Outdoor Irrigation Measurement and Verification Protocol

Guidelines for Energy Service Companies and Water Efficiency Service Companies to Determine Water Savings of Outdoor Irrigation Efficiency Measures for Use in Performance Contracts

August 2017

KL McMordie Stoughton

SA Loper

JR Figueroa

Western Resource Advocates has spent more than 25 years protecting the West's land, air, and water so that our communities thrive in balance with nature. We use law, science, and economics to craft innovative solutions to the most pressing conservation issues in the region.

The Pacific Northwest National Laboratory's mission is to transform the world through courageous discovery and innovation. For more than 50 years, PNNL has advanced the frontiers of science and engineering in the service of the nation and the world, translating discoveries into tools and technologies in science, energy, the environment, and national security.

The National Renewable Energy Laboratory focuses on creative answers to today's energy challenges. From breakthroughs in fundamental science to new clean technologies to integrated energy systems that power our lives, NREL researchers are transforming the way the nation and the world use energy.

Outdoor Irrigation Measurement and Verification Technical Advisory Group

Brent Q. Mecham	Industry Development Director, Irrigation Association
Ben Slick	Senior Vice President of Business Development, HydroPoint
Cable Jones	Project Developer, Water Management, Inc.
Niffy Ovuworie	M&V Program Manager for the Rocky Mountain Region, McKinstry
Megan Ferguson	Energy Engineer, Siemens Industry, Inc.
Patrick Watson	Conservation Services Administrator, Southern Nevada Water Authority
Paul Basset	Senior Vice-President and Chief Technology Officer, Water Savers, LLC
Richard Chapman	President, Smart Use, LLC
Philip Neff	Engineering Manager, Honeywell Energy Services Group of North America
Scott Winter	Lead Water Conservation Specialist, Colorado Springs Utilities
William Travers	Sr. Project Developer, NORESCO

Technical Lead

Kate McMordie Stoughton	Water Efficiency Engineer, Pacific Northwest National Laboratory

Project Co-Leads

Jorge Figueroa	Senior Water Policy Analyst, Western Resource Advocates
Taylor Lewis, PE	Program Engineer, Colorado Energy Office

Senior Advisors

Chuck Kurnik	Engineer and Project Manager, National Renewable Energy Laboratory
Linda Smith	President, 9Kft Strategies in Energy
Amelia Nuding	Senior Water Resources Analyst, Western Resource Advocates

Steering Committee Members
Water, Measurement and Verification (M&V) Guidelines, and State Performance Contracts Project

Donald Gilligan	President, National Association of Energy Service Companies
Mary Ann Dickinson	President and CEO, Alliance for Water Efficiency
John Canfield	President, Trident Energy Services
Chris Halpin	President, Celtic Energy
Patrick Watson	Conservation Services Administrator, Southern Nevada Water Authority
Carlos Bustos	Water Conservation Program Manager, Albuquerque Bernalillo County Water Utility Authority
Frank Kinder	Senior Conservation Specialist, Colorado Springs Utilities
Paul Matuska	Manager, Water Accounting and Verification Group, U.S. Bureau of Reclamation
William D. Taylor	Private Sector Co-Chair, Energy Services Coalition-Nevada Chapter
Oscar Rangel	Private Sector Co-Chair, Energy Services Coalition-Colorado Chapter
Scott Griffith	Private Sector Co-Chair, Energy Services Coalition-New Mexico Chapter
Harold Trujillo	Chief, New Mexico Energy Technology and Engineering Bureau, New Mexico EPC Program
Kelly Thomas	Energy Program Manager, Nevada Governor's Office of Energy, Nevada EPC Program
Taylor Lewis, PE	Program Engineer, Colorado Energy Office, Colorado EPC Program

Acknowledgements

Table of Contents

Tables

Figures

1.0 Acronyms, Abbreviations, and Definitions

ASBE   American Society of Agricultural and Biological Engineers

CAWQuer   Climate Atlas Web Query (online tool and database)

Climate normal   Average weather conditions for a given location that is over the latest three-decade period

CoAgMet   Colorado Agricultural Meteorological Network

Commissioning   The process whereby the measure improvements made to the equipment or the control system have been verified to comply with the approved plan, and visually inspected and evaluated for proper operation

Effective precipitation   The amount of rainfall that is added and stored in the soil

ESCO   energy service company (performance contractor)

Evapotranspiration (ET)   The combination of loss of water due to evaporation from soil and plant surfaces and the amount of water transpired by the plant over a given time frame

Hydrozone   A distinct area of the landscape that receives irrigation from the same system

Irrigation efficiency   The percentage of irrigation water that is stored in the soil and available for use by the landscape (as compared to the total amount of water provided to the landscape)

IPMVP   International Performance Measurement and Verification Protocol

IWMI   International Water Management Institute

M&V   measurement and verification

Measurement boundary   The specific landscape areas that are impacted by the WCM and monitored for water savings

Measurement frequency   The number of measurements that will be collected over the measurement period to determine water-use savings

Measurement period   The time frame within which water use is monitored, defined by the irrigation season

NOAA   National Oceanic and Atmospheric Administration

Plant factor   The fraction of reference evapotranspiration required by the plant type for acceptable appearance

Reference ET (ET$_o$)   The loss of water from the defined vegetated surface (e.g., alfalfa grass) which serves as an evaporative index by which evapotranspiration can be predicted for a range of vegetation and surface conditions

Study period   The total time frame that water use will be monitored per the contractual arrangement for the baseline and post-installation periods

WCM   water conservation measure

WESCO   water efficiency service company (performance contractor)

2.0   Introduction

This measurement and verification (M&V) protocol provides procedures for energy service companies (ESCOs) and water efficiency service companies (WESCOs) to determine water savings resulting from water conservation measures (WCMs) in energy performance contracts associated with outdoor irrigation efficiency projects. The water savings are determined by comparing the baseline water use to the water use after the WCM has been implemented. This protocol outlines the basic structure of the M&V plan, and details the procedures to use to determine water savings. **It is vital that the customer reviews the M&V plan thoroughly and agrees to the procedures used by the ESCO and WESCO to collect data and measure water savings.**

The procedures presented in this protocol are performance based. In performance contracts, ESCOs and WESCOs are required to measure the amount of water savings directly and do not have to prove the effectiveness of the measure itself. This protocol does not cover other cost streams such as operation and maintenance or energy costs.

