2009 Literature Review to Assist in Quantification of Expected Benefits of Landscape Water Conservation Best Management Practices (BMPs)

Prepared for
Colorado Water Conservation Board

Prepared by
Wright Water Engineers, Inc. and
Green Industries of Colorado

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Project Team

Jane Clary, Wright Water Engineers, Inc.
Brenda O'Brien, Green Industries of Colorado
Shannon Tillack, Wright Water Engineers, Inc.
Patricia Flood, P.E., Wright Water Engineers, Inc.

Contributors

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Drew Beckwith, Western Resource Advocates
Doug Bennett, Southern Nevada Water Authority
Christina Bickelmann and Marjie Risk, Arizona Department of Water Resources
Tracy Bouvette, Great Western Institute
Bill DeOreo, Aquacraft
Michael Dukes, University of Florida
Garry Grabow, North Carolina State University
Kristen Fefes, Associated Landscape Contractors of Colorado (ALCC)
Stu Feinglass, City of Westminster
Ram Dhan Khalsa, U.S. Bureau of Reclamation
Doug Kenney, University of Colorado Natural Resources Law Center
Kelly Kopp, Utah State University (via request from Reagan Waskom)
Larry Lesser, ASLA, ISA, The Laughing Earth
Tim Lipan, Denver Water
Dan Matsch, EcoCycle, Inc.
Peter Mayer, Aquacraft
Brent Mecham, Irrigation Association
Donna Pacetti, Denver Water
Alison Peck, Matrix Gardens
Dick Ruppel, Horizon Turf
Don Schlup, Scienturfic
Jeanine Shaw, Denver Water
Scott Winter, Colorado Spring Utilities
Reagan Waskom, Colorado Water Resources Institute
Jill Wuertz, Denver Water

Project Purpose

As communities develop and implement Water Conservation Plans to meet the requirements of the Colorado Water Conservation Board (CWCB), significant opportunities for outdoor water conservation exist. 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 to Water Conservation Plans. 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 that support landscape water conservation objectives; however, water conservation benefits of these practices are not quantified in the BMP Manual. (Attachment 1 summarizes the GreenCO BMPs.) Given CWCB's desire to quantitatively assess the role that conservation measures can play in statewide water supply planning and to see landscape water conservation better integrated into Water Conservation Plans, CWCB has provided support for a targeted literature review, which is the subject of this report. The goals of this review are as follows:

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

Project Approach

A variety of literature sources describe and identify 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:

1. Published academic research in peer-reviewed journals (e.g., American Water Works Association [AWWA] Journal, Colorado State University Extension) or text books.

2. 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).

3. 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).

4. Other "grey" literature including periodicals (e.g., *Water Efficiency*) and general website searches.

The initial reference list was developed from the GreenCO BMP Manual Bibliography (Attachment 4) and solicitation of references via email and direct requests from Colorado WaterWise Council members.

Based on preliminary review of literature compiled, a standard reporting framework for summarizing the available data was developed and agreed upon with CWCB staff and project advisors. Literature sources that appeared to be potential sources of quantitative data were reviewed, with notes taken on a standard form. The completed review forms are provided in Attachment 3. Attachment 2 contains a condensed summary of quantitative water savings reported in the literature reviewed. The findings of the review were then synthesized according to extent of knowledge for various BMP groups and are discussed. Based on these findings, an assessment of the extent to which existing knowledge is adequate to develop quantitative estimates of water conservation practices was completed, and recommendations regarding "next steps" in developing such estimates and/or needed research to fill data gaps was provided.

Scope Limitations and Excluded Literature

This literature review was focused primarily on demand-side physical practices associated with landscape water conservation and efficiency. There are a number of related supply side and behavioral measures that could have been included in this literature review, but that have not been included at this time, including:

- **Water Rate Structures/Pricing**: This topic has been covered in multiple publications such as Klein et al. (2007), Western Resource Advocates (2003, 2004, 2007, 2008), Mayer et al. (2008), Kenney et al. (2008), and others. From a landscape design and planning perspective, a closely related topic is water budgeting. To the extent that literature was available on establishing water budgets, this information has been included; however, pricing issues have not been addressed, other than a brief synopsis of the findings of Kenney at al. (2008) in Aurora.

- **Reclaimed Water**: Use of reclaimed water in the landscape is an important supply-side tool to help stretch potable water supplies and is a practice included in the GreenCO

BMP Manual. Much literature is available regarding the benefits of reclaimed water in the context of landscape irrigation. For example, Sharvelle et al. (2009) have estimated that reclaimed water used for irrigation of a typical residential landscape could supply about 30% of the demand. They further note that "…with increasing emphasis on xeriscape in the semi-arid West, it has the potential to supply 100% of the irrigation demand in some areas."

- **Rainwater Harvesting**: Currently, rainwater harvesting is not legally viable at a significant level in Colorado. Many other states have substantial guidance available promoting and facilitating use of rainwater harvesting, both as a water supply supplement and as a stormwater management tool. If rainwater harvesting becomes viable on a more widespread scale in Colorado at some point in the future, it would be appropriate to further evaluate the literature available on this topic, particularly from other semi-arid and arid states such as Texas and Arizona.

- **Utility-mandated Water Restrictions/Drought Response:** Watering restrictions are not considered to be a day-to-day landscape water conservation practice since they are artificially imposed to achieve utility objectives, regardless of the agronomic water requirements of the landscape. Many utilities in Colorado reported water savings of 30% or more during the peak of the recent Colorado drought, with Kenney et al. (2004) documenting a range of 13% to 56%. Nonetheless, these water savings may provide some type of benchmark or reality check on what could potentially be achievable through water conservation practices. These estimates, however, do not typically separate indoor and outdoor savings and are generally perceived as short-term.

- **Behavioral Studies**: A large factor influencing landscape water conservation is human behavior. Both price and non-price factors affect water conservation. Behavioral studies are not a central focus of this literature review, but are a fundamental factor in determining market penetration. Several studies associated with public behavior were identified during the course of this literature review, but were not reviewed in detail.

- **Other Literature Sources:** The focus of journal reviews was primarily in the arena of water resources engineering and management. An additional body of scientific literature that could also be reviewed in the future is in the realm of horticultural sciences. This body of literature could prove to be useful in the context of turf management, plant selection and soil preparation, as several examples. Exclusion of this literature was purely due to project scope limitations. Representative literature sources not included in this review, but that should be reviewed in the future, include the following:

  Agricultural Water Management
  Agronomy Journal
  Crop Science
  Horticultural Science
  International Turfgrass Research Journal
  Journal of Environmental Horticulture
  Journal of the American Society for Horticultural Science

Previous Work

Estimating the role of water conservation in water supply planning is not a new topic, although the role of conservation has consistently been a topic of debate. Several previously developed statewide water conservation estimates are summarized below. Additionally, two literature reviews conducted in the last several years by Colorado researchers are also summarized, in order to avoid "reinventing the wheel."

Previous Estimates of the Role of Water Conservation

During the course of the literature review, various estimates and projections regarding the role of water conservation in meeting the state water supply needs were identified. Some of these estimates include:

- Rozaklis (1997) at the 8th Annual South Platte Forum in Longmont estimated: "Currently anticipated conservation efforts will reduce future demand by about 17 percent compared to what it otherwise would be…there are still additional savings that could be gained from water conservation. My estimate is that additional "reasonable" water conservation efforts can reduce M&I demand by an additional 10 to 15 percent basin-wide. And of all six categories of water supply sources, conservation probably has the least impact to other resource interests—to West Slope supplies, to stream flows for endangered species, and to continuance of irrigated agriculture."

