(54) **AUTOMATICALLY ADJUSTING IRRIGATION CONTROLLER**

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(21) Appl. No.: **13/438,805**

(22) Filed: **Apr. 3, 2012**

Related U.S. Application Data

(63) Continuation of application No. 12/857,485, filed on Aug. 16, 2010, now Pat. No. 8,170,721, which is a continuation of application No. 11/750,257, filed on May 17, 2007, now Pat. No. 7,805,221.

Publication Classification

(51) **Int. Cl.**
G05D 7/06 (2006.01)
(52) **U.S. Cl.** **700/284**

(57) **ABSTRACT**
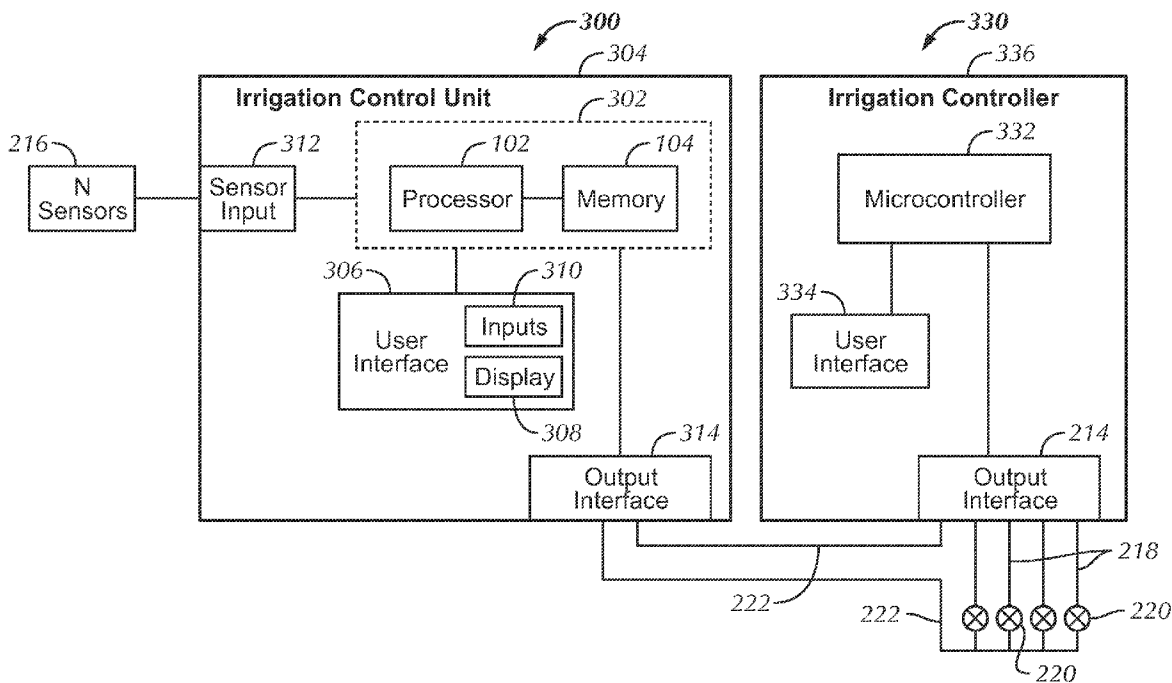
Methods and devices are provided to automatically determine plant water requirements and adjust irrigation in order to make efficient use of water. In one implementation, an irrigation control unit comprises a memory storing historical values of a plurality of variables used at least in part in calculating plant water requirements, and at least one input adapted to receive signals corresponding to current values of one or more of the plurality of variables. The unit also comprises a processor coupled to the at least one input and the memory, the processor adapted to determine the plant water requirements at least in part using, for each of the plurality of variables, a current value in the event the current value is available and at least in part using, for each of the plurality of variables, a stored historical value in the event the current value is not available.

100

Irrigation Control Unit

106	*102*	*104*
Input	Processor	Memory

108

Output

FIG. 1

200

204

Irrigation Control Unit

202

216

| N Sensors |

212

Sensor Input

102

Processor

104

Memory

206

User Interface

210

Inputs

208

Display

214

Output Interface

222

218

220

220

FIG. 2

FIG. 3

_402_

Determining, for Each Variable Needed
to at Least in Part Determine Plant Water
Requirements, whether a
Current Value is Available

_404_

Determining the Plant Water Requirements
at Least in Part Using, for Each of the Plurality
of Variables, a Current Value in the Event it is
Available, and at Least in Part Using, for Each
of the Plurality of Variables, a Historical Value
in the Event the Current Value is Not Available

_406_

Creating a Watering
Schedule Based at Least
in Part on the Plant
Water Requirements

