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New testing standards for irrigation controllers

Smart Water Application Technologies, a collaborative effort between the irrigation industry and water providers have developed a number of testing protocols for irrigation products that improve irrigation efficiency and potentially save water. Reduced water use generally would also be a reduction in energy used for pumping and pressurizing water. The Irrigation Association/SWAT has been working with the American Society of Agricultural and Biological Engineers in the development of a standards for testing of irrigation controllers. For weather-based controllers, the current testing protocol used by SWAT and referenced in the USEPA testing specification for controllers is the bases for the standard. After a number of year's and testing of numerous irrigation controllers, the standard is a little more rigorous, especially in determining how the controller handles rainfall events. Some other changes include defined landscapes with different soil types but shallower root zones so that irrigation would need to take place more often. Thus the controller would need to make more irrigation management decisions. The standard has not been completed yet, because of the recommendation to beta test the standard by a laboratory to verify that it can be executed correctly. The IA is moving forward by contracting to test three irrigation controllers that have been labeled by WaterSense to see how well they perform against a the proposed modified testing protocol that should be updated. The X627 standard is attached for reference. ASABE also is working on a standard for soil moisture sensors that will work with existing irrigation controllers. currently being beta-tested with two labs to verify that the described procedures will work and are repeatable.

Additional submitted attachment is included below.

DRAFT, to become BSR/ASABE S627 MonYEAR Weather-based Landscape Irrigation Control Systems

1.0 Purpose and Scope

1.1 This protocol was developed to test an irrigation controller's ability to respond to weather conditions found within the typical landscape. Sometimes called "smart control systems" or "smart controllers," these are controllers or devices that respond to environmental conditions by estimating or measuring depletion of available plant soil moisture in order to operate an irrigation system, replenishing water as needed while minimizing excess water use. A properly programmed smart controller requires initial site specific set-up and will make irrigation schedule adjustments, including run times and/or required cycles throughout the irrigation season without human intervention. The protocol will measure the ability of the controllers to provide adequate and efficient irrigation while minimizing potential run-off.

1.2 The objective of this protocol is to evaluate how well technology has integrated scientific data into a practical system that meets the agronomic needs of the turfgrass and landscape plants. This evaluation concept requires the use of accepted formulas for calculating crop evapotranspiration (ET_c). Versions of this type of controller could include one or more of the following:

- Controllers that utilize on-site weather sensors to determine irrigation needs
- Controllers that receive weather data from an off-site source
- Control technology that is added on to existing time based controllers that interfaces with either the controller program or electrical output to zone valves
- Controllers that utilize historical ET_c data characteristic of the site, in conjunction with other inputs.

1.2.1 This evaluation shall be accomplished by defining a virtual landscape and connecting an irrigation controller to a datalogger that emulates irrigation control valves. Any weather sensors will then be subjected to actual, real-time climate conditions. The output of the irrigation controller will be evaluated to determine the ability of the landscape irrigation control system to adequately and efficiently manage water applied to the landscape. The individual irrigation zones within the virtual landscape represent a range of landscape conditions. As a standard from which to judge the control system's performance, a detailed moisture balance calculation shall be made for each zone. Irrigation adequacy is determined by the total accumulated deficit of irrigation over the test period. The accumulated surplus of irrigation over the test period is a measure of excess.

1.3 It is recognized that controlling the irrigation of turf and landscape is a combination of scientific theory and subjective judgments. The attempt in developing this protocol is to use only generally recognized theory and to avoid judgments involving the art of irrigation. The protocol then recognizes that only the theory of irrigation is controllable by the skill of the controller manufacturer.

1.4 A control system meeting this standard may include additional features not covered in this document.

1.5 This protocol is not intended for testing computerized central control systems often used in parks, golf courses or agricultural settings, etc.

1.6 This standard is a testing document; numbers given in this standard are used for illustrative purposes only, and may not reflect the conditions at any specific location.

2.0 Normative References

The ASCE standardized reference evapotranspiration equation. Reston, VA:American Society of Civil Engineers. Jan. 2005.

ASAE EP505, Measurement and Reporting Practices for Automatic Agricultural Weather Stations.