- SWSI (CDM 2004, p. ES-37) notes, "It is estimated that by 2030, Level 1 conservation will result in demand reduction in Colorado of approximately 101,900 AF…SWSI estimates these current active conservation programs [beyond Level 1] could result in additional water demand savings ranging from 3 to 14 percent by basin, or an estimated 231,000 AF statewide by 2030." (The landscape component of this estimate is not broken out separately.) "Also, as Colorado water providers and water customers continue to implement long-term water conservation, it may be harder to expect the 20 to 30 percent demand reductions that were seen in recent drought years in future drought years."

- In SWSI II (CDM 2007, pp. 2-6 & 2-7), the Conservation and Efficiency Roundtable further refined estimates of projected potential long-term savings from conservation alternatives. Based on information provided in a summary table from several sources, the group concluded, "the various conservation measures, if fully and successfully implemented, represent a range of potential demand reduction from 287,000 AF to 459,000 AF per year (AFY) by 2030 with a mid-point estimate of these potential statewide savings of 372,000 AF." The group further concluded, "The level of penetration, which can be defined as the extent to which the conservation measure is implemented or adopted, is the most sensitive variable that affects the amount of reduction in water demand (conservation) that may be achieved…. This point is central to the debate over how far conservation measures can go in reducing current and future water demand." Estimated savings associated with various landscaping conservation/efficiency measures are included in the summary of General Conservation Programs in Attachment 2.

Previous Literature Reviews

Two previous literature reviews conducted in Colorado closely relate to this project, including:

- Barta, R., Ward, R., Waskom, R., & Smith, D. (2004). *Stretching Urban Water Supplies in Colorado, Strategies for Landscape Water Conservation.* Special Report Number 13. Fort Collins: Colorado Water Resources Research Institute. http://www.cwi.colostate.edu/publications/sr/13.pdf

- Klein, B., Kenney, D., Lowrey, J., & Goemans, C. (2007). *Factors Influencing Residential Demand: A Review of the Literature (Updated 1/20/07).*

It is recommended that users of this literature obtain both Barta et al. (2004) and Klein et al. (2007) because the focus of the reviews is slightly different, and the reviews are complementary. The scope of this literature review is more narrowly defined regarding landscape conservation BMPs in terms of physical actions taken in the landscape, whereas the Barta et al. (2004) review is broader and the Klein et al. (2007) review focuses more in depth on price-related and behavioral aspects of residential demand. Key conclusions and highlights of these literature reviews are briefly provided as general background. Additionally, work by Kenney et al. (2007) in Aurora ties in closely to the Klein et al. (2007) literature review and is also discussed.

Barta et al. (2004)

Barta et al. (2004) focuses on conservation strategies categorized according to the general categories of price and non-price strategies. Non-price strategies are considered to include outreach and education as well as policy and regulation. Price strategies include inclining block rates, water budget based rate structures, and seasonal rate structures. A review of these strategies and an analysis of the advantages, disadvantages, and effectiveness of strategies are provided in the literature review. Perhaps one of the most important findings of the review was: "There is not sufficient peer-reviewed literature to scientifically evaluate the effectiveness of urban landscape water conservation strategies." Specific conclusions, which are largely consistent with the findings of the current literature review, include:

- Overall, there is a lack of information available regarding the implementation of non-price conservation programs and a lack of detail and consistency of water use information necessary to evaluate changes in demand.

- More research is needed to understand how the interaction of conservation strategy incentives influences the overall reduction in water consumption.

- Failure to account for non-price conservation efforts, primarily outreach and education programs, may result in an overestimation of the effectiveness of price strategies for conservation.

- Education and outreach conservation programs tend to be a part of all conservation efforts and are generally believed to be very important in all conservation programs.

- A majority of conservation studies are site-specific and are not necessarily applicable in all settings.

- There is very little consistency in terminology used by various water managers and members of the green industry regarding water conservation for landscapes.

Klein et al (2007) and Kenney et al. (2007)

Klein at al. (2007) focused primarily on pricing factors, but divided the literature review into factors utilities can control (e.g., price, policies) and factors that they cannot control (e.g., weather, household characteristics, behavior). The literature review also discusses two historical approaches to evaluating water demand: a water requirements approach (how much water is needed) and an economics approach (how people make decisions about water consumed). The overall literature review should be accessed for more in-depth information, but selected conclusions extracted from the report (*quoted directly*) that are relevant to this literature review include:

- A consistent point in the literature is the need to understand how price influences demand (price elasticity). Multiple studies confirm the hypothesis that raising prices reduces demand, albeit only modestly (i.e., demand is largely price inelastic), with estimates of price elasticity varying widely.

- A key research question that remains is the extent to which individuals understand their rate structure and water bill, raising difficult research issues about which price signals customers actually respond to.

- It is also clear that price elasticity can vary significantly among seasons, uses, regions, and various social/economic conditions. A more sophisticated understanding of these influences is key to translating a general understanding of price elasticity into effective demand management policies.

- Similarly, the interaction of price and non-price demand management programs is of particular concern, as many utilities employ multi-faceted programs to manage consumer demand for water. The range of non-price strategies for managing water demand can generally be grouped into three categories: water restrictions, public education, and technological improvements.

- Research into the first category, water restrictions, generally focuses on the comparison of voluntary versus mandatory programs, usually focused on outdoor water uses during drought emergencies. The literature is consistent in showing significant (often 30 percent or more) savings from mandatory restrictions; findings regarding voluntary restrictions are much more variable, but with savings estimates generally lagging far behind the mandatory programs. Part of the challenge in assessing the impact of restrictions programs is that they are usually combined with other efforts, particularly public information campaigns.

- Research into these educational efforts generally shows them to be modestly beneficial, especially in the short-term. Research seems to suggest that a certain "critical mass" of educational programs are necessary to generate significant benefits, but that utilities soon reach a point of declining returns as additional efforts are implemented thereafter.

- Less confusion generally surrounds efforts focusing on technological changes, such as household-level retrofitting of water-using devices such as toilets, showerheads, and washing machines. Among these approaches, the significant water-saving benefits of toilet retrofits are best documented. Technological upgrades regarding outdoor sprinkler systems do not appear to offer similar conservation benefits.

- It is well documented that weather can impact short-term water demand decisions (particularly for landscape irrigation), and for this reason, weather variables are typically controlled for in studies focused on price and non-price tools. But beyond the intuitive conclusion that hot-dry weather generates higher demands than cool-wet conditions, the exact nature of the weather/water demand relationship has several areas of uncertainty.

- Research is often frequently constrained by the fact that household-level consumption data is typically only available at a monthly scale while weather variables change daily.

- Data limitations are also a common impediment to assessing the impact of demographic characteristics on residential water demand, as researchers rarely have data sets that allow them to match household level consumption data with demographic data about the people and house associated with a residential water account.

- Nonetheless, research that distinguishes water demand trends between single-family versus multi-family dwellings, between urban and suburban settings, and between purely residential and mixed residential/commercial regions can provide useful information, especially since it may influence the types of management options (e.g., customer-specific water billing) available to the utility, and may help illuminate how a community (and its water demand) will evolve over time. Even in a community dominated by single family homes that is not undergoing a transformation regarding the types or mix of dwellings, the addition of new homes and the aging of the preexisting housing stock is important.