3.0   Measure Description

This protocol specifies M&V requirements for WCMs associated with improving the efficiency of irrigation systems. Irrigation systems include all components that deliver and control the application of supplemental water in landscapes. System components include piping infrastructure, valves, sprinkler heads, and irrigation controls. The WCMs that are covered by this M&V protocol include, but are not limited to, the following.

Irrigation System Efficiency Improvements

The objective of this measure is to increase irrigation system efficiency by improving the uniform distribution of water to meet the landscape irrigation requirements and minimize waste and losses from the system.[1] This WCM category can include measures such as reconfiguring the irrigation system, repairing system components, repairing system leaks, and replacing irrigation systems with more efficient technology such as drip irrigation and subsurface irrigation.

Advanced Controls

Irrigation controllers manage the application of water to a landscape. This measure includes installing advanced controllers that use real-time data to irrigate landscape based on local conditions. Such measures can reduce overall watering times, thereby decreasing water use. Advanced controllers include weather-based systems that use weather data to calculate evapotranspiration (ET) to determine the landscape's current irrigation requirements. Another type of advanced controller is the soil-moisture-based controller, which uses real-time soil moisture data and adjusts the irrigation schedule to meet the specific water needs.

---

[1] Irrigation efficiency is defined as the percentage of irrigation water that is stored in the soil and available for use by the landscape as compared to the total amount of water provided to the landscape.

Real-Time Sensors

Real-time sensors monitor live conditions of the landscape, and can temporarily suspend irrigation when irrigation is not optimal. Examples of real-time sensors include rain, wind, and freeze sensors. These typically are tied into an automated control system to optimize the irrigation schedule, thereby reducing the overall amount of irrigation of the landscape.

Another type of real-time sensor is the flow sensor. Flow sensors monitor water flowing in the irrigation distribution pipes that can detect abnormal flow conditions that could indicate a system problem. The flow sensor can interface with an irrigation controller to suspend irrigation when needed.

4.0   Measurement and Verification Plan Elements

In a performance contract, the ESCO and the WESCO are required to develop a plan that specifies how the M&V will be performed. This section provides the basic structure of the M&V plan.

4.1   Measurement and Verification Method

The International Performance Measurement and Verification Protocol (IPMVP) has four options (A, B, C, and D) that can be used to verify the savings of measures.

For outdoor irrigation efficiency measures, the recommended IPMVP option to verify water savings is Option B, "Retrofit Isolation."

The objective of Option B — Retrofit Isolation — is to verify performance by measuring the system usage, which increases the accuracy of the verified savings. The retrofit isolation method uses real-time field measurements of the irrigation system to verify the savings, whereby short-term or continuous measurements are taken throughout the study period. The flow of each irrigation hydrozone is the key parameter that is required to be measured using Option B.

The IPMVP Option A — Partially Measured Retrofit Isolation — allows some stipulated savings. This is a less-desirable method because it does not accurately measure the full impact of the measure. Option C ("Whole Building") and Option D ("Calibrated Simulation") are not appropriate M&V methods for outdoor irrigation efficiency projects because they assess usage at the building level rather than the system level.

The following section provides information on the main elements of data collection that should be included in the M&V plan when using the Option B M&V method.

4.2   Measure Description and Measurement Boundary

The M&V plan should describe the specific WCMs and the intended results. Additionally, the plan should clearly define the measurement boundary. The measurement boundary defines the specific landscaped areas that will be impacted by the WCM and monitored for water savings.

4.3   Baseline and Post-Installation Condition

The M&V plan should provide a detailed description of the baseline and post-installation conditions. It includes information related to the irrigation audit, irrigation schedule, and the condition of the landscape.

4.3.1   Baseline Condition

The plan should include information relevant to the baseline conditions collected during the irrigation audit. The information collected describes the state of the existing irrigation-system components such as, but not limited to, component leaks, nozzle type, and head spacing. The plan also should detail the irrigation schedule, including the type of controller and specific changes made to the irrigation schedule during the baseline year that impact the baseline water use.

The plan also should document the area of the landscape, the vegetation in the landscape, and overall landscape condition. The description of the baseline condition of the landscape can include, among other things, the landscape slope, soil type, significant drainage issues, and current planting type and condition (from aesthetic/visual quality to general plant health). The customer could require that the baseline condition be maintained in the post-installation period. If this is the case, then the ESCO and WESCO should estimate the savings potential based on the required level of irrigation to maintain the landscape at the desired level.

4.3.2   Post-Installation Condition

The M&V plan should specify the condition of the irrigation systems and landscapes that will be achieved through the study period per the commissioning plan (*see* section 6.0). This should include information on the irrigation system components and schedules. The required appearance of the landscape can also be included. The customer might require that a specific appearance of the landscape be maintained during the study period.

4.4   Water Use Calculations

The M&V plan should include the procedures used to determine the baseline water use and post-installation water use, which are used to calculate the water savings and to properly normalize the data if required. Section 5.0 of this protocol provides detailed procedures on the calculation methods. **The procedures should be described in detail, and reviewed and approved by the customer.**

4.5   Data Categories

The M&V plan should specify the distinct categories of data that will be gathered and the methods used to gather the data. It is important for the customer to review and approve the type of data that will be used to determine water-use savings. The following describes the type of data that can be collected.

