# Western Resource Advocates
## 75% COMPLETION REPORT
## Colorado Water Conservation Board

June 29, 2017

To: Ben Wade, CWCB
Reported by: Jorge Figueroa, WRA

**RE: Water Efficiency Grant - POGGI PDAA 20170000000000000521**
**"Best-practices and Technical Guidelines for High-Performance, Comprehensive, Water Efficiency Retrofit Projects"**

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Corresponding to our proposal, this report includes updates on:

I. Summary of monitoring and verification and commissioning protocol development, including:
   A. List of Steering Committee and three Technical Advisory Group members
   B. Summary of protocol development
   C. Updated protocol development timeline
II. Summary of best practices development
III. Draft protocols and best practices as of time of submission of 75% completion report.

### I. SUMMARY OF MONITORING AND VERIFICATION AND COMMISSIONING PROTOCOL DEVELOPMENT

I.A.1. LIST OF THE STEERING COMMITTEE MEMBERS

| Steering Commitee Members \| Water, Measurement and Verification (M&V) Guidelines, State Performance Contracts Project | | |
|---|---|---|
| **Name** | **Affiliation** | **Title** |
| Donald Gilligan | National Association of Energy Service Companies | President |
| Mary Ann Dickinson | Alliance for Water Efficiency | President and CEO |
| John Canfield | Trident Energy Services | President |
| Chris Halpin | Celtic Energy | President |
| Patrick Watson | Southern Nevada Water Authority | Conservation Services Administrator |
| Carlos Bustos | Albuquerque Bernalillo County Water Utility Authority | Water Conservation Program Manager |
| Frank Kinder | Colorado Springs Utilities | Senior Conservation Specialist |
| Paul Matuska | US Bureau of Reclamation | Manager, Water Accounting and Verification Group |
| William D. Taylor | Energy Services Coalition-Nevada Chapter | Private Sector Co-Chair |
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| Kelly Thomas | Nevada Governor's Office of Energy<br>Nevada EPC Program | Energy Program Manager |
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## I.A.2. LIST OF OUTDOOR IRRIGATION TECHNICAL ADVISORY GROUP

**Outdoor Irrigation TAG Members | Water, Measurement and Verification (M&V) Guidelines, State Performance Contracts Project**

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

## I.A.3. LIST OF TURF CONVERSION TECHNICAL ADVISORY GROUP

**Turf Conversion TAG Members | Water, Measurement and Verification (M&V) Guidelines, State Performance Contracts Project**

| Name | Affiliation | Title |
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| Mark Graham | Metropolitan Water District | Resource Specialist |
| Mike Mendenhall | Trane | Senior Project Developer |
| Morgan Shimabuku | Center For ReSource Conservation | Senior Manager of Sustainability Programs |
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| Philip Neff | Honeywell Energy Services Group of North America | Engineering Manager |
| Richard Chapman | Smart Use, llc | President |
| Scott Winter | Colorado Springs Utilities | Lead Water Conservation Specialist |
| Thomas Chesnutt | A & N Technical Services Inc. | President |
| William Travers | NORESCO | Sr. Project Developer |

## I.A.4. LIST OF COOLING TOWER TECHNICAL ADVISORY GROUP

**Cooling Tower TAG Members | Water, Measurement and Verification (M&V) Guidelines, State Performance Contracts Project**

| Name | Affiliation | Title |
|---|---|---|
| Andrew Landfather | Ameresco | Measurement & Verification Engineer |
| Bill Hoffman | H.W. (Bill) Hoffman & Assocates, LLC | President |
| Philip Neff | Honeywell Energy Services Group of North America | Engineering Manager |
| Niffy Ovuworie | McKinstry | M&V Program Manager for the Rocky Mountain Region |
| Mike Mendenhall | Trane | Senior Project Developer |
| Kent Sovocool | Southern Nevada Water Authority | Senior Conservation Research Analyst |
| Thomas Pape | Best Management Partners | Principal |
| Mark R. Gentili | Los Angeles Dept. of Water and Power | Manager of Water Conservation Group and Response Unit |
| Scott Winter | Colorado Springs Utilities | Lead Water Conservation Specialist |
| Chuck Silkman | Ameresco | Regional Director |
| Richard Chapman | Smart Use, llc | President |

## I.B. SUMMARY OF MONITORING & VERIFICATION (M&V), AND COMMISSIONING PROTOCOL DEVELOPMENT

1. T*echnical Advisory Groups (TAGs).* All three TAGs have been convened. As shown in Figure 1, each TAG meets once (via online webinar) to review and collectively discuss their respective protocols. Two of the three TAG calls have already occurred. Below is a list of the TAG calls:
   - Outdoor Irrigation TAG Call: Completed on April 21, 2017.
   - Turf Conversion TAG Call: Completed on June 1, 2017.
   - Cooling Tower TAG Call: Confirmed for July 11, 2017.

2. *Development of Protocols.* The protocol development process has 4 iterations:
    i. Version .01: Draft circulated to TAG for first review prior to the TAG call.
    ii. Version .02: Draft incorporates written and oral input received prior to, and at TAG call.
    iii. Version .03: Draft incorporates second round of TAG review/input. This is the Draft Protocol that is posted for a 30-day *Public Comment Period*. During the *Public Comment Period*, each protocol is sent to the members of the following industry groups:
        - Alliance for Water Efficiency
        - National Association of Energy Service Companies
        - Energy Services Coalition-Colorado Chapter
        - Energy Services Coalition-New Mexico Chapter
        - Energy Services Coalition-Nevada Chapter
    iv. Version .04: Final Protocol incorporates comments from the *Public Comment Period*. The Steering Committee and TAGs receive Version .03 Draft Protocols a week before they are posted for the broader stakeholder community to review.

I.C. UPDATED PROTOCOL DEVELOPMENT TIMELINE

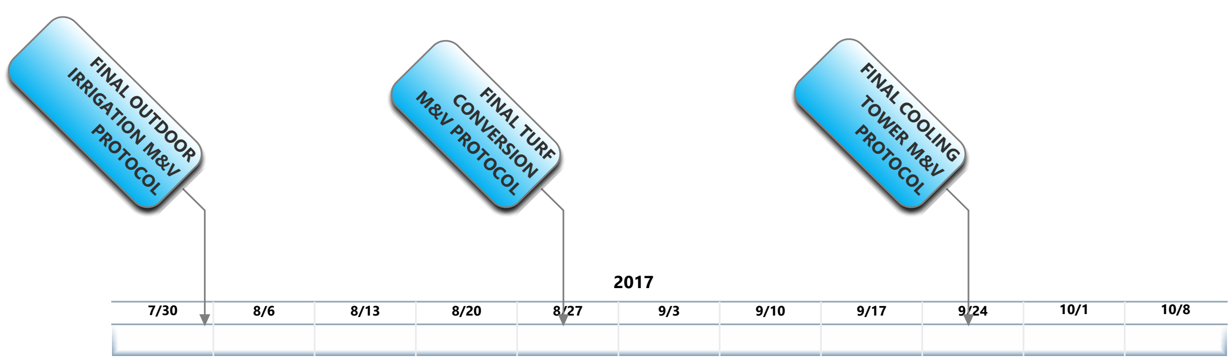
**Figure 1. Draft protocol iterations completed as of June 29, 2017**

**First TAG Review ➔ TAG Call ➔ TAG Review #2 ➔ 30-day Public Comment Period➔Final Protocol**

| PROTOCOL | VERSION .01 | VERSION .02 | VERSION .03 | VERSION .04 |
|---|---|---|---|---|
| Outdoor Irrigation | ⦿ | ⦿ | ⦿ | ⦿ |
| Turf Conversion | ⦿ | ⦿ | ⦿ | ○ |
| Cooling Tower | ⦿ | ○ | ○ | ○ |

These will be the nation's first standardized Outdoor Irrigation, Turf Conversion, and Cooling Tower M&V Protocols.

**Figure 2. Final protocol production timeline**




The project is on schedule to complete all protocols by September 2017.

## II. SUMMARY OF BEST PRACTICES DEVELOPMENT

This grant proposed to develop 4 best practices—outdoor irrigation, turf conversion, cooling tower, and water auditing—for the state of Colorado's performance contracting program.

*Outdoor Irrigation, Turf Conversion and Cooling Tower Retrofits:*
The 50% completion report provided outlines of these best practices documents. After numerous conversations between WRA and the Colorado Energy Office, the project team decided to include these best practices in the Commissioning Protocols (Section 6) of each measure's M&V protocol guidelines.

*Water Audits for Public Buildings:*
This remaining best practices document will be produced as a separate reference document for the state performance contracting program. Unlike the other three, a water audit is not a measure, and therefore doesn't have an M&V protocol in which to be included, thus the document will be standalone. An outline of the document is attached as Appendix D to this report, with a draft to be produced by the end of July, and the final document expected to be completed by September 2017.

## III. DRAFT PROTOCOLS AND BEST PRACTICES AS OF TIME OF SUBMISSION

The following are included with this report:

- Appendix A: Outdoor Irrigation M&V and Commission Protocol, Version .04[1]
- Appendix B: Turf Conversion M&V and Commission Protocols, Version .03
- Appendix C: Cooling Towers M&V and Commission Protocols, Version .01
- Appendix D: Outline of Water Auditing Best Practices

## *SUMMARY AND NEXT STEPS*

The project is expected to be completed as scheduled at the end of September, with excellent support from the Colorado Energy Office as the project's co-Lead, as well as from the Pacific Northwest National Laboratory, our main contractor. Three expert Technical Advisory Groups (TAGs) have been convened, one for each measure, with strong representation from key water utilities, industry experts, and leading consultants with subject-matter expertise specific to each measure. Two of the three TAG calls have been completed, with the last (Cooling Tower) TAG call scheduled for July 11. Both the Outdoor Irrigation and Turf Conversion Protocols are currently under review under their respective 1-month *Public Comment Period*. The final protocols for the three measures and best practices are expected to be completed by the end of September of 2017, as planned.

[1] The current v.04 is not the final version (the *Public Comment Period* for this protocol has not closed).

# DRAFT Outdoor Irrigation M&V Protocol V.04

**June 2017**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Prepared by Pacific Northwest National Laboratory and Western Resource Advocates
as model guidelines for the State Performance Contracting Programs of Colorado, Nevada,
and New Mexico.


