An ET based irrigation system includes a stand alone irrigation controller with a seasonal adjust feature and a stand alone weather station including at least one environmental sensor. The ET based irrigation system further includes a stand alone ET unit operatively connected to the irrigation controller and the weather station. The ET unit includes programming configured to calculate an estimated ET value using a signal from the environmental sensor and to automatically modify a watering schedule of the irrigation controller through the seasonal adjust feature based on the estimated ET value to thereby conserve water while maintaining plant health.
Enhanced ProC main flowchart

Initialization routine

Update time and date routine

Check AC and battery routine

Process UI routine

Check rain sensor routine

Run schedule routine

Update display routine

FIG. 8A
Initialization routine

Reset watchdog timer and check Smartport routine

Initialize hardware

Tester pin low?

Yes

Diagnostic Mode 2

Software reset button pushed or data at EEPROM signature address != signature?

No

Yes

Is data at EEPROM signature address != signature?

No

Yes

Write signature to EEPROM

Initialize hardware

Initialize software

End Initialization routine

FIG. 8B
Reset Watchdog timer and Check Smartport routine

Reset Watchdog timer

Smartport pin low longer than 500ms?

Yes

Smartport pin high?

Yes

Smartport routine

No

Smartport pin high?

Yes

End reset Watchdog timer and check Smartport routine

FIG. 8C
FIG. 8D
(Cont'd)
Check AC and battery routine

Reset watchdog timer and check smartport routine

Turn on display, switch to main system clock, clear supercap flag

Power failure detected flag set?

No

Station running in background?

Yes

Resume watering

No

Power failure flag set?

No

Turn off pump and stations, keep it running in background; set power failure flag

Yes

No battery?

Yes

End check AC and battery routine

No

Turn off display, switch to subsystem clock, set supercap flag, enter idle mode

Switch to main system clock, clear supercap flag, turn on display

FIG. 8E
FIG. 8F
(Cont'd)
FIG. 8G
FIG. 8G
(Cont’d)
Process UI routine 3

No UI action for 15s?

Yes

Controller in diagnostic mode?

No

Put controller in OFF mode

No

2s delay expired?

Yes

Ready to enter OFF mode?

No

Ready to start manual watering?

No

End process UI routine

FIG. 8I
Check rain sensor routine

Reset watchdog timer and check smartport routine

Rain sensor on?

Yes

Controller in water mode?

Yes

Manual station watering?

Yes

End check rain sensor routine

No

Put controller to water mode

No

Controller in water mode?

Yes

Manual program or scheduled watering?

Yes

Rain sensor override?

Yes

Rain sensor activated 3 times?

Yes

Turn off station

No

Suspend watering

Manual program or scheduled watering?

Yes

Manual station watering?

No

Rain sensor override?

No

Rain sensor activated 3 times?

No

Turn on next station

Yes

FIG. 8J
FIG. 8K (Cont'd)

1. Is passed?
   - Yes → End run schedule routine
   - No → Short circuit or delay finished or self testing?
     - No → E
     - Yes → B

2. B → C

3. C → D

4. D → E

5. E
Update display routine

Reset watchdog timer and check smartport routine

0.5s passed or UI action?

Blink cursor

1s passed?

Power failure flag set?

Check if a module added

Check if a module removed

Station watering?

Turn on station

Turn on pump routine

Station running?

Turn off pump and stations

End update display routine

FIG. 8L
Smartport Routine

Wait 15ms

Wait 3μs

Smartport pin low?

Yes

Has checked less than 15ms?

Yes

Wait 3μs

Smartport pin high?

Yes

Checked for 100ms?

Yes

Exit Smartport Routine

No

Smartport pin high?

Yes

Checked for 2.3ms?

Yes

Smartport Routine 2

No

Smartport routine 1

No

Smartport pin high?

No

Checked for 2.3ms?

No

Wait 3μs

No

Smartport pin low?

No

FIG. 8M
Smartport routine

Power failure flag not set and dial at RUN or OFF positions?

Yes

Smartport pin low?

No

Wait 15ms

Wait 3us

Smartport pin high?

No

Smartport pin low?

Yes

Checked for 500ms?

No

Smartport routine 1

Yes

Exit smartport routine

FIG. 8N
Smartport Routine 2

Smartport pin low? Two Wait 3μs

Smartport pin low? Yes Checked for NomS2 l1 Exit Smartport Routine

No

data size = 9 bits

Wait 3μs

Smartport pin low?

Yes

Smartport Routine 3

No

Checked for 0.5ms?

No

Exit smartport routine

FIG. 80
FIG. 8P (Cont'd)
FIG. 8Q
FIG. 8Q
(Cont'd)
Smartport routine 5

Smartport pin low?

No

Yes

Checked for 250ms?

No

Yes

Exit data receiving

Goto beginning of loop

End loop

FIG. 8R
Exit data receiving

Display 'Err'

(From remote and received data == 254) or (Not from remote and received data == 4094)?

Yes

Configuration received?

No

Display 'Done'; save shuttle data to EEPROM

From remote?

Yes

Remote program?

No

Wait 500ms

End smartport routine

Yes

Remote program < maximum programs?

Yes

Start manual program

No

Remote program < maximum stations?

Yes

Start manual station

FIG. 8S
Short circuit interrupt

Turn off station

Wait 23ms

AC pin change state?

Set AC pin changed flag

Checked for 30ms?

AC pin changed flag set?

Set AC interrupt occurred flag

Set power failure flag, set power failure detected flag

End short circuit interrupt

FIG. 8T
AC interrupt

Set AC interrupt occurred flag

End AC interrupt

FIG. 8U
Turn on pump routine

Power failure flag set?

No

Station needs pump?

Yes

Turn on pump

Wait 23ms

Short circuit interrupt pin low?

No

Checked for 23ms?

Yes

Short circuit interrupt pin low flag set?