3.0 Definitions

3.1 Allowable Depletion (AD). That part of available water capacity stored in the plant root zone and managed for use by plants. This value integrates the effects of rooting depth (RZ), available water capacity (AWC), and management allowable depletion (MAD).

3.2 Allowable Surface Accumulation (ASA). Initial depth of irrigation water that can be applied before surface runoff occurs, typically by application rates that exceed soil intake rates (IR). This water is restrained from running off by the combined effects of surface detention, presence of the crop canopy, thatch layer, or accumulated vegetative waste/debris/mulch on the soil surface.

3.3 Application Efficiency (E). Ratio of net irrigation (I_N) to gross irrigation (I_G) typically expressed as a percentage, where net irrigation has been reduced to reflect losses associated with pattern non-uniformities, over-spray, and surface runoff. *NOTES: The units of net and gross irrigation are identical. Using a constant application efficiency for each zone is a recognized simplification for purposes of this standard. Distribution uniformity is not equivalent to application efficiency.*

3.4 Application Rate (AR). The amount (depth or volume/area) of irrigation water applied per unit of time. Sometimes referred to as precipitation rate.

3.5 Available Water Capacity (AWC). The portion of soil water that can be readily absorbed by plant roots of most crops. It is the amount of water stored in the soil between field capacity (FC) and permanent wilting point (PWP), typically expressed as inch/inch.

3.6 Effective Irrigation (I_E). Number of inches (or mm) of irrigation water infiltrated and stored in the root zone and usable by the plants.

3.7 Effective Rainfall (R_E). Rain infiltrated and stored in the root zone and available for use by the plants. That portion of total measured rainfall (R_G) which becomes available to sustain plant health.

3.8 Evapotranspiration (ET). The combination of water transpired by vegetation and evaporated from soil, water, and plant surfaces.

3.8.1 Reference Evapotranspiration (ET_o). Estimates of evapotranspiration for uniform surface of dense actively growing vegetation similar to clipped cool season grass, with approximate height of 0.12 meter, not short of water, and representative of a large expanse of same or similar vegetation. See: ASCE-EWRI, Ref. 5.2.

3.8.2 Plant Evapotranspiration (ET_p). Moisture used by given plant type as determined by lysimeter studies or calculated by formulas. For purposes of this standard, $ET_L = ET_p$, because the plants in the irrigation zones are homogeneous. This may not be true for all landscapes. The amount of water used by the plants in transpiration and building of plant tissue and that evaporated from adjacent soil or plant foliage.

3.8.3 Landscape Evapotranspiration (ET_L). The moisture used by the given landscape in the irrigation zone. For purposes of this standard, $ET_L = ET_p$, because the plants in each irrigation zone are homogeneous. This may not be true for all landscapes.

3.9 Field Capacity (FC). Amount of water remaining in a soil when the downward water flow due to gravity becomes negligible.

3.10 Gross Irrigation (I_G). Total water applied by the irrigation system.

3.11 Irrigation Adequacy. Ratio of ET_L less deficit (D), over ET_L, expressed as a percentage.

3.11.1 Deficit (D). Amount of water needed to replenish root zone soil moisture depletion enough to avoid undesirable or excessive plant stress, typically when depletions exceed the management allowable depletion (MAD).

3.11.2 Surplus (S). Water applied that exceeds the remaining capacity of the available root zone storage.

3.12 Irrigation Cycle Time. Irrigation cycle time equals runtime (RT) plus soak time (ST).

3.13 Irrigation Zone. Section of an irrigation system served by a single control valve for distribution of water to a defined target area. Zones are typically comprised of similar sprinkler types and plant materials with similar water requirements.

3.14 Landscape Coefficient (K_L). The plant factor (PF) multiplied by microclimate factors to modify reference evapotranspiration (ET_o). For purposes of this standard, turf density and managed stress factor are both assumed equal to 1. The coefficients used in this standard are examples only and should not be hard coded directly into a controller.

3.15 Net Irrigation (I_N). Water applied by the irrigation system adjusted by application efficiency. Typically considered to be the number of inches (or mm) of water that infiltrate into the soil.