WESTERN RESOURCE ADVOCATES
PROTECTING THE WEST'S LAND, AIR & WATER

Pacific Northwest NATIONAL LABORATORY

NREL NATIONAL RENEWABLE ENERGY LABORATORY

**Western Resource Advocates** has spent over 25 years protecting the West's land, air, and water. 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**

| | |
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| Brent Q. Mecham | Industry Development Director, Irrigation Association |
| Ben Slick | Senior Vice President of Business Development, HydroPoint |
| Cable Jones | Project Developer, Water Management, Inc. |
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## Contents



## Tables



## Figures

# 1.0 Acronyms, Abbreviations, and Definitions

| | |
|---|---|
| **ASBE** | American Society of Agricultural and Biological Engineers |
| **Climate normal** | Average weather conditions for a given location that is over the latest three-decade time period. |
| **CAWQuer** | Climate Atlas Web Query (online tool and database) |
| **CoAgMet** | Colorado Agricultural Meteorological Network |
| **Commissioning** | The process whereby the measure improvements made to the equipment and/or the control system have been verified to comply with the approved plan, and visually inspected and evaluated for proper operation. |
| **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 timeframe. |
| **Hydrozone** | A distinct area of the landscape that receives irrigation from the same system. |
| **Irrigation efficiency** | The percentage of irrigation water that is actually 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 |
| **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 timeframe water use is monitored, defined by the irrigation season. |
| **M&V** | measurement and verification |
| **NOAA** | National Oceanic and Atmospheric Administration |
| **Study period** | The total timeframe that water use will be monitored per the contractual arrangement for the baseline and post-installation periods. |
| **WCM** | water conservation measure |

## 2.0 Introduction

This measurement and verification (M&V) protocol provides procedures for energy service companies (ESCOs) to determine water savings as a result of 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 to collect data and measure water savings.**

The procedures presented in this protocol are performance based. ESCOs 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. 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 may 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 sub-surface irrigation.

**Advanced Controls**

Irrigation controllers manage the application of water on a landscape. This measure includes installing advanced controllers that use real-time data to irrigate landscape based on local conditions, which 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.

**Real-Time Sensors**

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

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

A flow sensor is another type of real-time sensor. Flow sensors monitor water flowing in the irrigation distribution pipes, and can detect abnormal flow conditions that may indicate a system problem. The flow sensor can interface with an irrigation controller to suspend irrigation under abnormal conditions.

## 4.0 Measurement and Verification Plan Elements

The ESCO is 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 M&V 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 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.

IPMVP's Option A, "Partially Measured Retrofit Isolation", allows some stipulated savings, and 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.

This section provides information on the main elements of data collection that should be included in the M&V plan when using the IPMVP's 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. In addition, 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 that includes information related to the irrigation audit, irrigation schedule, and the general condition of the landscape.

#### 4.3.1 Baseline Condition

The plan should include information relevant to the baseline conditions that is collected during the irrigation audit that describes the state of the existing irrigation system components such as, but not limited to, component leaks, nozzle type, and head spacing.

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

#### 4.3.2 Post-Installation Condition

Similarly, 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. If the customer requires maintaining the general baseline appearance of the landscape during the study period, the required appearance of the landscape should also be included.

### 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 used to determine baseline and post installation water use 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 may 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 time 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 the 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*
    - ET 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.)

## 4.6 Study Period

The study period covers the total timeframe that water use will be 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]

**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 should also define the study period for the post-installation water use measurement. For example, in the state of Colorado ESCOs are required by statute to provide a written cost savings guarantee for the first 3 years of the contract period.[3] At the agency's discretion, the savings guarantee can be extended beyond the legislatively required time period. At the end of each performance year, the ESCO is 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 runs from mid-April through October.

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

[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.

## 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 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 will ensure that an accurate flow rate is determined. Flow rates may vary due to system issues such as line leaks or broken heads. Therefore it is important that system leaks are detected and corrected prior to flow rate measurement for post-installation water use determination. In addition, it is recommended that flow rate data is collected from a dedicated meter rather than from a controller because a meter records flow rate directly.

- Irrigation runtime
  - Runtime for each hydrozone should be collected over distinct time 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, which may be customer-owned or provided by the water utility.

**It is important that the meters 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 should provide the method used to calibrate the meters and provide a calibration certificate to their customer, which should follow the established M&V requirements of the State Performance Contracting Program. If there are potential metering inaccuracies, the ESCO should follow any established dispute resolution steps identified in the State Performance Contracting Program relevant to this issue.

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

- Data logging capability that allows for collection of volumetric water use over distinct interval 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 of the document 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:

> ***Preferable:*** *Continuous measurement using dedicated meters*
>
> ***Acceptable:*** *Flow rate determination*
> *Irrigation audit to determine system precipitation rate*

1. **Continuous measurement using a 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 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 time periods.

2. **Flow rate determination**. If a dedicated meter is not installed on the existing system or does not record volumetric data, 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, 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 American Society of Agricultural and Biological

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

Engineers (ASBE) Standard S626 *Landscape Irrigation System Uniformity and Application Rate Testing*[5]. The precipitation rate for each hydrozone is applied to the hydrozone's run-time and 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, 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. However, the irrigation demand method should not be used solely to estimate the baseline because it does not accurately reflect actual water use.

ASBE Standard S623, *Determining Landscape Water Demands*[6] is the preferred method to determining the irrigation demand. The M&V plan should clearly state all of 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" where 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**:

- The existing irrigation controller is a weather-based and/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.

[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 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

The IPMVP Option B M&V method requires a meter to measure the post-installation water use over the measurement period. The two methods 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 meters.** In-line meters 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 cannot accurately determine the water use of the measurement boundary, 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:

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

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

### 5.2.1 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

This section provides the procedures that should be used to normalize irrigation water use.

As described in Sections 5.1.2 and 5.2.1, 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, the landscape will need more water to survive because of reduced rainfall. Conversely, weather can be abnormally wet, where more precipitation is received than normal, 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 represents the average weather conditions for a given location. This M&V protocol adopts the National Oceanic and Atmospheric Administration (NOAA's) Climate Data Center definition of climate normal as "the latest three-decade averages of climatological variables".[7]**

The historical average (climate normal) ET and precipitation data can provide an estimate of the typical irrigation requirements of a landscape and can thereby be used to normalize water use. ET 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 is typically measured in inches over a given timeframe (e.g., inches per week).[8] Reference ET ($ET_o$) is the amount of water that is needed to keep a reference plant (e.g., alfalfa) healthy. The amount of precipitation received over the timeframe is subtracted from $ET_o$ requirements to determine the "net $ET_o$."

The method for determining water demand is described in the ASBE Standard S623, *Determining Landscape Water Demands.*[6] 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).

1. Determine the average 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. Calculate the historical average (climate normal) monthly net $ET_o$ by subtracting local monthly historical average precipitation (climate normal) from average $ET_o$ to determine the monthly net ET, represented in this formula:

$$Monthly\ Average\ Net\ ETo\ (inches) = (Average\ ETo - Average\ Precpitation)$$

---

[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.

4. Calculate the current measurement period monthly net $ET_o$ by subtracting local monthly current precipitation from $ET_o$ during the measurement period to determine the monthly net ET, represented in:

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

5. Determine the monthly ratio of average net $ET_o$ to the current study period net $ET_o$, represented by:

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

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

7. Normalize each month's water use by multiplying the monthly post-installation water use by monthly net $ET_o$ ratio. Then sum all of the monthly values to determine the total post-installation water use, represented in:

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

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. Abnormally hot and dry conditions were experienced during the irrigation season, whereby the total net ET over the measurement period was 44.2 inches, compared to the historical average of 34.5 inches, giving a net ET ratio of 78%. Applying this value, the normalized post-installation water use is 381,219 gallons.

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

| Irrigation Month | Average $ET_o$ (inches) | Average Precipitation (inches) | Average Net $ET_o$ (inches) | Current Measurement Period $ET_o$ (inches) | Current Measurement Period Precipitation (inches) | Current Measurement Period Net $ET_o$ (inches) | Monthly Net $ET_o$ Ratio | Post-Installation Water Use (gallons) | Normalized Post-Installation Water Use (gallons) |
|---|---|---|---|---|---|---|---|---|---|
| **Apr** | 4.86 | 1.44 | 3.42 | 5.84 | 1.33 | 4.51 | 0.76 | 29,997 | 22,761 |
| **May** | 6.08 | 2.40 | 3.69 | 7.30 | 2.21 | 5.09 | 0.72 | 63,501 | 45,942 |
| **Jun** | 7.76 | 1.37 | 6.39 | 9.31 | 1.26 | 8.05 | 0.79 | 100,369 | 79,670 |
| **Jul** | 8.45 | 1.88 | 6.57 | 10.14 | 1.73 | 8.41 | 0.78 | 104,859 | 81,909 |
| **Aug** | 7.52 | 1.36 | 6.16 | 9.03 | 1.25 | 7.78 | 0.79 | 96,934 | 76,821 |
| **Sep** | 5.73 | 0.88 | 4.85 | 6.88 | 0.81 | 6.07 | 0.80 | 75,628 | 60,450 |
| **Oct** | 4.05 | 0.65 | 3.40 | 4.86 | 0.60 | 4.26 | 0.80 | 17,133 | 13,666 |
| **Total** | 44.46 | 9.98 | 34.48 | 53.36 | 9.19 | 44.17 | 0.78 | 488,422 | **381,219** |

## 5.4 Other Considerations

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

- Changes to irrigation control settings, such as local grounds maintenance crews overriding pre-programmed controllers.
- Changes in landscape area or planting type at any time during the study period, which may 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 and other types of watering restrictions imposed by the water utility, or local or state government entities that may reduce water use and change the appearance of the landscape.
- Deficit watering during the baseline period, which is a reduction in water use compared to the required water needs of the landscape—this may 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 the WCM will achieve the guaranteed savings. Commissioning is the process whereby the WCM improvements made to irrigation equipment and/or control system have been verified to comply with the approved plan and visually inspected and evaluated for proper operation. In addition, 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 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*.[9] Critical components of the commissioning plan include:

[9] 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

- **Qualified inspector**. A commissioning agent should have the training and competencies to perform the required steps. Examples of qualifications may include the Irrigation Association certifications such as Certified Landscape Irrigation Auditor, Certified Landscape Manager, and Certified Irrigation Designer[10]; and the Qualified Water Efficient Landscaper Program[11].