Yes

Turn off pump, turn off all stations

State = short circuit, set short circuit flag, set pump short circuit flag

Enable short circuit interrupt

End turn on pump routine

FIG. 8W
AC interrupt

AC valid? Yes → Return
No → Power Conserve

FIG. 11A

RTC interrupt

RTC tick update

Return

FIG. 11B

Button debounce interrupt

Debounced button update

Return

FIG. 11C

Power up

Initialization

AC interrupt

AC valid? No → Power Conserve

Power up delay

Clear LCD screen

AM/PM time display mode

50 Hz

AC?

Yes → 24Hr time display mode

No → 50 Hz

Retrieve sensor data (2 wire)

Process debounced button input (UI)

Update RTC

Yes → RTC tick update?

No → Update sensor data

Sensor update?

Yes → Update sensor data

No → FIG. 11D
A solar sensor (160) is connected to a transimpedance amplifier Microchip MCP6001T-I/LT (164). Input conditioning includes a 4 DL4007 diode bridge, 9.1V electrolytic capacitor, zener DL4739, 1000uf electrolytic capacitor (172).

A wired or wireless module communication interface: BST39TA for transmitting, plus resistor divider network for receiving (170) is connected to a microcontroller: Microchip PIC16F684-I/SL (166).

A temperature sensor: Microchip MCP9700T-E/LT (168) is connected to a linear Hall Effect sensor (156) which has a (rain click) interface: Microchip A1395SEHLT-T.

A magnet (154) with a sensor arm (140) is connected to a moisture absorbent stack (136).

More water (154) is connected to Less water (174).

FIG. 13
Flowchart for Power Up Initialization, Sample Sesos

- Minute timer passed?
  - Yes: Sample Sensors for minute, Minute average flag valid
  - No:
    - 8 minute samples taken?
      - Yes: Update 8 minute average, 8 Minute average flag valid
      - No: Hours worth of samples taken?
        - Yes: Update hour average, Hour average flag valid
        - No: Rain Sensor update?
          - Yes: Update rain sensor status flag, transmit status change bits out
          - No:
            - Request from Module to xmit data?
              - Yes: transmit full message
              - No
IRRIGATION SYSTEM WITH ET BASED SEASONAL WATERING ADJUSTMENT

INTEGRATION BY REFERENCE TO ANY PRIORITY APPLICATIONS

[0001] Any and all applications for which a foreign or domestic priority claim is identified in the Application Data Sheet as filed with the present application are hereby incorporated by reference under 37 CFR 1.57.

BACKGROUND OF THE INVENTION

[0002] The present invention relates to residential and commercial irrigation systems, and more particularly to irrigation controllers that use evapotranspiration (ET) data in calculating and executing watering schedules.

[0003] Electronic irrigation controllers have long been used on residential and commercial sites to water turf and landscaping. They typically comprise a plastic housing that encloses circuitry including a processor that executes a watering program. Watering schedules are typically manually entered or selected by a user with pushbutton and/or rotary controls while observing an LCD display. The processor turns a plurality of solenoid actuated valves ON and OFF with solid state switches in accordance with the watering schedules that are carried out by the watering program. The valves deliver water to sprinklers connected by subterranean pipes.

[0004] There is presently a large demand for conventional irrigation controllers that are easy for users to set up in terms of entering and modifying the watering schedules. One example is the ProC® irrigation controller commercially available from Hunter Industries, Inc., the assignee of the subject application. The user simply enters the start times for a selected watering schedule, assigns a station to one or more schedules, and sets each station to run a predetermined number of minutes to meet the irrigation needs of the site. The problem with conventional irrigation controllers is that they are often set up to provide the maximum amount of irrigation required for the hottest and driest season, and then either left that way for the whole year, or in some cases the watering schedules are modified once or twice per year by the user. The result is that large amounts of water are wasted. Water is a precious natural resource and there is an increasing need to conserve the same.

[0005] In one type of prior art irrigation controller the run cycles times for individual stations can be increased or decreased by pushing “more” and “less” watering buttons. Another conventional irrigation controller of the type that is used in the commercial market typically includes a seasonal adjustment feature. This feature is typically a simple global adjustment implemented by the user that adjusts the overall watering as a percentage of the originally scheduled cycle times. It is common for the seasonal adjustment to vary between a range of about ten percent to about one hundred and fifty percent of the scheduled watering. This is the simplest and most common overall watering adjustment that users of irrigation controllers can effectuate. Users can move the amount of adjustment down to ten to thirty percent in the winter, depending on their local requirements. They may run the system at fifty percent during the spring or fall seasons, and then at one hundred percent for the summer. The ability to seasonally adjust up to one hundred and fifty percent of the scheduled watering accommodates the occasional heat wave when turf and landscaping require significantly increased watering. The seasonal adjustment feature does not produce the optimum watering schedules because it does not take into consideration all of the ET factors such as soil type, 15 plant type, slope, temperature, humidity, solar radiation, wind speed, etc. Instead, the seasonal adjustment feature simply adjusts the watering schedules globally to run a longer or shorter period of time based on the existing watering program. When the seasonal adjustment feature is re-set on a regular basis a substantial amount of water is conserved and while still providing adequate irrigation in a variety of weather conditions. The problem is that most users forget about the seasonal adjustment feature and do not re-set it on a regular basis, so a considerable amount of water is still wasted, or turf and landscaping die.

[0006] In the past, irrigation controllers used with turf and landscaping have used ET data to calculate watering schedules based on actual weather conditions. Irrigation controllers that utilize ET data are quite cumbersome to set up and use, and require knowledge of horticulture that is lacking with most end users. The typical ET based irrigation controller requires the user to enter the following types of information: soil type, soil infiltration rates, sprinkler precipitation rate, plant type, slope percentage, root zone depth, and plant maturity. The controller then receives information, either directly or indirectly, from a weather station that monitors weather conditions such as: amount of rainfall, humidity, hours of available sunlight, amount of solar radiation, temperature, and wind speed. The typical ET based irrigation controller then automatically calculates an appropriate watering schedule that may change daily based on the weather conditions and individual plant requirements. These changes typically include the number of minutes each irrigation station operates, the number of times it operates per day (cycles), and the number of days 5 between watering. All of these factors are important in achieving the optimum watering schedules for maximum water conservation while maintaining the health of turf and landscaping.