_408_

Adjusting a Programmed
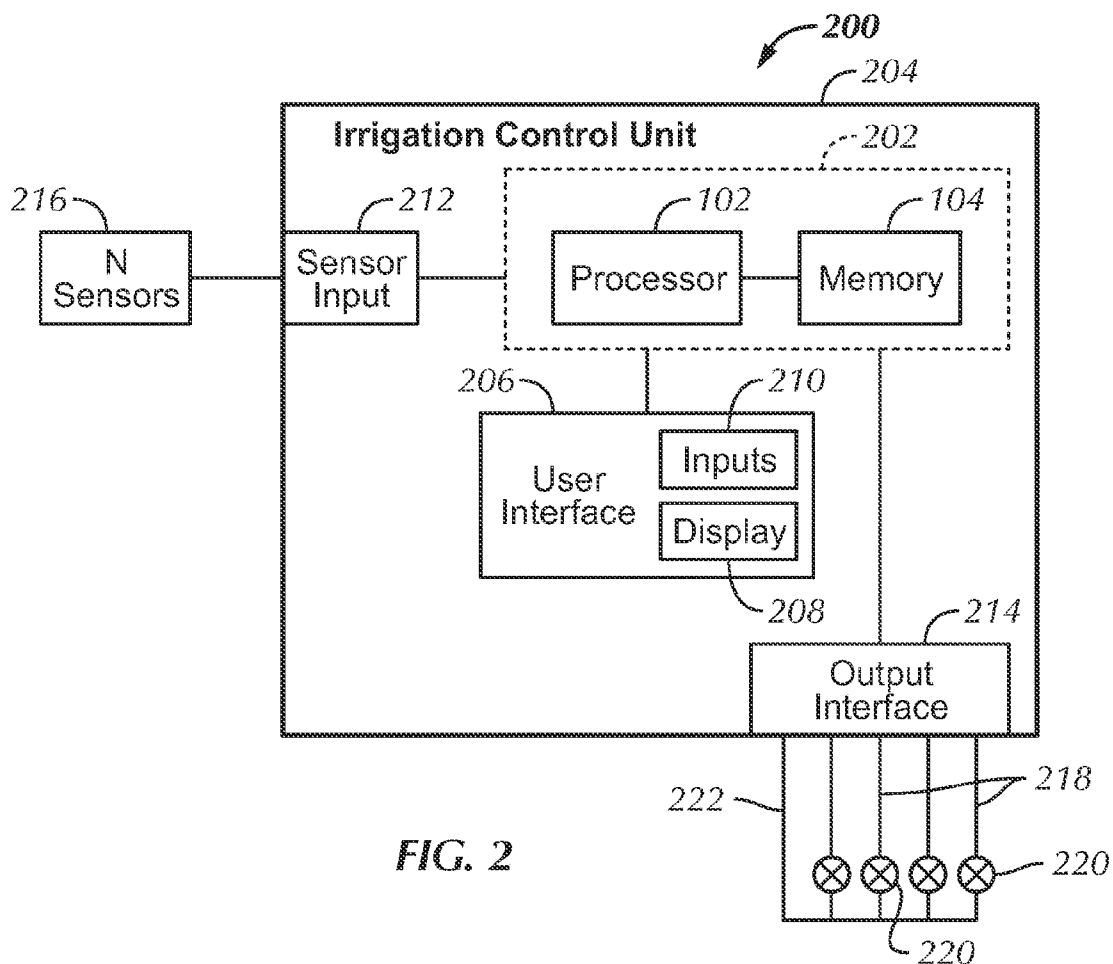Watering Schedule Based at
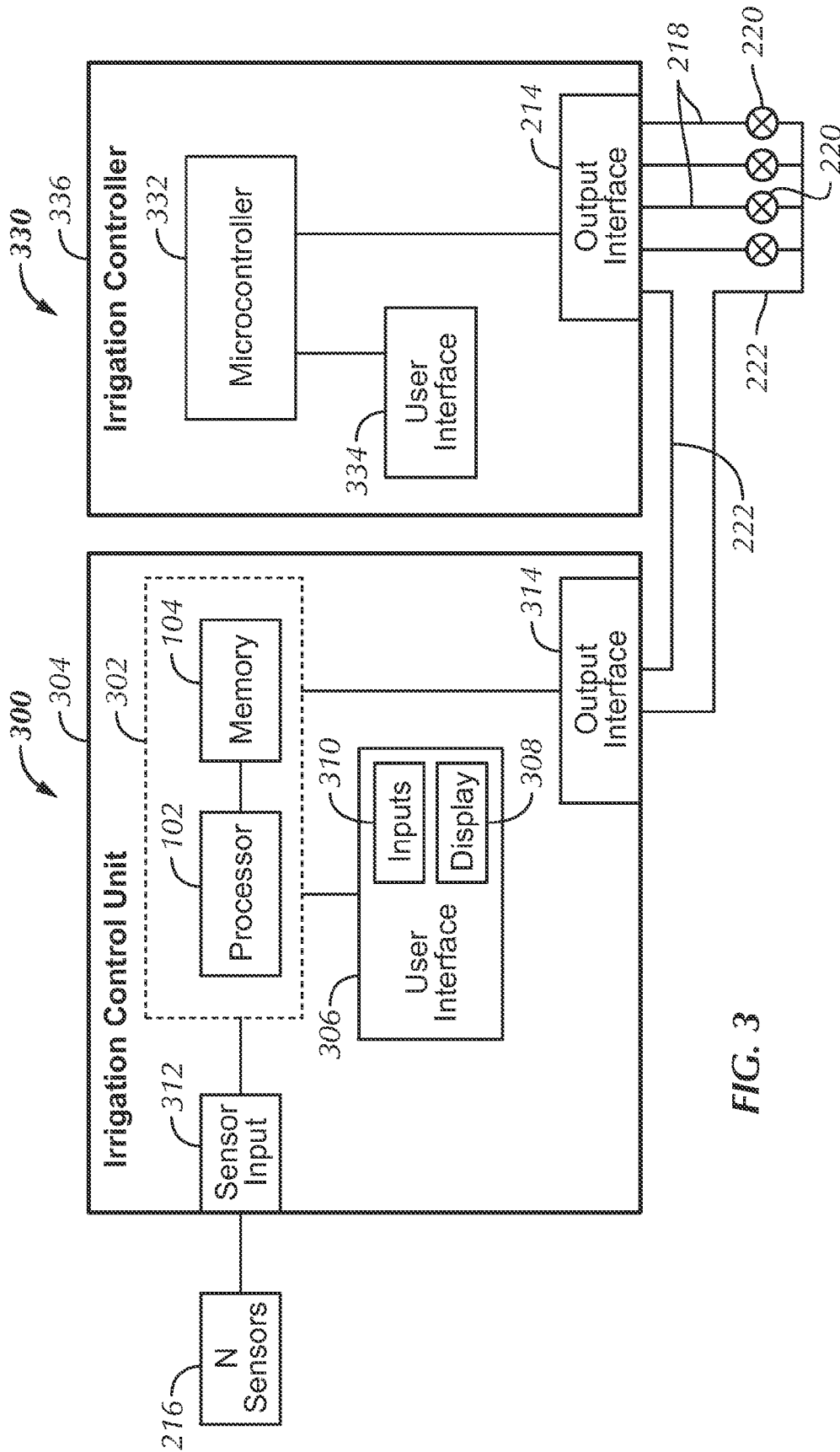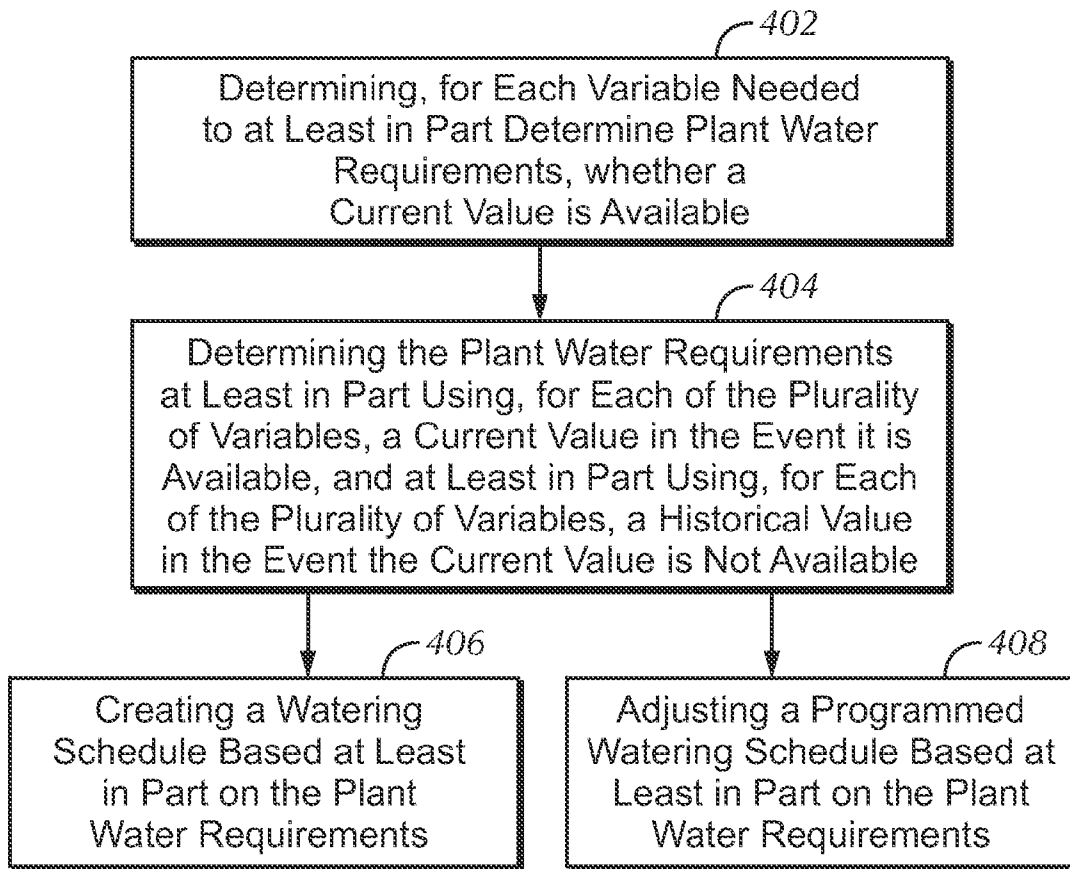Least in Part on the Plant
Water Requirements