- Generally, new homes are shown to consume less water than older homes… On the other hand, to the extent that newer homes are more likely to have automatic in-ground sprinkler systems, these technologies generally increase water demand when compared to homes reliant on hose-based irrigation technologies. The relative size of lots and homes is an important consideration, especially if these averages are changing as a community builds out and matures. As expected, larger lot sizes tend to be correlated with higher water demands; however, establishing a similar correlation between house size and demand has proven elusive.

- Overall, the literature is clear in showing that residential water demand is largely a function of water price, the impact of non-price demand management programs, weather

> (and climate), and demographic characteristics of households and the homes they occupy. To the extent that this research is being pursued with the ultimate aim of informing and empowering water managers to better predict and manipulate demand, future investigations will need to better illuminate the interplay among these factors. This suggests a need to better understand water-use decision-making processes at the household level, which in turn will require the assembly of datasets featuring multiple, customer-level observations across time to augment citywide (aggregated) data. This seems particularly important as water utilities adopt dynamic, customer-specific water budgets, with the competing aims of managing water demand (and water revenues), encouraging economic efficiency in water use, all within a framework that customers can understand and endorse as equitable. To achieve these goals, in both "normal" and drought years, is a formidable challenge, and is deserving of the same level of intellectual effort as has traditionally been devoted to understanding and managing water supplies.

Closely related to the work by Klein et al (2007) as part of the Western Water Assessment, is the *Residential Water Demand Study in Aurora* (Kenney et al. 2009) where over 10,000 water billing records covering multiple years were reviewed with regard to changes in water use, straddling the 2002 drought. Key landscape-related findings from the Aurora study, extracted and quoted directly from a recent presentation by (Kenney & Reidy, 2009) include:

- Overall price elasticity of demand: -0.60 (10% price increase reduces demand by 6%)
- High-volume users are most responsive to price (-0.75) (7.5% decrease)
- Low-volume users are least responsive to price (-0.34) (3.4% reduction)
- Water Use Restrictions: -0.12 (12% reduction) assuming average prices
- Pricing-Restrictions Interactions. Savings from pricing and restrictions are not fully additive: people respond to one or the other
    - Overall price elasticity declines when restrictions are in effect (from 6% to 3.7%)
    - The effect of pricing on the high-volume users is significantly constrained when restrictions are in effect (7.5% to 2.4% decrease)
- Block Rate: -0.05 (5% reduction) [controlling for price and other factors]
- WaterSmart Readers. For those households that have a WaterSmart Reader:
    - Use actually went up 16% overall
    - However, the frequency that these households went into the second or third pricing tier dropped
- The effectiveness of demand management policies is mostly determined by how they influence the behavior of the high-volume users, who are:

    - Highly responsive to price in non-drought periods
    - Highly responsive to restrictions during drought periods

- Increasing block rate structures work (even if the pricing tiers are only modestly punitive). (Reduce demand 5%, irrespective of pricing)

- Customers will hit water-use targets if you provide them with proper incentives (via rate structures) and information (via a Water Smart Reader)

Summary and Evaluation of Literature Sources

Literature Sources

During April-June 2009, the following literature sources were reviewed:

- GreenCO BMP Manual references (Attachment 4). The majority of these references provided information on how to implement a wide range of landscape BMPs, but did not quantify the expected water savings of each practice.
- Colorado State University (CSU) and CSU Extension research
- Northern Colorado Water Conservancy District (NCWCD) (and other conservancy districts) research
- Western Resource Advocates publications (e.g., *Water Meter*, *Smart Water*)
- Center for ReSource Conservation (Slow the Flow Colorado)
- CWCB resources
- EPA WaterSense website
- U.S. Bureau of Reclamation (USBR)
- Irrigation Association website
- Peer-reviewed journals (representative examples)
    - *Journal AWWA*
    - *Journal of the American Water Resources Association*
    - *Journal of Irrigation and Drainage Engineering*
- Conference Proceedings (representative examples)
    - *2008 Sustainable Sources Conference* in Reno, NV by AWWA
    - *WaterSmart Innovations '08* in Las Vegas, NV
    - *2009 EWRI Congress* in Kansas City, MO
    - Water Environment Federation (WEF) conference proceedings (various years)
- Other periodicals:
    - *Colorado Water*, newsletter of Colorado Water Resources Research Institute
    - *Water Efficiency* Magazine
    - *Colorado Green* Magazine
    - *Water Wise*, newsletter of the Colorado WaterWise Council
    - *Headwaters*, magazine of the Colorado Foundation for Water Education
- Various state conservation related websites (e.g., California, Arizona, Nevada, Texas, New Mexico, Florida)

Interviews and Correspondence

In addition to review of published literature, numerous phone calls and emails were initiated to identify key literature sources. The following individuals provided valued input on the literature review, whether it was identifying leads, emailing studies, or providing recommendations or direction in phone interviews.

- Drew Beckwith, Western Resource Advocates
- Tracy Bouvette, Great Western Institute
- Bill DeOreo, Aquacraft
- Kristen Fefes, Associated Landscape Contractors of Colorado (ALCC)
- Stu Feinglass, City of Westminster
- Ram Dhan Khalsa, U.S. Bureau of Reclamation
- Doug Kenney, University of Colorado Natural Resources Law Center
- Larry Lesser, ASLA, ISA, The Laughing Earth
- Tim Lipan, Denver Water
- Dan Matsch, EcoCycle, Inc.
- Peter Mayer, Aquacraft
- Brent Mecham, Irrigation Association
- Donna Pacetti, Denver Water
- Alison Peck, Matrix Gardens
- Dick Ruppel, Horizon Turf
- Don Schlup, Scienturfic
- Jeanine Shaw, Denver Water (formerly Center for ReSource Conservation)
- Scott Winter, Colorado Spring Utilities
- Reagan Waskom, Colorado Water Resources Institute
- Jill Wuertz, Denver Water

A number of additional Green Industry members were also pursued; however, the short timeframe associated with the literature review, which corresponded to the peak of the landscaping season, limited the information obtained from these individuals. Similarly, several professors at Colorado universities active in horticultural research were pursued, but the timing of the study may have conflicted with priorities at the close of the academic year. Finally, requests for information were submitted to a broader range of Colorado WaterWise Council members several times via email distribution and via the June 2009 Board meeting. A group discussion regarding availability of quantitative landscape water conservation information at the June 2009 Board meeting, but did not result in additional data. In general, it appears that utility records associated with landscape conservation practices may be limited, possibly due to conservation historically being lower priority than other water utility issues.

Water conservation leaders and researchers in several states were also pursued, with the following individuals providing helpful information:

- Doug Bennett, Southern Nevada Water Authority
- Christina Bickelmann and Marjie Risk, Arizona Department of Water Resources
- Michael Dukes, University of Florida

- Garry Grabow, North Carolina State University
- Kelly Kopp, Utah State University (*via request from Reagan Waskom*)

Assessment and Findings

After completion of the literature review, a key objective was to answer the questions: 1) "what do we know" and 2) "how can we use it." At the initiation of the project, several possible project outcomes were envisioned, including:

1) Quantification of water conservation benefits for certain BMPs based on a significant base of literature.