[0007] While conventional ET based irrigation controllers help to conserve water and maintain plant health over a wide range of weather conditions they are complex and their set up is intimidating to many users. They typically require a locally mounted weather station having a complement of environmental sensors. Such locally mounted weather stations are complex, expensive and require frequent maintenance. Instead of receiving data from a locally mounted weather station, home owners and property owners can arrange for their ET based irrigation controllers to receive weather data collected by a private company on a daily basis and transmitted to the end user wirelessly, via phone lines, or over an Internet connection. This reduces the user’s up-front costs, and maintenance challenges, but requires an ongoing subscription expense for the life of the ET based irrigation controller. In addition, the user must still have a substantial understanding of horticulture to set up the ET based irrigation controller. For these reasons, most ET based irrigation controllers are set up by irrigation professionals for a fee. These same irrigation professionals must be called back to the property when changes need to be made, because the set up procedures are complex and not intuitive to most users. These challenges are limiting the sale and use of ET based irrigation controllers to a very small minority of irrigation sites. This impairs water conservation efforts that would otherwise occur if ET based irrigation controllers were easier to set up and adjust.
The present invention may take the form of a standalone irrigation controller connected to a stand-alone weather station. Alternatively, the system may take the form of a standalone irrigation controller with a removable ET module that is connectable to a specially configured stand-alone weather station. In yet another embodiment, the system may take the form of a standalone irrigation controller with all the components mounted in a single box-like housing that is connectable to a specially configured stand-alone weather station.

In accordance with one aspect of the present invention, an irrigation system includes a stand-alone irrigation controller with a seasonal adjust feature and a specially configured stand-alone weather station including at least one environmental sensor. The irrigation system further includes a stand-alone unit operatively connected to the irrigation controller and the weather station. The stand-alone unit includes programming configured to calculate a seasonal adjustment value using a signal from the environmental sensor and to automatically modify a watering schedule of the irrigation controller through the seasonal adjust feature based on the calculated seasonal adjustment value to thereby conserve water while maintaining plant health.

In accordance with another aspect of the present invention, an ET based irrigation system includes an interface that enables a user to select and/or enter a watering schedule and a memory for storing the watering schedule. The system further includes at least one sensor for generating a signal representative of an environmental condition. A processor is included in the system that is capable of calculating an estimated ET value based at least in part on the signal from the sensor. The system further includes a program executable by the processor to enable the processor to generate commands for selectively turning a plurality of valves ON and OFF in accordance with the watering schedule. The program includes a seasonal adjust feature that provides the capability for automatically modifying the watering schedule based on the estimated ET value to thereby conserve water while maintaining plant health.

The present invention also provides a unique method of controlling a plurality of valves on an irrigation site using a calculated seasonal adjustment value. The method includes the step of calculating the seasonal adjustment value based on a signal from an environmental sensor. The method further includes the step of automatically modifying a watering schedule based on the calculated seasonal adjustment value using a seasonal adjust algorithm to thereby conserve water while maintaining the health of plants on the irrigation site. Optionally, the method of present invention may further include the step of inputting an overall watering adjustment and automatically modifying the watering schedule through the seasonal adjust algorithm based on an estimated ET value as increased or decreased by the inputted overall watering adjustment.

The present invention also provides a weather station for use with an irrigation controller. The weather station includes a housing that supports a rain sensor, a solar radiation sensor and a temperature sensor. A micro-controller is also supported by the housing and is connected to the sensors. A communications interface permits communications between the micro-controller and an irrigation controller. Firmware is executable by the micro-controller for periodically sampling the output of the sensors and providing representative sensor data to the irrigation controller.

**SUMMARY**

**BRIEF DESCRIPTION OF THE DRAWINGS**

**DETAILED DESCRIPTION**


The present invention addresses the hesitancy or inability of users to learn the horticultural factors required to set up a conventional ET based irrigation controller. The irrigation system of the present invention has a familiar manner of entering, selecting and modifying its watering schedules, and either built-in or add-on capability to automatically modify its watering schedules based on ET data in order to conserve water and effectively irrigate vegetation throughout the year in weather conditions vary. The user friendly irrigation system of the present invention is capable of achieving, for example, eighty-five percent of the maximum amount of water that can theoretically be conserved on a given irrigation site, but is still able to be used by most non-professionals. Therefore, a large percentage of users of the irrigation system of the present invention will have a much more beneficial environmental impact than a near perfect solution provided by complex prior art ET based irrigation controllers that might at best be adopted a small percentage of users. Even within the small percentage of users that adopt the full ET device, many of them may not be set up correctly because of the complexities of ET, and may therefore operate inefficiently.

Referring to FIG. 1, in accordance with an embodiment of the present invention, an irrigation system 10 comprises a stand alone irrigation controller 12 connected via cable 14 to a stand alone ET unit 16 that is in turn connected via cable 18 to a stand alone weather station 20. The controller 12 and ET unit 16 would typically be mounted in a garage or other protected location, although they can have a waterproof construction that allows them to be mounted out of doors. The weather station 20 is typically mounted on an exterior wall, gutter, post or fence near the garage. The cables 14 and 18 typically include copper wires so that power can be supplied to the ET 16 unit and the weather station 20 from the irrigation controller 12. Data and commands are sent on other copper wires in the cables. Fiber optic cables can also be utilized for sending data and commands. The controller 12, ET unit 16 and weather station 20 may exchange data and commands via wireless communication links 22 and 24. A transformer 25 that plugs into a standard household 110 volt AC duplex outlet supplies twenty-four volt AC power to the stand alone irrigation controller 12. In its preferred form, the irrigation system 10 employs a hard wired communication link 14 between the stand alone irrigation controller 12 and the stand alone ET unit 16 that are normally mounted adjacent one another, such as on a garage wall, and a wireless communication link 24 between the stand alone ET unit 16 and the stand alone weather station 20.

