Smart Water Application Technologies™ (SWAT)

Turf and Landscape Irrigation Systems Smart Controllers

SOIL MOISTURE SENSOR-BASED CONTROLLERS

Phase 2: Operational Test on a Virtual Landscape

4th Draft Testing Protocol (October 2008)

Developed by

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FOREWORD

The Irrigation Association has established a Smart Water Application Technologies™, or SWAT, committee to oversee the development of product testing protocols. This committee is assisted by a Technical Working Group (TWG) and project leaders. The protocol development process involves a drafting of the document followed by a public review and comments period. If required, the document is redrafted and a second review process is initiated. Ultimately the SWAT committee votes on the acceptability of the last protocol. All protocols will be reviewed for possible revision every three years. The development of this testing protocol represents the first attempt by the Irrigation Association to develop product testing protocols. The actual product testing began in 2004 when the first climatologically based commercial controller was tested using the 5th Draft Testing Protocol dated May 3, 2004. The documents have no known predecessors.

This protocol was developed to test products designed and sold for use with residential and similar scale light commercial and institutional properties. This protocol may not be suitable for testing products used in larger more demanding irrigation systems as used at parks, golf courses, etc.

This testing protocol consists of the following parts under the general title of "Turf and Landscape Irrigation System Smart Controllers":

Climatologically Based Controllers

Additional protocols address the following parts under the general title of "Turf and Landscape Irrigation System Smart Controllers."

Soil Moisture Sensor Based Controllers
- Phase 1: Laboratory Screening Tests
- Phase 2: Operational Test on a Virtual Landscape

INTRODUCTION

This protocol is designed to test the efficacy of a soil moisture sensor-based controller suitable for use with residential and light commercial irrigation systems. Conditions unique to this controller application are as follows:

- The system must function without human intervention. [1]
- The system must provide high levels of irrigation adequacy and scheduling efficiency.
- The system must function over a wide range of field conditions including:
  1. Climate
  2. Plant materials
  3. Topography
  4. Soils
  5. Water quality and quantity
- The system must be adjustable to reflect the homeowner's preferences relative to vegetative quality.

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. The protocol will measure the ability of the controllers to provide adequate and efficient irrigation while minimizing potential run-off. The sensors provide feedback on root zone moisture status to the controller. The controller interprets the feedback and sets irrigation schedules accordingly. Soil moisture sensors are an important component of some sensor-based irrigation system controllers. With a standard time-based system controller, they act to provide closed-loop control feedback. They may also find application by closing the loop or giving feedback to climate-based system controllers. The objective of this protocol is to evaluate how well current commercial technology has integrated the scientific data into a practical system that meets the agronomic needs of the turf and landscape vegetation.

In general there are a least two types of standards. The first is a standard that defines the details of how a performance test is to be conducted and what data will be recorded. This SWAT testing protocol is that type of test. It does not result in a pass or fail evaluation. The second type of standard defines performance limits that must be met to quantify the capabilities of the product. The performance standards in this case are established by related considerations and organizations.

In order to realize the full potential of the smart controller concept the following issues must be addressed:

- The quality of the input data must be verified by a certified professional

[1] The protocol recognizes that the root zone environment can change dramatically as for example, water tables drop and irrigation water becomes more saline. With the current state of the art, soil moisture sensors are not automatically compensated for this root zone environmental change. In this case a periodic manual change in the threshold sensor settings is anticipated.

- The controller must be set up and programmed by individuals familiar with the technology
- The irrigation system must be properly designed and maintained

The Phase 1: Laboratory Screening Tests are estimated to take approximately 6-8 months.

The Phase 2: Operational Test on a Virtual Landscape takes at least one month or longer until the required climatic conditions of 0.40 in. of gross rainfall and a minimum of 2.50 in. of ETo.

Soil moisture sensors, by their nature, operate in a responsive mode. The specifics of the mode are defined by the sensor laboratory results (Phase 1) and site considerations including soil classification, planting materials, and water quality. As a result then for a specific sensor, the operating mode can be different for different zones. In any case, the manufacturer must specify the mode(s) before the Phase 2 test evaluation can be conducted. Representative modes include the following:

a) when the soil moisture sensor reaches a lower threshold value then;
   1) a fixed runtime application is made **or**
   2) a variable runtime application is made with irrigation terminated when an upper threshold setting is reached.
b) Irrigations are scheduled on a time framed basis (e.g. daily) for a given runtime. If the soil moisture sensor shows readings above a wetter threshold value, the irrigation is aborted. If the soil moisture is below the threshold value, the irrigation proceeds for a runtime sufficient to reach at least the threshold value.