2) Identification of BMPs for which literature is currently inadequate to develop quantifiable water conservation estimates.

3) Identification of BMPs for which literature is not currently available, but scientific understanding is adequate to calculate expected water conservation estimates.

As the literature review evolved, a relatively large number of potentially useful information sources was identified. This resulted in a coarser review of the studies, as opposed to a detailed processing of the study information. In general, a very strong base of information on "how to" implement landscape water conservation practices was available. Virtually every state website in arid/semi-arid climates has this type of information available; however, significantly less quantitative information regarding water savings was readily available. Nonetheless, the following general categories of BMP practices have quantitative information to varying extents:

- Xeriscape
- Irrigation Technology
- Irrigation Efficiency Audits
- Plant Selection
- Turf Management
- Soil Preparation/Amendment
- Water Budgeting

Although some of these practices have moderate amounts of information available (e.g., Xeriscape, irrigation practices), the findings are reported in an inconsistent manner, may be located in other climates or may be limited to the science behind the practice, without accounting for the behavioral variables in real-world applications. A summary of findings based on the literature reviewed follows, along with recommendations for additional research and next steps regarding quantifying various landscape water conservation practices.

General Water Conservation Planning

As an initial step in assessing literature available for landscape water conservation planning, several summary-level documents were reviewed to develop a sense of the range of water

savings associated with landscape conservation practices and programs reported by others. Key documents reviewed included:

- *Water Conservation Programs- A Planning Manual, Manual of Water Supply Practices M52* (AWWA 2006)
- *Water Conservation Plan Guidelines* (EPA 1998)
- *Front Range Water Meter: Water Conservation Ratings and Recommendations for 13 Colorado Communities* (Western Resource Advocates 2007)
- *Colorado's Water Supply Future, Statewide Water Supply Initiative, Phase II* ("SWSI II")(CDM 2008)

These and other general water conservation planning estimates from others as summarized in Attachment 2. Additional discussion of AWWA M52 and the EPA Planning Guidelines follows.

AWWA M52

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" and "C" factors.

EPA Landscape Water Conservation Benchmarks

Appendix B of *Water Conservation Plan Guidelines* (EPA 1998) summarizes water savings estimates from a broad range of indoor and outdoor practices, as "compiled from various sources." EPA provides a footnote stating: "Actual water savings can vary substantially according to a number of factors. These data are provided for illustrative purposes only and may not be current or applicable. To the extent practical, planners should regionally appropriate or system-specific assumptions and estimates." A subset of findings related to landscape measures is provided in Table 1 below.

Table 1. Landscape-related Excerpts from EPA's Benchmarks for Savings from Selected Conservation Measures (Table B-4) (Source: EPA 1998)

Category and Implementation Level (1-3)	Conservation Measure	Estimated Reduction in End Use
Universal metering (1)	Connection metering	20 percent
	Submetering	20 to 40 percent
Water accounting and loss control (1)	System audits and leak detection	Based on system
Costing and pricing (1)	10% increase in residential prices	2 to 4 percent
	10% increase in nonresidential prices	5 to 8 percent
Information and education (1)	Public education and behavior changes	2 to 5 percent
End-use audits (2)	Outdoor residential use	5 to 10 percent
	Large landscape water audits	10 to 20 percent
Pressure management (2)	Pressure reduction, system	3 to 6 percent of total production
	Pressure-reducing valves, residential	5 to 30 percent
Outdoor water-use efficiency (2)	Low water-use plants	7.5 percent
	Lawn watering guides	15 to 20 percent
	Large landscape management	10 to 25 percent
	Irrigation timer	10 gpcd
Water-use regulation (3)	Landscape requirements for new developments	10 to 20 percent in sector
	Graywater reuse, residential	20 to 30 gpcd

Xeriscape

The U.S. Bureau of Reclamation sponsored five field demonstration projects as part of its decade-long National Xeriscape Demonstration Project (NXDP), which began in 1996. Partnering communities included Fargo, North Dakota; Austin, Texas; Phoenix, Arizona; Las Vegas, Nevada; and Denver, Colorado. The most comprehensive Colorado-based Xeriscape study reviewed was the Yield and Reliability Demonstration in Xeriscape (YARDX) study conducted along the Colorado Front Range (Medina and Gumper 2004) as part of the NXDP program. Table 2, reproduced below directly from the Medina and Gumper (2004) report, demonstrates statistically significant saving from implementation of Xeriscape. The study also recognizes differences in water savings among new installations, retrofits and older existing Xeriscape sites. Information on participation, cost and maintenance are also provided in the study. The standardized and statistically designed study methodology enables comparison of the Denver results to other studies participating in the NXDP studies, as summarized in Table 3. Medina and Gumper (2004) provide the following observations from the YARDX report:

- "Computation of water use savings between Xeriscape samples and respective control properties ranged from 18 percent savings in the Colorado Springs new start demonstration (28 percent in data without year 2002 water use values) to 63 percent water savings in the Highlands Ranch new start demonstration. All comparisons tested with the Wilcoxon method yielded P-values less than 0.01. The retrofit demonstration in Colorado Springs yielded a water savings of 23 percent (32 percent excluding year 2002 data) while the Denver retrofit demonstration ("hose drag") produced a 28-percent savings. The new start demonstration in Fort Collins, consisting of large area, and more expensive properties, produced a 36-percent savings." (p. 5-4)

- "The <u>retrofit</u> demonstrations did not achieve water savings levels consistent with expected savings from the Xeriscape design developed for retrofits. This design called for Xeriscape plant area according to⅓ low (or no), ⅓ moderate, and ⅓ high water use, and overall water savings of about 60 percent. Water savings may have been negatively impacted by some participants employing greater than⅓ high water use area (of total landscape)." (p. 5-5)

- "Plausible explanations for the Colorado Springs year 2002 results include unrestricted watering regulation of Xeriscapes during the drought year. Xeriscape owners apparently hand watered their plants or used their drip irrigation systems allowable under the restrictions. Watering turf was more restricted and thus affected the controls more severely." (p. 5-4)

It is anticipated that additional statistical analysis of this data set could be beneficial. In the report, Metro Water Conservation Incorporated (MWCI) indicated willingness to share the data set with others for additional data exploration.

Table 2.
Water Use Comparisons Between Xeriscape and Traditional Landscape Samples
Source: YARDX Final Report, Table 5-1 (Medina and Gumper 2004)

	Seasonal (Apr-Oct) water use savings (%) per square foot of landscapable area, using growing season values adjusted for winter[1] average use[2]			Seasonal savings without adjustment for area	Winter[1] median daily water use (gal/day) N=number of properties Landscape average area (A) in square feet	
Demonstration	All project years	Years except 2002	Year 2002 only	All years	Xeriscapes	Control group
Colorado Springs new start	18 savings P<0.01	28 savings P<0.01	50 increase	22 savings P<0.01	169 (N=27) A=4608	182 (N=37) A=5190
Colorado Springs retrofit	23 savings P<0.01	32 savings P<0.01	34 increase	24 savings P<0.01	194 (N=27) A=5374	191 (N=32) A=5472
Denver retrofit	28 savings P<0.01	26 savings P<0.01	33 savings	17 savings P<0.01	146 (N=34) A=3047	152 (N=31) A=2537
Fort Collins new start	36 savings P<0.01	39 savings P<0.01	29 savings	32 savings P<0.01	191 (N=34) A=7583	182 (N=38) A=8859
Highlands Ranch new start	63 savings P<0.01	69 savings P<0.01	63 savings	50 savings P<0.01	165 (N=13) A=3971	218 (N=17) A=3576
Greeley retrofit	54 savings	56 savings	30 savings	40 savings	130 (N=6) A=9290	185 (N=4) A=9348
Wheat Ridge & Arvada pre-existing Xeriscapes	1 savings P>0.05	1 savings P>0.05	3 savings	25 savings	164 (N=26) A=4068	198 (N=28) A=5558

1 Winter months included January, February, March, November and December.
2 P-values (probability that sample differences could have occurred by chance) are not given for small samples.

