.8	11.0	10.9	11.1	8.8	8.1	6.8
No. Irrig Events	66.0	38.0	16.0	28.0	8.0	15.0	9.0	9.0	38.0	27.0	20.0	8.0
Kc effective	0.9	0.8	0.7	0.7	0.6	0.6	0.7	0.7	0.7	0.6	0.6	0.5
Water Savings - Typical		2.5	5.2	4.3	10.0	7.4	6.2	6.3	6.2	8.4	9.1	10.4
Water Savings - Efficient			2.6	1.8	7.5	4.9	3.7	3.8	3.7	5.9	6.6	7.9

Theoretical Irrigation Requirement Summaries Calculated Using FAO-56 Dual Kc Method

Station	Berthoud	ber	
Precipitation in inches	Avg 2004-2014	Dry 2012	Wet 2005
	15.1	8.8	15.9

Landscape	T-Base 1	T-Base 2	T-MAD	T-Soil	T-Soil&MAD	T-Warm	Mix-Spk	Mix-Drip	Ann-Spk	Ann-Drip	X-GC	X-Deep
	L	C	F	H	I	K	B	A	E	G	D	J
	15	15	15	15	15	15	15	15	15	15	15	15
Planting	Cool Season Turf	Cool Season Turf	Cool Season Turf	Cool Season Turf	Cool Season Turf	Warm Season Turf	Mixture of Trees, Shrubs & Ground Cover	Mixture of Trees, Shrubs & Ground Cover	Annuals (flowers)	Annuals (flowers)	Ground Cover	Ground Cover
Irrigation Method	SPRINKLER	SPRINKLER	SPRINKLER	SPRINKLER	SPRINKLER	SPRINKLER	SPRINKLER	DRIP	SPRINKLER	DRIP	DRIP	DRIP
Irrigation Turn-On	April 15th	April 15th	April 15th	April 15th	April 15th	April 15th	April 15th	April 15th	April 15th	April 15th	April 15th	April 15th
Irrigation Turn-Off	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st	Oct 31st
Irrigation Interval	Month Adj	MWF	MAD	MWF	MAD	MWF	Every 3 days	Every 3 days	MWF	MWF	Wed	Wed
Max Eff Root Zone (in)	7.35	7.35	12	7.35	12	9.80	18	18	4.5	6	6	12
MAD Target (%)	50	50	69	65	80	85	90	90	64	65	70	90
Soil	Silty clay soil	Silty clay soil	Silty clay soil	Loam	Loam	Silty clay soil	Silty clay soil	Silty clay soil	Silty clay soil	Silty clay soil	Silty clay soil	Silty clay soil
						Values in inches						
All Years Avg Eto = 46.67 in												
Prec	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1
Eto	46.7	46.7	46.7	46.7	46.7	46.7	46.7	46.7	46.7	46.7	46.7	46.7
ETc actual	38.4	36.4	31.9	32.0	26.3	26.3	31.0	30.7	27.3	24.1	23.8	22.8
Irrig Net	30.3	27.7	21.1	22.6	14.8	15.4	19.2	18.7	18.5	15.0	14.1	11.1
No. Irrig Events	71.3	45.8	18.1	31.4	10.8	14.6	9.9	9.6	40.7	27.5	21.4	8.2
Kc effective	0.8	0.8	0.7	0.7	0.6	0.6	0.7	0.7	0.6	0.5	0.5	0.5
Water Savings - Typical		2.6	9.2	7.6	15.4	14.8	11.1	11.6	11.8	15.2	16.2	19.2
Water Savings - Efficient			6.6	5.0	12.8	12.2	8.5	9.0	9.2	12.6	13.6	16.6
Dry Year Avg Eto = 50.83 in												
Prec	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8
Eto	50.8	50.8	50.8	50.8	50.8	50.8	50.8	50.8	50.8	50.8	50.8	50.8
ETc actual	37.9	37.2	33.2	33.3	26.7	26.6	32.5	31.9	27.8	24.4	22.6	22.8
Irrig Net	31.1	31.1	25.2	26.8	20.0	19.4	25.4	24.6	21.3	17.6	15.7	15.3
No. Irrig Events	73.0	49.0	21.0	36.0	14.0	17.0	13.0	12.0	46.0	31.0	23.0	11.0
Kc effective	0.7	0.7	0.7	0.7	0.5	0.5	0.6	0.6	0.5	0.5	0.4	0.4
Water Savings - Typical		0	5.9	4.2	11.1	11.6	5.7	6.5	9.8	13.4	15.4	15.8
Water Savings - Efficient			5.9	4.3	11.1	11.7	5.7	6.6	9.8	13.5	15.5	15.9
Wet Year Avg Eto = 43.75 in												
Prec	15.9	15.9	15.9	15.9	15.9	15.9	15.9	15.9	15.9	15.9	15.9	15.9
Eto	43.7	43.7	43.7	43.7	43.7	43.7	43.7	43.7	43.7	43.7	43.7	43.7
ETc actual	38.9	35.4	30.7	31.1	25.5	27.0	29.1	28.6	29.3	26.7	23.6	21.2
Irrig Net	29.0	25.3	20.9	20.6	14.0	16.7	16.2	16.3	19.4	16.6	13.0	10.0
No. Irrig Events	67.0	42.0	19.0	29.0	11.0	15.0	8.0	8.0	43.0	31.0	20.0	7.0
Kc effective	0.9	0.8	0.7	0.7	0.6	0.6	0.7	0.7	0.7	0.6	0.5	0.5
Water Savings - Typical		3.6	8.1	8.3	15.0	12.3	12.8	12.7	9.6	12.4	16.0	19.0
Water Savings - Efficient			4.5	4.7	11.3	8.6	9.2	9.0	6.0	8.8	12.3	15.4