While not a part of this protocol, the dynamics of these control concepts need to be anticipated and dealt with. Specifically, the dynamics of the response time required for surface-applied water (rainfall or irrigation) to be reflected in the sensor reading is not scientifically characterized. This probably means, for example, that the soil moisture sensor will not function satisfactorily as an instantly responding rain switch. While an intuitive judgment characterizing their performance on coarse soils and shallow root zones is probably satisfactory, the same judgment on fine soils and deeper root zones would be misleading. This suggests that yesterday's moisture status readings that have reached at least near equilibrium conditions are a better basis for making today's irrigation decisions than to attempt a real time-based program. Because of the fundamental dynamic of root zones, moisture gradients are always present. Perhaps the best temporal judgment is to read the sensor at the same time each day for purposes of scheduling the next day's irrigation events.

Turf and Landscape Irrigation Systems Smart Controllers – Soil Moisture Sensor Based Controllers

Phase 2: Operational Test on a Virtual Landscape

1.0 Introduction

This protocol provides a procedure for characterizing the efficacy of irrigation system controllers that utilize soil moisture sensors as a basis for scheduling irrigations. This evaluation concept requires the use of accepted formulas for calculating crop evapotranspiration (ETc). CIMIS Weather Station data will be used to provide the moisture balance calculation required for this evaluation.

This evaluation also makes use of the results of the "Phase 1: Laboratory Screening Tests." The manufacturer is required to provide the controller and/or controller interface module AND a data conversion device that will be unique to each manufacturer that accepts moisture data from the testing facility computer and converts the same to a format readable by the manufacturer's controller. The data conversion device is based upon their principles of operation and also scales the computer generated moisture readings into the irrigation controller/controller interface in accordance with the measured sensor properties determined in Phase 1.

The protocol will measure the ability of the controllers to provide adequate and efficient irrigation while minimizing potential runoff. Allowance is made for the variability in soil properties and the inherent problems of trying to characterize them with scientific instruments.

The objective of this protocol is to evaluate how well current soil moisture technology integrates into a practical control system that meets the agronomic needs of the turf and landscape plants. This is the first step in an evaluation procedure that must also eventually include other secondary considerations that affect market acceptance.

2.0 Scope

This evaluation will be accomplished by creating a virtual landscape subjected to a representative climate and by evaluating the ability of soil moisture-based controllers to adequately and efficiently irrigate that landscape. The individual zones within the landscape will represent a range of exposures and agronomic conditions. Soil types will be as used in the Phase 1 laboratory evaluation. As a standard from which to judge the controller's performance, a detailed moisture balance calculation will be made for each zone. The total accumulated moisture deficit over time will be a measure of the adequacy. The accumulated surplus of applied water over time will be a measure of system efficiency. Water applied beyond the soil's ability to store it will be characterized as runoff or deep percolation, further degrading the application efficiency. The study will use weather data from a representative CIMIS weather station. The study is not meant to include individualized water management strategies aimed at producing special physiological affects. If the controller maintains root zone moistures at the levels specified, it is assumed that the crop growth and quality will be adequate. The soil moisture-based controller concept has the unique capability to measure actual root zone stresses which in turn affects the quality of vegetative growth. Through a period of system startup threshold adjustment, the operator can then customize the system operation to meet his quality requirements.

The operational concepts also assume that threshold adjustments can be made manually in response to seasonal changes in on-site conditions. These changes could be represented for example by a change in the water quality as aquifers are over-pumped during drought conditions.

The protocol solicits, by zones (see Table 1-A), the mode of operation specified by the manufacturer. The data from Phase 1 allows the protocol to convert the sensor readings provided by the manufacturer to be converted into the equivalent root zone moisture. This value is used to then calculate the runtime. Runtime is calculated by the following formula:

$$R_T = \frac{60(MC_1 - MC_2)\,(RZWD),\ \text{minutes}}{PR_E}$$

Where: MC_1 = upper threshold moisture content as decimal equivalent
MC_2 = measured moisture content as decimal equivalent
RZWD = root zone working depth, in.
PR_E = effective precipitation rate [PR (App. Eff.)], in./h

This runtime is used to calculate the water applied today in response to the previous day's consumptive use. These runtime calculations will be administered by the manufacturer's controller. An electronic link is required between the protocol's computer and the manufacturer's controller. The signal must be electronically readable by the manufacturer's controller as described in 1.0 Introduction.