FIG. 4

AUTOMATICALLY ADJUSTING IRRIGATION CONTROLLER

[0001] This application is a continuation of U.S. application Ser. No. 12/857,485 filed Aug. 16, 2010, which is a continuation of U.S. application Ser. No. 11/750,257 filed May 17, 2007, for Nickerson, entitled AUTOMATICALLY ADJUSTING IRRIGATION CONTROLLER, now U.S. Pat. No. 7,805,221, both of which are incorporated herein by reference in their entirety.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention
[0003] The present invention relates to irrigation and, in particular, to a system and method for automatically controlling irrigation.
[0004] 2. Discussion of the Related Art
[0005] It is becoming increasingly important that irrigation controllers make efficient use of water. There have been several attempts to adjust the amount of water applied to landscape plant life based on weather conditions. Some attempts are based on mathematical models (known as evapotranspiration or ET) to determine plant watering requirements based on weather conditions. Most industry accepted ET models (such as the Penman-Monteith model) require weather data for temperature, solar radiation, humidity and wind speed. However, the sensors necessary to provide this weather data can be expensive and, as in the case of residential controllers, often cost prohibitive. Others have attempted to create solutions that approximate the results of the ET models by storing historical ET values which are adjusted using currently sensed temperature. However, the results are often questionable since weather is not always repeatable from year to year and factors other than temperature affect ET. Other attempts have tried alternatives to the accepted ET models in an attempt to approximate the accepted ET models. These approaches again have unproven and uncertain results.

SUMMARY OF THE INVENTION

[0006] Several embodiments of the present invention generally relates to an automatically adjusting controller that determines plant water requirements and adjusts irrigation in order to make efficient use of water.
[0007] One embodiment can be characterized as an irrigation control unit comprising a memory storing historical values of a plurality of variables used at least in part in calculating plant water requirements, and at least one input adapted to receive signals corresponding to current values of one or more of the plurality of variables. The unit also comprises a processor coupled to the at least one input and the memory, the processor adapted to determine the plant water requirements at least in part using, for each of the plurality of variables, a current value in the event the current value is available and at least in part using, for each of the plurality of variables, a stored historical value in the event the current value is not available.
[0008] In another embodiment, the invention may be characterized as a method for use in irrigation control, and means for performing the method, the method comprising the steps: determining, for each of a plurality of variables used at least in part to determine plant water requirements, whether a current value is available; and determining the plant water requirements at least in part using, for each of the plurality of variables on a variable by variable basis, the current value in the event the current value is available and at least in part using, for each of the plurality of variables, a stored historical value in the event the current value is not available.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The above and other aspects, features and advantages of the present invention will be more apparent from the following more particular description thereof, presented in conjunction with the following drawings, wherein:
[0010] FIG. 1 is a block diagram illustrating an irrigation control unit in accordance with one embodiment;
[0011] FIG. 2 is a block diagram of one embodiment of the irrigation control unit of FIG. 1;
[0012] FIG. 3 is block diagram of another embodiment of the irrigation control unit of FIG. 1; and
[0013] FIG. 4 is a flow chart illustrating a method of determining plant water requirements in accordance with several embodiments.
[0014] Corresponding reference characters indicate corresponding components throughout the several views of the drawings. Skilled artisans will appreciate that elements in the figures are illustrated for simplicity and clarity and have not necessarily been drawn to scale. For example, the dimensions, sizing, and/or relative placement of some of the elements in the figures may be exaggerated relative to other elements to help to improve understanding of various embodiments of the present invention. Also, common but well-understood elements that are useful or necessary in a commercially feasible embodiment are often not depicted in order to facilitate a less obstructed view of these various embodiments of the present invention. It will also be understood that the terms and expressions used herein have the ordinary meaning as is usually accorded to such terms and expressions by those skilled in the corresponding respective areas of inquiry and study except where other specific meanings have otherwise been set forth herein.

DETAILED DESCRIPTION

[0015] The following description is not to be taken in a limiting sense, but is made merely for the purpose of describing the general principles of the embodiments of the invention. The scope of the embodiments should be determined with reference to the claims. The present embodiments address the problems described in the background while also addressing other additional problems as will be seen from the following detailed description. It is noted that, as used in this specification and the appended claims, the singular forms "a," "an," and "the" include plural referents unless the context clearly dictates otherwise. As used herein, "comprising," "including," "containing," "characterized by," and grammatical equivalents thereof are inclusive or open-ended terms that do not exclude additional, unrecited elements or method steps.
[0016] Referring to FIG. 1, a block diagram is shown illustrating an irrigation control unit 100 in accordance with one embodiment. The irrigation control unit 100 includes a processor 102 coupled to a memory 104, at least one input 106 and an output 108. In some embodiments, the processor 102 and the memory 104 may be referred to collectively as a microcontroller. The at least one input 106 may include one or more of a variety of types of inputs, such as, user entered

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inputs or measured/sensed inputs from one or more sensor devices. The output **108** may be any output to cause or interrupt irrigation or may be a control output to provide messages to cause or interrupt irrigation.

[0017] According to several embodiments, the irrigation control unit **100** comprises a programmable irrigation controller that controls water flow to one or more irrigation stations, where each irrigation station comprises a water flow control device such as a valve or pump (for example, see FIG. **2**). In other embodiments, the irrigation control unit **100** is a control device that is coupled to a programmable irrigation controller (for example, see FIG. **3**). In many embodiments, the irrigation control unit **100** is adapted to make automatically generate and/or adjust watering schedules.

[0018] According to several embodiments, the irrigation control unit **100** is adapted to make efficient use of water by determining or calculating plant water requirements on a periodic basis for plant life to be irrigated. In some embodiments, the memory **104** stores historical values of one or more of the variables needed to calculate the plant water requirements. These historical values are preferably values corresponding to the geographic location of the irrigation control unit **100** and/or an irrigation controller coupled to the irrigation control unit **100**. In some forms, multiple sets of historical values are stored in the memory **104**, each set of historical values corresponding to a different geographic location. In use, the user inputs an indication of a specific geographic location, for example, by inputting a zip code, a map code (e.g., a THOMAS GUIDE code), a latitude and/or a longitude, or other geographic identifier. The processor **102** uses this input to select which set of historical values will be used in determining plant water requirements. In some embodiments, the historical values are pre-stored during manufacture and/or prior to sale of the irrigation control unit. In other embodiments, the historical values are entered by the user via the input **106**, which is helpful in cases where historical values are not known for a given region that the irrigation control unit will be operated.