Table 3. Results from other National Xersicape Demonstration Project (NXDP) Studies

Location	Study Name	Savings Relative to Control Group
Colorado Front Range (YARDX)	Medina, J. & J. Gumper (2004). *YARDX: Yield And Reliability Demonstrated in Xeriscape: Final Report*. Metro Water Conservation, Incorporated, Littleton, CO, 140 p. www.coloradowaterwise.org Includes studies in Denver, Fort Collins, Greeley, Highland Ranch, Colorado Springs, Wheatridge and Arvada. See Table 2.	18-63% (Approx 30%- range expected)
Phoenix, AZ	Stinnett, R. (2003). *Landscape Trends and Water Use in the Phoenix Metropolitan Area.* Available from the Bureau of Reclamation, Phoenix Area Office. This project was similar to a YARDX pre-existing Xeriscape landscape study conducted in Arvada/Wheat Ridge neighborhoods, except for lack of an observation period. The Phoenix study involved selecting, acquiring, and evaluating landscape historical water use data.	53%
Las Vegas, NV	Sovocool, A.K, and J.L. Rosales. (2003). *A Five-Year Investigation into the Potential Water and Monetary Savings of Residential Xeriscape in the Mojave Desert*. Las Vegas, Nevada: Southern Nevada Water Authority.	39%
Austin, TX	Gregg, Tony, J. Curry, and C. Grigsby. (1994). *Xeriscaping: Promises and Pitfalls.* Report for the Texas Water Development Board. City of Austin.	31%
Fargo, ND	Medina, J., & Lee, A. (2006). *FX Project, Fargo Xeriscape Project, Final Report*. Bureau of Reclamation and City of Fargo.	29% (new starts) 10-50% (retrofits)
Other Xeriscape Studies Cited in the NXDP Studies:		
North Marin	Nelson, J. (1994). "Water Saved by Single Family Xeriscapes." Preliminary Draft for AWWA National Conference. New York, June.	25%
Mesa, AZ	Testa, A., and A. Newton. 1993. "An Evaluation of a Landscape Rebate Program." AWWA Conserv'93 Proceedings. December.	33%

In summary, both data within and outside of Colorado indicate that Xeriscape can produce considerable water savings. Priority should be given to Colorado-based studies, given that landscape retrofits in more arid communities such as Phoenix and Las Vegas involved desert landscaping, which differs from the natural ecological communities associated with Colorado's Front Range. Additionally, a key long-term issue with regard to Xeriscape evaluations is the durability of savings achieved over time. This is one of the reasons that it is important to emphasize all seven principles of Xeriscape, which include efficient irrigation and proper

maintenance. In other words, Xeriscape and turf replacement are not synonymous terms, although some literature treats them synonymously.

Finally, it is anticipated that more Xeriscape case studies within Colorado exist, but perhaps have not been formally documented. An example is a recent Denver Parks and Recreation (2009) fact sheet regarding retrofitting medians along Martin Luther King Boulevard, which has shown an estimated water savings of approximately 48% in initial estimates comparing 2001/2002 data to 2007/2008 data. The new median design included combinations of turf, planting areas, hardscape and mulched tree beds, combined with a significant irrigation system upgrade. This, once again, emphasizes that plant selection is only one part of a Xeriscape retrofit.

Irrigation Technology/Retrofits

A number of irrigation-related studies are available, typically either controller technology or overall irrigation system retrofits. The largest group of studies is associated with evaluation of "smart" irrigation controllers, either weather-based or soil moisture-based. Irrigation controller testing has been conducted by both the U.S. Bureau of Reclamation and the Irrigation Association through its Smart Water Application Technology (SWAT) program. Multiple studies have shown statistically significant savings associated with smart irrigation control technology.

In Colorado, several small-scale studies have been conducted by City of Boulder (1998), Aquacraft (2001, 2002), Mecham and Boyd (2004) and Keesen (2004) that demonstrated water savings associated with irrigation controller technology. The Mecham and Boyd (2004) study combined a soil preparation variable with several types of irrigation controller technologies at their study of nine model homes. Attachment 2 reports water savings associated with these and other studies, but additional standardization of the savings metrics is needed, since the results range from percent of water applied relative to a water budget, gallons saved, or percent water savings. Range of savings is quite variable and more processing of this data set is needed.

In 2009, Mayer et al. released a large-scale ET controller study based in California. Although the study was not located in Colorado, the study is particularly important due to the very large sample size and the strong experimental design basis associated with the project, enabling meaningful statistical analysis at a more robust level than is typically found. Additionally, the study is important because it demonstrates the difference between technologically achievable water savings versus real-world water savings when the human behavior factor is considered. A brief summary of this study follows.

The California Weather-Based Irrigation Controller (WBIC) study (Mayer et al. 2009) presents empirical data on the performance of smart controller products distributed and installed through different methodologies in a wide variety of settings over a four-year time period. The study was completed in cooperation with the California Department of Water Resources, the California Urban Water Conservation Council, the Metropolitan Water District of Southern California and their 26 member agencies, and a consortium of six water agencies in northern California led by the East Bay Municipal Utility District. Utility partners were able to provide the necessary data for 2,294 sites with 3,112 smart controllers. Fourteen different brands of controller were included in the analysis portion of this study, with varying installation conditions (owner versus

professional). Overall, outdoor water use was reduced by an average of 47.3 kgal per site (-6.1% of average outdoor use) across the 2,294 sites. This reduction was found to be statistically significant at the 95% confidence level. Multiple nuances and community specific findings were also presented. The report should be referenced for more detail, with the following findings and conclusions briefly quoted directly from the Executive Summary prepared by Mayer et al. (2009):

- On average smart controllers are a moderately effective measure for reducing the amount of water applied by automatic irrigation systems, while maintaining the health, and appearance of landscapes.

- When seeking irrigation water savings, the pre-existing level of excess irrigation at the site is the most important factor to consider.

- The water savings achieved through installation of smart controllers can be maximized by targeting the technology to irrigators with historically high irrigation application rates, not simply customers with high irrigation use.

- The many irrigators who historically apply less than the theoretical irrigation requirement for their landscape are likely to increase their irrigation application rate after installing a smart controller.

- Survey results indicate that smart controllers are likely to achieve a high degree of customer acceptance once they more broadly penetrate the consciousness of irrigation contractors and the general public.

- The utility programs implemented through the Division of Water Resources grant have succeeded in raising public awareness of this technology, but survey results suggest most consumers have no knowledge of smart irrigation control.

- Smart controllers can achieve cost effective water savings for utilities and irrigators under some cost and pricing scenarios, however this technology will not be cost effective for all utilities and customers.