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

- **Inspection frequency**. The plan should provide the timeframe of the commissioning inspection, which should be done during and after construction. It may be necessary to recommission the system within the study period to ensure 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 may 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
        - 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 pressure
        - Leak tests
        - Valve operation
        - Verification that equipment matches design plans
        - Proper head spacing
        - Backflow prevention

    - *Landscape condition assessment*. Conduct an evaluation that determines the general condition of the landscape, including:
        - Plant health
        - Plant appearance and visual quality

          (See Sections 4.3.1 and 4.3.2)

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[10] Irrigation Association Certification Program: http://www.irrigation.org/Certification/

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

- **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, 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 if 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. ET is the combination of water loss due to evaporation from soil and plant surfaces and the amount of water transpired by the plant, which is typically 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. 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 timeframe (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.[12] However, the simplified Hargreaves method can be used to approximate $ET_o$ and is appropriate to use when there is limited metrological data.[13]

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

[12] 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

[13] 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

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

### A.1.1 Climate Normal Data

To determine the climate normal net $ET_o$, climate normal data for $ET_o$ and precipitation needs to be collected monthly over the measurement period. Climate normal data is considered average weather conditions over the latest three-decade time period. This data is accessible at the National Oceanic and Atmospheric Administration (NOAA's) *1981-2010 Climate Normals* landing page: https://www.ncdc.noaa.gov/oa/climate/normals/usnormals.html

## A.2 International Water Management Institute Data

The IWMI database provides an alternate means for gathering average $ET_o$ instead of using the above calculation methods. 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 world-wide and averaged from 1961 to 1990. The dataset includes average $ET_o$ and precipitation. Even though this time period is not officially considered "climate normal" because it does not span the latest three-decade timeframe, this dataset is a reasonable approximation of average climate data and is allowed to be used in the normalization process described in Section 5.3.

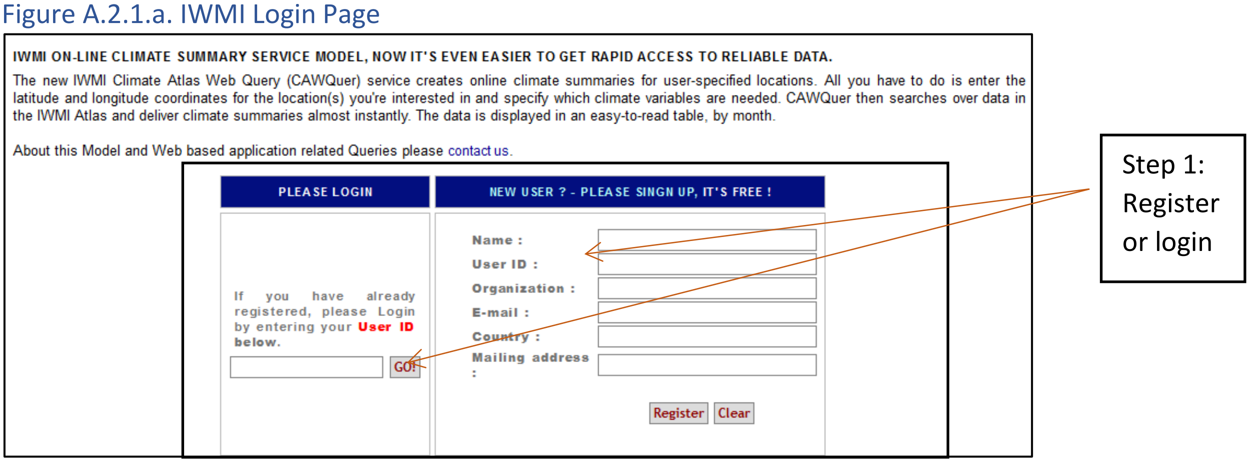
The following sections of this appendix provides a step-by-step process for gathering data from the IWMI web-based tool.

### 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
3. Figure A.2.1.a. IWMI Login Page

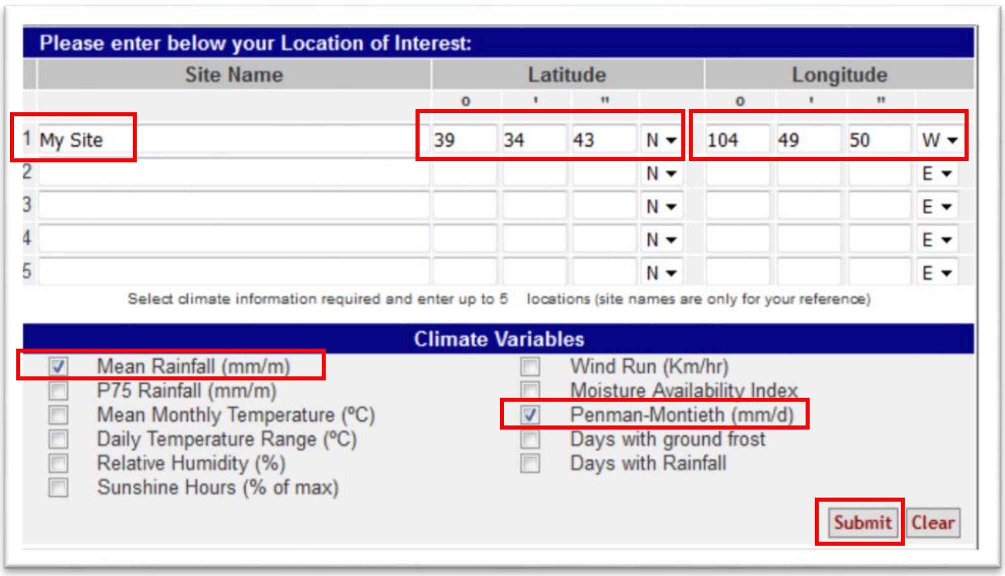
Figure A.2.1.a. IWMI Login Page




4. Enter site name(s). See Figure A.2 for an example of IWMI data entry for user-specified location information and climate variables available for download.

5. Enter site's latitude in degrees, minutes, seconds and whether north or south (see Section A.2.3 below for instructions on how to get site location latitude.)
6. Enter site's longitude in degrees, minutes, seconds, and whether east or west (see Section A.2.3 for instructions on how to get site location longitude).
7. Climate variables that need to be checked are P50 (mm/m) and Penman $ET_o$ (mm/d) for normalization.
8. 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.

### A.2.3 Latitude and Longitude

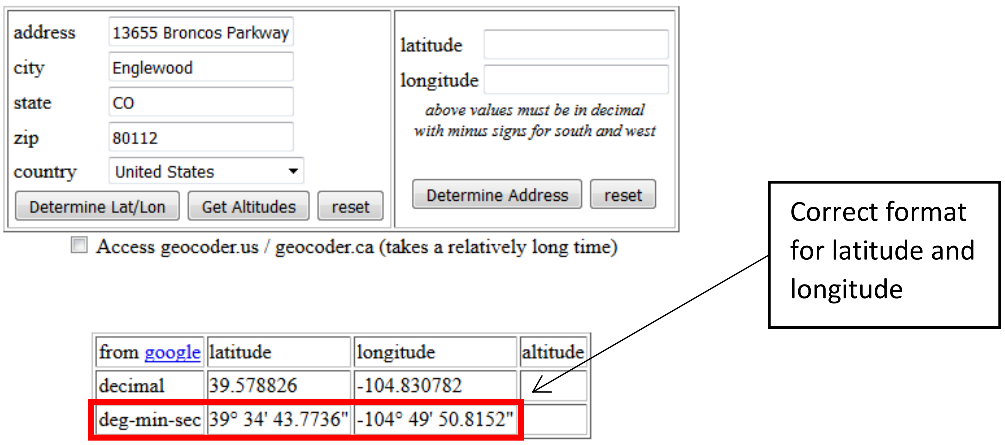
Below is a step-by-step process for obtaining latitude and longitude for a user-specified location, which is needed for the IWMI web-based tool covered in Section A.2.1.

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

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

3. See Figure A.**2.**3 below 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.




## 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 below:

- 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, accessed at: https://www.ncdc.noaa.gov/cdo-web/

# DRAFT Turf Conversion M&V Protocol V.03

**June 2017**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Prepared by Pacific Northwest National Laboratory and Western Resource Advocates as model guidelines for the State Performance Contracting Programs of Colorado, Nevada, and New Mexico.

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## Contents

## Tables



## Figures

## 1.0 Acronyms, Abbreviations, and Definitions

| | |
|---|---|
| **ASBE** | American Society of Agricultural and Biological Engineers |
| **Climate normal** | Average weather conditions for a given location that is over the latest three-decade time period. |
| **CAWQuer** | Climate Atlas Web Query (online tool and database) |
| **CoAgMet** | Colorado Agricultural Meteorological Network |
| **Commissioning** | The process whereby the measure improvements made to the equipment and/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 timeframe. |
| **Hydrozone** | A distinct area of the landscape that receives irrigation from the same system. |
| **Irrigation efficiency** | The percentage of irrigation water that is actually 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 |
| **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 timeframe water use is monitored, defined by the irrigation season. |
| **M&V** | measurement and verification |
| **NOAA** | National Oceanic and Atmospheric Administration |
| **Plant factor** | The fraction of reference ET 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 ET can be predicted for a range of vegetation and surface conditions. |
| **Study period** | The total timeframe that water use will be monitored per the contractual arrangement for the baseline and post-installation periods. |

| | |
|---|---|
| **Sustainable landscapes** | Landscapes that foster living soils, conserve and stretch water supplies, and have an appropriate selection and installation of plant and landscape materials. |
| **Water-wise landscapes** | Landscapes that focus on water conservation and are designed to address human desires while using drought-tolerant native or introduced plants. |
| **WCM** | water conservation measure |

## 2.0 Introduction

This measurement and verification (M&V) protocol provides procedures for energy service companies (ESCOs) to determine water savings as a result of water conservation measures (WCMs) in energy performance contracts associated with converting turfgrass or other water-intensive plantings to water-wise and sustainable landscapes.[1, 2] 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 to collect data and measure water savings.**

The procedures presented in this protocol are performance based. ESCOs 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 removing existing high water consuming turfgrass or other water-intensive plantings. WCMs that are covered by this M&V protocol include, but are not limited to, the following:

**Water-wise/Sustainable Landscape Conversion**

This WCM is the conversion of water intensive turfgrass and/or other water-intensive plantings and practices with water-wise and sustainable landscapes that are well adapted to the local climate and thrive while using water efficiently. It is common for the landscape to have a combination of low-density planting and permeable hardscape (such as rocks or mulch) that reduces the amount of area covered, thereby lowering the supplemental irrigation requirements.

**Synthetic Turf Conversion**

This WCM is the conversion of water intensive turfgrass or other water-intensive plantings with synthetic turf, commonly installed in athletic fields. It should be noted that synthetic turf may have some water requirements for cleaning and cooling the surface.

[1] The California Water Efficiency Partnership defines sustainable landscapes as landscapes that focus on three central practices: fostering living soils, conserving water and stretching potable water supplies, and selecting and properly installing appropriate plant and landscape materials.

[2] Water-wise landscaping focuses on water conservation, designs that address human desires, and use of drought-tolerant native or introduced plants. Keane T. 1995. Water-wise Landscaping. Utah State University Cooperative Extension. EC 458. January.