- *Continuous measurement using a dedicated meter*

    Volume of water logged by the metering system over the measurement period. Specify the interval at which the volumetric water use will be logged. If multiple meters are in place

that measure water use in the measurement boundary, make sure that all meters are included. Data should be gathered monthly, which is required in the normalization process (*see* Section 5.3).

- *Flow rate determination*

  Hydrozone flow rate logged by a dedicated or temporary metering system over distinct periods, typically measured in gallons per minute. The plan should include the procedure to isolate the flow rate of the specific hydrozones within the measurement boundary (*see* Section 4.8 for additional information on flow rate determination).

- *Irrigation audit to determine the irrigation precipitation rate (baseline water use only; see Section 5.1 for additional information)*
  - Hydrozone precipitation rate, which is the amount of water distributed to a specific area, typically measured in inches per hour.

  - Landscape area that defines the irrigation coverage of the hydrozone, typically measured in square feet. The plan should specify how the irrigation area is measured (e.g., aerial map, direct measurement).

- *Irrigation system's runtime logged over the measurement period*

  The amount of time that the irrigation system operates over the same time frame as the flow rate, measured in minutes (e.g., irrigation control system, manual logs). The runtime should be collected from irrigation controller or operator logs. The total runtime should be the sum of the total daily runtime over the measurement period for each hydrozone.

- *Weather data*

  Evapotranspiration and precipitation data used to normalize water use. The plan should include the data source and the location of the weather data relative to the site location (*see* Appendix A for local ET and precipitation data sources and methods).

- *Landscape area*
  - The total area of the landscape should be documented, typically expressed in square feet.
  - The area of specific plant types identified in Table 1 in American Society of Agricultural and Biological Engineers (ASBE) Standard S623[8]: Cool season turf, warm season turf, annual flowers, woody plants and herbaceous perennials (wet and dry), and desert plants. (This information can be used in the normalization process, *see* Section 5.3.)

4.6 Study Period

The study period covers the total time frame that water use is monitored per the contractual arrangement for the baseline and post-installation periods. The study period should follow the established M&V requirements of the State Performance Contracting Program.[2]

---

[2] *See*, for example, the "State of Colorado's M&V Guidelines for Energy Savings Performance Contracts." Nexant. June 2008. *Measurement and Verification (M&V) Guidelines for Energy Saving Performance Contracts in State of Colorado Facilities*. Boulder, CO.

The plan should define the baseline period. The baseline study period should be a minimum of one full irrigation season, but preferably is an average of multiple irrigation seasons. Using an average of multiple years for the baseline study period is preferable because it helps to dampen anomalies in water use caused by operation changes, such as scheduling issues or system maintenance problems.

Preferable: baseline study period is an average of multiple irrigation seasons

Acceptable: baseline study period is minimum of one full irrigation season

---

The plan also should define the study period for the post-installation water use measurement. In the state of Colorado, for example, ESCOs and WESCOs are required by statute to provide a written cost savings guarantee for the first three years of the contract period.[3] At the agency's discretion, the savings guarantee can be extended beyond the legislatively required period. At the end of each performance year, the ESCO and WESCO are required to submit an annual M&V report to demonstrate that the savings have occurred.

4.7   Measurement Period

The M&V plan should specify the measurement period, which defines the irrigation season. For Colorado, the typical irrigation season is from mid-April through October.

4.8   Measurement Frequency

The measurement frequency is the number of measurements that will be collected over the measurement period to determine water-use savings. To properly normalize the data, water use should be collected monthly.

- *Water use with a dedicated meter*

  Water use-data should be collected from the dedicated meter at least monthly, and should capture the full measurement period.

- *Flow rate determination*

  Flow rate for each hydrozone in the measurement boundary should be measured at the beginning, mid-point, and end of the measurement period to determine an average flow rate. This ensures that an accurate flow rate is determined. Flow rates can vary due to system issues such as line leaks or broken heads. It therefore is important that system leaks are detected and corrected prior to flow-rate measurement for post-installation water use determination. Additionally, it is recommended that flow rate data be collected

---

[3] Colorado Energy Performance Contracting Office. *Colorado Statutes Regarding Energy Performance Contracts for State Government*. Title 24 Government — State: Principal Departments: Article 30 Department of Personnel — State Administrative Support Services, Part 20 Utility Cost-Savings Measures.

from a dedicated meter rather than from a controller, because a meter records the flow rate directly.

- *Irrigation runtime*

  Runtime for each hydrozone should be collected over distinct periods from the irrigation controller or operator logs (e.g., monthly, daily).

- *Precipitation rate*

  Precipitation rate for each hydrozone in the measurement boundary should be measured at least once during the baseline measurement period if an irrigation audit is being used to determine baseline water use. (*See* Section 5.1.1 for additional information.)

4.9   Metering Equipment

The M&V plan should specify the metering equipment that will be used to measure water use, which should be dedicated meters that monitor only the irrigated landscape within the measurement boundary. An existing dedicated meter can be used to determine the baseline water use, and can be customer owned or provided by the water utility.

It is important that the meter(s) used to determine the water use are calibrated. Uncalibrated meters can under-record or over-record water use and therefore can underestimate or overestimate the water use. The ESCO and WESCO should provide the method used to calibrate the meters and provide a calibration certificate to the customer. The certificate should follow the established M&V requirements of the state performance contracting program. If there are potential metering inaccuracies, then the ESCO and WESCO should follow any established dispute-resolution steps relevant to this issue that are identified in the state performance contracting program.

For post-installation water-use measurement, the M&V plan should provide detailed information on the metering equipment, including the manufacturer, model number, and quantity being installed as part of the measure. The M&V plan also should provide the metering equipment's installation procedure that includes the length of straight pipe required. The following meter information should be provided in the M&V plan.