3.0 Normative References

The Environmental and Water Resource Institute (EWRI) of the American Society of Civil Engineers, study on the standardization of reference Evapotranspiration (ETo) formulas. See http://www.kimberly.uidaho.edu/water/asceewri/

4.0 Terms and Definitions

4.1 Crop (Turf) Coefficient (Kc)

Coefficients as determined for specific crops (e.g. warm and cool season turf grasses) that relate ETo to ETc as follows:

$$ETc = Kc\,(ETo)$$

This provides a convenient method for calculating ETc when direct field data is not available.

4.2 Crop Evapotranspiration (ETc)
Specific crop moisture requirements as determined by lysimeter studies or calculated by formulas.

4.3 Evapotranspiration (ET)
Water transpired by vegetation plus that evaporated from the soil surface.

4.4 Field Capacity
The percentage of water remaining in the soil 2 or 3 days after the soil has been saturated and free drainage has practically ceased. The percentage may be expressed in terms of weight or volume.

4.5 Design Application (DA)
The net irrigation amount determined by taking the gross irrigation times irrigation system application efficiency.

4.6 Allowable Surface Accumulation (ASA)
Free standing water created on top of the soil surface by application rates that exceed soil intake rates that are generally restrained from running off by the combined effects of surface detention and the presence of the crop canopy, thatch layer, or accumulated vegetative waste.

4.7 Landscape Coefficient (K_L)
A functional equivalent of the crop coefficient for turf that integrates the effects of species factor (ks), density factor (kd) and microclimate factor (kmc) for landscapes.

$K_L = (ks)\,(kd)\,(kmc)$
$ETc = K_L\,(ETo)$

4.8 Permanent Wilting Point
The largest content of water in a soil at which plants will wilt and not recover when placed in a humidity chamber

4.9 Reference Evapotranspiration (ETo)
Estimates of crop evapotranspiration as calculated using climatological information and accepted formulas. See: ASCE-EWRI, Ref. 6.2.

4.10 Root Zone Working Water Storage (RZWWS)
A root zone water storage value that integrates the effects of actual root zone depth, soil moisture storage capacity, and allowable moisture depletion

4.11 Root Zone Working Depth (RZWD)
A measure of the effective root zone depth for purposes of calculating soil moisture storage

4.12 Runtime (R_T)

The time that a zone valve is opened to permit an irrigation event

4.13 Precipitation Rate (PR)

The amount of irrigation water applied per unit of time.

4.14 Soak Time

The time required for a given application to infiltrate into the root zone.

4.15 Zones

A portion of the system, which is connected to a common water supply and intended to be managed and operated as an individual unit.

4.16 (Irrigation) Mode

Instructions from the vendor that define the role of the sensor in supporting the controller. This information will be used to set runtimes. This runtime history will be logged and used in the performance analysis.

4.17 Effective Precipitation

The amount of precipitation stored in the root zone after a correction for an arbitrary loss of 20% to runoff and non-uniformity.

5.0 Functional Tests

5.1 General

Soil moisture-based system controllers from individual companies will be installed on-site at the testing agency complete with required sensors and/or communication links. The controller will be wired to six zones as defined in Table 1-A. A data logger will automatically record the runtime signal from the controller to the individual zone "control valves." Combining runtimes with application rate data and estimated efficiencies will provide the net irrigation application. Rainfall effectively stored in the root zone will be accounted for before the irrigation amount is credited. This runtime requirement will be downloaded to the vendor's controller. Evaluation runs will begin at an agreed upon time with all zones at 50% of the RZWWS values given in Table 1-A.

5.2 Sampling

The soil moisture sensors used in Phase 1 testing will be used in the Phase 2 test and will be connected/interfaced to the irrigation controller. The soil moisture sensor manufacturer will specify the make and model of irrigation controller to be used in the Phase 2 test. The testing agency will randomly purchase the irrigation controller from a retailer/distributor. The manufacturer will reimburse the testing agency for the cost of the controller. The unit selected will remain the property of the testing agency. At the manufacturer's option, he can provide a feature set that the controller must have to interrelate with his sensor. The performance summary will identify the controller actually used in the test. The manufacturer will have to make the "or equal" argument to the SWAT committee.