## 4.0 Measurement and Verification Plan Elements

The ESCO is 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 M&V Method

The International Performance Measurement and Verification Protocol[3] (IPMVP) has four options (A, B, C, and D) that can be used to verify the savings of measures.

**For turf conversion projects, the recommended IPMVP option to verify water savings is Option B, "Retrofit Isolation."** The objective of Option B 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.

IPMVP's Option A, "Partially Measured Retrofit Isolation", allows some stipulated savings. Option A may be an appropriate method if the WCM requires short term water use, such as cleaning or cooling, where runtime and/or flow rate of these activities may be stipulated. However for WCMs that have metered water use post-installation, Option B is the best method to accurately monitor water use.

Option C ("Whole Building") and Option D ("Calibrated Simulation") are not appropriate M&V methods for turf conversion projects because they assess usage at the building level rather than the system level.

This 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 methods.

### 4.2 Measure Description and Measurement Boundary

The M&V plan should describe the specific WCM. In addition, 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 landscape conditions, which 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 that describes the state of the existing landscape and irrigation system. The plan should also 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 description of the baseline condition of the landscape may 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).

[3] Efficiency Valuation Organization. 2014. *International Performance Measurement and Verification Protocol: Core Concepts.* EVO 1000—1:2014. June.

### 4.3.2 Post-Installation Condition

Similarly, the M&V plan should specify the condition of the landscapes and irrigation systems that will be installed as part of the WCM that will be achieved through the study period per the commissioning plan (see section 6.0).

The M&V plan should include the following information on the WCM:

- *Plant species*
  - The plan should include a full list of plants that will be installed and should state if these plants are native or adaptive vegetation that is drought tolerant for the specific location.
- *Plant establishment period*
  - The time period it takes for plants' roots to become established in the soil should be specified. The M&V plan should also provide an estimate of the amount of water that will be required during the establishment period. It is common for native and low water-using landscape to have an establishment period whereby supplemental irrigation can be greater than the normally required water needs, which may decrease water savings during the establishment period. Upon agreement between the ESCO and customer, the water use during the establishment period can be excluded from the guaranteed water savings for up to two years of the study period. **However, the water consumption during the establishment period should be quantified and reported so that the customer understands the water use implications.**
- *Soil type and preparation*
  - Information on the type of soil and preparation that will be implemented as part of the measure should be detailed. Soil quality and texture can have a large impact on plant health and water use.
- *Irrigation requirements and systems*
  - The supplemental irrigation requirement for each hydrozone should be documented in the plan. The water requirements and schedules during the establishment period and post-establishment period should be specified.
  - The plan should document how the landscape will be irrigated (if required) during the establishment and post-establishment period. If an irrigation system is part of the WCM, the plan should specify the type of irrigation systems that will be installed that includes specific information on system components, distribution uniformity, and irrigation controls.
- *Landscape area*
  - The total area of the landscape that is being converted should be documented, typically expressed in square feet. The area should include both vegetation and hardscape.
  - The area of specific plant types identified in Table 1 in ASBE Standard S623[8]: cool season turf, warm season turf, annual flowers, woody plants and herbaceous perennials (wet and dry), and desert plants. (This is used in the normalization process, see Section 5.3.)
- *Percent of landscape canopy cover at full maturity*
  - The percent of landscape canopy cover is the sum of plant's canopy cover (the amount of ground that is shaded by the plant based on the estimated plant diameter at full

maturity), divided by the total landscape area. (E.g., a landscape with a total area of 10,000 square feet with 8,000 square feet of plant canopy cover at full maturity has an 80% landscape canopy cover.)

  - The percent landscape canopy cover at full maturity is a useful metric to show how much of the landscape will be covered by vegetation. **Having a sufficient canopy cover can avoid a landscape that is mainly hardscape or rock, which can be seen as unattractive and can increase the heat island effect.[4] However, a higher percent of landscape canopy cover can increase the supplemental irrigation requirement. Therefore, this metric should be carefully evaluated to balance these two issues. It is important that this metric is reviewed and approved by the customer.**

  - The Agricultural and Biological Engineers (ASBE) Standard S623, *Determining Landscape Water Demands,* should be used for determining the percent of landscape canopy cover. [5]

- *Adjusted plant factor*
  - The plant factor is the relative amount of water required by a plant compared to a reference plant (such as alfalfa grass). The adjusted plant factor is used to determine the water requirements of the landscape and takes into account the landscape canopy cover for landscapes that are not densely planted.

  - The Agricultural and Biological Engineers (ASBE) Standard S623, *Determining Landscape Water Demands,* should be used for determining the adjusted plant factor.[3]

- *Non-vegetated materials*
  - The type and total area of hardscape materials should be documented in the plan such as rock, mulch, or concrete.

  - Maintenance requirements of these materials should also be documented such as weeding or cleaning.

- *Synthetic turf*
  - If synthetic turf is part of the WCM, the type of product and total area should be specified.

  - Maintenance requirements should also be documented such as cleaning or cooling. The plan should include the frequency and duration of the maintenance activities that require water.

## 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. The plan should also include how water use will be normalized. Section 5.0 of this protocol provides detailed procedures on the

[4] Environmental Protection Agency. *Reducing Urban Heat Islands: Compendium of Strategies.* 2008. Accessed at: https://www.epa.gov/heat-islands/reducing-urban-heat-islands-compendium-strategies

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

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 that will be used to measure water use. (See Section 5.0 for additional information.) **It is important for the customer to review and approve the type of data that will be used.** The following describes the type of data that may be collected.

- *Continuous measurement using a dedicated meter/s*
    - Volume of water logged by the metering system over the measurement period. (See Section 4.9 for additional information on metering.) 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 at least monthly, which is required in the normalization process (see Section 5.3).
- *Flow rate of hyrdozone*
    - Hydrozone flow rate logged by a dedicated or temporary metering system over distinct time 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.
- *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.
- *Short term post-installation water activities flow rate and runtime*
    - For short term water activities such as irrigation during the plant establishment period or maintenance requirements (e.g., cleaning or cooling of synthetic turf), flow rates and the duration and frequency of these activities should be specified in the plan. (If short term irrigation is not included in the guaranteed savings, flow rate and runtime should still be included in the M&V plan).
- *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).
- *Weather data*
    - ET 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.)

## 4.6 Study Period

The study period covers the total timeframe that water use will be 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.[6]

> ***Preferable:*** *baseline study period is an average of multiple irrigation seasons*
>
> ***Acceptable:*** *baseline study period is a minimum of one full irrigation season*

The plan should define the baseline study period, which 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.

The plan should also define the study period for the post-installation water use measurement. For example, in the state of Colorado ESCOs are required by statute to provide a written cost savings guarantee for the first 3 years of the contract period. [7] At the agency's discretion, the savings guarantee can be extended beyond the legislatively required time period. At the end of each performance year, the ESCO is 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. The measurement period should start after the defined establishment period if the establishment period is excluded from the guaranteed savings (see Section 4.3.2).

## 4.8 Measurement Frequency

The measurement frequency is the number of measurements that will be collected over the measurement period to calculate baseline and post-installation water use. (See Section 5.0 for additional information.). Water use should be at least collected monthly.

- *Water use with a dedicated meter*
  - Water use data should be collected from the dedicated meter at least monthly and capture the full measurement period.
- *Hydrozone flow rate*
  - 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 will ensure that an accurate flow rate is determined. Flow rates may vary due to system issues such as line leaks or broken heads. Therefore it is important that system leaks are detected and corrected prior to flow rate measurement for post-

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

[7] 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.

installation water use determination. In addition, it is recommended that flow rate data is collected from a dedicated meter rather than from a controller because a meter records flow rate directly.

- *Irrigation runtime*
    - Runtime for each hydrozone should be collected over distinct time 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.
- *Short term post-installation water activities flow rate and runtime*
    - For short term water activities such as short-term irrigation during the establishment period and cleaning or cooling, the activity's flow rate can be measured by a temporary flow meter or estimated based on specified flow rate of the equipment. If metered, it is recommended that the flow rate is measured several times over the measurement period and averaged. The runtime and frequency of the activity should be logged over the measurement period.

## 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, which may 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 should provide the method used to calibrate the meters and provide a calibration certificate to their customer, which should follow the established M&V requirements of the State Performance Contracting Program. If there are potential metering inaccuracies, the ESCO should follow any established dispute resolution steps identified in the State Performance Contracting Program relevant to this issue.

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 should also 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 the material to protect against high pressure and corrosion (e.g., plastic versus brass)
- Water quality requirements (e.g., treated versus  untreated 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 should also provide the type of data management system that will log water use. The following data management options should also be considered when selecting an appropriate metering system:

- Data logging capability that allows for collection of volumetric water use over distinct interval 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 of the document 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:

***Preferable:*** *Continuous measurement using a dedicated meter/s*

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

1. **Continuous measurement using a 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 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 time periods.

2. **Flow rate determination**. If a dedicated meter is not installed on the existing system or does not record volumetric data, flow rates for each hydrozone 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, 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*[8] or American Society of Agricultural and Biological Engineers (ASBE) Standard S626 *Landscape Irrigation System Uniformity and Application Rate Testing*[9]. The precipitation rate for each hydrozone is applied to the hydrozone's run-time and landscape area that the hydrozone covers. The total baseline irrigation water use is the sum of the hydrozone's water use, represented by:

$$\sum_{Z=1}^{n}(PR_{Z} \times A_{Z} \times RT_{Z} \times 0.0104)$$

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

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

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, measured in minutes

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

$n$ = The total number of hydrozones

### 5.1.2 Baseline Normalization

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

- The existing irrigation controller is a weather-based and/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, which is documented with metered interval data that shows fluctuations in water use throughout the irrigation season indicating schedule changes.

## 5.2 Post-Installation Water Use Determination

This section provides the procedures to determine post-installation water use for two scenarios:

- Projects that have permanent irrigation systems and require long term supplemental irrigation
- Projects that do not have permanent irrigation systems and only require short term supplemental irrigation during the plant establishment period

### 5.2.1 Permanent Irrigation System with Long Term Supplemental Irrigation

For projects that have permanent irrigation systems and require long term supplemental irrigation, a meter is required to measure the post-installation water use over the study period. The two options for

***Preferable:*** *Continuous measurement using dedicated meter*

***Acceptable:*** *Flow rate determination*

determining the post-installation water use are described below, listed in order of accuracy.

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, flow rates of the hydrozones, logged by a dedicated or temporary metering system 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:

$$\sum_{Z=1}^{n}(FR_{\mathrm{Z}} \times RT_{\mathrm{Z}})$$

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

### 5.2.2 Short Term Water Activities

For projects that do not have permanent irrigation systems and only require short term irrigation (e.g., hand-watered) during the establishment period or other water use activities (e.g., cleaning or cooling), water use can be measured using the following method. Note, if the establishment period is excluded from the guaranteed water savings, the water use should be quantified using this method but the water use does not need to be included in the post-installation water use (see Section 4.3.2).