- Most of the smart controller brands and technologies evaluated in this study reduced irrigation demands on average, but not all of these reductions were statistically significant.

Additionally, Keesen (2004) has calculated savings associated with overall irrigation retrofits at several locations in Colorado, demonstrating significant water savings associated with retrofits and providing cost data and return on investment calculations. More information on irrigation retrofits in Colorado is believed to be available; however, it appears that data compilations are often not completed. Denver Parks and Recreation is a likely source of future information as a number of large irrigation retrofits of Denver parks have either been completed or are planned.

Several additional behavioral observations related to irrigation technology identified in the literature that were noteworthy include:

- Mayer et al. (2009) state, "The irrigation controller is important, but only one piece of the puzzle. Even the best, most water efficient controller cannot make up for poor system design, installation, and maintenance. The focus of [the California WBIC] report is on irrigation controllers, but a holistic approach to irrigation systems and landscape design and maintenance is required to achieve the full potential of water savings in the urban irrigation sector."

- Kenney and Reidy (2009) posed the following question, which may warrant additional study: "To what extent is outdoor water use a function of the types of irrigation technologies in use (e.g., hoses, sprinklers, timers), and what opportunities exist to strategically manipulate this as part of demand management programs?"

- Barnes et al. (2008) identified some issues with residential rebate programs or distribution of ET controllers in California that fall in the "behavioral" category:

    - Controllers not in ET mode
    - Weather monitors installed improperly (upside down, under roof, near heat source)
    - Incorrect programming (plant type, sprinkler type, etc.)
    - Lack of fine-tuning of programming after installation
    - Initial starting point as "deficit irrigators"

Irrigation Efficiency Audits

Several studies documenting the effectiveness of irrigation efficiency audits in semi-arid and arid locations were identified. All of these studies demonstrated or estimated water savings, but once again, results vary and are reported according to varying performance metrics.

A study of particular interest is the Center for ReSource Conservation (CRC)'s Slow the Flow Colorado Program, which included performing 1,256 irrigation inspections across Colorado's Front Range in 2007. As part of the inspection, a CRC auditor tested a property's irrigation system for efficiency and recommended an irrigation schedule, as well as other improvements that could improve the system's efficiency. Common problems identified included poor distribution uniformity and systems operating at incorrect pressure, with only 12 percent of inspections showing systems considered to be operating efficiently. Following the inspections, 79% of participants that watered at rates above ET prior to the inspection reduced their water usage after the inspection.

A similar "Water Check" program has been conducted by Utah State Center for Water Efficient Landscaping. Annual reports include water use analysis compared to a baseline year, property characteristics, irrigation system characteristics, and cost data. Table 4 summarizes study results from the 2008 annual report (Waters et al. 2009). This table is also important because it shows variability over time, emphasizing the importance of long-term data collection in terms of assessing durability of conservation measures.

Table 4.
Average Annual Water Savings (kgal) per Household for Sandy, West Jordan, and Salt Lake City Water Check Participants Over the Course of the Water Check Program
(Source: Waters et al. 2009)

	Water Service Area Savings in Kgal/year/household		
Year	**Sandy**	**West Jordan**	**Salt Lake City (based on available data)**
2002	78.72	40.40	60
2003	32.49	5.63	27
2004	22.40	6.45	33
2005	2.23	-20.14	-
2006	-11.76	-17.63	-
Average Annual Savings per Household (kgal) (excluding Salt Lake City)	**13.88****		

Waters et al. (2009) provided these broad-scale observations:

- To date, 6,325 residential Water Checks have been completed along with 286 large Water Checks.
- The main techniques by which Water Check Program effectiveness has been evaluated is the comparison of water use and billing data from Program participants to matched control groups and also to the participants themselves over time.
- When averaged over all post water check years per household, Salt Lake City Program participants conserved the most (40,000 gallons/year in years with available data), West Jordan the least, (3,000 gallons/year to date), and Sandy at an intermediate level (25,000 gallons/year to date).
- Analysis of individual household patterns of water use showed that 60-70% of Program participants had a high capacity to conserve, and most of them reduced their water use as a result of program participation.
- The increased water use observed statewide in 2006 (and 2007) may indicate that desensitization to the conservation message of the Slow the Flow program occurred during those years. However, the climatic conditions of 2007—the hottest summer on record—should have led to an increased, not decreased, conservation response by Utahns. The decreased water use observed statewide in 2008 may indicate that Utahns response to conservation as a result of climatic conditions shows a predictable delay. With further observation of statewide trends and the water savings of Water Check participants, these responses may be quantifiably determined.

- To date, large water check participants within the Jordan Valley Water Conservancy District's retail service area (n=7) have shown approximately 5 million gallons of savings over the baseline year. This represents an average of 16,500 gallons of water saved per acre audited.

- Large water check participants within West Jordan City's retail service area (n=28) have shown an approximate savings of over 31 million gallons of savings over their respective baseline years. This represents an average of 319,000 gallons of water saved per acre audited.

Soils

Proper soil preparation and amendment is the top issue cited by turfgrowers as a reason for poor turf establishment and shallow rooting. Multiple cities across the Front Range have also recognized this and are now requiring soil amendment at new turf installations. The only control and test case study related to soil preparation identified during this literature review was conducted by Mecham and Boyd (2004) at nine model homes in Loveland. The study concurrently evaluated performance of two different types of ET controllers. Additional studies are believed to exist in the horticultural literature, but were not obtained during the course of this review. One related study by Johnson et al. (2006) showed that topdressing turf with compost extended the number of days between watering.

Plant Selection

From the scientific side of water conservation, it is important to have an understanding of how much water plants require. A reasonable base of scientific information regarding expected plant water requirements is available through the X-rated Gardening program, the 2004 GreenCO/Colorado State University (CSU) Crop Coefficient Survey (Kc) Survey and an ongoing CSU shrub water requirement study. Multiple CSU professors such as Dr. Jim Klett and others continue research in this area. Dr. Tony Koski has conducted significant research on water requirements and selection considerations for numerous turfgrass varieties. The research should be used as a scientific basis to separate plant requirements from behavioral water application practices.

Actual water savings are dependent on education regarding water needs, irrigation scheduling, etc. Unless plant choice is combined with good cultivation practices, water savings will be less than potentially achievable. A lesson from nursery professionals during the development of the GreenCO BMP Manual is that the most common reason that failing plants are returned to nurseries is overwatering. This is important in the context of turf replacement programs, where replacement of turf with other plants may or may not result in significantly reduced water application.

Turf Management

Good Colorado-based turf-related scientific data are available from the Colorado Turf Research directed by Tony Koski. Table 5 provides a summary prepared by Barta et al. (2004) that

integrates data from Koski (2004) and Denver Water's experience (Gardner 2004). See the "General Turf Management References" on the Colorado Turf Research program website for over 175 sources related to turf and golf courses. Using this research, water budgets for turf are relatively straightforward to develop, with many tools available such as the Turf Irrigation Management System (TIMS) program at Northern Water Conservancy District.