Alternatively, the testing laboratory will select the controller to be tested at random from a sample of at least 10 units supplied by the manufacturer. The testing agency will retain the controller.

5.3 Test for Adequacy, Efficiency and Runoff Potential

Communicate with the soil moisture-based system controller manufacturer the starting time/date of the test run, the source of the real time weather data. The manufacturer will be responsible for the initial programming of the controller according to the descriptions of the virtual landscape and the water conductivity as given in Table 1-A or Table 1-B as needed to correspond with Phase 1 water conductivity levels.

The testing agency will then begin collecting data to establish the adequacy and efficiency of irrigation events as well as runoff potential. The moisture balance calculation is updated minute by minute when irrigation is taking place, otherwise daily as described in 5.1.

Phase 2 Table 1-A: Description of Zones

Item No.	Description	Zone #1	Zone #2	Zone #3	Zone #4	Zone #5	Zone #6
1	Soil Texture [1]	Medium (sandy loam)	Fine (clay)	Coarse (loamy sand)	Medium (sandy loam)	Fine (clay)	Fine (clay)
2	Average Daily Temperature	25°C	25°C	25°C	20°C	25°C	25°C
3	Water Conductivity	2.5 dS/m	5.0 dS/m	2.5 dS/m	0 dS/m	0 dS/m	2.5 dS/m
4	Slope, %	6	10	8	12	2	20
5	Exposure	75% shade	Full sun	Full sun	50% shade	Full sun	Full Sun
6	Root Zone Working Depth (RZWD), in.	7.0	5.0	18.0	18.0	24.0	5.0
7	Root Zone Working Water Storage (RZWWS), in. [2]	.85	.55	.90	2.00	2.25	.55
8	Vegetation	Fescue (tall)	Bermuda	Ground cover	Woody shrubs	Trees & ground cover	Bermuda
9	Crop (Turf) Coefficient (Kc)	See Table 2	See Table 2	N/A	N/A	N/A	See Table 2
10	Landscape Coefficient (K_L) [3]	N/A	N/A	0.55	0.40	0.61	N/A
11	Irrigation System	Pop-up spray heads	Pop-up spray heads	Pop-up spray heads	Pop-up spray heads	Surface drip	Rotors
12	Precipitation Rate (PR), in./h	1.60	1.60	1.40	1.40	0.20	0.35
13	Estimated Application Efficiency, %	55	60	70	75	80	65
14	Gross Area, ft^2 [4]	1,000	1,200	800	500	650	1600

See Table 1-B Footnotes 1-4

Table 1-B: Description of Zones to be used for Sensors Tested under 6th Draft Phase 1

Item No.	Description	Zone #1	Zone #2	Zone #3	Zone #4	Zone #5	Zone #6
1	Soil Texture [1]	Medium (sandy loam)	Fine (clay)	Coarse (loamy sand)	Medium (sandy loam)	Fine (clay)	Fine (clay)
2	Average Daily Temperature	25°C	25°C	25°C	20°C	25°C	25°C
3	**Water Conductivity**	**1.5** dS/m	**3.0** dS/m	**1.5** dS/m	0 dS/m	0 dS/m	**1.5** dS/m
4	Slope, %	6	10	8	12	2	20
5	Exposure	75% shade	full sun	full sun	50% shade	full sun	Full Sun
6	Root Zone Working Depth (RZWD), in.	7.0	5.0	18.0	18.0	24.0	5.0
7	Root Zone Working Water Storage (RZWWS), in. [2]	.85	.55	.90	2.00	2.25	.55
8	Vegetation	Fescue (tall)	Bermuda	Ground cover	Woody shrubs	Trees & ground cover	Bermuda
9	Crop (Turf) Coefficient (Kc)	See Table 2	See Table 2	N/A	N/A	N/A	See Table 2
10	Landscape Coefficient (K_L) [3]	N/A	N/A	0.55	0.40	0.61	N/A
11	Irrigation System	Pop-up spray heads	Pop-up spray heads	Pop-up spray heads	Pop-up spray heads	Surface drip	Rotors
12	Precipitation Rate (PR), in./h	1.60	1.60	1.40	1.40	0.20	0.35
13	Estimated Application Efficiency, %	55	60	70	75	80	65
14	Gross Area, ft^2 [4]	1,000	1,200	800	500	650	1600

Changes are indicated in bold type from Table 1.