[0019] In one embodiment, plant water requirements are based on mathematical models of evapotranspiration (ET), such as the industry accepted Penman-Monteith model. The Penman-Monteith equation can be found in Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements published by Food & Agriculture Organization of the United States (June 2000) and also located at http://www.fao.org on the internet and such as described in U.S. Publication Nos. 2004/0039489 and 2006/0161309 to Moore, all of which are hereby incorporated by reference in their entirety. It should be noted that as used herein, the term evapotranspiration at least refers to the actual evapotranspiration or the potential evapotranspiration determined from any of the methodologies now known or may become known in the future. This model utilizes weather data for temperature, solar radiation, humidity and wind speed to determine the amount of moisture lost by plant life due to evaporation and transpiration, i.e., ET, typically expressed in terms of inches of water. Typical systems include rain gauge sensors that measure an amount of rainfall, which can be used to offset a calculated ET value. Thus, in one embodiment, plant water requirements are determined by calculating an ET value given the temperature, solar radiation, humidity and wind speed, which is then offset by any measured amount of recent rainfall. Given the determined plant water requirements, the irrigation control unit **100** implements or adjusts a watering schedule to provide the amount of water needed by the plant life. As is recognized in the art, this watering approach is based on the needs of the plant life as opposed to a watering schedule set by user (who is often an unsophisticated user, particularly with residential irrigation controllers). It is understood that other models may be used to determine plant water requirements, such as the Penman equation, the Blaney-Criddle equation, the Makkink equation, the Hargreaves equation or other equation that can calculate or approximate an ET value, such as described in U.S. Publication Nos. 2004/0039489 and 2006/0161309 to Moore, and U.S. Pat. No. 6,314,340 to Mecham, all of which are incorporated herein by reference. For the Hargreaves equation, see Hargreaves, George H., "Defining and Using Reference Evapotranspiration", Journal of Irrigation and Drainage Engineering, vol. 120, No. 6, pp. 1132-1139, November/December 1994, and such as described in U.S. Pat. No. 6,314,340 to Mecham, both of which are incorporated herein by reference. Furthermore, one or more of these models include sub-models to calculate or approximate one or more of the variables used in the model. For example, a sub-model may approximate humidity from minimum and maximum temperature, time of year, etc. Thus, it is understood that in some embodiments, one or more of these sub-models are used at least in part to determine the plant water requirements.

[0020] However, by relying solely on pre-stored historical values of the variables needed to determine the plant water requirements, watering needs of plant life are often miscalculated since historical values of these variables are often averaged and not necessarily reflective of current weather conditions. On the other hand, it may be cost prohibitive to obtain current values of all of the variables needed to determine the plant water requirements. Some attempts have been made to approximate ET calculations using unproven models and/or sensing current values of temperature as an approximation of a current calculation of ET. According to several embodiments of the invention, it is recognized that each geographic location to be irrigated potentially has its own unique weather qualities, one or more of which may be relatively consistent with historical values and one or more of which may not be consistent with historical values. For example, an area to be irrigated within a sheltered forest region may not experience sufficient wind variability to warrant the need for wind speed sensor. In another example, a dry desert region may not experience sufficient humidity variability to warrant the need for a humidity sensor. Accordingly, in some embodiments, the irrigation control unit **100** includes the input **106** to receive signals corresponding to current values of one or more of the variables used in determining or calculating plant water requirements. Recognizing that it is not always cost-effective in all implementations of an irrigation controller to include sensors to measure all of the variables needed to determine plant water requirements, a user is provided the flexibility to add one or more sensors to sense current values of one or more variables depending on the budget of a user and the specific weather characteristics of a location or geographic region to be irrigated. Depending on the embodiment, the input **106** receives current values of variables from sensor devices or from user inputs via a user interface, for example.

[0021] The processor **102** determines, for each variable to be used in the plant water requirement determination on a variable by variable basis, whether or not a current value for that variable is available. For example, the processor **102** makes this determination, by: being informed by the sensor/s

corresponding to the variable/s (either directly in signaling or in response to a query from the processor **102**); being informed by the user via user input when the sensor/s corresponding to the variable/s is/are connected to the irrigation control unit; or detecting the presence or connection of the sensor/s corresponding to the variable/s. Then, plant water requirements are determined (e.g., calculated, estimated, etc.) at least in part using, for each variable, a current value in the event it is available instead of a stored historical value, and at least in part using, for each variable, the stored historical value in the event the current value is not available. As a result, in some embodiments, the plant water requirements are determined using a combination of current values for one or more variables and stored historical values for one or more other variables. In some embodiments, this provides an advantage in that watering schedules or adjustments to watering schedules are determined using the known and proven mathematical models but without requiring currently sensed values for all variables used in the calculation. For example, this would eliminate the need to purchase a full weather station capable of sensing current values or the need to receive periodic broadcasts of current values of these variables, which often requires a recurring subscription (e.g., paying for the paging of information to an irrigation controller).

[0022] It is recognized that obtaining current values for all of the variables generally leads to the most accurate results when determining plant water requirements, and that sole reliance on stored historical values may lead to the inaccurate results in some geographic locations. Accordingly, the user can decide for a particular geographic location to be irrigated how many, if any, sensor devices should be used. In some cases, a user may be willing to accept a certain amount of inaccuracy in the calculation of plant water requirements given the cost of one or more sensors. However, the user has the flexibility to pick and choose which sensors will be used to provide current values of weather data for the given location or region and for which variables historical values will suffice. In one example of a residential irrigation controller, the user determines that for that particular location, humidity and wind speed are relatively consistent with historical values, whereas temperature and solar radiation tend to vary with respect to historical values for that location. Accordingly, the user couples a temperature sensor and a solar radiation sensor to the input **106**. The processor **102** determines that current values are available for temperature and solar radiation and uses those current values together with the historical values of wind speed and humidity when determining the plant water requirements. Additionally, the determined plant water requirements may be further adjusted by local offsets, such as crop or soil characteristics, slope or other local conditions.

[0023] Depending on the embodiment, the determined plant water requirements may be used in a variety of ways. In one embodiment, the plant water requirement is used to create a watering schedule for one or more irrigation stations controlling the flow of water to an area to be irrigated. Typically, each irrigation station includes a flow control device, such as a valve or pump, that controls the flow of water therethrough to one or more sprinkler or watering devices. The watering schedule may be as simple as defining a start time for irrigation and a duration for irrigation for each station. In many embodiments, the plant water requirements will determine if irrigation is needed at a particular point in time, and if needed, then for how long irrigation is needed. Plant water require-

ments can be recalculated on a periodic basis as needed, for example hourly, daily, weekly, monthly, etc.

[0024] In another embodiment, the plant water requirement is used to adjust, modify or limit an existing watering schedule. For example, for each station, an existing watering schedule may be programmed to irrigate on defined watering days, at defined start times, and for defined durations. If the calculated plant water requirement indicates that watering is not needed on a particular watering day, the already programmed irrigation schedule will be interrupted on that day. If the calculated plant water requirement indicates that watering is needed on a particular watering day but for more or less than the predefined duration, the already programmed irrigation schedule will be adjusted or interrupted. For example, interruption of a programmed irrigation schedule can occur within the processor **102** (e.g., in the event the processor **102** is part of an irrigation controller) or can occur as a result of an interruption of the common line **222** return in a typical irrigation actuation line (e.g., in the event the processor **102** is part of a control device coupled to an irrigation controller). Several embodiments of the invention are used with time-based preprogrammed irrigation schedules, while several embodiments are used with weather-based and/or ET-based irrigation schedules.

[0025] Generally, while referring to historical and current values of variables used to determine plant water requirements, historical values refer to values corresponding to previous periods of time in terms of weather conditions whereas current values refer to values corresponding to a current period of time in terms of weather conditions. Depending on the embodiment and variability of weather conditions, historical values may be considered a value as early as one date prior to the current time.

[0026] The historical measurements may be stored according to day of the year, month of the year, season of the year, particular time of a particular day of the year, or other periodic reference point. For example, in some embodiments historical temperature data is stored for each day of the year for a variety of locations, such as in each zip code in the United States.