- **Flow rate determination.** Water use of short term activities can be determined using the flow rates, runtime, and frequency of the activities. The flow rate of the activity should be logged by a dedicated or temporary metering system or can be estimated based on specified flow rate of the equipment. The flow rate for each activity is multiplied by the activity's runtime to determine the volume of water used for each hydrozone. The total post-installation irrigation water use is the sum of water use activities, represented by:

$$\sum_{A=1}^{n}(FR_{\mathrm{A}} \times RT_{\mathrm{A}})$$

Where:

$FZ_A$ = The flow rate of the activity, measured in gallons per minute

$RT_A$ = The runtime of the system over the measurement period, measured in minutes

$n$ = The total number of activities

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 flow rate (see Section 4.8)
- Describe how the average flow rate was determined
- Describe how the activity runtime was collected over the measurement period

### 5.2.3 Post-Installation Normalization

**Post-installation water use will be normalized only if the landscape is irrigated with 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 5.2.3, 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, the landscape may need more water to survive because of reduced rainfall. Conversely, weather can be abnormally wet, where more precipitation is received than normal, 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, as is defined by the National Oceanic and Atmospheric Administration (NOAA) National Climate Data Center as the "latest three-decade averages of climatological variables".[10]**

The historical average (climate normal) ET and effective precipitation can provide an estimate of the typical irrigation requirements of a landscape and can thereby be used to normalize water use. ET 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 is typically measured in inches over a given timeframe (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 and surface conditions. The ET of the measurement boundary 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. In addition, the amount of rainfall that is available to the vegetation in the landscape, known as effective precipitation, needs to be determined to normalize the water use.[11] The amount of effective precipitation received over the timeframe is subtracted from ET requirements to determine the "net ET."

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.

[10] 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

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

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, the following procedure specifies normalizing water use over a monthly timeframe. However, shorter intervals (such as daily) can be performed if it is 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:
   - 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].
   - Determine the plant factor for each of these plant types using Table 1 in ASBE Standard S623[8], use adjusted plant factors for areas that are not densely planted (see Section 4.3.2)
   - For each plant type, multiply the plant factor by the percent area and sum these values, which 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 actually stored in the soil available to the plant's root zone.[12]

**Commented [PNNL-KMS1]:** A method for determining effective precipitation is currently being formulated and will be added once finalized.

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:

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

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

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:

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

8. Determine the monthly ratio of monthly average net ET to the current monthly measurement period net ET, represented by:

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

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 all of the monthly values to determine the total post-installation water use, represented in:

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

Table 1 below provides an example of this normalization method. This example depicts a water smart landscape in Aurora, Colorado. The post-installation water use was 53,445 gallons measured by the metering system. The effective precipitation was determined to be 50%. The weighted average plant factor was determined to be 0.4. Abnormally hot and dry conditions were experienced during the irrigation season, whereby the total net ET over the measurement period was 18.3 inches, compared to the historical average of 14.1 inches, giving a net ET ratio of 77%. Applying this value, the normalized post-installation water use is 75,118 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 $ET_o$ Ratio | Post-Installation Water Use (gallons) | Normalized Post-Installation Water Use (gallons) |
|---|---|---|---|---|---|---|---|---|---|
| **Apr** | 4.86 | 1.44 | 1.36 | 5.84 | 1.33 | 1.84 | 0.74 | 5,306 | 4,451 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **May** | 6.08 | 2.40 | 1.41 | 7.30 | 2.21 | 2.03 | 0.70 | 5,712 | 8,829 |
| **Jun** | 7.76 | 1.37 | 2.64 | 9.31 | 1.26 | 3.36 | 0.79 | 9,906 | 15,777 |
| **Jul** | 8.45 | 1.88 | 2.68 | 10.14 | 1.73 | 3.48 | 0.77 | 10,184 | 16,154 |
| **Aug** | 7.52 | 1.36 | 2.54 | 9.03 | 1.25 | 3.24 | 0.78 | 9,552 | 15,207 |
| **Sep** | 5.73 | 0.88 | 2.02 | 6.88 | 0.81 | 2.54 | 0.79 | 7,516 | 11,991 |
| **Oct** | 4.05 | 0.65 | 1.41 | 4.86 | 0.60 | 1.78 | 0.79 | 5,268 | 2,709 |
| **Total** | **44.46** | **9.98** | 14.06 | **53.36** | **9.19** | **18.27** | **0.77** | **53,445** | **75,118** |

### 5.4 Other Considerations

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

- Changes to irrigation control settings, such as local grounds maintenance crews overriding pre-programmed controllers.
- Changes in landscape area or planting type at any time during the study period, which may change the irrigation requirements.
- Undetected leaks that are not repaired quickly.
- Extreme weather events that may significantly impact water requirements or landscape condition such as flooding.
- Grounds maintenance issues such as disease of landscape that requires extra watering not anticipated in the savings estimate.
- Drought management (and other types of) watering restrictions imposed by the water utility, or local or state government entities that may reduce water use and change the appearance of the landscape.
- Deficit watering during the baseline period, which is a reduction in water use compared to the required water needs of the landscape—this may 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 the WCM will achieve the guaranteed savings. Commissioning is the process whereby the landscape conversion has been verified to comply with the approved plan and visually inspected. In addition, commissioning verifies that the correct irrigation schedule has been implemented for post-installation landscape needs (if applicable), and that the manager of the irrigation system has been trained to properly operate it.

Commissioning ensures that landscape has been planted and the irrigation 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. For WCMs that include the installation of an irrigation system, the commissioning plan should follow the Irrigation Association's *Irrigation System Inspection and Commissioning Guidelines,* found in the *Landscape Irrigation Best Management Practices*.[13] Critical components of the commissioning plan include:

- **Qualified inspector**. A commissioning agent should have the training and competencies to perform the required steps. Examples of qualifications may include the Irrigation Association certifications such as Certified Landscape Irrigation Auditor, Certified Landscape Manager, and Certified Irrigation Designer[14]; and the Qualified Water Efficient Landscaper Program[15].

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

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

- **Training**. The plan should also include the training that is required to maintain the landscape and 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, which may include, but are not limited to:

    - *Landscape condition assessment*. Conduct an evaluation that determines the condition of the landscape plantings, including: (See Section 4.3.2)
        - Plant species planted in landscape
        - Total landscape area
        - Landscape canopy cover (as a percent of the total landscape)
        - Plant health and visual quality
        - Plant establishment timeline

    - *Controller irrigation schedule.* If applicable, 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.

---

[13] 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

[14] Irrigation Association Certification Program: http://www.irrigation.org/Certification/

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

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

- *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
    - Backflow prevention

- **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, 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 if the system is functioning per the design, and list necessary corrections.

# Appendix A – Local Weather Data Sources and Evapotranspiration Calculation Methods

***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*

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. ET 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 is typically a calculated value.

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 time period (see Section A.1.1). 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 timeframe (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.[16] However, the simplified Hargreaves method can be used to approximate $ET_o$ and is appropriate to use when there is limited metrological data.[17]

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

[16] 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

[17] 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

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

### A.1.1 Climate Normal Data

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

## A.2 International Water Management Institute Data

The IWMI database provides an alternate means for gathering average $ET_o$ instead of using the above calculation methods. 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 world-wide and averaged from 1961 to 1990. The dataset includes average $ET_o$ and precipitation. Even though this time period is not officially considered "climate normal" because it does not span the latest three-decade timeframe, this dataset is a reasonable approximation of average climate data and is allowed to be used in the normalization process described in Section 5.3.

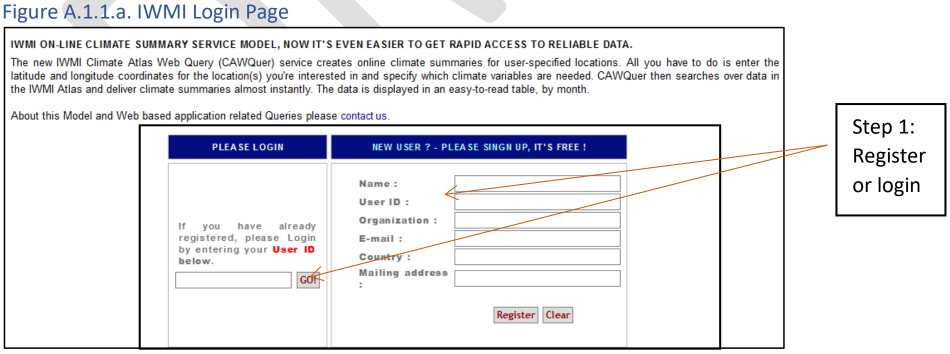
The following sections of this appendix provides a step-by-step process for gathering data from the IWMI web-based tool. Data should be collected only over the measurement period (irrigation season) (see Section **Error! Reference source not found.**).

### 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
3. Figure A.1.1.a. IWMI Login Page

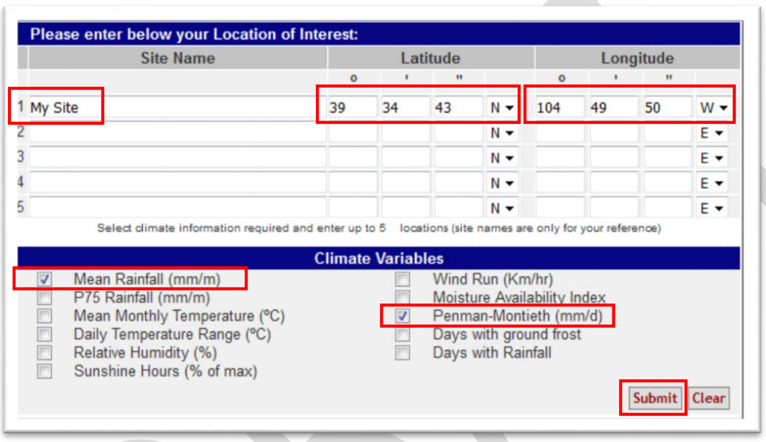
Figure A.1.1.a. IWMI Login Page




4. Enter site name(s). See Figure A.2 for an example of IWMI data entry for user-specified location information and climate variables available for download.

5. 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.)
6. 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).
7. Climate variables that need to be checked are P50 (mm/m) and Penman $ET_o$ (mm/d) for normalization.
8. Click the **Submit** button.

Figure A.1.1.b. IWMI User-Specified Location and Climate Variables.