Table 1-B Footnotes:

[1] See Table 3 for soil intake rate. Soil textural classes as shown in Phase 1 Table 2 and as used in the laboratory testing.

Table 1-B Footnotes (cont.):

[2] RZWWS workup calculations

Item No.	Description	Zone #1	Zone #2	Zone #3	Zone #4	Zone #5	Zone #6
1	Vegetation	Fescue	Bermuda	Ground cover	Woody shrubs	Trees & ground cover	Bermuda
2	Soil Texture	Loam	Silty clay	Loamy sand	Sandy loam	Clay loam	Clay
3	Allowable Depletion	50	40	50	55	50	35
4	Available Water, in./in.	0.17	0.17	0.09	0.13	0.18	0.17
5	Root Zone Depth, in.	10.0	8.1	20.0	28.0	25.0	9.2
6	Root Zone Working Water Storage, in.	0.85	0.55	0.90	2.00	2.25	0.55

[3] Landscape coefficients work-up from Ref. 5.3

Parameter	Zone 3	Zone 4	Zone 5
ks	0.5	0.5	0.5
kd	1.0	1.0	1.1
kmc	1.1	0.8	1.1
K_L	0.55	0.40	0.61

[4] Area as defined by extent of vegetative planting. Make no allowance for geometrically complex boundaries.

Provide crop (turf) coefficients. See Table 2.

Table 2: Crop (Turf) Coefficients (Kc) [1]

	Full Sun		75% Shade	
Month	**Fescue**	**Bermuda**	**Fescue**	**Bermuda**
January	0.61	0.52	0.41	0.35
February	0.69	0.64	0.46	0.43
March	0.77	0.70	0.52	0.47
April	0.84	0.73	0.56	0.49
May	0.90	0.73	0.60	0.49
June	0.93	0.71	0.62	0.48
July	0.93	0.69	0.62	0.46
August	0.89	0.67	0.60	0.45
September	0.83	0.64	0.56	0.43
October	0.75	0.60	0.50	0.40
November	0.67	0.57	0.45	0.38
December	0.59	0.53	0.40	0.36

[1] As modified from Table A.1 Ref: 8.4

Provide basic soil intake rate and allowable surface accumulation for the soil textural classes and field slopes as shown in Table 3.

Table 3: Basic Soil Intake Rate (IR) and Allowable Surface Accumulation (ASA) as it Relates to Soil Textural Class [1] and Slope

Soil Textural Class	Basic Soil Intake Rate in./h	Allowable Surface Accumulation (ASA) in.			
	(IR)	Slope, 0 to 3%	Slope, 4 to 6%	Slope, 7 to 12%	Slope, ≥ 13%
Clay	0.1	0.2	0.15	0.1	0.1
Silty Clay	0.15	0.23	0.19	0.16	0.13
Clay Loam	0.2	0.26	0.22	0.18	0.15
Loam	0.35	0.3	0.25	0.21	0.17
Sandy Loam	0.4	0.33	0.29	0.24	0.2
Loamy Sand	0.5	0.36	0.3	0.26	0.22
Sand	0.6	0.4	0.35	0.3	0.25

[1] As taken from the IA-CLIA Training Manual Table Pg. 73 (September, 2004)

Access the valve runtime monitors to determine the runtimes per valve as specified by the manufacturer's system. Use the runtimes, the specified precipitation rate, and application efficiency to calculate the net application. Develop a moisture balance calculation assuming the calculation starts with a one-half full root zone. Continue the calculation for a time period long enough to demonstrate the controller's ability to adequately meet a range of climatic conditions. The calculation utilizes the valve runtime as recorded by the data logger. Accumulate surplus and deficit values during the evaluation period and express as system adequacy and efficiency.

The maximum runtime allowable before runoff occurs will be calculated from the following formula:

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

All time in excess of Rt_{max} will be accumulated, converted to inches of water and logged as runoff. It will also affect system adequacy and efficiency characterizations.