- Volumetric resolution (e.g., within 0.1 gallons)

- Accuracy range at specified ranges of flow rates

- Flow range

- Durability of construction to protect against high pressure and corrosion (e.g., plastic versus brass)

- Water-quality requirements (e.g., filtered versus unfiltered water)

- Line size

- Minimum and maximum operating pressure

- Calibration method and frequency to ensure that the post-installation water use is accurately determined

The M&V plan also should provide the type of data-management system that will log water use. The following data-management options should be considered when selecting an appropriate metering system.

- Data-logging capability that enables collection of volumetric water use over distinct periods (such as 15-minute or 1-hour intervals)

- Web-enabled interface with secure data-storage options

- Automated software updates that patch programming issues

- Capability to interface with other building-automation systems

- Customizable data forms and trending options that allow for short- and long-term graphing of data to evaluate operational issues

5.0   Water Savings Calculations

This section of the document provides the procedures that are used to calculate water savings. The general water savings equation is:

Water Use Savings = (Baseline Water Use – Post Installation Water Use) ± Adjustments

Where:

Baseline Water Use = Irrigation water use of the existing system prior to WCM implementation
Post Installation Water Use = Irrigation water use after implementation of WCM
Adjustments = Factor applied to normalize water use when appropriate

5.1   Baseline Water Use

This section describes methods to determine the baseline water use and the required normalization of the baseline.

5.1.1   Baseline Water Use Determination

The following options can be used to estimate baseline water use, listed in order of accuracy.

1. **Continuous measurement using dedicated meter(s)**. If the existing irrigation system has a flow meter that monitors water use for the measurement boundary, metered data should be collected to

Preferable: Continuous measurement using dedicated meter(s)

Acceptable: Flow-rate determination
Irrigation audit to determine system precipitation rate

determine the baseline water use (*see* Section 4.5).

This is the preferable method because it most accurately measures water over the measurement period. If metered data is not available for the baseline, then the other options listed below can be used to supplement missing periods.

2. **Flow-rate determination**. If a dedicated meter is not installed on the existing system or does not record volumetric data, then flow rates for each hydrozone — logged by a dedicated or temporary metering system within the measurement boundary — can be determined using a temporary meter or other procedure that is agreed upon in the M&V plan. The flow rate for each hydrozone is multiplied by the hydrozone's runtime to determine the volume of water used for each hydrozone. The total baseline irrigation water use is the sum of each hydrozone's water use, represented by:

$$\sum_{Z=1}^{n} (FR_Z \times RT_Z)$$

Where:

FR_Z = The hydrozone's flow rate, measured in gallons per minute
RT_Z = The runtime of the hydrozone irrigation system during the baseline, measured in minutes
n = The total number of hydrozones

When calculating the water consumption using the flow-rate method, it is important to document the following items in the M&V plan.
- Designate the measurement frequency for hydrozone flow rate (*see* Section 4.8)
- Describe how the average hydrozone flow rate was determined
- Describe how the irrigation runtime was collected over the baseline

3. **Irrigation audit to determine system precipitation rate**. If metering the baseline water use or using flow rates to calculate the baseline is not an option, then the third most-accurate approach is to perform an irrigation audit. An irrigation audit measures the precipitation rate of each irrigation hydrozone by capturing and measuring the amount of water distributed by the irrigation system, typically measured in inches per hour. The irrigation audit should follow the protocol set in the Irrigation Association's *Recommended Audit Guidelines*[4] or in the American Society of Agricultural and Biological Engineers (ASBE) Standard S626 *Landscape Irrigation System Uniformity and Application*

---

[4] Irrigation Association. *Recommended Audit Guidelines*. September 2009. Available at:
https://www.irrigation.org/uploadedFiles/Certification/CLIA-CGIA_AuditGuidelines.pdf.

Rate Testing.[5] The precipitation rate for each hydrozone is applied to the hydrozone's runtime and the landscape area that the hydrozone covers. The total baseline irrigation water use is the sum of the hydrozone's water use, represented by:

$$\sum_{Z=1}^{n} (PR_Z \times A_Z \times RT_Z \times 0.0104)$$

Where:

PR_Z = The hydrozone's precipitation rate, measured in inches per hour

A_Z = The hydrozone's irrigation area, measured in square feet

RT_Z = The runtime of the irrigation system during the baseline period, measured in minutes

0.0104 = A conversion factor that converts precipitation rate and hydrozone square footage to gallons

n = The total number of hydrozones

Irrigation demand using a calibrated model can provide additional information on the baseline water use when using the three prescribed methods above. An irrigation-demand method uses ET and precipitation data to calculate the amount of water needed to maintain a healthy landscape for a given location, based on the amount of water transpired and evaporated from the plants and the precipitation received at that location. Determining the irrigation demand of specific landscapes can provide critical information on the overall performance of the current irrigation system by comparing the actual water use to the water requirements of the landscape. This information can provide insight on the water-savings potential. The irrigation demand method, however, should not be used solely to estimate the baseline because it does not accurately reflect actual water use.

The ASBE Standard S623, *Determining Landscape Water Demands*[6] is the preferred method for determining the irrigation demand. The M&V plan should clearly state all the assumptions that are used in this method.

5.1.2   Baseline Normalization

If the existing irrigation is scheduled with a conventional system that irrigates based on a set "clock" schedule for which adjustments are not made, then the baseline water use should not be normalized. However, **the baseline water use should be normalized (*see* Section 5.3 for the normalizing procedure) under the following circumstances**.

---

[5] American Society of Agricultural and Biological Engineers Standard S626. *Landscape Irrigation System Uniformity and Application Rate Testing.* October 2016.

[6] American Society of Agricultural and Biological Engineers Standard S623. *Determining Landscape Water Demands.* January 2017.

- The existing irrigation controller is a weather-based or soil-moisture-based controller that uses live data to adjust the irrigation schedule based on actual conditions.