### A.2.2 IWMI Web-Based Tool Ouputs

Figure A.1.2. 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:

**Error! Reference source not found.**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 converter to monthly values by multiplying by the number of days in the month by the daily $ET_o$ value.

### A.2.3 Latitude and Longitude

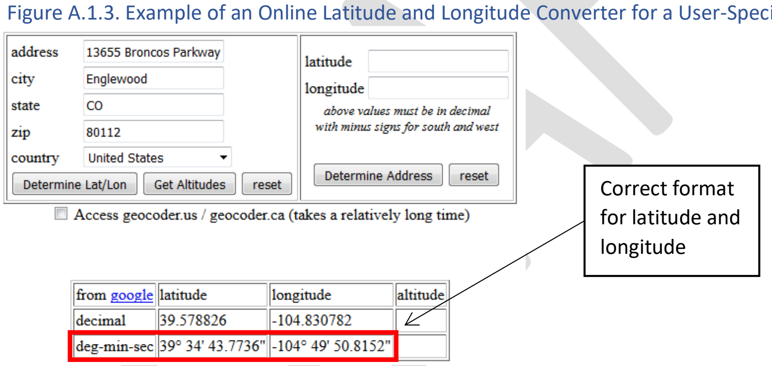
Below is a step-by-step process for obtaining latitude and longitude for a user-specified location, which is needed for the IWMI web-based tool covered in Section A.1.1.

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

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

3. See below Figure A.1.3 for an example of an online latitude/longitude converter with the input and resulting output.

Figure A.1.3. Example of an Online Latitude and Longitude Converter for a User-Specified Address.




## 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 below:

- 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, accessed at: https://www.ncdc.noaa.gov/cdo-web/

# DRAFT Cooling Tower (Evaporative Cooling System) M&V Protocol V.01

**June 2017**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Prepared by Pacific Northwest National Laboratory and Western Resource Advocates as model guidelines for the State Performance Contracting Programs of Colorado, Nevada, and New Mexico.


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## Contents



## Figures



## Tables

## 1.0 Acronyms, Abbreviations, and Definitions

| | |
|---|---|
| **Commissioning** | The process whereby the measure improvements made to the equipment and/or the control system have been verified to comply with the approved plan, and visually inspected and evaluated for proper operation. |
| **ESCO** | Energy Service Company (performance contractor) |
| **Cycles of concentration** | Term that describes the mass flow relationship between the volume of makeup water and the volume of blowdown water. Sometimes also referred as *concentration ratio*, this technical term correlates to the effective use of water in a cooling tower system. |
| **IPMVP** | International Performance Measurement and Verification Protocol |
| **HVAC** | heating, ventilation and air conditioning technology |
| **IWMI** | International Water Management Institute |
| **Measurement boundary** | The specific cooling towers 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 timeframe water use is monitored, defined by the cooling season. |
| **M&V** | measurement and verification |
| **NOAA** | National Oceanic and Atmospheric Administration |
| **Study period** | The total timeframe that water use will be monitored per the contractual arrangement for the baseline and post-installation periods. |
| **WCM** | water conservation measure |

## 2.0 Introduction

This measurement and verification (M&V) protocol provides procedures for energy service companies (ESCOs) to determine water savings as a result of water conservation measures (WCMs) in energy performance contracts associated with cooling tower 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 to collect data and measure water savings.**

The procedures presented in this protocol are performance based. ESCOs 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 cooling tower systems. Cooling tower systems include all components that provide comfort or process cooling by rejecting heat to the atmosphere through the evaporative process. System components include piping infrastructure, valves, pumps, heat exchangers, the cooling tower structure, and cooling tower controls. WCMs that are covered by this M&V protocol include, but are not limited to, the following:

**Cooling Tower System Efficiency Improvements**

The objective of this measure is to optimize cooling tower efficiency by ensuring all mechanical components are working properly, and by maximizing the operating cycles of concentration. This WCM category may include minimizing the expected losses from the system, reducing or eliminating unnecessary losses, and inspecting and repairing system components that are not functioning properly.

**Conductivity Controls Upgrades**

Conductivity controllers manage the cycles of concentration in the tower system. This measure includes installing controllers that continuously measure the conductivity of the recirculating water and maintain the tower system blowdown to a programmed setpoint.[1] These controllers can also control liquid chemical treatment based on pulse input from a water meter, in conjunction with blowdown, or based on a timer.

**Advanced Control Platforms**

Advanced control platforms are available with multiple sensors that monitor and control system conductivity, chemical treatment levels, pH, corrosion rates, and holding time index. These systems continuously ensure cooling tower systems operate at optimal cycles of concentration and maintain the desired chemical residuals, while monitoring other critical system parameters such as pH, corrosion rates, holding time index and indirect measurement of biological activity.

## 4.0 Measurement and Verification Plan Elements

The ESCO is 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.

[1] Conductivity is an indirect measurement of the dissolved mineral content in the water.

## 4.1 M&V 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 cooling tower efficiency measures, the recommended IPMVP option to verify water savings is Option B, "Retrofit Isolation."**

The objective of Option B 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 cooling tower system to verify the savings, whereby short-term or continuous measurements are taken throughout the study period.

The cooling tower makeup water flow is the key parameter that is required to be measured using Option B, as this must be equal to all of the expected or unexpected losses of water from the system.

IPMVP's Option A, "Partially Measured Retrofit Isolation", allows some stipulated savings, which 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 cooling tower efficiency projects because they assess usage at the building level rather than the system level.

This 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. In addition, the plan should clearly define the measurement boundary. The measurement boundary defines the specific cooling tower system 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 that includes information related to the cooling tower system, operating schedule, and the condition of the system before and after the WCM is implemented.

### 4.3.1 Baseline Condition

The plan should include information relevant to the baseline conditions that is collected during the inspection of the cooling tower system that describes the state of the system components prior to implementation of the WCM. This will include items such as, but not limited to: pipe connections, valves, pumps, tower structure, tower fill, distribution deck, drift eliminators, basin level controls, cooling tower fans, fan and pump drives, heat exchangers, and sources of leaks and losses.

The plan should detail the baseline cycles of concentration and the existing means of controlling cycles of concentration. The plan should also include the operating schedule, and specific changes made to the operating schedule during the baseline year that impact the baseline water use.

The description of the baseline condition of the operating parameters may include, among other things, freeze protection schedules or free cooling schedules where the tower system supplies condenser water to a plate and frame heat exchanger rather than to a chiller system.

### 4.3.2 Post-Installation Condition

Similarly, the M&V plan should specify the condition of the cooling tower system that will be achieved through the study period per the commissioning plan (see Section 6.0). This should include information on the cooling tower system components and schedules.

## 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 may be collected.

- *Continuous measurement using a dedicated meter*
  - Volume of water logged by the metering system over the measurement period. Continuous meters can be installed on the cooling tower makeup water supply and the blowdown line. 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)
- *Short-term measurement using a temporary meter*
  - Temporary, non-intrusive meters such as ultrasonic meters can be installed to measure system water use for a specified duration of time. The plan should include an agreed upon duration of time for the temporary metering to be performed to establish typical operating conditions and typical system water consumption.
- *Weather data*
  - Average monthly wet bulb temperature data will be used to normalize water use. Average monthly temperature, relative humidity, and barometric pressure can be used to calculate average monthly wet bulb temperature (See Appendix A for methodology to determine wet bulb temperatures.)

## 4.6 Study Period

The study period covers the total timeframe that water use will be 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. 2008. *Measurement and Verification (M&V) Guidelines for Energy Saving Performance Contracts in State of Colorado Facilities*. Boulder, CO. June.

**The plan should define the baseline period**. The baseline study period should be a minimum of one full cooling season, but preferably an average of multiple cooling seasons.[3] Using an average of multiple years for the baseline study period is preferable because it helps minimize anomalies in water use caused by weather patterns or operation changes such as scheduling issues or system maintenance problems.

> ***Preferable:*** *baseline study period is an average of multiple cooling seasons*
>
> ***Acceptable:*** *baseline study period is minimum of one full cooling season*

The plan should also define the study period for the post-installation water use measurement. For example, in the state of Colorado ESCOs are required by statute to provide a written cost savings guarantee for the first 3 years of the contract period.[4] At the agency's discretion, the savings guarantee can be extended beyond the legislatively required time period. At the end of each performance year, the ESCO is 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 cooling season. For Colorado, the typical cooling season runs from the middle of May through the end of September[5].

## 4.8 Measurement Frequency

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 capture the full measurement period.

- *Water use with a temporary meter*.
  - Water use data can alternately be collected from a temporary meter if a dedicated meter is not installed on the tower system. Data should be collected monthly, and preferably capture the full measurement period. If data collection cannot be accomplished for the full measurement period, it should be done for an agreed upon duration of time that includes the full range of operating conditions from low cooling demand to peak design cooling demand.

---

[3] Multiple cooling seasons should encompass three or more years of data.

[4] 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.

[5] This is based on historical cooling degree days for Denver from 1948 through 2013 from the Western Regional Climate Center. Accessed at www.wrcc.dri.edu/cgi-bin/cliMONtcdd.pl?co2220

## 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 cooling tower system within the measurement boundary. An existing dedicated meter can be used to determine the baseline water use, which may be customer owned or provided by the water utility.

**It is important that the meters 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 should provide the method used to calibrate the meters and provide a calibration certificate to their customer, which should follow the established M&V requirements of the State Performance Contracting Program. If there are potential metering inaccuracies, the ESCO should follow any established dispute resolution steps identified in the State Performance Contracting Program relevant to this issue.

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 should also 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 post-installation water use is accurately determined

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

- Data logging capability that allows for collection of volumetric water use over distinct interval 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* = Cooling tower water use of the system prior to WCM implementation
*Post Installation Water Use* = Cooling tower water use after implementation of WCM
*Adjustments* = Factor applied to normalize water use when appropriate

### 5.1 Baseline Water Use

This section of the document 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:

***Preferable:*** *Continuous measurement using dedicated meters*

***Acceptable:*** *Short-term measurement using temporary meters during typical operating conditions*

1. **Continuous measurement using a dedicated meter/s**. If the existing cooling tower system has a flow meter on the tower makeup that monitors water use over the measurement period for the measurement boundary, metered data should be collected to determine the baseline water use (see Section 4.5).