[0027] The at least one input **106** is adapted to receive a variety of types of inputs. For example, in several embodiments at least one input **106** receives signals from one or more sensor devices. For example, N sensors are coupled to the at least one input **106**, where N=0, 1, 2, 3, 4, ... A sensor may output signaling corresponding to a single variable, or maybe a combination sensor that output signaling corresponding to multiple variables. According to several embodiments, sensors may include one or more of a temperature sensor, a solar radiation sensor, a humidity sensor, a wind speed sensor, a rain sensor, etc. Additionally, one or more of the sensor devices may be integrated into or internal to the irrigation control unit **100**. In some embodiments, one or more sensors are external to the irrigation control unit **100** in a location proximate to or local in relation to the location of the irrigation control unit **100**. In some embodiments, one or more sensor devices may be located away from or remote in relationship to the location of the irrigation control unit **100**. According to different embodiments, the at least one input **106** comprises one or more of a wireline input, a fiber-optic input or a wireless input in order to receive signals from sensors via wireline, fiber-optic connection, or wirelessly (e.g., using radio frequency or infrared signaling). In one form, the processor **102** receives the signals from the at least

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one input **106** and determines the number and type of sensor/s coupled to or integral with the irrigation control unit **100**.

[0028] Additionally, the input **106** is adapted to receive user input values that are used as the historical values stored in the memory **104** for future use or to receive user input values that are current values. User input current values may be used where the user determines or knows the current value of a variable and a sensor is not available. For example, the user input includes one or more of a keypad, a touchpad, a touch screen, a mouse, a dial, a switch, a button, a lever or other types of devices used to input information into the irrigation control unit.

[0029] Generally, the memory **104** is any type of storage medium capable of temporarily or permanently storing or buffering information, for example, a built-in hard disk drive, non-volatile flash memory, RAM, ROM, EEPROM, removable/insertable memory or any combination thereof. All or a portion of the memory **104** may be in the form of one or more removable blocks, modules or chips. The memory **104** need not be one physical memory device, but can include one or more separate memory devices. Furthermore, the memory **104** may be separate from or integrated with the processor **102**. The functionality of the processor **102** and the memory **104** may be implemented as one of more of hardware, software or firmware.

[0030] The output **108** may be an output interface to cause irrigation, e.g., an interface for one or more actuation lines to couple to flow control devices (such as valves or pumps). In such case, the output **108** includes controllable switches and drivers to switch AC voltage signals or DC pulse voltage signals to a particular actuation line. DC pulse signals are commonly used with latching solenoids. In other embodiments, the output **108** is an encoder adapted to be coupled to a multi-wire path coupled to multiple decoder devices. In such case, the output **108** switches and modulates an AC or DC signal with data instructing one or more of the decoder devices to start or stop irrigation. In other embodiments, the output **108** is a control message output that outputs signaling to a wireline or wireless transmitter to send control signals to another device, e.g., an irrigation controller executing a watering schedule. In further embodiments, the output **108** is a controllable switch, e.g., that can electrically complete or break a return common line path for irrigation actuation lines of another irrigation controller.

[0031] Referring next to FIG. **2**, a block diagram is shown of one embodiment of the irrigation control unit of FIG. **1**. In this embodiment, an irrigation control unit **200** includes the processor **102**, the memory **104** (which in this embodiment, are collectively as a microcontroller **202**), a user interface **206** including a display **208** and user inputs **210**, a sensor input interface **212** and an output interface **214**, all generally contained within or integrated with a housing **204**. Also illustrated are N number of sensors **216** (where N=0, 1, 2, 3, 4, . . .), one or more actuation lines **218** each coupled to a flow control device **220** (e.g., a valve or pump) and a common line **222**.

[0032] In this embodiment, the irrigation control unit **200** comprises a programmable irrigation controller including functionality in accordance with several embodiments for automatically determining plant water requirements and creating, adjusting or limiting watering schedules. That is, as generally understood, a user interacts with the user interface **206** to input, program or create one or more watering schedules or programs stored in the memory **104** and executed by

the processor **102**. In a typical irrigation controller, the processor **102** outputs signaling to the output interface **214** to cause actuation signals (e.g., AC voltage signals or DC pulse signals) to be applied to one or more of the actuation lines **218**. When an actuation signal is applied to a given actuation line **218**, the corresponding flow control device **220** is actuated (e.g., opened or closed) to allow or stop watering. For example, the output interface **214** includes drivers and switches that selectively switch a 24 volt AC power signal to one or more of the actuation lines **218**. Additionally, the sensor input interface **212** provides a coupling point for one or more sensors **216**, such as the sensors described above. Signaling received at the sensor input interface **212** is sent to the microcontroller **202** for storage and processing. In other embodiments, the output interface **214** may be an encoder output to a multi-wire path (e.g., a two-wire path) including multiple decoder devices.

[0033] The user interface **206** includes user inputs **210** and the display **208**. The user inputs include, for example, one or more of a keypad, a touchpad, a touch screen, a mouse, a dial, a switch, a button, a lever or other types of devices used to input information into the irrigation control unit **200**. The display **208** includes one or more of a display screen, indicator lights (e.g., LEDs), and audible indicators or other types of display devices. The user interface **206** is used to program and operate the irrigation control unit **200**. According to some embodiments, during the initial setup or at a later time, the user inputs a variety of information, including, for example, location of the irrigation control unit **200**, day of the year, soil type, gradient of the landscape, vegetation or plant type that is to be watered, number or type of sensor(s) **216** coupled to the irrigation control unit **200**, start times, watering durations, water windows, non-watering days, or other factors or variables used in creating or adjusting watering schedules. In other embodiments, the number/type of sensors **216** coupled to the irrigation control unit **200** is automatically determined by the irrigation control unit **200**. In some forms, the location of the irrigation control unit **200** location is entered by inputting a zip code, a map code (e.g., a THOMAS GUIDE code) or longitudinal and/or latitudinal coordinate for the location to be irrigated. In several embodiments, the processor uses this location information to select a given set of historical values stored in the memory **104**. Using the date and/or time, the processor **102** determines what portion of the given set of historical values will be used in determining plant water requirements.

[0034] In some embodiments, the user interface **206** is used to enter historical data values for one or more of the variables used to determine the water plant requirements. This historical data may be used to replace or supplement any historical data already stored in the memory. In some embodiments where historical data is unknown for the region of operation during manufacture, the user interface allows the user to enter historical data specific to the region of operation. In some embodiments, no historical data values are pre-stored prior to sale because it is known beforehand that the irrigation control unit will be sold for use in a region with unknown historical data.

[0035] The sensor input **212** receives signals from one or more sensors and forwards this information to the processor **102** and/or the memory **104**. These signals correspond to current values of one or more of the variables used to determine plant water requirements. Depending on the type of sensor, the signals received at the sensor input **212** are elec-

trical signals having a characteristic that relates to a particular value. For example, a signal having a certain voltage level corresponds to a given value for a variable. In another embodiment, the presence of a signal at the sensor input **212** corresponds to a given value. For example, the signal may be a pulse signal, each pulse corresponding to a certain incremental value of a variable. In other embodiments, the signals received at the sensor input **212** are data signals defining one or more values for one or more variables. In each case, the signals received at the sensor input **212** correspond to a current value of a given variable. As described above, the sensor input **212** may receive signals corresponding to values of temperature, solar radiation, humidity, wind speed, an amount of rainfall, soil moisture, or other variables used by irrigation controllers.