- There are existing weather sensors, such as rain or wind gauges, that use live data to adjust the irrigation schedule based on actual conditions.

- The irrigation schedule is routinely monitored and adjusted by grounds maintenance staff. The system has a flow meter that shows water-use fluctuations throughout the irrigation season that reflect these adjustments.

5.2 Post-Installation Water Use Determination

As part of the requirements of using an IPMVP Option B M&V method, a meter is required to measure the post-installation water use over the measurement period. The two options for determining the post-installation water use are described below, listed in order of accuracy.

Preferable: Continuous measurement using dedicated meter(s)

Acceptable: Flow rate determination

1. **Continuous measurement using dedicated meter(s).**
   In-line meter(s) should be connected to a centralized control system or a data logger to continuously record water-use data over the study period within the measurement boundary. This is the preferable method because it most accurately measures water over the measurement period.

2. **Flow-rate determination.** If the dedicated meter(s) cannot accurately determine the water use of the measurement boundary, then the flow rates of the hydrozones within the measurement boundary can be used to estimate water use. (*See* Section 4.8 for additional information.) The flow rate for each hydrozone is multiplied by the hydrozone runtime to determine the volume of water used for each hydrozone. The total post-installation irrigation water use is the sum of hydrozone's water use, represented by the following.

$$\sum_{Z=1}^{n} (FR_Z \times RT_Z)$$

Where:

FR_Z = The hydrozone's flow-rate, measured in gallons per minute

RT_Z = The runtime of the hydrozone irrigation system over the study period, measured in minutes

n = The total number of hydrozones

When calculating the water consumption using the spot-measurement method, it is important to document the following items in the M&V plan.
- Designate measurement frequency for hydrozone flow rate (*see* Section 4.8)

- Describe how the average hydrozone flow rate was determined
- Describe how the irrigation runtime was collected over the measurement period

Post-Installation Normalization

Post-installation water use will be normalized only if the WCMs includes a weather-based control system or weather-sensing technology that adjusts the irrigation schedule for weather changes. *See* Section 5.3 for detailed normalization procedures.

5.3   Data Normalization

As described in Sections 5.1.2 and 0, irrigation water use should be normalized if the irrigation schedule is altered for weather changes. For example, if a drought occurs during the measurement period, then the landscape will need more water to survive because of reduced rainfall. Conversely, weather can be abnormally wet if more precipitation than normal is received, thus decreasing irrigation demand. In these cases, the water use should be normalized to be commensurate with water used during a typical irrigation season.

The normalization method accounts for variations in the weather and adjusts water use to historical average weather patterns, also referred to as "climate normal." **Climate normal weather data is considered average weather conditions for a given location. This is defined by the National Oceanic and Atmospheric Administration (NOAA) National Climate Data Center as the "latest three-decade averages of climatological variables."[7]**

The historical average (climate normal) ET and effective precipitation can provide an estimate of the typical irrigation requirements of a landscape and thereby can be used to normalize water use. Evapotranspiration is the combination of loss of water due to evaporation from soil and plant surfaces and the amount of water transpired by the plant, and typically is measured in inches over a given time frame (e.g., inches per week). Reference ET (ET_o) is the loss of water from a defined vegetation (e.g., alfalfa grass), which serves as an evaporative index by which ET can be predicted for a range of vegetation types. The ET of the vegetation is determined by applying a plant factor to ET_o. The plant factor is the fraction of ET_o required by the plant type for acceptable appearance. For example, cool season turf has a plant factor of 0.8. Additionally, the amount of rainfall that is available to the vegetation in the landscape — known as effective precipitation — must be determined and subtracted from ETo to calculate the amount of water that must be replaced to meet plant requirements.[8] The amount of effective precipitation received over the time frame is subtracted from ET requirements to determine the "net ET."

---

[7] NOAA's National Climate Data Center. Satellite and Information Service. "NOAA's 1981-2010 Climate Normals" website, accessed at: https://www.ncdc.noaa.gov/oa/climate/normals/usnormals.html.

[8] American Society of Agricultural and Biological Engineers Standard S623. *Determining Landscape Water Demands* January 2017.

This section provides the procedures that should be used to normalize irrigation water use. The method for determining water demand is described in the ASBE Standard S623, *Determining Landscape Water Demands.*[8] This standard was used to develop the normalization methods used below.

Follow these steps to normalize the post-installation water use over the measurement-period water use. These same procedures can be used to normalize baseline water use if required (*see* Section 5.1.1). Note that the following procedure specifies normalizing water use over a monthly time frame. Shorter intervals (such as daily), however, can be performed if deemed beneficial.

1. Determine the average (climate normal) monthly ET_o and precipitation for the location over the current measurement period.
   (*See* Appendix A for average ET_o and precipitation data sources and calculation methods.)

2. Determine the current monthly ET_o and precipitation for the location over the current measurement period.
   (*See* Appendix A for approaches to determining current-year ET_o and precipitation.)

3. Determine the weighted average plant factor of the measurement boundary, following these steps:
   o Determine the percentage of area covered by each plant type in the measurement boundary; use plant material types identified in Table 1 in ASBE Standard S623.[8]
   o Determine the plant factor for each of these plant types using Table 1 in ASBE Standard S623 (use the method in this standard to calculate the adjusted plant factors for areas that are not densely planted).[8]
   o For each plant type, multiply the plant factor by the percent area and sum these values. This provides the weighted average plant factor, represented in:

$$\sum_{n=1}^{n} (Plant\ Factor\ \times\ Percent\ Area)$$

4. Determine the ET of the measurement boundary for the average (climate normal) and current measurement period by multiplying the weighted average plant factor by the ET_o, represented in:

$Monthly\ Average\ ET\ (inches) = (Weighted\ Average\ Plant\ Factor\ \times\ Mothly\ Average\ ET_o)$

$Monthly\ Measurement\ Period\ ET\ (inches) = (Weighted\ Average\ Plant\ Factor\ \times\ Monthly\ Measurement\ Period\ ET_o)$

5. Determine the effective precipitation for the average and current monthly precipitation data over the measurement period. Effective precipitation is considered the amount of rainfall that is stored in the soil and available to the plant's root zone.[9] Effective precipitation can be obtained from the United States Department of Agriculture Soil Conservation Service *Part 623 National Engineering Handbook,* Chapter 2: Irrigation Water Requirements, Table 2-43.[10] This table provides the average monthly effective precipitation, knowing the mean monthly precipitation and average ETo. This handbook also offers a more detailed method to determining effective precipitation that includes other important parameters, such as soil type. This more detailed approach can be used if deemed necessary.