Theoretical Irrigation Requirement Summaries Calculated Using FAO-56 Dual Kc Method

Landscape	T-Base 1	T-Base 2	T-MAD	T-Soil	T-Soil&MAD	T-Warm	Mix-Spk	Mix-Drip	Ann-Spk	Ann-Drip	X-GC	X-Deep
Planting	Cool Season Turf	Cool Season Turf	Cool Season Turf	Cool Season Turf	Cool Season Turf	Warm Season Turf	Mixture of Trees, Shrubs & Ground Cover	Mixture of Trees, Shrubs & Ground Cover	Annuals (flowers)	Annuals (flowers)	Ground Cover	Ground Cover
Irrigation Method	SPRINKLER	SPRINKLER	SPRINKLER	SPRINKLER	SPRINKLER	SPRINKLER	SPRINKLER	DRIP	SPRINKLER	DRIP	DRIP	DRIP
Soil	Silty clay soil	Silty clay soil	Silty clay soil	Loam	Loam	Silty clay soil	Silty clay soil	Silty clay soil	Silty clay soil	Silty clay soil	Silty clay soil	Silty clay soil
Berhoud Values in gal/sf												
All Years **Avg Eto = 29.09 gal**												
Prec	9.4	9.4	9.4	9.4	9.4	9.4	9.4	9.4	9.4	9.4	9.4	9.4
Eto	29.1	29.1	29.1	29.1	29.1	29.1	29.1	29.1	29.1	29.1	29.1	29.1
ETc actual	23.9	22.7	19.9	19.9	16.4	16.4	19.3	19.1	17.0	15.0	14.8	14.2
Irrig Net	18.9	17.2	13.1	14.1	9.3	9.6	12.0	11.7	11.5	9.4	8.8	6.9
No. Irrig Events	71.3	45.8	18.1	31.4	10.8	14.6	9.9	9.6	40.7	27.5	21.4	8.2
Kc effective	0.8	0.8	0.7	0.7	0.6	0.6	0.7	0.7	0.6	0.5	0.5	0.5
Water Savings - Typical		1.6	5.7	4.8	9.6	9.2	6.9	7.2	7.4	9.5	10.1	12.0
Water Savings - Efficient			4.1	3.1	8.0	7.6	5.3	5.6	5.7	7.9	8.5	10.3
Dry Year **Avg Eto = 31.68 gal**												
Prec	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
Eto	31.7	31.7	31.7	31.7	31.7	31.7	31.7	31.7	31.7	31.7	31.7	31.7
ETc actual	23.6	23.2	20.7	20.7	16.6	16.6	20.2	19.9	17.4	15.2	14.1	14.2
Irrig Net	19.4	19.4	15.7	16.7	12.5	12.1	15.8	15.3	13.3	11.0	9.8	9.5
No. Irrig Events	73.0	49.0	21.0	36.0	14.0	17.0	13.0	12.0	46.0	31.0	23.0	11.0
Kc effective	0.7	0.7	0.7	0.7	0.5	0.5	0.6	0.6	0.5	0.5	0.4	0.4
Water Savings - Typical		0.0	3.7	2.6	6.9	7.3	3.5	4.1	6.1	8.4	9.6	9.8
Water Savings - Efficient			3.7	2.7	6.9	7.3	3.6	4.1	6.1	8.4	9.6	9.9
Wet Year **Avg Eto = 27.27 gal**												
Prec	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9
Eto	27.3	27.3	27.3	27.3	27.3	27.3	27.3	27.3	27.3	27.3	27.3	27.3
ETc actual	24.2	22.1	19.1	19.4	15.9	16.8	18.1	17.8	18.2	16.7	14.7	13.2
Irrig Net	18.1	15.8	13.0	12.9	8.7	10.4	10.1	10.2	12.1	10.3	8.1	6.2
No. Irrig Events	67.0	42.0	19.0	29.0	11.0	15.0	8.0	8.0	43.0	31.0	20.0	7.0
Kc effective	0.9	0.8	0.7	0.7	0.6	0.6	0.7	0.7	0.7	0.6	0.5	0.5
Water Savings - Typical		2.3	5.1	5.2	9.3	7.6	8.0	7.9	6.0	7.7	10.0	11.8
Water Savings - Efficient			2.8	2.9	7.1	5.4	5.7	5.6	3.7	5.5	7.7	9.6