Referring to FIG. 2, the stand alone irrigation controller 12 may be the Pro-C modular irrigation controller commercially available from Hunter Industries, Inc. The irrigation controller 12 includes a wall-mountable plastic housing in the form of a generally box-shaped front door 26 hinged along one vertical edge to a generally box-shaped back panel 28 (FIG. 3). A generally rectangular face pack 30 (FIG. 2) is removably mounted over the back panel 28 and is normally concealed by the front door 26 when not being accessed for programming. The face pack 30 has an interface in the form of a plurality of manually actuable controls including a rotary knob switch 31 and push button switches 32a-32g in conjunction with observing numbers, words and/or graphic symbols indicated on a liquid crystal display (LCD) 36. Push buttons 32e and 32d are used to increase or decrease the seasonal adjust value. The watering schedules can be a complicated set of run time and cycle algorithms, or a portion thereof, such as a simple five minute cycle for a single station. Alternatively, existing preprogrammed watering schedules can be selected, such as selected zones every other day. Any or sub-combination of manually actuable input devices such as rotary switches, dials, push buttons, slide switches, rocker switches, toggle switches, membrane switches, track balls, conventional switches, touch screens, etc. may be used to provide an interface that enables a user to select and/or enter a watering schedule. Still another alternative involves uploading watering schedules through the SMART PORT (Trademark) feature of the irrigation controller 12, more details of which are set forth in the aforementioned U.S. Pat. No. 6,088,621.

The face pack 30 (FIG. 2) encloses and supports a printed circuit board (not illustrated) with a processor for executing and implementing a stored watering program. An electrical connection is made between the face pack 30 and the components in the back panel 28 through a detachable ribbon cable including a plurality of conductors 38a-g (FIG. 4). The circuitry inside the face pack can be powered by a battery to allow a person to remove the face pack 30, unplug the ribbon cable, and walk around the lawn, garden area or golf course while entering watering schedules or altering pre-existing watering schedules.

A processor 40 (FIG. 5) is mounted on the printed circuit board inside the face pack 30. A watering program stored in a memory 42 is executable by the processor 40 to enable the processor to generate commands for selectively
turning a plurality of solenoid actuated irrigation valves (not illustrated) ON and OFF in accordance with the selected or entered watering schedule. An example of such an irrigation valve is disclosed in U.S. Pat. No. 5,996,608 granted Dec. 7, 1999 of Richard E. Hunter et al. entitled DIAPHRAGM VALVE WITH FILTER SCREEN AND MOVEABLE WIPER ELEMENT, the entire disclosure of which is hereby incorporated by reference. Said patent is also assigned to Hunter Industries, Inc. Typically the solenoid actuated valves are mounted in subterranean plastic boxes (not illustrated) on the irrigated site.

[0034] The processor 40 communicates with removable modules 44 and 46a-c (FIG. 3) each containing a circuit that includes a plurality of solid state switches, such as triacs. These switches turn twenty-four volt AC current ON and OFF to open and close corresponding solenoid actuated valves via connected to dedicated field valve wires and a common return line to screw terminals 48 on the modules 44 and 46a-c.

[0035] In FIG. 3, the modules 44 and 46a are shown installed in side-by-side fashion in station module receptacles formed in the back panel 28. The module 44 serves as a base module that can turn a master valve ON and OFF in addition to a plurality of separate station valves. Each module includes an outer generally rectangular plastic housing with a slot at its forward end. A small printed circuit board (not illustrated) within the module housing supports the station module circuit that includes conductive traces that lead to the screw terminals 48 and to V-shaped spring-type electrical contacts (not illustrated) that are accessible via the slot in the forward end of the module housing. These V-shaped electrical contacts register with corresponding flat electrical contacts on the underside of a relatively large printed circuit board 49 (FIG. 4) mounted inside the back panel 28 when the module 44 is slid into its corresponding receptacle. The relatively large printed circuit board 49 is referred to as a “back plane.” The base module 44 and station modules 46a-c and the back plane 49 are thus electrically and mechanically connected in releasable fashion through a so-called “card edge” connection scheme when the base module 44 and station modules 46a-c are inserted or plugged into their respective receptacles. Opposing raised projections 52 formed on the locking bar 50 facilitate sliding the locking bar 50 with a thumb. A pointer 54 extends from one of the raised projections 52 and serves as a position indicator that aligns with LOCKED and UNLOCKED indicia (not illustrated) molded into the upper surface of another plastic support structure 56 mounted inside back panel 28.

[0037] The receptacles for the modules such as 44 and 46a-c are partially defined by vertical walls 58 (FIG. 3) formed on the back panel 28. Vertical walls 60 also formed on the back panel 28 to provide support to the modules 44 and 46a-c. An auxiliary terminal strip provides additional screw terminals 62 for connecting remote sensors and accessories. The term “receptacles” should be broadly construed as defined in one or more of the patents and pending applications incorporated by reference above.

[0038] FIGS. 4 and 5 are block diagrams of the electronic portion of the stand alone irrigation controller 12. The electronic components are mounted on printed circuit boards contained within the face pack 30, back panel 28, base module 44 and station modules 46a-c. The processor 40 (FIG. 4) is mounted on the printed circuit board inside the face pack 30 and executes the watering program stored in the memory 42. By way of example, the processor 40 may be a Samsung S3F8289 processor that executes a program stored in the separate memory 42 which can be an industry standard designation Serial EEPROM 93AA64 non-volatile memory device. Alternatively, the processor 40 and memory 42 may be provided in the form of a micro-computer with on-chip memory. The manually actuable controls 31, 32a-32c and 34 and the LCD display 36 of the face pack 30 are connected to the processor 40. The processor 40 sends drive signals through buffer 64 and back plane 49 to the base module 44. By way of example the buffer 64 may be an industry standard designation 74HC125 device. The processor 40 sends data signals to the modules 46a-c through buffer 66. The buffer may be an H-bridge buffer including industry standard 2N3904/3906 discrete bipolar transistors.