6. Calculate the historical average (climate normal) monthly net ET by subtracting local monthly historical average effective precipitation (climate normal) from monthly average ET to determine the monthly net ET, represented in this formula.

$$Monthly\ Average\ Net\ ET\ (inches) = (Monthly\ Average\ ET - Monthly\ Average\ Effective\ Precpitation)$$

7. Calculate the current measurement period monthly net ET_o by subtracting local monthly current effective precipitation from monthly ET during the measurement period to determine the monthly net ET, represented in this formula.

$$Monthly\ Measurement\ Period\ Net\ ET\ (inches)\ = (Monthly\ Measurement\ Period\ ET - Monthly\ Measurement\ Period\ Effective\ Precpitation)$$

8. Determine the monthly ratio of monthly average net ET to the current monthly measurement period net ET, represented in this formula.

$$Monthly\ Net\ ET\ Ratio = (Monthly\ Average\ Net\ ET\ \div Monthly\ Measurement\ Period\ Net\ ET)$$

9. Gather the post-installation water use for each month from metered data collected during the study period.

10. Normalize each month's water use by multiplying the monthly post-installation water use by monthly net ET ratio. Then sum the monthly values to determine the total post-installation water use, represented in:

---

[9] FOA. *Irrigation Water Management Chapter 3: Effective Rainfall*. http://www.fao.org/docrep/s2022e/s2022e03.htm.

[10] United States Department of Agriculture Soil Conservation Service *Part 623 National Engineering Handbook*, Chapter 2. https://www.wcc.nrcs.usda.gov/ftpref/wntsc/waterMgt/irrigation/NEH15/ch2.pdf.

$$\sum_{n=1}^{n} (Monthly\ Post\text{-}Installation\ Water\ Use\ \times\ Monthly\ Net\ ET\ Ratio)$$

Table 1 below provides an example of this normalization method. This example depicts an irrigated landscape in Aurora, Colorado. The post-installation water use was 488,422 gallons measured by the metering system. The effective precipitation was determined to be 50%. The weighted average plant factor was determined to be 0.7. Abnormally hot and dry conditions were experienced during the irrigation season, whereby the total net ET over the measurement period was 33.4 inches, compared to the historical average of 26.6 inches, giving a net ET ratio of 80%. Applying this value, the normalized post-installation water use is 390,122 gallons.

Table 1. Sample Normalization of Post-Installation Water Use in Aurora, Colorado

Irrigation Month	Average ET_o (inches)	Average Precipitation (inches)	Average Net ET (inches)	Current Measurement Period ET_o (inches)	Current Measurement Period Precipitation (inches)	Current Measurement Period Net ET (inches)	Monthly Net ET Ratio	Post-Installation Water Use (gallons)	Normalized Post-Installation Water Use (gallons)
April	4.86	1.44	2.74	5.84	1.33	3.49	0.79	29,997	23,551
May	6.08	2.40	3.13	7.30	2.21	4.09	0.76	63,501	48,572
June	7.76	1.37	4.83	9.31	1.26	5.99	0.81	100,369	80,972
July	8.45	1.88	5.07	10.14	1.73	6.35	0.80	104,859	83,756
Aug	7.52	1.36	4.67	9.03	1.25	5.79	0.81	96,934	78,123
Sept	5.73	0.88	3.64	6.88	0.81	4.49	0.81	75,628	61,284
Oct	4.05	0.65	2.55	4.86	0.60	3.16	0.81	17,133	13,865
Total	44.46	9.98	26.63	53.36	9.19	33.35	0.80	488,422	390,122

5.4   Other Considerations

The M&V plan should state any potential issue that could significantly impact water use. If there are potential issues that might significantly impact water use, the baseline water use might need to be adjusted to account for the increased water use. The ESCO and WESCO should follow the established dispute-resolution steps identified in the State Performance Contracting Program, which should be reviewed and agreed upon between the ESCO or WESCO and the customer. Such issues can include:

- Changes to irrigation-control settings, such as local grounds maintenance crews overriding pre-programmed controllers;

- Changes in landscape area or planting type occurring at any time during the study period, which could change the irrigation requirements;

- Undetected leaks that are not repaired quickly;

- Grounds maintenance issues such as disease of landscape that require extra watering not anticipated in the savings estimate;

- Drought management watering restrictions (and other types) imposed by the water utility, or local or state government entities that could reduce water use and change the appearance of the landscape; and

- Deficit watering during the baseline period, which is a reduction in water use as compared to the required water needs of the landscape — this could reduce the overall potential water savings of the WCM.

The annual M&V report should provide a detailed description of any significant issue that was experienced, the subsequent impact on water use, and adjustments made to the baseline estimate as a result of the issues.

6.0   Commissioning Protocol

Commissioning is an important step to ensure that the water conservation measure will achieve the guaranteed savings. Commissioning is the process whereby the WCM improvements made to the irrigation equipment and control system have been verified to comply with the approved plan and visually inspected and evaluated for proper operation. Additionally, commissioning verifies that the correct irrigation schedule has been implemented for current landscape needs, and that the manager of the irrigation system has been trained to properly operate it.