2. **Short-term measurement using a temporary meter/s**. If a dedicated meter is not installed on the existing system, the baseline water use can be determined using a temporary meter on the cooling tower makeup to monitor water use for an agreed upon period of time that includes the full range of operating conditions from low cooling demand to peak design cooling demand. The temporary meter flow measurement needs to be extrapolated across the full cooling season to determine the baseline water use. This can be done by multiplying the temporary meter measurement by the time duration of the total cooling season divided by the amount of time the temporary meter was installed.[6] The calculation is represented by the following equation:

$$Baseline\ Water\ Use = TMMg \times \left(\frac{CS}{TMt}\right)$$

Where:

$TMM_G$ = The temporary meter measurement, measured in gallons
$CS$ = The time duration of the total cooling season, measured in days or weeks
$TM_T$ = The temporary metering time, measured in days or weeks

[6] Make sure to use the same units of time (days or weeks) for time duration of the total cooling season, and for the amount of time the temporary meter was installed.

### 5.1.2 Baseline Normalization

If the study period for the baseline water use is an average of multiple cooling seasons, normalization of the cooling tower water use is not necessary. **However, if the study period only encompasses one cooling season, then the baseline water use should be normalized against historical wet bulb temperatures using the procedure described in section 5.3.**

## 5.2 Post-Installation Water Use Determination

As part of the requirements of using the IPMVP Option B M&V method, a meter is required to measure the post-installation water use over the measurement period.

**Continuous measurement using a dedicated meter/s** is the method that meets the requirements of IPMVP Option B because it accurately measures water use over the full measurement period. Therefore, in-line meters should be connected to a centralized control system or a data logger to continuously record water use data over the measurement period within the measurement boundary.

### 5.2.1 Post-Installation Normalization

The post-installation water use should be normalized against historical wet bulb temperature conditions using the procedure described below in Section 5.3.

## 5.3 Data Normalization

As described in Sections 5.1.2 and 5.2.1, cooling tower water use should be normalized to account for weather variations and adjust the current water use to historical weather patterns.

The cooling tower's water use and heat rejection process of evaporation is governed by the physical and thermodynamic properties of gas and vapor mixtures. This process is dependent on more than just temperature. It relies on the inter-relationship of ambient air temperature, relative humidity, and barometric pressure which are graphically depicted by the psychrometric chart for water. A key measurement in this inter-relationship is wet bulb temperature. In simple terms, wet bulb temperature is the lowest temperature that can be achieved by evaporative cooling.[7]

Wet bulb temperature of the air entering the cooling tower is the primary thermal design basis for any evaporative cooling system, and for this reason, monthly average wet bulb temperature and historical monthly average wet bulb temperature should be used to normalize cooling tower water use.

Accordingly, follow these steps to normalize the baseline or post-installation water use over the measurement period.

1. Gather the baseline or post-installation water use for each month from metered data collected during the study period as described in Section 5.1.

2. Determine the average monthly wet bulb temperature for the measurement period using average temperature, average relative humidity, and average barometric pressure for a weather station near the location of the cooling tower. These measurements are available for numerous weather

[7] For an expanded discussion on wet bulb temperature, see www.engineeringtoolbox.com/dry-wet-bulb-dew-point-air-d_682.html .

stations at Weather Underground.[8] These variables can then be entered into a simple online calculator produced by the National Weather Service to determine the average monthly wet bulb temperature.[9] See 6.0Appendix A for wet bulb determination method.

3. Look up the average historical monthly wet bulb temperatures for a weather station near the location of the cooling tower.[10] The Western Regional Climate Center has data from the mid 1990's to 2011 listed by state for multiple weather stations.[11]

4. Determine the monthly ratio of average current wet bulb temperature to the average historical wet bulb temperature during the study period, represented by:

$$\begin{aligned} &\mathit{Monthly\ Wet\ Bulb\ Temperature\ Ratio} \\ &\qquad = (\mathit{Historic\ Monthly\ Wet\ Bulb\ Temperature} \\ &\qquad \div \mathit{Current\ Monthly\ Wet\ Bulb\ Temperature}) \end{aligned}$$

5. Normalize each month's water use by multiplying the metered water use by the monthly wet bulb temperature ratio. Then sum all of the monthly values to determine the baseline or post-installation total water use, represented in:

$$\sum_{n=1}^{n} (\mathit{Monthly\ Metered\ Water\ Use}\ \times \mathit{Monthly\ Wet\ Bulb\ Temperature\ Ratio})$$

Table 1 below provides an example of this normalization method. This example depicts a cooling tower system near the Denver International Airport for a hypothetical study period of May through September of 2016. The water use was 247,000 gallons measured by the metering system. The average monthly wet bulb temperature was slightly higher during the study period than the historical values, and the resulting normalized water use is 233,168 gallons.

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[8] Available at www.wunderground.com/ .

[9] This calculator is available at www.weather.gov/epz/wxcalc_rh .

[10] Although ideally this would be the same weather station used in Step 2, the list of weather stations on the Western Regional Climate Center website is not comprehensive. If the same weather station cannot be used for the average historical monthly wet bulb temperature, use the nearest location to the cooling tower or a weather station with similar climate characteristics.

[11] Available at www.wrcc.dri.edu/htmlfiles/westcomp.wb.html .

Table 1. Sample Normalization of Cooling Tower Water Use

| Operating Month | Metered Tower Water Use (gallons) | Average Temp (°F) | Average Relative Humidity (%) | Average Barometric Pressure (in Hg) | Current Average Wet Bulb Temp (°F) | Historic Average Wet Bulb Temp (°F) | Monthly Wet Bulb Temp Ratio | Normalized Water Use (gallons) |
|---|---|---|---|---|---|---|---|---|
| **May** | 23,000 | 54.6 | 59.7 | 29.9 | 47.7 | 46.7 | 0.98 | 22,518 |
| **Jun** | 58,000 | 71.0 | 52.5 | 29.9 | 60.1 | 53.9 | 0.90 | 52,017 |
| **Jul** | 76,000 | 76.5 | 45.9 | 29.9 | 62.8 | 59.2 | 0.94 | 71,643 |
| **Aug** | 61,000 | 71.5 | 46.9 | 29.9 | 59.0 | 58.1 | 0.98 | 60,069 |
| **Sep** | 29,000 | 66.3 | 45.2 | 29.9 | 54.4 | 50.5 | 0.93 | 26,921 |
| **Total** | 247,000 | | | | | | | **233,168** |

## 5.4 Other Considerations

The M&V plan should state any potential issue that may significantly impact water use. If there are potential issues that may significantly impact water use, the ESCO should follow the established dispute resolution steps identified in the State Performance Contracting Program, which should be reviewed and agreed upon between the ESCO and the customer. Such issues may include, among other things:

- Changes to cooling tower control settings, such as building operators and maintenance crews modifying controller setpoints.
- Mechanical issues, such as failed valves, level controllers, or drives that control pumps and fans.
- Undetected leaks that are not repaired quickly.
- Vendor adjustments made by chemical suppliers.

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 savings estimate as a result of the issues.

# 6.0 Commissioning Protocol

Commissioning is an important step to ensure the WCM will achieve the guaranteed savings. Commissioning is the process whereby the WCM improvements made to the cooling tower equipment and/or control system have been verified to comply with the approved plan and visually inspected and evaluated for proper operation. In addition, commissioning verifies that the correct operating schedule has been implemented for current cooling needs, and that the building operations and maintenance staff has been trained to properly operate it.

Commissioning ensures system components are functioning optimally per the measure's design and checks system performance.[12] A commissioning plan should be established that outlines the specific steps that will be performed. Critical components of the commissioning plan include:

- **Qualified inspector**. A commissioning agent should have the training and competencies to perform the required steps, including electrical, mechanical, and plumbing certifications associated with heating, ventilation and air conditioning (HVAC) equipment installation and operation. This may include the inspection and verification of a Professional Engineer.

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

- **Inspection frequency**. The plan should provide the timeframe of the commissioning inspection, which should be done during and after implementation of the WCM. It may be necessary to recommission the system within the study period to ensure the system is operating optimally.

- **Training**. The plan should also include the training that is required to operate any new equipment installed as part of the WCM.

- **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 may include, among other things:

    - *Controller programming.* Ensure the controller has been properly programmed to meet the specific operating parameters of the cooling tower system. This may include, but is not limited to, conductivity setpoint to maintain blowdown control, pulse input from water meters to control chemical feed, system volume, pH, and target active chemical treatment levels if the control platform has real-time capabilities.

    - *Sensor calibration.* Ensure all sensors that are monitoring and controlling any parameter are calibrated and working properly.

    - *System tests.* Conduct tests to ensure the system meets the specifications of the design, including: [13]
        - Verification that equipment matches design plans
        - Minimum speed ratings of VFDs are coordinated with the requirements of the cooling drive train
        - Proper operation of all sensors controlling the fans, pumps, and valves
        - Proper operation of all safety interlocks
        - Loop performance and stability at all operating load conditions
        - Proper operation of freeze protection sequencing
        - Proper operation of basin heaters including shutting off when temperatures rise above freezing

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[12] For an overview of commissioning guidelines and recommendations for cooling tower systems, refer to www.watco-group.co/images/pdf/Commissioning%20of%20Cooling%20Towers.pdf .

[13] Selected items are from the startup and operation checklist at www.watco-group.co/images/pdf/Commissioning%20of%20Cooling%20Towers.pdf .

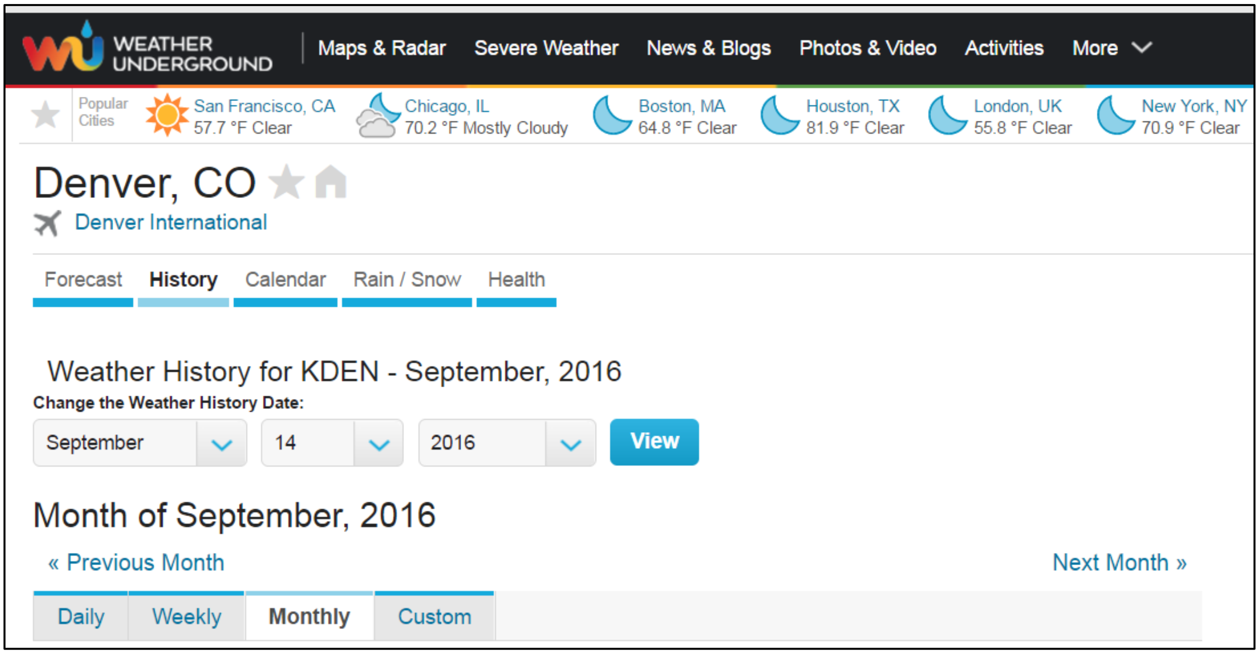
- **Minimum performance requirements**. The commissioning plan should specify the minimum requirements of the inspection and tests to meet the expected performance of system.