[0039] The processor 40 (FIG. 4) controls the base module 44 and the station modules 46a-c in accordance with one or more watering schedules. Serial or multiplexed communication is enabled via the back plane 49 to the base module 44 and to each of the output modules 46a-c. Suitable synchronous serial data and asynchronous serial data station module circuits are disclosed in the aforementioned U.S. Pat. No. 6,721,630. The location of each module in terms of which receptacle it is plugged into is sensed using resistors on the back plane 49 and a comparator 68 (FIG. 5) which may be an industry standard LM393 device. The face pack 30 receives twenty-four volt AC power from the transformer 25 through the back plane 49 and regulates the same via a power supply circuit 70 (FIG. 5). The power supply circuit 70 includes a National Semiconductor LM7906 voltage regulator, a Micropchip Technology MCP101-450 power supervisor, and a Samsung KA431 voltage regulator. A lithium battery 72 such as an industry standard CR2032 battery is included in the power supply circuit 70 and provides backup power to the microcontroller to maintain the internal clock in the event of a power failure. The face pack ribbon cable 38a-g (FIG. 4) that connects the face pack 30 and the back plane 49 can be disconnected, and a nine volt battery (FIG. 5) then supplies power to the face pack 30. This allows a user to remove the face pack 30 from the back panel 28 and enter or modify watering schedules as he or she walks around the irrigation site.

[0040] The modules 44 and 46a-c have contacts 74 (FIG. 4) on the top sides of their outer plastic housings. When the modules are first plugged into their receptacles, only a communication path is established with the processor 40 via the back plane 49. At this time the locking bar 50 (FIG. 3) is in its UNLOCKED position. Thereafter, when the locking bar is slid to its LOCKED position finger-like contacts 76 (FIG. 4) on the underside of the locking bar 50 register with the contacts 74 on the tops of the modules 44 and 46a-c to supply twenty-four volt AC power to the modules that is switched ON and OFF to the valves that are connected to the modules. The finger-like contacts 76 are connected to a common conductor 78 carried by the locking bar 50. When the locking bar 50 is slid to its LOCKED position projections and tabs that extend from the locking bar 50 and the modules are aligned to prevent withdrawal of the modules. See the aforementioned U.S. Pat. No. 7,225,058 for further details.

[0041] FIG. 6 is a block diagram illustrating details of the electronic circuit of the base module 44. The base module
circuit includes transistor drivers 80 and triacs 82 for switching the twenty-four volt AC signal ON and OFF to different solenoid actuators. By way of example, the transistor drivers 80 may be industry standard 2N4403 transistors and the triacs may be ST Microelectronics (Trademark) T410 triacs. The twenty-four volt AC signal is supplied to the triacs 82 via contact 74 and line 83. The twenty-four volt AC signal from each of the triacs 82 is routed through an inductor/MOV network 84 for surge suppression to four field valve lines 86a-d. Each of which can be connected to a corresponding solenoid actuated valve. The valves are each connected to a valve common return line 88. The twenty-four volt AC signal is also supplied to a rectifier/filter circuit 90. The unregulated DC signal from the rectifier/filter circuit 90 is supplied to a National Semiconductor LM7905 voltage regulator 92 which supplies five volt DC power to the face pack 30 via a conductor 38e (FIG. 4) in the ribbon cable.

FIG. 7 is a block diagram illustrating details of the electronic circuit in each of the station modules 46a-c. The station module circuit includes a microcontroller such as the Microchip (Trademark) PIC 12C508 processor 94. The station module circuit further includes triacs 96 for switching the twenty-four volt AC signal ON and OFF to three different solenoid actuators. The twenty-four volt AC signal is supplied to the triacs 96 via contact 74 and line 98. The twenty-four volt AC signal from each of the triacs 94 is routed through an inductor/MOV network 98 including Epcos Inc. S10K5 MOV’s for surge suppression to three field valve lines 100a-c. Each of which can be connected to a corresponding solenoid actuated valve. The valves are each connected to the valve common return line 98. The twenty-four volt AC signal is also supplied to a rectifier/filter circuit 90. The unregulated DC signal from the rectifier/filter circuit 102 is supplied to a National Semiconductor LM7905 voltage regulator 104 which supplies five volt DC power to 30 the microcontroller through a conductor (not illustrated).

FIGS. 8A-8W are detailed flow diagrams illustrating the operation of the stand alone irrigation controller 12 of FIG. 2. Those skilled in the art of designing and programming irrigation controllers for residential and commercial applications will readily understand the logical flow and algorithms that permit the processor 40 to execute the watering program stored in the memory 42. This watering program enables the processor 40 to generate commands for selectively turning the plurality of valves ON and OFF in accordance with the selected or entered watering schedules. The watering program includes a seasonal adjustment feature that provides the capability for automatically modifying the watering schedules to thereby conserve water while maintaining plant health. By actuating one of the push buttons 32c or 32d the user can increase or decrease the run times for all stations by a selected scaling factor, such as ten percent, to account for seasonal variations in temperature and rainfall.

Referring to FIG. 9, the stand alone ET unit 16 includes a rectangular outer plastic housing 106 enclosing a printed circuit board (not illustrated) which supports the electronic circuit of the ET unit 16 that is illustrated in the block diagram of FIG. 10. A microcontroller 108 such as a Microchip PIC18F46590 processor executes firmware programming stored in a memory 110 such as an industry standard 93AA66A EEPROM memory. The microcontroller 108 can receive DC power from a lithium battery 112 such an industry standard CR2032 battery, which allows accurate time keeping in the event of a power failure. Insulating strip 113 (FIG. 9) must be manually pulled out to establish an operative connection of the battery 112. External power for the ET unit 16 is supplied from the transformer 25 (FIG. 1) via the cable 14. The twenty-four volt AC power from the transformer 25 is supplied to a rectifier/filter circuit 114 (FIG. 10) which supplies twenty-four volt DC power to a power regulation circuit 116 which may be an ST Microelectronics L78M24CDT-TR regulator. Power from the power regulation circuit 116 is fed to a microcontroller power regulator 118 which may be a Microchip MCP1702T-25021/CH regulator. Power from the power regulation circuit 116 is also fed to a wired or wireless sensor communications device 120 that may include, by way of example, an industry standard MMBTA92 for the signal transmitter and an industry standard LM393 comparator for the receiver.