Commissioning ensures that system components are functioning optimally per the measure's design and checks system performance and operational issues such as misaligned heads or leaks. A commissioning plan should be established that outlines the specific steps that will be performed. The commissioning plan should follow the Irrigation Association's "Irrigation System Inspection and Commissioning Guidelines," found in the *Landscape Irrigation Best Management Practices*.[11] Critical components of the commissioning plan include the following.

- **Qualified inspector**. A commissioning agent should have the training and competencies to perform the required steps. Examples of qualifications include the Irrigation Association certifications such as Certified Landscape Irrigation Auditor, Certified Landscape Manager, Certified Irrigation Designer,[12] and the Qualified Water Efficient Landscaper Program.[13]

---

[11] Irrigation Association and American Society of Irrigation Consultants. *Landscape Irrigation Best Management Practices*. March 2014. Falls Church, VA. https://www.irrigation.org/uploadedFiles/Standards/BMPDesign-Install-Manage.3-18-14(2).pdf

[12] Irrigation Association Certification Program: http://www.irrigation.org/IA/Certification/IA/Certification/Certification.aspx

[13] Qualified Water Efficient Landscaper Program: http://www.qwel.net/

- **Equipment**. The plan should detail the type of equipment necessary to perform the commissioning steps.

- **Inspection frequency**. The plan should provide the time frame of the commissioning inspection, which should be done during and after construction. It might be necessary to recommission the system within the study period to ensure that the system is operating optimally.

- **Training**. The plan should also include the training that is required to operate the new equipment, including training personnel on controller programming.

- **Inspections and tests**. The plan should specify the types of inspections and tests that will be performed to gauge the performance of the system, which can include, but are not limited to:

  - *Controller irrigation schedule.* Ensure the controller has been properly programmed to meet the specific requirements of the landscape, which should include among other things, accounting for plant types, landscape slope, and exposure.

  - *Irrigation audit.* Perform an irrigation audit to check the performance of the irrigation system to determine:
    - Precipitation rate,
    - Distribution uniformity, and
    - Sensor performance.

  - *System tests.* Conduct tests to ensure that the system meets the specifications of the design, including:
    - Flow rate tests,
    - Pressure tests for both high and low,
    - Leak tests,
    - Valve operation,
    - Verification that equipment matches design plans,
    - Proper head spacing, and
    - Backflow prevention.

  - *Landscape condition assessment*. Conduct an evaluation that determines the condition of the landscape, including: (*see* Section 4.3.2)
    - Plant health, and
    - Plant appearance/visual quality.

- **Minimum performance requirements**. The commissioning plan should specify the minimum requirements of the inspection and tests to meet the expected performance of system.

After the commissioning has been performed, the contractor should provide a report that outlines the findings. **It is recommended that the customer (or consultants) witness commissioning activities, review the commissioning report, provide comments to the ESCO or WESCO, and have comments resolved to the customer's satisfaction prior to approving the WCM.** The report should include the results of all tests performed, state whether the system is functioning per the design, and list necessary corrections.

Appendix A. Local Weather Data Sources and Evapotranspiration Calculation Methods

Precipitation and reference evapotranspiration (ET_o) data is needed to normalize water use to a typical year, as described in Section 5.3. Precipitation data is relatively easy to locate but ET data can be more difficult to access. E Evapotranspiration is the combination of loss of water due to evaporation from soil and plant surfaces and the amount of water transpired by the plant, which typically is a calculated value.

Preferable: *Penman-Monteith equation using climate normal weather data*

Acceptable: *Hargreaves equation with climate normal weather data or weather data obtained in IWMI CAWQuer database*

The preferable method for determining ET_o is the Penman-Monteith equation using climate normal weather data because it is the most accurate process. **Climate normal data is considered average weather conditions over the latest three-decade period**. Alternate acceptable methods for determining ET_o are the Hargreaves equation with climate normal weather data or weather data obtained in the International Water Management Institute (IWMI) database, as described below.

A.1   Evapotranspiration Calculation Methods

Two common methods to calculate ET_o are the Penman-Monteith and the Hargreaves equations. The Penman-Monteith equation uses daily mean temperature, wind speed, relative humidity, and solar radiation to determine ET_o. The Hargreaves equation is a simplified method to estimate ET_o that only requires solar radiation and minimum and maximum temperatures over a distinct time frame (e.g., daily, weekly, or monthly).

For the purposes of normalizing water use, ET_o can be determined using either method. Generally, the Penman-Monteith method is considered more accurate because it uses multiple metrological factors to calculate to the total water losses from the reference plant.[14] The simplified Hargreaves method can be used to approximate ET_o, however, and is appropriate to use when there is limited metrological data.[15]

If ET_o is calculated using either of these the equations, the methods described in the following reference documents should be used, in order of preferred method.

1. **Penman-Monteith equation:** Chapter 4 "Determination of ET_o" in the *Crop Evapotranspiration — Guidelines for Computing Crop Water Requirements*, produced by the

---

[14] Allen RG et al. *Crop Evapotranspiration — Guidelines for Computing Crop Water Requirements*. Food and Agricultural Organization for the United Nations. Rome, Italy. 1998. Accessed at: http://www.fao.org/docrep/X0490E/X0490E00.htm.

[15] Hargreaves GH and Allen RG. "History and Evaluation of Hargreaves Evapotranspiration Equation." *Journal of Irrigation and Drainage Engineering*. January 2003. Accessed at: http://onlinecalc.sdsu.edu/onlinehargreaves.pdf.

Food and Agricultural Organization for the United Nations, accessed at: http://www.fao.org/docrep/X0490E/X0490E00.htm.