3.16 Net Rainfall (R_N). Portion of gross rainfall (R_G) that infiltrates the soil. Principle losses result from surface runoff.

3.17 Permanent Wilting Point (PWP). Soil water content below which plants cannot readily obtain water and permanently wilt. Sometimes called ''permanent wilting percentage''.

3.18 Plant Factor (PF). The fraction of reference evapotranspiration (ET_o) required for acceptable plant appearance. When multiplied by ET_o, the plant factor estimates the depth of water required by plants. This standard implements PF rather than traditional "crop coefficients" (K values) to acknowledge the variability inherent in empirical water use adjustments for landscapes, rather than the implied precision of a coefficient. This provides a convenient method for calculating ET_p when field data is not available. Note: the term "Crop (Turf) Coefficient" is sometimes used, but is not exactly equivalent.

3.19 Rainfall Efficiency. Ratio of the rainfall infiltrated and stored in the root zone and available for use by the plants (R_E) over the gross rainfall (R_G), typically expressed as a percentage.

3.20 Runoff. The portion of precipitation or irrigation that flows over the soil surface and does not soak into the soil.

3.20.1 Direct Runoff (RO). Water applied that exceeds the soil infiltration rate and does not accumulate. For irrigation, this occurs when the actual runtime exceeds the maximum allowable runtime or the soak time between irrigation runtimes was insufficient to allow the previous application to infiltrate before the subsequent cycle began. Typically, this is the portion of applied water that flows over the ground surface and out of the irrigated area or zone.

3.20.2 Soak Runoff (SRO). The portion of direct runoff (RO) losses attributable to scheduling multiple irrigation cycles without allowing sufficient soak time between run time (RT) cycles

3.21 Scheduling Efficiency. Ratio of effective irrigation (I_E) to net irrigation (I_N), expressed as a percentage. Scheduling efficiency = $I_E/I_N*100\%$.

3.22 Soak Time (ST). The time required for a given irrigation application to finish infiltrating into the root zone without surface runoff.

3.23 Soil Moisture Balance (MB). A water accounting practice used to determine the amount of remaining water available in the soil after subtracting plant water use (ET_L) and adding effective rainfall (R_E) and effective irrigation (I_E). Maximum soil moisture balance is equal to the allowable depletion (AD) and occurs at field capacity (FC). The MB is the remaining moisture in the root zone that is readily available for use by the plants at the end of the given time period.

4.0 Test Methods

4.1 Sampling. A representative of the testing laboratory shall select a test specimen for each test at random from a sample of at least 3 identical units.

4.2 General. System controllers shall be installed at the test site complete with sensors and/or communication links. The controller shall include instructions that list the settings and specific parts and/or accessories used for this test. Controllers shall be programmed and installed per these instructions. The controller output shall be connected to 6 irrigation zone relays representing the control valves of the virtual yard. A data logger shall be connected to the 6 zone relays. The data logger shall record valve open and closing events. Valve run times (RT) shall be used with given application rate (AR) to provide the gross irrigation application (I_G). This data is used in the soil moisture balance (MB) calculation.

Develop an hourly moisture balance calculation using the actual valve run times taken from the data logger. ET_o, irrigation, and rainfall are determined hourly, but the plant factor (PF) is considered a constant throughout the given day. Calculate the system performance parameters as required to summarize the controller's performance including:

- Gross irrigation (I_G)
- Direct runoff (RO)
- Soak runoff (SRO)
- Effective irrigation (I_E)
- Deficit (D)
- Surplus (S)
- Irrigation adequacy
- Scheduling efficiency
- Rainfall efficiency

4.3 Test for Adequacy, Efficiency and Runoff Potential. Communicate with the controller manufacturer to determine the required setup and setting needed for the controller performance to satisfy the conditions defined in the virtual landscape as given in Table 1. Values in Table 1 for Turf Factor or Plant Factor account for sun exposure. If the controller is capable of adjusting for exposure, it shall be set for full sun.