The microcontroller 108 (FIG. 10) interfaces with the SmartPort (Trademark) connector of the irrigation controller 12 with a combination interface/optocoupler 122 which may be provided by an industry standard 4N26S device. The microcontroller 108 interfaces with the weather station illustrated in FIG. 12. An LCD display 126 is mounted in the housing 106. Three manually actuable controls in the form of push buttons 128a-c (FIG. 9) are mounted in the housing 106 for enabling the user to make selections when setting up and modifying the operation of the ET unit 16 in conjunction with information indicated on the display 126 which is facilitated by column and row indicia 130 and 132, respectively, affixed to the housing 106 adjacent the horizontal and vertical margins of the display 126. Row indicia 132 include, from top to bottom, AM, PM, 24 hr, START and END which are printed, painted, molded or otherwise applied to the outer plastic housing such as by a sticker. Column indicia 130 are illustrated diagrammatically as A-E in FIG. 9 due to space constraints in the drawing. A-E correspond, respectively, to TIME, TYPE, REGION, NO WATER and WATER +/- with associated icons which are printed, painted, molded or otherwise applied to the outer plastic housing 106 such as by a sticker.

FIGS. 11A-11D are flow diagrams illustrating the operation of the stand alone ET unit 16. A watering schedule typically includes inputted parameters such as start times, run times and days to water. The ET unit 16 can automatically set the seasonal adjustment of the irrigation controller 12 to reduce watering time, or increase watering times, depending on the weather conditions at the time. The ET unit 16 utilizes actual ET data as its basis for making the modifications to the watering schedules implemented by the irrigation controller 12. However, to simplify the system and reduce the costs, some of the ET parameters may be pre-programmed into the ET unit 16 as constants. These constants may be selected from a group of geographical areas to approximately assimilate the local conditions and estimate a maximum ET value. Other climatic factors are monitored on a daily 25 basis and are the variables. The variables may include one or more pieces of environmental data such as temperature, humidity, solar radiation, wind, and rain. In the preferred embodiment of the present invention, the measured variables are temperature and solar radiation. The variables and any constants are used by the processor 108 to calculate an estimated ET value. This estimated ET value is then used by the ET unit 16 to automatically set the seasonal adjustment feature of the irrigation controller 12. The weather station 20 can also include a sensor that indicates a rain event. A rain event does not effect calculation of an estimated ET value. However, it does shut of the
irrigation during, and for a period of time following, the rain event as a further conservation measure.

[0047] The user can modify the run and cycle times for individual stations in the usual manner in the irrigation controller 12. As an example, if one station is watering too much, but all of the other stations are watering the correct amount, the user can easily reduce the run time of that particular station and balance the system out. Then the ET unit 16 continues modifying the watering schedules executed by the irrigation controller 12 on a global basis as a percentage of run time, based on the calculated estimated ET value. Irrigation controllers can be used to control landscape lighting and other non-irrigation devices such as decorative water fountains. The controller 12 may have features in it such that the ET unit 16 only modifies the watering schedules of the irrigation controller 12.

[0048] One of the difficulties with conventional weather-based controllers is attributable to the difficulty of fine-tuning the weather data being received. The environmental sensors may not always be able to be placed in an optimum location on the irrigation site. As an example, a solar radiation sensor may be placed in an area that receives late afternoon shade. This will result in the calculation of an abnormally low estimated ET value. The entire irrigation site may receive too little water and the plant material may become stressed from too little water if the watering schedules are based on an abnormally low estimated ET. If a conventional ET based irrigation controller receives input from such an incorrectly located solar radiation sensor, the user can attempt to compensate by increasing the run times for each zone by modifying precipitation rates to compensate for the error. This is cumbersome and makes it difficult and frustrating for the user to adjust a conventional ET based irrigation controller for optimum watering.

[0049] An advantage of the present invention is the ability to globally modify the watering schedules of the stand alone irrigation controller 12 to compensate for this type of condition. If at any time the user realizes that the property is receiving too little water, the user can simply manually change an overall watering adjustment feature. The overall watering adjustment feature is implemented as a simple plus or minus control via actuation of an assigned pair of the push buttons 128a-c. This changes the reference point of the ET calculation either up or down. After this adjustment is made, the ET adjustment executed by the ET unit 16 references the new setting and then compensates for under watering that would otherwise occur. Likewise, if the overall watering is too much for the irrigation site, the user can simply adjust the overall watering adjustment feature down and create a new lower reference for the automatic ET based adjustments. The overall watering adjustment feature makes it easy for the user to fine-tune the system to the particular requirements of the irrigation site. The overall watering adjustment feature can be indicated by showing “global adjustment,” or “more/less, water +/-,” or similar naming conventions.

[0050] The overall watering adjustment feature of the ET unit 16 directly alters the station run times executed by the irrigation controller 12. This adjustment modifies the estimated maximum expected ET setting, which is a constant that is used in the calculating the seasonal adjust value. When the user makes overall watering adjustments by pressing plus or minus push buttons on the ET unit 16, this directly affects the ET value that is used to reset the seasonal adjustment in the host 15 controller 12. In calculating the estimated ET, the microcontroller 108 in the ET unit 16 uses only select data points as variables (temperature and solar radiation) and uses other data points that may consist of pre-programmed constants, and/or data entered by the user that defines some one or more constants of the site. Estimated ET is calculated using the Penman-Monteith formula, taking into account geographical data for peak estimated summer ET.

[0051] Another feature provided by the ET unit 16 is an automatic shut down feature for irrigation that overrides any scheduled run times. There are several times when this is important. A rain sensor in the weather station 20 can send signals to the ET unit representing the occurrence of a rain event. The ET unit 16 will then signal the irrigation controller 12 to shut down and suspend any watering, regardless of any scheduled irrigation running or not running at the time. As another example, during a freeze or near freeze condition, irrigation may produce ice that can be dangerous to people walking or vehicles diving by. Many cities therefore require that irrigation be automatically turned off in the event of a freeze condition. A temperature sensor in the weather station 20 can detect a freeze or near freeze condition and the ET unit 16 will signal the irrigation controller 12 to shut down, regardless of any scheduled irrigation running or not running at the time.