2. **Hargreaves equation**: Equation 8 listed in the "History and Evaluation of Hargreaves Evapotranspiration Equation" published in the *Journal of Irrigation and Drainage Engineering,* January 2003, accessed at: http://onlinecalc.sdsu.edu/onlinehargreaves.pdf.

Climate Normal Data

To determine the climate normal net ET_o, climate normal data for ET_o and precipitation must be collected monthly over the measurement period. This data is accessible at the National Oceanic and Atmospheric Administration (NOAA) *1981–2010 Climate Normals* webpage: https://www.ncdc.noaa.gov/oa/climate/normals/usnormals.html.

A.2   International Water Management Institute Data

The International Water Management Institute database provides an alternate means for gathering average ET_o instead of using the calculation methods provided above. The IWMI Climate Atlas Web Query (CAWQuer) is a web-based tool that allows users to access historical climate summary data for specified locations, assembled from weather stations worldwide and averaged from 1961 to 1990. The dataset includes average ET_o and precipitation. Even though this period is not officially considered "climate normal" because it does not span the latest three-decade time frame, this dataset is a reasonable approximation of average climate data and can be used in the normalization process described in Section 5.3.

The following sections of this appendix provide a step-by-step process for gathering data from the IWMI web-based tool. Data should be collected only over the measurement period (irrigation season) (*see* Section 4.7).

A.2.1   IWMI Web-Based Tool Inputs

Below is the step-by-step process for inputting information into the IWMI web-based tool.

1. Go to http://wcatlas.iwmi.org/Default.asp.
2. Register if a new user, or login if you are an existing user (*see* Figure A.2.1.a. IWMI Login Page).

IWMI ON-LINE CLIMATE SUMMARY SERVICE MODEL, NOW IT'S EVEN EASIER TO GET RAPID ACCESS TO RELIABLE DATA.

The new IWMI Climate Atlas Web Query (CAWQuer) service creates online climate summaries for user-specified locations. All you have to do is enter the latitude and longitude coordinates for the location(s) you're interested in and specify which climate variables are needed. CAWQuer then searches over data in the IWMI Atlas and deliver climate summaries almost instantly. The data is displayed in an easy-to-read table, by month.

About this Model and Web based application related Queries please contact us.

Step 1: Register or login

3. Enter site name(s). *See* Figure A.2.1.b. for an example of IWMI data entry for user-specified location information and climate variables available for download.

4. Enter site's latitude in degrees, minutes, seconds and whether north or south (*see* Section A.1.3 below for instructions on how to get site location latitude).

5. Enter site's longitude in degrees, minutes, seconds, and whether east or west (*see* Section A.1.3 for instructions on how to get site location latitude).

6. Climate variables to be checked are P50 (mm/m) and Penman ET_o (mm/d) for normalization.

7. Click the **Submit** button.

Figure A.2.1.b. IWMI User-Specified Location and Climate Variables

A.2.2   IWMI Web-Based Tool Ouputs

Figure A.2.2. Example of IWMI Climate Variable Outputs Needed for Normalization

	P50 (Mm/month)	Penman ETo (mm/day)
Jan	9.35	1.51
Feb	13.99	1.94
Mar	28.61	2.64
Apr	35.05	3.95
May	55.87	4.98
Jun	39.10	6.31
Jul	57.20	6.71
Aug	50.35	5.89
Sep	23.95	4.63
Oct	17.30	3.34
Nov	16.73	1.94
Dec	11.33	1.46

The following covers the IWMI web-based tool outputs needed for normalization as discussed in Section 5.3.

Figure A.2.2 provides an example of the climate variable outputs of the IWMI web-based tool.

a.   P50 is the 30-year historical amount of rainfall in millimeters for the month.

b.   Penman ET_o is the 30-year historical reference evapotranspiration in millimeters per day. To determine monthly ET_o, this data is required to be converted to monthly values by multiplying the number of days in the month by the daily ET_o value.

A.2.3   Latitude and Longitude

Below is a step-by-step process for obtaining latitude and longitude for a user-specified location, which is needed for the IWMI web-based tool discussed in Section A.2.1.

1. Any online latitude/longitude converter can be used (e.g. http://stevemorse.org/jcal/latlon.php).

2. Latitude and longitude format must be rendered in degrees, minutes, seconds. Also, note north, south, west, or east. Colorado: Latitude = North; Longitude = West.

3. *See* Figure A.2.3 for an example of an online latitude/longitude converter with the input and resulting output.

Figure A.2.3. Example of an Online Latitude and Longitude Converter for a User-Specified Address

address	13655 Broncos Parkway
city	Englewood
state	CO
zip	80112
country	United States

Determine Lat/Lon   Get Altitudes   reset

latitude [ ]
longitude [ ]

above values must be in decimal with minus signs for south and west

Determine Address   reset

☐ Access geocoder.us / geocoder.ca (takes a relatively long time)

from google	latitude	longitude	altitude
decimal	39.578826	-104.830782	
deg-min-sec	39° 34' 43.7736"	-104° 49' 50.8152"	

Correct format for latitude and longitude

A.3   Current Weather Data Sources

As part of the normalization process, ET_o data for the current study period must be identified. One possible data source is the Colorado Agricultural Meteorological Network's CoAgMet Crop ET_o home page: http://ccc.atmos.colostate.edu/cgi-bin/extended_etr_form.pl. This website provides monthly ET_o data for multiple weather stations across Colorado.

Other possible data sources are:

- Northern Water: http://www.northernwater.org/WaterConservation/WeatherandETInfo.aspx

- Denver Water provides a daily weather report including 24-hour total ET (inches) and historical monthly weather data for 2016 and 2017
  http://www.denverwater.org/Conservation/WeatherReporting/WeatherData/

For current precipitation data, a reliable source of data can be found at NOAA's National Centers for Environmental Information, which can be accessed at: https://www.ncdc.noaa.gov/cdo-web/.