Table 1: Description of Virtual Irrigation Zones

Item No.	Description	Zone #1	Zone #2	Zone #3	Zone #4	Zone #5	Zone #6
1	Soil Texture	Loam	Silty Clay	Loamy Sand	Sandy Loam	Clay Loam	Clay
	Basic Soil Intake Rate (IR), in./hr	0.35	0.15	0.50	0.40	0.20	0.10
2	Slope, %	6	10	8	12	2	20
	Allowable Surface Accumulation (ASA), in.	0.25	0.16	0.26	0.24	0.23	0.10
3	Vegetation	Fescue	Bermuda	Ground cover	Woody shrubs	Trees	Bermuda
4	Management Allowable Depletion (MAD), %	50	45	40	55	50	45
5	Available Water Capacity (AWC), in./in.[1]	0.17	0.17	0.09	0.13	0.18	0.17
6	Root Zone Depth, in.	8.0	6.1	10.0	12.0	20.0	6.2
7	Allowable Depletion (AD), in.	0.68	0.47	0.36	0.86	1.80	0.47
8	Turf Factor (K_T)	0.56	0.64	N/A	N/A	N/A	0.64
9	Plant Factor (PF)[2]	N/A	N/A	0.55	0.40	0.61	N/A
10	Irrigation System	Pop-Up Spray Heads	Pop-Up Spray Heads	Pop-Up Spray Heads	Pop-Up Spray Heads	Surface Drip	Rotors
11	Application Rate (AR), in./h	1.60	1.60	1.40	1.40	0.20	0.35
12	Estimated Application Efficiency (E), %[3]	55	60	70	75	80	65

(1) Available Water holding capacity varies with changes in soil composition and compaction. These values may not represent actual field conditions.

(2) The PF values used for this testing standard do not match those in ANSI/ASABE S623. The values used here are an example of a case where very specific values for PF are known about the landscape in question.

(3)**This standard is a testing document; numbers given in this standard are used for illustrative purposes only, and may not reflect the conditions or equipment at any specific location.** Note that application efficiency may not be the same as distribution uniformity for a particular system.

Report each run time for each zone as managed by the controller. Use the run times, the specified application rate, and application efficiency to calculate the net irrigation. Calculate a soil moisture balance (MB) with a beginning balance of 50% of the Allowable Depletion (AD). Continue the calculation for the time period meeting the minimum requirements in Section 4.6. Record the accumulated surplus and deficit values during the evaluation period and express as irrigation adequacy and efficiency.

The Maximum Runtime allowable before runoff occurs is calculated from the following formula:

$$RT_{(max)} = 60\ (ASA)/(AR - IR),\ \text{minutes}$$

All time in excess of $RT_{(max)}$ is accumulated, converted to inches of gross water applied and logged as runoff (RO). It also affects system adequacy and efficiency characterizations.

The required cycle time between the starting of consecutive irrigation cycles is calculated by dividing the gross irrigation amount (I_G), by the basic soil intake rate (IR). Soak times less than the required will result in runoff and be accounted for in a lower scheduling efficiency value and system adequacy. Required soak time (ST) will be calculated from actual run time (RT). Irrigation application efficiency is not considered in either $RT_{(max)}$ or ST.

$$ST = (AR/IR - 1)\ RT_{(prev)},\ \text{minutes}$$

Where $RT_{(prev)}$ = the immediately previous run time

4.5 Test Report. The moisture balance by irrigation zones for each manufacturer's controller shall be developed. Total deficit and surplus for each zone shall be calculated. The magnitude of the deficit will suggest an effect on the quality of the vegetation. The magnitude of the surplus will impact the scheduling and overall efficiency. The total accumulated amount of runoff (if any) due to inadequate soak time shall be determined as an addition to potential direct surface runoff (RO).

If $ST_{(actual)} < ST$,
$RO_{(soak)} = (ST - ST_{(actual)})\ AR$

If $ST_{(actual)} >= ST$,
$RO_{(soak)} = 0$

In the calculation of the moisture balance, the protocol credits rainfall before accounting for the irrigation contribution.