[0052] The automatic shut down feature of the ET unit 16 is also useful in geographic areas where watering agencies and municipalities impose restrictions that limit the times when irrigation can occur. The user is able to enter a no-water window into the ET unit 16, which consists of the times when irrigation is not allowed to take place. When a no-water window is entered by the user, the ET unit 16 will signal the irrigation controller 12 to shut down, regardless of any scheduled irrigation running or not running at the time. The ET unit 16 will then allow the irrigation controller 12 to return to its normal run mode after the selected no-water window time has elapsed. The irrigation controller 12 may have sensor input terminals, as in the case of the Pro-C irrigation controller, which can be used to shut down all watering on receipt of a shut down command from the ET unit 16.

[0053] FIG. 12A is an enlarged vertical cross-section of an embodiment of the stand alone weather station 20 of the system of FIG. 1. The compact and inexpensive weather station 20 measures solar radiation, ambient air temperature, and detects a rain event. The weather station 20 is a one-piece unit that readily attaches to an exterior side of a building structure, a fence, or a rain gutter. The weather station 20 can be hard wired to the ET unit 16 via cable 18, or the communications between the weather station 20 and the ET unit 16 may take place via wireless communications link 24. The basic construction of the weather station 20 is similar to that disclosed in U.S. Pat. No. 6,570,109 granted May 27, 2003 to Paul A. Klinefelter et al. entitled QUICK SHUT-OFF EXTENDED RANGE HYDROSCOPIC RAIN SENSOR FOR IRRIGATION SYSTEMS, and U.S. Pat. No. 6,977,351 granted Dec. 20, 2005 to Peter J. Woyотовitz entitled MOISTURE ABSORPTIVE RAIN SENSOR WITH SEALED POSITION SENSING ELEMENT FOR IRRIGATION WATERING PROGRAM INTERRUPT, the entire disclosures of both of which are incorporated herein by reference. Both of the aforementioned U.S. patents are assigned to Hunter Industries, Inc.

[0054] The weather station 20 (FIG. 12A) includes an outer injection molded plastic housing 134 that encloses a pair of moisture absorbing members in the form of a larger stack 136
of moisture absorbing hygroscopic discs and a smaller stack 138 of moisture absorbing hygroscopic discs. These discs are typically made of untreated wood fibers pressed together into a material that resembles cardboard in appearance. One suitable commercially available hygroscopic material is Kraft Press Board which is made from cellulose pulp.

[F0055] The stacks 136 and 138 (FIG. 12 A) of hygroscopic discs are supported on a common pivot arm 140 for vertical reciprocal motion relative to a vertical shaft 142 that extends through the arm 140. A coil spring 144 surrounds the shaft 142 and normally pushes the stack 136 upward against stop 146. A torsion spring 147 (FIG. 12 B) associated with the pivot axis of the arm 140 lifts the arm 140 and the stack 138 upward to a fixed stop (not illustrated). When rain water enters the housing 134 (FIG. 12 A) via aperture 150 and funnel 152 the hygroscopic discs of the stacks 136 10 and 138 absorb water and swell, pushing the arm 140 downward. A magnet 154 is mounted on one end of the arm 140. A stationary Hall effect sensor 156 mounted on a vertically mounted printed circuit board 158 generates a signal representative of the position of the magnet 154 that is proportional to the amount of rain water that has entered the weather station 20. The Hall effect sensor 156 may be provided by part number A13955SEHIT-1 manufactured by Allegro. The small stack 138 absorbs water quickly via funnel 148 so that a rain event will be quickly detected. The large stack 136 dries out slowly so that the rain interrupt signal from the weather station 20 will not be terminated too quickly as the hygroscopic discs dry out. A solar radiation sensor 160 is mounted on one end of the printed circuit board 158 and receives solar radiation through a clear plastic dome 162 snap fit over the uppermost part of the housing 134. The solar radiation sensor 160 may be an industry standard PDB-C131 photodiode with low current leakage.

[F0056] FIG. 13 is a block diagram illustrating the electronic circuit of the stand alone weather station 20 that is mounted on the printed circuit board 158. The solar radiation sensor 160 which may comprise a PDB-C131 photodiode that is connected to a Microchip MCP6001-T-I/SL transimpedance amplifier 164 that is in turn connected to a Microchip PIC16F684-I/SL microcontroller 166. A Microchip MCP9700-T-E/T temperature sensor 168 with an A/D interface is also connected to the microcontroller 166. The micro controller 166 also receives the output signal from the Hall effect sensor 156. The microcontroller 166 may comprise a Microchip A13955SEHIT-T Hall effect sensor and interface circuit. The communications interface 170 between the microcontroller 166 and the ET unit 16 may be a hard wire interface, or more preferably, a wireless interface that may comprise a Microchip Technology RF PIC675 transmitter and a Maxim MAX1473 receiver. The transmitter sends signals representative of actual components of ET data across the irrigation site to the ET unit 16. Power for the hard wired weather station 20 is derived from the communications link to the ET unit 16 and is fed to an input conditioner 172 which feeds a Microchip MCP1702T-3002UCB3 power regulator 174. The power regulator 174 supplies three volt DC power to the microcontroller 166. Power for a wireless weather station is supplied by a dedicated battery (not illustrated) installed within the weather station.

[F0057] FIG. 14 is a flow diagram illustrating the operation of the stand alone weather station 20 of FIG. 12. Firmware executed by the micro controller 166 allows the weather station 20 to perform the logical operations illustrated in the flow diagram. These include periodic sampling of the outputs from the solar radiation sensor 162, temperature sensor 168 and Hall effect sensor 156, averaging readings, and responding to requests for sensor data that are periodically transmitted by the ET unit 16.

[F0058] In conclusion, the ET unit 16 of the present invention utilizes the watering program set up procedures that the users are already accustomed to. Start times, station run times, and days-to-water are manually entered into the irrigation controller 12. The user also selects from one of a group of geographical regions in the ET unit 16. The ET unit 16 then automatically takes over setting of the seasonal adjustment feature of the irrigation controller 12 on a regular basis. Instead of a user changing that feature several times per year, the ET unit 16 sets that seasonal adjustment daily depending on current weather conditions gathered on site. Furthermore, the ET unit 16 shuts down any scheduled watering by the irrigation controller 12 in response to a rain event or a freeze event, and then when there is a scheduled no-water window. Cost savings are achieved since only a small number of the weather parameters need to be measured. These variables are then used with preprogrammed constants to calculate an estimated ET value. This approach allows for cost savings since the stand alone weather station 20 need not have a more solar radiation sensor, a temperature sensor and a rain sensor.