Table 5.
Water Needs for a Variety of Landscape Conditions
(as summarized by Barta et al. 2004)

Landscape Type/Condition	**Annual Water Need [inches]**
Koski (2004) Recommendation	
Adequate for healthy bluegrass	24
Maintenance level for healthy bluegrass	18
Denver Water Experience (Gardner 2004)	
Recommended amount for healthy bluegrass	29
Single Family Residential (SFR) average	35
Average for SFR with clock-controlled sprinkler	39
Average for SFR with manual watering (hose)	32

In the literature review by Barta et al. (2004), the following observations regarding turf water requirements are noteworthy:

- "Cool season grasses do require more water than many common landscape plants, but it is not for this reason alone that landscapes constitute a majority of our urban water uses. Mismanagement and uninformed decisions about landscapes are as much a reason for high water use as is cool season turfgrass. There is often little consideration put into limiting turfgrass to practical turf areas, or those areas where lawns serve a functional or practical use. Instead society tends to place turfgrass throughout cities, even on medians and along roadways because it aesthetically appealing and is relatively inexpensive to install. In addition, very few people are informed about how much water turfgrass needs to maintain a healthy, green lawn." (p. 7)

- "A significant conservation issue associated with using water for turfgrass and landscapes is that they tend to be overwatered. Poor irrigation scheduling, or watering too often or for too long, is the primary source of water waste in landscapes. It has been suggested that the average landscape is overwatered by more than 10% to 50% (Reed, 2002; Ash, 2002; Kjelgren et al., 2002). A majority of overwatering occurs through the mismanagement of some of the more technically advanced irrigation systems." (p. 7)

Echoing these findings, Wright Water Engineers has compiled irrigation usage data at several locations along the Front Range. This work was completed as part of data collection efforts related to work for insurance companies for claims associated with building foundation

damage/wet basements. Overwatering at several homeowner's associations ranged from 220 to 275 percent of irrigation requirements based on an estimated water budget (Clary et al. 2004).

In addition to current research at the CSU Turfgrass Research Center, several Colorado Water Resources Research Institute studies from the late 1970s and early 1980's provide some historical context on conservation and urban lawn care. (These studies were not evaluated in Attachment 3, but can be downloaded from http://www.cwi.colostate.edu/publications.asp.) A few selected notes include:

- In "The Effect of Conservation Programs on the Quality of Urban Lawns," Winje and Flack (1986) conducted a study of 209 properties along the Front Range and found that good lawn quality can be achieved along with moderate water conservation and that conservation education leading to good maintenance habitats can actually lead to high quality lawns. The study findings were in contrast to their survey findings where water utilities and homeowners expressed concerns regarding brown lawns anticipated due to conservation. The study also showed that water is probably over-applied to lawns in most communities and that water conservation can be achieved when the public is informed that water conservation is in their best interest.

- In "Water Requirements for Urban Lawns in Colorado," Danielson et al. (1980) conducted studies in 1977 and 1978 regarding irrigation application rates to lawns in Fort Collins and Northglenn. The study found that irrigation application rates in Fort Collins were appreciably higher than in Northglenn, even though the lawn water requirements were higher in Northglenn. Total water application in Fort Collins was 135% of potential ET, whereas water application in Northglenn was about 80% of potential ET. The pricing in Fort Collins at that time was a flat rate system, whereas Northglenn charged for the amount of water delivered. The study also found that lawn quality ratings reflected the amount of water being applied to the lawn. Because lawn quality is not assessed based on yield (as are crops), the amount of water to be applied is more subjective in terms of achieving a desired aesthetic. As a result of the study, irrigation guidelines were developed to maintain a high, medium and low quality lawn for various cities in Colorado based on historic precipitation, temperature and solar radiation.

- In "Urban Lawn Irrigation and Management Practices for Water Savings with Minimum Effect on Lawn Quality," Danielson and Feldhake (1981) reported research findings from research conducted at CSU during 1979 and 1980. Lysimeters were used to measure the effect of various lawn management practices on maximum water use and the response of turf to limited irrigation levels. Maximum water use was influenced by these factors: mowing height, nitrogen fertility, shade level, grass species and soil properties. The study found that proper management can minimize the loss of quality in turfgrass. The study also noted the ability of bluegrass to go dormant during drought and that regular periods of mild water stress help promote soil aeration and growth of a vigorous root system, increased drought tolerance and water conservation without greatly reducing quality. The study also presents some perspectives on the values of lawns in urban areas.

SWSI II (CDM 2007) places significant emphasis on turf replacement as a landscape water conservation measure (40% of overall conservation savings); however, proper management of turf (e.g., irrigation scheduling, water budgeting) is not included. Reduction of overwatering of turf and proper soil preparation prior to turf installation may also provide measurable conservation benefits, particularly in existing developments. Additionally, the long-term irrigation practices associated with non-turf replacements are not clearly defined. During the development of the GreenCO BMP manual, nursery professionals noted that the most common reason for return of failing plants to nurseries is overwatering.

Water Budgeting

Although this literature review has not focused on price-related aspects of landscape water conservation, the concept of developing a landscape water budget (and following it) is closely tied to tiered rate structures based on water budgets. The Irvine Ranch Water District model is likely the most well known of these approaches. Within Colorado, the City of Boulder and Centennial Water and Sanitation District are two utilities to continue following with regard to the effectiveness of water budget-based rate structures. In support of this literature review, Centennial Water and Sanitation District (Klassen 2009) provided a summary of findings related to implementation of a water budget based rated structure. A few highlights include:

- For the purpose of estimating water savings due to the implementation of the water budget rate structure, the District uses 2001 as a benchmark. It is estimated that the water budget rate structure has helped achieve a 21 percent savings compared to projected demand numbers prior to implementation.

- Approximately 75 percent of residential and multi-family customers are at or under water budget annually. Water use as a percentage of water budget is typically around 85 to 90 percent. Residential water use has decreased from 126 gpcd in 2001 to 102 gpcd in 2007.

- Non-residential irrigation customer water use is typically over water budget. Water use as a percentage of water budget for this customer class is around 110 percent. Centennial will continue to focus additional efforts towards this customer group to help reduce their water usage.

See Klein et al (2007) for more detailed exploration of water budgeting in the context of water rate structures.

Education/Outreach

Quantifying the benefits of education/outreach is challenging. The Seattle 1% Annual Conservation report provides some insight into possible approaches (Seattle Public Utilities 2009). Of particular interest to the Green Industry is the partnering that Seattle Public Utilities has done with regard to contractor training and offering programs in Spanish. This may provide a model for CWCB to encourage, working with GreenCO, ProGreen and other Green Industry programs already established in Colorado. The Town of Castle Rock and the City of Boulder

both have implemented landscape-training education programs. It would be instructive to obtain an assessment of the expected benefits achieved by these local efforts.

A key finding of several of the National Xeriscape Demonstration Project (NXDP) studies was the challenge of getting people to participate in programs. Recent literature regarding conservation and social marketing Silva (2008) and studies documenting property owner perception of Xeriscape such as the NXDP studies, studies by Atwood et al. (2008) reporting residential assessments of outdoor conservation program, and others may useful in identifying social and behavioral parameters to track when evaluating potential effectiveness of water conservation programs. Hanak (2007) and Gleick et al. (2003) note that there may be considerable educational, political, and social barriers to achieving conservation savings, even when the savings should be achievable from a scientific/technology perspective.