The total number of 24-hour periods when an irrigation event cycle occurred compared to the minimum number of watering days as dictated by the soil moisture balance shall be reported. (Total ET_L-Effective Rain)/AD

4.6 Test Duration. In addition to testing with the parameters given in Table 1 of the protocol, performance results are only valid if the controller must make adjustments for varying weather conditions relative to evapotranspiration and rainfall. Therefore actual time undergoing testing may be longer than one month. Valid performance data is then downloaded from the minimum 30 consecutive day period of testing exhibiting a minimum of four rainfall events of at least 0.1 in. each, a minimum of 2.0 in. gross rainfall, and a minimum of 5.0 in. of ET_o. Four zones shall have irrigated at least once. The test shall not end until at least one week after the criteria above has been met.

4.7 Weather Data Source. The testing agency and the controller manufacturer shall mutually agree on an accredited weather data source to be used in the calculations of the evaluation. The weather data source shall be able to provide all data required for the test. The protocol uses weather data available on an hourly or smaller basis. An accredited weather data source shall be one recognized by the United States Weather Bureau or shall meet the requirements of ASAE EP505.

4.7.1 Missing weather data. For the test to be valid there shall be no more than two consecutive days, and no more than three days total out of the test period, missing hourly ET data generated by the weather data source. If ET data is missing, the corresponding hour of the previous day's data shall be used instead. There shall be no missing rainfall data during the test period, but data from a backup rain gauge located at the same site as the reference weather station may be substituted and is not considered missing data.

5.0 Normative Annex

5.1 Moisture Balance and Run-off Potential Calculation Details:

Symbols:	Definition:
ASA	Allowable surface accumulation, in.
D	The accumulated moisture deficit when ET_L depletes available water below the desired level (depletions >MAD and MB<=0).
I_N	Net Irrigation Amount per event, in.
E	Irrigation system application efficiency, % -- for the purposes of this standard
ET_L	Landscape evapotranspiration, in./hr
ET_o	Reference crop evapotranspiration, in./hr
RO	Water applied that exceeds soil intake properties and results in surface runoff, in.
I_G	Gross irrigation water applied, in.
IR	Basic soil intake rate, in./hr
K_L	Landscape coefficient
PF or K_T	Plant factor or turf factor
k_{mc}	Microclimate factor
MB	Hourly calculation of root zone moisture balance, in.

MB_o	Prior moisture balance, in.
AR	Application rate, in./hr
R_G	Gross amount of hourly rainfall measured, in.
R_N	Net amount of hourly rainfall to be used in moisture balance calculation, in.
R_E	Infiltrated rainfall limited to the current capacity of the moisture balance.
Rainfall efficiency	R_E / R_G, %
RT	System runtime per cycle, min.
$RT_{(max)}$	Maximum runtime before run-off will occur
AW	Amount of moisture that can effectively be stored in the root zone and available for plant use, in.
S	Surplus irrigation water applied that exceeds the root zone capacity, in.
ST	Required minimum time between the ending and start of consecutive irrigation cycles, minutes.

5.2 Formulas:

Formulas:	**Comment:**
Note: All values are calculated hourly, and summed for the test period	
$ET_L = K_L(ET_o)$, **in./hr**	Landscape evapotranspiration
$K_L = PF(k_{mc})$ **or** $K_L = K_T(k_{mc})$	Landscape coefficient, for this test only, k_{mc} = 1
$R_N = R_G - RO$, **in.**	This is a recognized simplification for purposes of this standard.
$R_E = R_N$, **in. if** $R_N < AD - MB_o$ $R_E = AD - MB_o$, **in. if** $R_N > AD - MB_o$	Rainfall limited to the current capacity of the soil moisture balance
$MB = (MB_o + R_E + I_E - ET_L)$, **in.** **if** $MB \leq AD$ **(see footnotes re:** I_E **and** R_E**)**	Hourly moisture balance calculation; all terms from the previous hour
$D = Sum\ of\ negative\ MB$, **in.** **if** $AD < MAD$	Definition of Deficit
$S = Sum\ of\ MB - AD$, **in.** **if** $MB > AD$	Definition of Surplus
$ST = \left(\frac{AR}{IR} - 1\right) RT_{(prev)}$, **hr**	Required soak time calculation
$RO_{(soak)} = AR(ST - ST_{(actual)})$, **in.,** **if** $ST_{(actual)} < ST$ $RO_{(soak)} = 0$, **in., if** $ST_{(actual)} \geq ST$	Potential runoff calculation resulting from inadequate soak time.
$RT = \frac{I_G(60)}{AR}$, **min.**	Total runtime calculation per irrigation event.
$RT_{(max)} = 60\left(\frac{ASA}{AR-IR}\right)$, **min.**	Maximum allowable runtime to avoid runoff
$I_G = AR\left(\frac{RT}{60}\right)$, **in.**	Gross irrigation amount calculation
$I_N = (I_G)(E) - RO$, **in.**	Net irrigation calculation
$I_E = I_N - S$, **in.**	Effective irrigation calculation