[0036] In many embodiments, the processor determines the number and type of sensor/s connected to the sensor input **212** and; thus, knows for which variables current values are available. In one form, the processor detects the presence of a given sensor connected or coupled to the sensor input **212**. For example, the connection of a given sensor causes an electrical impedance at the sensor input to vary which allows the processor **102** to determine how many and what type of sensors are connected. In another form, the processor **102** makes this determination by being informed by the sensor/s. For example, some sensors are capable of providing signaling that indicates the type of sensor to the processor. This signaling may be directly transmitted to the sensor input **212** on connection, transmitted when data and/or signaling is output from the sensor or transmitted in response to a query issued by the processor **102**. In another form, the processor **102** is informed by the user via user input **210** when the sensor/s is/are connected to the irrigation control unit. For example, via user inputs, such as dials, buttons, etc together with displayed menus, the user inputs the type and number of sensors coupled to the sensor input **212**.

[0037] The sensor input **212** is adapted to receive signals from sensors in a variety of ways, e.g., by wireline, fiber optic cable, and wireless communication. One or more of the sensors **216** are local sensors in that they are located at or proximate to the location to be watered, whereas one or more of the sensors **216** are remote sensors in that they are located at a distance from the location to be watered. In some embodiments, the current values are broadcast by wireline and/or wirelessly and received at the sensor input **212**. In some embodiments (not illustrated), one or more sensors **216** are integrated into the housing **204** of the irrigation control unit **204**. In other embodiments, the current values are input by the user, for example, via the user interface **206**. For example, the user simply enters the current value for one or more variables. That is, in the appropriate menu option, the user enters the current values known to the user other than by using a sensor coupled to the irrigation control unit **200**.

[0038] The processor **102** and the memory **104** are similar to that described in FIG. **1**. The processor is generally coupled through one or more electrical connections (e.g., via a bus structure) to the user interface **206**, the output interface **214** and the sensor input **212**. The processor **102** is programmed to periodically determine or calculate plant water requirements based on a plurality of variables. For each variable used to determine the plant water requirements on a variable by variable basis, the processor **102** uses the historical value stored in the memory **104** unless a current value for that variable is available (e.g., as received at the sensor input **212** and/or

stored in the memory **104**). As a result, in some embodiments, the plant water requirements are determined at least using a combination of current values for one or more variables and stored historical values for one or more other variables. In this way, the user is given flexibility to decide for a particular region to be watered how many, if any, sensors should be used. That is, the user has the flexibility to pick and choose which sensors **216** will be used to provide current values of weather data for the region and for which variables historical values will suffice. Advantageously, watering schedules or adjustments to watering schedules are determined using known and proven mathematical models for plant water requirements, but without requiring currently sensed values for all variables used in the calculation. In one embodiment, the plant water requirements are based on mathematical models of ET. Most industry accepted models, such as the Penman-Monteith model require values for temperature, solar radiation, humidity and wind speed. Additionally, the calculated values of ET are offset in some embodiments by measurements of rainfall or other local factors.

[0039] As described above, the plant water requirements are used in different ways by the processor **102** in different embodiments. For example, in one implementation, the irrigation control unit **200** is programmed with a watering schedule including, for example, watering days, start times, frequency of watering per watering day, and durations for one or more flow control devices **220**. However, it is understood that a watering schedule may not require all of these variables to be programmed. For example, one or more of these variables may be set or not otherwise programmable. In one embodiment, a user inputs a start time and a watering duration to define a watering schedule for each station. This schedule is stored in the memory **104** and executed by the processor **102**. However, the sensor input **212** receives currently sensed values for one or more variables. These variables are stored in the memory **104**. On a periodic basis, the processor **102** determines what are the actual plant water requirements and makes adjustments to or overrides the programmed watering schedules. For example, the processor **102** determines the plant water requirements using at least in part the stored historical values for each variable unless a current value for the given historical value is available. If it is determined that the plants to be watered require less water than would be provided by the programmed watering schedule, the processor **102** adjusts the watering schedule. For example, the processor **102** shortens watering durations or eliminates one or more watering events altogether. This adjustment or overriding can be performed in the execution of the schedule or may be performed by simply disallowing or disabling the output interface **214** from outputting control signals on the actuation lines **218**. For example, the processor **102** may generate a signal that opens a switch that breaks the common line **222** that acts as a return line for the actuation lines **218**. Once broken, the electrical path for the signaling on the actuation lines is interrupted and the watering schedule is overridden or interrupted. If it is determined that the plants to be watered require more water than would be provided by the programmed watering schedule, the processor **102** adjusts the watering schedule. For example, the processor **102** extends watering durations or adds one or more watering events.

[0040] In other embodiments, the user does not program a watering schedule as is normally understood. Instead, the user simply programs the processor **102** (via the user interface **206**) to define certain watering days and start times, without

defining watering durations or frequency of watering per day. On a periodic basis (e.g., every day, every other day, every week, etc.), the processor **102** determines plant water requirements based on the historical/current values of the variables as described above. In several embodiments, the plant water requirements are expressed in terms of a unit of measurement water (e.g., inches or centimeters) that is lost by plant life and should be replenished through irrigation. Once the plant water requirements are determined, the processor **102** determines whether or not the plant life requires watering at all. If it is determined that watering is required, the processor **102** then determines what duration of watering will provide the determined plant water requirement. For example, if the plant water requirements (e.g., a calculated ET value adjusted by any rainfall received since the last calculation) result in that 0.25 inches of water should be applied by the irrigation control unit **200**, then the processor **102** determines (given flow control device **220** flow rate, water pressure, etc.) the duration of irrigation. The processor **102** then outputs signaling to the output interface **214** at the start time to cause irrigation for the specified duration. In this embodiment, the watering schedule is calculated based on the plant water requirements, as opposed to adjusting or limiting a programmed watering schedule. In either case, these embodiments allow for the efficient use of water.

[0041] Referring next to FIG. **3**, a block diagram is shown of another embodiment of the irrigation control unit of FIG. **1**. In this embodiment, an irrigation control unit **300** is separate from (non-integrated with) a traditional programmable irrigation controller **330**. The irrigation control unit **300** includes the processor **102**, the memory **104** (which in this embodiment, are collectively as a microcontroller **302**), a user interface **306** including a display **308** and user inputs **310**, a sensor input **312** and an output interface **314**, all generally contained within or integrated with a housing **304**. The irrigation controller **330** includes a microcontroller **332**, a user interface **334**, and an output interface **214** all generally contained within or integrated with a housing **336**. Also illustrated are N number of sensors **216** (where N=0, 1, 2, 3, 4, . . .) coupled to the sensor input **312**, one or more actuation lines **218** each coupling the output interface **214** to a flow control device **220** (e.g., a valve or pump) and a common line **222**.

[0042] In this embodiment, the irrigation control unit **300** is an add-on or accessory control device that is coupled to the traditional programmable irrigation controller **330**. As is well known, the controller **330** irrigates based on programmed time-based watering schedules. For example, a user interacts with the user interface **334** to set or program one or more watering schedules stored in and executed by the microcontroller **332**. In one example, for each flow control device **220** (often referred to as a zone or station), the microcontroller **332** is programmed to water on certain days and at certain times and for certain durations as set by the user. As described above, when the schedule indicates that watering should occur for a given flow control device **220**, the output interface **214** switches an activation signal on a given actuation line **218** to the given flow control device **220** causing water to flow therethrough to one or more sprinkler devices.