[F0059] The present invention also provides a unique method of controlling a plurality of valves on an irrigation site. The method includes the steps of selecting and/or creating a watering schedule, storing the watering schedule and generating a signal representative of an environmental condition on an irrigation site. The method also includes the steps of calculating an estimated ET value based at least in part on the signal and selectively turning a plurality of valves located on the irrigation site ON and OFF in accordance with the watering schedule. Importantly, the method includes the further step of automatically modifying the watering schedule based on the estimated ET value using a seasonal adjust algorithm to thereby conserve water while maintaining the health of plants on the irrigation site. Optionally, the method of present invention may further include the step of inputting an overall watering adjustment and automatically modifying the watering schedule through the seasonal adjust algorithm based on the estimated ET value as increased or decreased by the inputted overall watering adjustment.

[F0060] While an embodiment of an irrigation system comprising a stand alone ET unit connected to a stand alone irrigation controller and linked to a separate stand alone weather station has been described in detail, persons skilled in the art will appreciate that the present invention can be modified in arrangement and detail. The features and functionality described could be provided by combining the irrigation controller and the ET unit into a single integrated unit in which case a single microcontroller would replace the microcontrollers 40 and 108. Alternatively, the ET unit could be packaged in an ET module designed for removable insertion into a receptacle in a stand alone irrigation controller. Therefore, the protection afforded the subject invention should only be limited in accordance with the scope of the following claims.

What is claimed is:

1. An irrigation system comprising:
   a stand alone irrigation controller comprising a first plurality of user inputs that enable a user to enter a watering schedule including a run time and to manually adjust a percentage adjustment value of a percentage adjustment
feature, a computer processor operatively connected to the plurality of user inputs, and a memory connected to the computer processor, wherein programming stored in the memory implements said percentage adjustment feature to change the run time of the watering schedule by the percentage adjustment value;

a stand alone weather station including at least one environmental sensor; and

a stand alone control unit comprising a memory storing programming that calculates an irrigation value using a signal from the at least one environmental sensor and communicates an irrigation adjustment value responsive to the irrigation value to the computer processor of the stand alone irrigation controller to automatically modify said percentage adjustment value.

2. The irrigation system of claim 1 wherein the at least one environmental sensor comprises a solar radiation sensor configured to detect solar radiation and a temperature sensor configured to detect temperature.

3. The irrigation system of claim 2 wherein the irrigation value is calculated based at least in part on the solar radiation, the temperature, and at least one constant.

4. The irrigation system of claim 3 wherein the at least one constant is selected to simulate local environmental conditions of the irrigation site.

5. The irrigation system of claim 1 wherein the stand alone weather station further comprises a rain sensor configured to detect a rain event.

6. The irrigation system of claim 5 wherein the stand alone control unit communicates an automatic irrigation shut down to the computer processor of the stand alone irrigation controller based at least in part on the rain event.

7. The irrigation system of claim 3 wherein the temperature sensor is further configured to detect a freeze condition and the stand alone control unit communicates an automatic irrigation shut down to the computer processor of the stand alone irrigation controller based at least in part on the freeze condition.

8. The irrigation system of claim 1 wherein the irrigation value is calculated based at least in part on the signal from the at least one environmental sensor and a reference point.

9. The irrigation system of claim 8 wherein the reference point comprises a maximum expected irrigation setting calculated based on constants selected to simulate local conditions of an irrigation site.

10. The irrigation system of claim 9 wherein the stand alone control unit further comprises a second plurality of user inputs that enable the user to change the reference point.

11. An irrigation system comprising:

a plurality of user inputs that enable a user to enter a watering schedule including a run time and to manually adjust a percentage adjustment value of a percentage adjustment feature;

a computer processor operatively connected to the plurality of user inputs;

a memory connected to the computer processor to store the watering schedule;

at least one environmental sensor configured to generate a signal representative of an environmental condition, the computer processor configured to calculate an irrigation value based at least in part on the signal from the at least one environmental sensor and determine an irrigation adjustment value responsive to the irrigation value; and

programming stored in the memory to implement said percentage adjustment feature to increase or decrease the run time of the watering schedule by the percentage adjustment value, the programming automatically increasing or decreasing said percentage adjustment value based on the irrigation adjustment value.

12. The irrigation system of claim 11 wherein the signal from the at least one environmental sensor comprises at least one of temperature, humidity, solar radiation, wind, and rain.

13. The irrigation system of claim 12 wherein the irrigation value is calculated based at least in part on the signal from the at least one environmental sensor and one or more constants representative of a geographical region associated with an irrigation site.

14. The irrigation system of claim 11 wherein the percentage adjustment value comprises a scaling factor.

15. The irrigation system of claim 11 wherein the at least one environmental sensor is located at an irrigation site.

16. A method of controlling a plurality of valves on an irrigation site, the method comprising:

accepting inputs from a user that enable the user to enter a watering schedule including a run time, and to manually adjust a percentage adjustment value of a percentage adjustment feature configured to change said watering schedule by said percentage adjustment value;

receiving a signal representative of a current environmental condition on an irrigation site;

determining an irrigation adjustment value based on the signal;

implementing said percentage adjustment feature to increase or decrease the run time of the watering schedule by the percentage adjustment value; and

automatically increasing or decreasing said percentage adjustment value based on the irrigation adjustment value.

17. The method of claim 16 wherein the signal comprises a solar radiation signal from a solar radiation sensor located on the irrigation site and temperature signal from a temperature sensor located on the irrigation site.

18. The method of claim 17 wherein the irrigation adjustment value is further based on one or more constants configured to approximate local environmental conditions of the irrigation site.

19. The method of claim 18 further comprising determining an estimated irrigation value based on the signal and the one or more constants.

20. The method of claim 19 further comprising determining the irrigation adjustment value based at least in part on the estimated irrigation value.

* * * * *