$Adequacy = \frac{ET_L - D}{ET_L} \times 100\%$ $Excess = \frac{S - ET_L}{ET_L} \times 100\%$ $Irrig. scheduling\ eff. = \frac{I_E}{I_N} \times 100\%$	
* “I” must be corrected for direct and soak runoff. It is also limited to the maximum amount of AD available after allowing for rainfall storage. ** “R_G” is limited to the maximum amount of AD available for rainfall storage.	

6 Annex A (informative) - report example

WBIC Sample Report

Controller: XYZ Controller

Testing dates: 9/1/2014 to 9/30/2014

Testing laboratory: Testing Laboratory

Parameter	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
Vegetation	Fescue	Bermuda	Ground Cover	Woody Shrubs	Trees & Ground Cover	Bermuda
Microclimate	75% shade	Full sun	Full sun	50% shade	Full sun	Full sun
Soil type	Loam	Silty clay	Loamy sand	Sandy Loam	Clay Loam	Clay
Slope, %	6.0	10.0	8.0	12.0	2.0	20.0
Soil intake Rate in./h	0.35	0.15	0.50	0.40	0.20	0.10
Root Zone Storage	0.68	0.47	0.36	0.86	1.80	0.47
Application Rate in./h	1.60	1.60	1.40	1.40	0.20	0.35
Application Efficiency, %	0.55	0.60	0.70	0.75	0.80	0.65
ASA, in.	0.25	0.16	0.26	0.24	0.23	0.10
Maximum run time, min.	12.0	6.6	17.3	14.4	n/a	24.0
ET_o, in.	5.80	5.80	5.80	5.80	5.80	5.80
ET_c, in.	3.25	3.71	3.19	2.32	3.54	3.71
Gross rainfall, in.	4.77	4.77	4.77	4.77	4.77	4.77
Net rainfall, in.	3.82	3.82	3.82	3.82	3.82	3.82
Effective rainfall, in.	2.04	1.78	1.37	1.81	2.77	1.93
Days with irrigation	2	5	6	1	1	6
Gross irrigation, in.	2.35	3.33	2.68	1.05	1.50	2.68
Net irrigation, in.	1.29	2.00	1.88	0.79	1.20	1.74
Direct Runoff, in.	0.00	0.00	0.00	0.03	0.00	0.00

Soak Runoff, in.	0.00	0.00	0.00	0.00	0.00	0.00
Effective irrigation, in.	1.26	2.00	1.80	0.76	1.20	1.74
Deficit, in.	0.00	0.00	0.00	0.00	0.00	0.00
Irrigation Surplus, in.	0.03	0.00	0.07	0.00	0.00	0.00
Irrigation Adequacy, %	100.0	100.0	100.0	100.0	100.0	100.0
Scheduling Efficiency, %	97.5	100.0	96.0	96.0	100.0	100.0
Scheduling Excess, %	2.5	0.0	4.0	4.0	0.0	0.0
Rainfall Efficiency, %	53.6	46.6	35.9	47.4	72.7	50.7
Ending Moisture Balance, in.	0.40	0.30	0.16	0.71	1.34	0.20

7 Annex B - Informative references

The following references may be useful in the application of this standard.

Certified Landscape Irrigation Auditor Training Manual. September, 2013. The Irrigation Association.

Irrigation, 6th Edition. 2011. The Irrigation Association.