The required minimum soak time between the starting of consecutive irrigation cycles will be calculated by dividing the design application (Da) by the basic soil intake rate (IR). Soak times less than the required minimum will result in runoff and be accounted for in a lower scheduling efficiency value and system adequacy. \

5.4 Test Report

The moisture balance by zones for each manufacturer's controller/soil moisture sensing system will be developed. Total deficit and surplus for each zone will be calculated. The magnitude of the deficit will suggest an effect on the quality of the vegetation or adequacy. The magnitude of the surplus will impact the scheduling and overall efficiency. The actual report will be in two sections: first a summary report giving the input and evaluation data and second a day-by-day moisture balance calculation. Summary reports will be posted on www.irrigation.org .

5.5 Test Duration

In addition to testing to the parameters given in Table 1-A or 1-B, performance results are only valid if the controller must make adjustments for varying weather conditions relative to evapotranspiration and rainfall. Valid performance data is from a 30 consecutive day period of testing exhibiting a minimum of 0.40 in. of gross rainfall and a minimum of 2.50 in. of ETo.

6.0 Bibliography

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6.3 University of California, Cooperative Extension leaflet #21493
"Estimating Water Requirements of Landscape Planting – The Landscape Coefficient Method" July, 1991

6.4 Walker, Robert E. and Gary F. Kah
"Landscape Water Management Handbook"
Office of Water Conservation, Department of Water Resources, State of California, Version 3.1 September, 1987

6.5 Certified Landscape Irrigation Auditor Training Manual
The Irrigation Association. September 2004

6.6 Glossary of Irrigation Terms
The Irrigation Association., Version 08/11/2006

7.0 Appendix:

Symbols:	Definition:
ASA	Allowable surface accumulation, in.
D	Deficit crop consumptive use not satisfied by moisture from rainfall or storage, in.
Da	Design application, in.
E	Irrigation system application efficiency, %
ETc	Turf or landscape moisture requirements, in./d
ETo	Reference crop evapotranspiration, in./d
Fw	Free water, water applied that exceeds soil intake properties, in.
I	Gross irrigation water applied, in.
In	Net irrigation water applied since last moisture balance calculations, in.
IR	Basic soil intake rate, in./h
K_L	Landscape coefficient
Kc	Crop (turf) coefficient
k_d	Density factor
k_{mc}	Microclimate factor
k_s	Species factor
MB	Daily calculation of root zone moisture balance, in.
MBo	Beginning daily moisture balance, in.
PR	Precipitation rate, in./h
R	Gross amount of daily rainfall as reported, in.
Rn	Net amount of daily rainfall to be used in moisture balance calculation, in.
Rt	System runtime per cycle, min.
RZWWS	Maximum amount of moisture that can effectively be stored in the root zone, in.
S	Surplus applied irrigation water that exceeds the RZWWS capacity, in.
St	Required minimum time between the start of consecutive irrigation cycles, min.
RZWD	A measure of the effective root zone depth for purposes of calculating soil moisture storage, in.
MC	Soil volumetric water content, %

Formulas:	Comment:
$ETc = Kc (ETo)$, in./d	Turf evapotranspiration
$ETc = K_L (ETo)$, in./d	Landscape evapotranspiration
$K_L = (k_s) (k_d) (k_{mc})$	Landscape coefficient
$R_N = 0.8 (R)$, in.	Allows for an arbitrary loss of 20% of the rainfall to non-uniformity and runoff
$MB = MBo + \frac{I^* (E)}{100} + 0.8 (R^{**}) - ETc$, in.	Daily moisture balance calculation
D = Sum of MB < 0, in.	Definition of deficit
S = Sum of MB > RZWWS, in.	Definition of surplus
$St = \frac{Da (60)}{IR}$, minutes	Minimum soak time calculation
$Fw = \frac{Rt}{60} (PR - IR)$, in.	Free water calculation
$Rt = \frac{Da (60)}{PR}$, min.	Runtime calculation per cycle
$Rt_{max} = 60 (ASA) / (PR - IR)$, min.	Maximum allowable runtime to avoid runoff
$I = (Rt) (PR) / 60$, in.	Gross irrigation amount calculation
$Da = (I) (E)$, in.	Net irrigation amount calculation

* "I" must be corrected for direct and soak runoff. It is also limited to the maximum amount of RZWWS available after allowing for rainfall storage.

** "R" is limited to the maximum amount of RZWWS available for rainfall storage.