[0043] According to several embodiments, the irrigation control unit **300** periodically and automatically adjusts, interrupts and/or overrides watering schedules implemented in the irrigation controller **330**. Depending on the embodiment, the irrigation control unit **300** can operate together with the irrigation controller **330** or operate completely independent of

the irrigation controller **330** without its knowledge. In the illustrated embodiment, the irrigation control unit **300** is coupled to the irrigation controller **300** in that the common line **222** serially connects through the output interface **314** back to the output interface **214**. In other words, the output interface **314** is in an electrical position on the common line **222** in between each flow control device **220** and the output interface **214**. In other embodiments, the irrigation control unit **300** is directly coupled to the irrigation controller **330** at an input (not illustrated) of the irrigation controller **330**. For example, the output interface **314** may be coupled by wireline or wirelessly to an interface (not shown) of the irrigation controller **330** which is coupled to the microcontroller **332**. In these embodiments, the irrigation control unit **300** can communicate directly with the microcontroller **332**. One advantage of the illustrated embodiment is that the irrigation control unit **300** can be coupled to any conventional programmable irrigation controller **330** independent of the functionality and make/model of the irrigation controller **330**.

[0044] The user interacts with the user interface **306** to program the irrigation control unit **300**. In preferred form, the irrigation control unit **300** should be programmed with the same or similar watering schedules as contained in irrigation controller **330**. In one embodiment, the user inputs the same preprogrammed watering schedules that are stored in the irrigation controller **330** into the irrigation control unit **300**. In another embodiment, the user inputs only the watering days and start times programmed into the irrigation controller **330**. In further embodiments, the output interface **314** monitors the common line **222** over time and learns watering schedules programmed in the irrigation controller **330**. For example, the output interface **314** is able to detect when an activation signal is applied to one of the activation lines **218** by sensing current flow on the common line **222**. The user interface **306** may vary depending on different embodiments of the irrigation control unit **300**. For example, the user interface **306** is similar to the user interface **206**; however, not all embodiments require all components of the user interface **306**.

[0045] Similar to the embodiments described above, the irrigation control unit **300** includes stored historical values of variables in the memory **104** (e.g., either pre-stored during manufacture, prior to sale or entered by the user) used at least in part to determine plant water requirements. Also, the processor **102** determines for each variable needed to determine the plant water requirements, whether a current value is available (e.g., from sensors or other user input). It also receives signals from one or more sensors **216** at the sensor input **312** that correspond to current values of the variables used at least in part to determine plant water requirements. Periodically, the processor **102** determines the plant water requirements such as described above. In different embodiments, the processor **102** uses the determined plant water requirements in different ways. For example in one embodiment, if the processor **102** determines that watering is not needed on a particular watering day, then the processor **102** ensures that watering does not occur on that day. For example, the processor **102** sends a signal to the output interface **314** to prevent irrigation. In one form, the output interface **314** comprises a controlled switch that when opened, electrically breaks the common line **222**, which eliminates an electrical path for any signaling on any of the actuation lines **218**. In another form, the output interface **314** sends a signal to the microcontroller **332** (via an input, not shown) instructing it to not irrigate on that particular day. In the event the microcontroller **302** deter-

mines that watering is needed but for a shorter duration than programmed, the processor **102** sends a signal to the output interface **314** at a specified time after irrigation has begun but before irrigation should be concluded. The output interface **314** then electrically breaks the common line **222** to interrupt irrigation. Alternatively, the processor **102** sends a signal to the microcontroller **332** via the output interface **314** instructing it to irrigate for a shortened duration. In some embodiments, the programmed watering duration is set for the peak watering duration that would be needed (e.g., set for peak summer watering needs); thus, there is no need to irrigate for a longer duration than preprogrammed. These embodiments are preferred when the output interface **314** is coupled to and acts as a switch to interrupt the common line **222**. In other embodiments, in the event the microcontroller **302** determines that watering is needed during a particular period, but for a longer duration than preprogrammed, the processor **102** sends a signal via the output interface **314** to the microcontroller **332** (direct connection not illustrated) to instruct it to temporarily increase the program duration.

[0046] Referring next to FIG. **4**, a flow chart is shown that illustrates a method of determining plant water requirements in accordance with several embodiments. These steps may be performed, for example, by the irrigation control units described herein, such as irrigation control units **100**, **200** and **300**. Generally, in order to make efficient use of water in an irrigation system in accordance for several embodiments, periodically, plant water requirements are determined based at least in part on a number of variables which are used to create and/or modify watering schedules. The plant water requirements are typically based on a mathematical model of the watering needs of plant life based on a number of variables including, but not limited to, temperature, solar radiation, humidity, wind speed, rainfall and soil moisture content. In preferred form, the plant water requirements are based on models for the evapotranspiration (ET), such as provided by the Penman-Monteith model, as described above. Other known models or approximations may be used. Furthermore, a user has selected how many sensors, and what type of sensors, will be used to provide current values of one of more variables. Additionally, historical values for one to more of these variables are pre-stored into a memory of irrigation control unit. The pre-stored values may be average or mean historical values for a given period of time, such as day, week, month, season, etc. In some embodiments, the pre-stored historical data values are stored in the irrigation control unit during manufacturing or otherwise prior to sale. In other embodiments, the pre-stored historical data is stored or loaded into the irrigation control unit at installation, for example downloaded or transferred from an external memory device into the memory of the irrigation control unit (e.g., via a computer or other input connection of the user interface). In other embodiments, the stored historical data is entered by the user, for example via the user interface. Such embodiments would allow the user to enter historical data for locations for which historical data is unavailable during manufacture or installation. In some embodiments, the historical data is pre-stored during manufacture, but can be replaced or supplemented with historical data entered by the user via the user interface.

[0047] Furthermore, other variables may have already been entered by a user. The user inputs may pertain to location, time of the year, soil type, gradient of the landscape, vegetation type, or other factor that may affect water schedules. In preferred form, the location information includes a zip code, a map code or a longitudinal or latitudinal coordinate to define the location that is being watered. In some embodiments, the user inputs the time of the year or some other periodic reference point so the controller can determine the current date (day, week, month), season or time of year. In some embodiments, the plant water requirements discussed below are adjusted by one or more local factors, such as some of the user entered variables.

[0048] Initially, for each variable needed to determine plant water requirements, it is determined whether a current value is available (Step **402**). For example, this may be accomplished by knowing if a sensor providing current values of a variable is connected to the irrigation control unit. As described above, a processor makes this determination, for example, by: being informed by the sensor/s corresponding to the variable/s (either directly in signaling or in response to a query from the processor **102**); being informed by the user via user input when the sensor/s corresponding to the variable/s is/are connected to the irrigation control unit; or detecting the presence or connection of the sensor/s corresponding to the variable/s. Alternatively, a processor (e.g., processor **102**) checks to see if a current value of the variable is stored in a designated location in memory (e.g., memory **104**). In other embodiments, a processor queries a sensor input to determine if a current value for that variable is available or can be readily obtained or measured. In some embodiments, the current value for one or more variables is input by the user (e.g., received directly from the user input or from memory storing the entered current value).