**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, 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 if the system is functioning per the design, and list necessary corrections.

## Appendix A – Average Wet Bulb Determination

Average temperature, relative humidity, and barometric pressure are needed to calculate average wet bulb temperature. Weather Underground (www.wunderground.com/) is a good resource to access local weather stations that also includes climate history reports. Figure A **1** below illustrates how to use the Weather Underground database to select of the monthly weather history for September 2016 for a weather station at Denver International Airport.

Figure A 1. Weather Underground Local Weather Database.




At the bottom of the webpage, details of the weather history are available, including temperature, relative humidity, and barometric pressure as illustrated in Table A 1 below.

Table A 1. Sample weather data outputs generated from Weather Underground Local Weather Database, Denver International airport station, September 2016.

Daily Weather History & Observations

| 2016 | Temp. (°F) | | | Dew Point (°F) | | | Humidity (%) | | | Sea Level Press. (in) | | | Visibility (mi) | | | Wind (mph) | | | Precip. (in) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sep | high | avg | low | high | avg | low | high | avg | low | high | avg | low | high | avg | low | high | avg | high | sum |
| 1 | 87 | 71 | 54 | 55 | 53 | 49 | 100 | 64 | 27 | 30.25 | 30.03 | 29.87 | 10 | 8 | 0 | 26 | 11 | 33 | 0.00 |
| 2 | 84 | 73 | 62 | 56 | 50 | 43 | 78 | 51 | 24 | 29.92 | 29.84 | 29.75 | 10 | 10 | 10 | 22 | 10 | 29 | 0.00 |
| 3 | 90 | 74 | 58 | 54 | 47 | 37 | 69 | 43 | 17 | 30.01 | 29.76 | 29.68 | 10 | 10 | 10 | 30 | 10 | 36 | 0.00 |
| 4 | 90 | 71 | 51 | 55 | 47 | 37 | 83 | 50 | 17 | 29.84 | 29.67 | 29.52 | 10 | 10 | 7 | 33 | 9 | 51 | 0.02 |
| 5 | 93 | 72 | 50 | 52 | 42 | 27 | 83 | 47 | 10 | 29.74 | 29.66 | 29.57 | 10 | 10 | 10 | 22 | 9 | 32 | 0.00 |
| 6 | 87 | 73 | 59 | 58 | 54 | 45 | 84 | 53 | 22 | 30.08 | 29.87 | 29.68 | 10 | 10 | 10 | 32 | 10 | 39 | 0.00 |
| 7 | 88 | 70 | 52 | 59 | 48 | 29 | 100 | 57 | 13 | 30.09 | 29.93 | 29.79 | 10 | 6 | 0 | 17 | 7 | 24 | 0.01 |
| 8 | 89 | 69 | 49 | 50 | 35 | 20 | 68 | 38 | 8 | 29.94 | 29.82 | 29.71 | 10 | 10 | 10 | 17 | 7 | 22 | 0.00 |
| 9 | 75 | 60 | 44 | 49 | 37 | 31 | 64 | 46 | 27 | 30.26 | 30.02 | 29.77 | 10 | 10 | 10 | 29 | 11 | 36 | 0.00 |
| 10 | 83 | 60 | 37 | 40 | 33 | 26 | 76 | 45 | 14 | 30.30 | 30.13 | 29.96 | 10 | 10 | 10 | 16 | 11 | 26 | 0.00 |
| 11 | 90 | 72 | 53 | 39 | 24 | 15 | 51 | 29 | 7 | 29.96 | 29.83 | 29.70 | 10 | 10 | 10 | 20 | 9 | 26 | 0.00 |
| 12 | 74 | 63 | 52 | 48 | 38 | 31 | 77 | 50 | 23 | 30.07 | 29.87 | 29.68 | 10 | 10 | 7 | 22 | 12 | 27 | 0.18 |
| 13 | 68 | 58 | 48 | 48 | 46 | 45 | 89 | 69 | 48 | 30.23 | 30.10 | 30.01 | 10 | 10 | 10 | 24 | 14 | 29 | T |
| 14 | 84 | 65 | 46 | 51 | 45 | 39 | 93 | 58 | 22 | 30.12 | 29.96 | 29.80 | 10 | 10 | 9 | 28 | 7 | 34 | T |
| 15 | 78 | 64 | 50 | 49 | 44 | 36 | 83 | 54 | 25 | 30.13 | 29.94 | 29.83 | 10 | 10 | 10 | 26 | 8 | 33 | 0.00 |
| 16 | 73 | 56 | 39 | 44 | 37 | 32 | 76 | 51 | 25 | 30.23 | 30.05 | 29.96 | 10 | 10 | 7 | 23 | 8 | 28 | 0.07 |
| 17 | 78 | 64 | 50 | 43 | 35 | 28 | 82 | 41 | 8 | 30.05 | 29.97 | 29.87 | 10 | 10 | 10 | 15 | 11 | 17 | 0.00 |
| 18 | 88 | 70 | 52 | 33 | 28 | 22 | 38 | 26 | 13 | 30.07 | 29.88 | 29.82 | 10 | 10 | 10 | 18 | 9 | 23 | 0.00 |
| 19 | 90 | 75 | 60 | 36 | 29 | 23 | 34 | 22 | 9 | 30.16 | 29.94 | 29.88 | 10 | 10 | 10 | 25 | 12 | 31 | 0.00 |
| 20 | 90 | 75 | 60 | 34 | 29 | 24 | 36 | 23 | 9 | 29.97 | 29.89 | 29.83 | 10 | 10 | 10 | 22 | 6 | 26 | 0.00 |
| 21 | 84 | 71 | 57 | 44 | 36 | 29 | 55 | 35 | 14 | 29.86 | 29.82 | 29.79 | 10 | 10 | 10 | 28 | 10 | 32 | 0.00 |
| 22 | 76 | 63 | 49 | 54 | 50 | 43 | 100 | 73 | 46 | 30.08 | 29.89 | 29.71 | 10 | 7 | 0 | 18 | 9 | 22 | 0.00 |
| 23 | 88 | 71 | 53 | 53 | 39 | 21 | 89 | 50 | 10 | 29.76 | 29.61 | 29.45 | 10 | 9 | 6 | 37 | 16 | 48 | 0.00 |
| 24 | 71 | 55 | 38 | 38 | 28 | 20 | 85 | 50 | 15 | 30.16 | 29.91 | 29.72 | 10 | 10 | 10 | 28 | 11 | 34 | 0.00 |
| 25 | 68 | 54 | 39 | 32 | 30 | 27 | 70 | 47 | 24 | 30.38 | 30.30 | 30.19 | 10 | 10 | 10 | 22 | 8 | 28 | 0.00 |
| 26 | 76 | 59 | 42 | 32 | 29 | 28 | 62 | 40 | 18 | 30.32 | 30.23 | 30.15 | 10 | 10 | 8 | 14 | 7 | 17 | 0.00 |
| 27 | 83 | 65 | 46 | 33 | 27 | 20 | 58 | 34 | 10 | 30.13 | 30.04 | 29.94 | 10 | 10 | 10 | 13 | 7 | 16 | 0.00 |
| 28 | 82 | 66 | 49 | 36 | 30 | 26 | 42 | 28 | 14 | 30.18 | 30.12 | 30.02 | 10 | 10 | 10 | 16 | 10 | 25 | 0.00 |
| 29 | 87 | 67 | 47 | 40 | 36 | 31 | 56 | 35 | 13 | 30.22 | 30.12 | 29.98 | 10 | 10 | 10 | 23 | 9 | 29 | 0.00 |
| 30 | 74 | 63 | 52 | 47 | 42 | 38 | 62 | 48 | 33 | 30.08 | 30.02 | 29.97 | 10 | 10 | 10 | 21 | 10 | 24 | 0.00 |

The National Weather Service has an online calculator that can be used to determine wet bulb temperature using ambient air temperature, relative humidity, and barometric pressure, shown in Figure A 2 below.[14]

[14] The calculator is available at www.weather.gov/epz/wxcalc_rh

Figure A 2. National Weather Service Wet Bulb Calculator.

# Dewpoint and Wet-bulb from Relative Humidity

Weather.gov > El Paso, TX > Dewpoint and Wet-bulb from Relative Humidity

Current Hazards Current Conditions Radar Forecasts Rivers and Lakes Climate and Past Weather

## Relative Humidity

**by Tim Brice and Todd Hall**

| Enter a temperature, relative humidity and actual station pressure | | | |
|---|---|---|---|
| Temperature: | wet-bulb | unit | dewpoint |
| 66.3 (•) Fahrenheit ( ) Celsius ( ) Kelvin | 54.41 | Fahrenheit | 44.46 |
| RH: | 12.45 | Celsius | 6.92 |
| 45.2 % | 285.6 | Kelvin | 280.07 |
| Enter your actual station pressure (not the altimeter setting): | | | |
| 29.9 (•) in of mercury ( ) mm of mercury ( ) millibars (hPA) | | | |
| Convert | Clear Values | | |

# Water Auditing BMP Outline

## Objective of a Water Audit

- Brief statement on goals and objectives

## Water Use Data

- Explanation of the type of water data to collect ahead of the audit

## Building Information

- List of key information to collect at the building level (operation hours, floor plan, etc…)

## Equipment Information

- List of the key information to collect on each piece of equipment and useful information on how to collect the data

## Occupancy Information

- List the information that should be gathered on the building occupants

## Water Balance

- Basic method on how to develop a water balance based on information collected in the audit
- Explanation of the importance of a water balance to drive water efficiency measures

## Water Efficiency Opportunity Assessment

- Information on how to use the results of the audit to assess water efficiency opportunities