Monitoring and Evaluation

While monitoring and evaluation are not specifically identified as a landscape BMP (i.e., a physical practice applied to the landscape), these activities are fundamental to developing the state of the science regarding water conservation practices throughout the U.S. and in Colorado. A handful of monitoring and reporting requirements associated with conservation programs in western and southwestern states were briefly reviewed, including Texas (TWDB 2009), Arizona (2009), New Mexico and others. Although covered entities in Colorado with Water Conservation Plans are also required to monitor and evaluate progress, the guidelines and requirements are general. A more systematic review of monitoring and reporting requirements in other states would be helpful as part of a follow-up to this literature review.

As an example of requirements in other states, Texas Water Development Board requires entities receiving financial assistance of more than $500,000 to implement a water conservation program for the life of the loan and report annually on the progress of program implementation. This reporting includes estimated savings associated with conservation measures. TWDB provides a standard reporting format to assist in this effort, although the landscaping reporting component is brief and narrative.

Arizona also has a standard form for reporting conservation efforts. In Arizona, “A Summary of Water Conservation Programs in Active Management Areas” (ADWR 2007) provides a publically accessible summary of conservation and educational measures, ordinances, etc., in place in these Active Management Areas.

Of particular interest, in Oregon, the “Statewide Conservation Inventory, Oregon Water Supply and Conservation Initiative” (HDR 2008) is conducting a conservation inventory for these purposes:

- Help the State better understand the nature and magnitude of conservation opportunities and how they might serve as solutions to supply shortfalls by reducing out of stream demands.

- Provide a data source for the state to use when identifying and prioritizing projects for possible state funding.

Based on a survey of utilities in Oregon, an inventory of parameters useful in data reporting on conservation measures has been developed to promote transfer of knowledge. A spreadsheet of conservation projects has also been developed. (Although this may have some similarities to the "Identified Projects and Processes" database already underway for CWCB, the Oregon database is more oriented to documenting study variables/data.)

The need for systematically collected landscape water conservation data in Colorado has been a common recommendation for over a decade, recurring in several key Colorado reports, including these representative findings by Colorado researchers:

- Michelson et al. (1998) stated: "A significant finding of this study is the overall lack of information available regarding the implementation of non-price conservation programs and the lack of detail and consistency of water use information necessary to evaluate changes in demand. With improved information, combinations of programs, proven to be successful in reducing water-use levels in one city, could be applied to cities with similar characteristics …"

- Heaney et al. (1998) further recommended, "A concerted effort is needed to devise more effective ways to reduce outdoor water use in urban areas. Intensive monitoring is needed to evaluate how irrigation water is actually used in urban areas."

- Barta (2004) echoed the same finding: "…in general, there is not sufficient peer-reviewed literature to scientifically evaluate the effectiveness of urban landscape water conservation strategies. While there have been studies of basic urban water conservation principles, applications of water conservation practices by municipalities are highly site-specific, are often inconclusive due to confounding factors, and a lack of strong backing of scientifically defensible information."

- Waskom (2008) states, "The question is not whether water conservation is achievable or desirable, but whether it can be a viable, long-term substitute for new water storage projects or agricultural transfer."

In summary, monitoring and reporting guidance from other states should be reviewed in more detail for potential application in Colorado. Guidance provided by CWCB could help facilitate standardized reporting of conservation measures. Additionally, studies conducted and water demand models developed previously by Michelson et al. (1998), Heaney et al. (1998), Kenney et al. (2008), and other studies (Colorado-based, whenever available) should be considered in developing such guidance and identifying parameters that should be reported in water conservation studies and assessments. With input from water utilities, it is possible that some standard reporting guidelines that are not overly burdensome could be helpful to providing a common base of knowledge for use by water providers throughout the state. This appears to be needed, in part, due to the difficulty experienced in trying to obtain this type of data from Colorado water providers (even those who are actively engaged in and committed to meaningful conservation).

Use of Data in Projecting Water Conservation Savings

In order to develop and apply estimates in longer term planning, several factors need to be taken into consideration:

- **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.

- **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.

- **Performance Benchmarks**. The studies reviewed 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 would 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,

implementation of a weather-based irrigation controller on a property that already applies minimal irrigation will show a low percent savings, 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.

- **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.

Lessons from Other Water Resources Disciplines

During the course of the literature review, several parallels between indoor/outdoor water use and the wastewater/stormwater disciplines emerged that may be worth further consideration in terms of next steps in quantifying or refining estimates of the potential savings associated with landscape water conservation. These are discussed briefly below.

Indoor/Outdoor Parallels to Wastewater/Stormwater: Development of a Stormwater BMP Database

Evaluation of outdoor water conservation potential is unquestionably more complex than indoor conservation, in part because it is not a matter of simply replacing old technology with new technology mandated under plumbing codes. Effective outdoor water conservation requires on-going maintenance and continual adjustment to variables. To some extent, these challenges have parallels in the water quality arena where installation of treatment technologies in wastewater treatment plants is much more controllable than performance of best management practices for stormwater treatment. In the stormwater arena, a significant problem has been reporting of pollutant removal efficiencies using differing assumptions and inadequate documentation of variables. As a result, a national stormwater BMP performance database (www.bmpdatabase.org) was established to provide standardized guidance on 1) parameters to report to evaluate BMP performance, 2) a standardized database where studies could be submitted for use by the broader technical community and 3) development of standardized performance analysis protocols, using statistically valid techniques. Development of a similar approach in the landscape conservation arena could be beneficial to Colorado in moving from a "fruit basket" of studies to a more standardized accounting of variables.

Use of GIS to Effectively Integrate Local Government Data for Planning Purposes

GIS appears to be an underutilized tool with regard to landscape water conservation planning. Although some communities such as Boulder and Centennial Water and Sanitation District have used GIS to develop customer-specific water budgets, there appears to be opportunity for broader, general planning application, as well. Utilities are increasingly using GIS to map and plan for system infrastructure, but more opportunity is believed to be present in terms of conservation planning and subsequent tracking of the effectiveness of conservation measures. As an example, in stormwater drainage planning, a common first step is to combine aerial photography (up-to-date coverage is available for the metro-Denver area) with tax assessor database records to generate impervious area coverage estimates based on zoning data. This information is then used as a key component in modeling existing and future runoff conditions to size drainage improvements. Additionally, in some areas, the impervious component of the landscape has already been calculated or estimated in support of stormwater utility fees. Whereas drainage planning focuses on impervious area, the reverse would be true for landscape water conservation planning. This type of land use information could be combined in conjunction with water billing records (subtracting estimating annual indoor use from winter billings) to target areas most likely to be sources of landscape water waste, using some basic water budgeting benchmarks. Once this information is known, more reasonable estimates of water conservation potential could be developed in a targeted manner that moves beyond "who has the largest water bill." Socioeconomic factors identified in the literature could be linked to surrogates such as home age and square footage and lot size. Using GIS in combination with basin round tables, it could be possible to develop an approach to refine estimates at a statewide level, although it is recognize that this would be a substantial undertaking at a statewide scale. A pilot project could be useful in determining whether a GIS-based approach could be effectively extrapolated to a larger statewide scale.

Conclusions and Recommendations

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, 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 within Colorado. Locally based studies are important due to both climate and social values influencing behavior.

2. A limitation of the compilation of data in this 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 this 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 attainable 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:

    - 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.

- 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 such as Geosyntec's Ambient Water Beacon also exist. These types of studies may be particularly beneficial in developing a better understanding of the behavioral/social component of water conservation.

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

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

- 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.

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

- 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.

- 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 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.

Recommended Near-term Actions

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.

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