[0049] Next, plant water requirements are determined (e.g., calculated, estimated, etc.) at least in part using, for each of the plurality of variables, a current value in the event it is available and at least in part using, for each of the plurality of variables, a stored historical value in the event the current value is not available (Step **404**). In one form, the current value/s are retrieved from the sensor input or are retrieved from memory (in the event the current value/s from the sensor input are buffered in or temporarily stored in memory). The historical values are retrieved from memory. As described above, and in accordance with several embodiments, historical values for the plurality of variables used to determine plant water requirements are stored in memory (e.g., pre-stored during manufacture or prior to sale or entered by the user). To the extent they are available, current values of those variables are used in place of the stored historical values. As a result, in some embodiments, the plant water requirements are determined at least using a combination of current values for one or more variables and stored historical values for one or more other variables. In some embodiments, multiple sets of historical values are stored in memory, each corresponding to a different geographic location or region (e.g., defined by zip code, map code, latitude and/or longitude, or other geographic identifier). The historical values corresponding to the specific geographic region are used to determine the plant water requirements. Furthermore, the historical values used (e.g., retrieved from memory) are stored values that correspond to the current date, season or time of year. In one example, if the current date is February 1, then the historical values that correspond to February 1 are used, e.g., either historical average values from previous years on this date, during the week of February 1, during the month of February, etc.

[0050] It is noted that in some embodiments, historical values for one or more of the plurality of variables are not stored in memory, for example when it is known that a sensor is available to provide a current value. For example, if a given irrigation control unit is manufactured with an integrated sensor (such as an integrated temperature sensor) or an external temperature sensor is provided with the sale of the unit, historical values of temperature are not required to be stored in the memory of irrigation control unit. In some embodiments, no historical values are pre-stored, but all historical data is entered by the user. As discussed above, a variety of models may be used to determine the plant water requirements. Additionally, other factors or adjustments not pre-stored in memory and not provided by sensors may be used at least in part to determine the plant water requirements. For example, user input variables such as crop characteristics, soil characteristics, slope, etc. may be used depending on the particular model used by the irrigation control unit or any local adjustments made. In preferred form, plant water requirements were determined using the Penman-Monteith model that uses temperature, solar radiation, humidity and wind speed to calculate a net ET value which is then adjusted by an amount of rainfall received since the last determination.

[0051] Again, as described above, the user has flexibility in determining for which variables the user will rely on historical values and for which variables the user will use currently sensed values. The user can make this decision based on the user's location, costs involved and tolerance for error.

[0052] Several embodiments may be used with a variety of models or equations to determine the plant water requirements. For example, several known models used to calculate evapotranspiration (one example of plant water requirements) include the Penman equation, the Penman-Monteith equation, the Blaney-Criddle equation, the Makkink equation and the Hargreaves equation. Furthermore, one or more of these models include sub-models to calculate or approximate one or more of the variables used in the model. For example, a sub-model may approximate humidity from minimum and maximum temperature, time of year, etc. Thus, it is understood that in some embodiments, one or more of these sub-models are used at least in part to determine the plant water requirements.

[0053] Once determined, the plant water requirements are used differently in different embodiments. According to several embodiments, a watering schedule is created based at least in part on the plant water requirements (Step 406). For example, if the plant water requirements are determined to be 0.1 inches of water that should be applied to the plant life, then the duration of watering needed to supply 0.1 inches of water is determined. Then, at a given start time, watering is initiated for the calculated duration. It is understood that the duration may be continuous or may be broken up into separate periods of time (i.e., separate start times). The time between separate start times may be short or long depending on the needs of the system, and may account for the slope of the soil. If it is determined that irrigation is not needed (e.g., the plant water requirements are negative), then watering is not supplied.

[0054] In a typical implementation, a user has preprogrammed a start time and watering days. Periodically (e.g., once per day), the irrigation control unit determines the plant water requirements and, for each watering day, determines if irrigation should occur. If irrigation should occur, the duration is calculated and watering is executed at the given start time for the duration.

[0055] Once the watering schedule is created, the schedule is either executed or transmitted to the device that executes the watering schedule. For example, at the determined start time, signals are generated by a processor to cause an activation signal to be applied to a given actuation line that will open/close a water flow control device (e.g., a latching or non-latching solenoid controlled valve or pump). The activation signal may be an AC voltage signal or DC pulse signal, for example. In some cases, the voltage signal is modulated by an encoder that outputs a signal to a multi-wire path having a plurality of decoder devices coupled thereto. Each decoder device is typically coupled to one or more water flow control devices.

[0056] According to several other embodiments, once the plant water requirements are determined, a programmed watering schedule is adjusted based at least in part on the plant water requirements (Step 408). In these embodiments, a preprogrammed water schedule exists, for example, preprogrammed by a user into an irrigation control unit that determined the plant water requirements (see for example, FIG. 2) or preprogrammed into an irrigation controller coupled to an irrigation control unit determining the plant water requirements (see for example, FIG. 3). In some embodiments, the schedule is adjusted by interrupting or overriding the scheduled watering completely or in part. Alternatively, a control message is generated to shorten the preprogrammed watering duration. This occurs when the plant water requirements are less than would be provided by the watering schedule. In other embodiments, the schedule is adjusted when it is determined that more watering should occur than preprogrammed, for example, by extending the watering duration or adding additional watering events.

[0057] Once the watering schedule is adjusted, the adjusted schedule is either executed or transmitted to the device that executes the watering schedule such as described above. Alternatively, the schedule being executed by another irrigation controller is interrupted at the appropriate time to effect the adjustment. For example, referring to the irrigation control unit 300 of FIG. 3, the processor 102 determines when watering should be interrupted (or even allowed at all), and outputs a signal to the output interface 314 to open or electrically break the common line 222, stopping all irrigation at the flow control devices 220. Alternatively, a signal is transmitted to the irrigation controller 330 executing the water schedule to be adjusted, the signal instructing that the controller should adjust the programmed water schedule.

[0058] While the invention herein disclosed has been described by means of specific embodiments and applications thereof, other modifications, variations, and arrangements of the present invention may be made in accordance with the above teachings other than as specifically described to practice the invention within the spirit and scope defined by the following claims.

What is claimed is:

1. An irrigation control unit comprising:

a memory storing historical values of a plurality of variables used at least in part in calculating plant water requirements;

at least one input adapted to receive signals corresponding to current values of one or more of the plurality of variables;

a processor coupled to the at least one input and the memory, the processor adapted to determine the plant water requirements at least in part using, for each of the plurality of variables on a variable by variable basis, a current value in the event the current value is available and at least in part using, for each of the plurality of variables, a stored historical value in the event the current value is not available.

2. The irrigation control unit of claim **1** wherein the plant water requirements are based on a determination of an evapotranspiration (ET) value.

3. The irrigation control unit of claim **1** wherein the plurality of variables comprises two or more parameters selected from a group consisting of: temperature, solar radiation, humidity, wind speed and an amount of rainfall.

4. The irrigation control unit of claim **1** further comprising at least one sensor coupled to the at least one input.

5. The irrigation control unit of claim **4** wherein the at least one sensor comprises a sensor selected from a group consisting of: a temperature sensor, a solar radiation sensor, a humidity sensor, a wind speed and a rainfall sensor.

6. The irrigation control unit of claim **1** wherein the memory stores multiple sets of the stored historical values, each set corresponding to a different geographic region.

7. The irrigation control unit of claim **6** wherein, based on a user input, the processor selects a given set of the stored historical values for use in determining the plant water requirements.

8. The irrigation control unit of claim **7** wherein the user input comprises an input selected from a group consisting of: a zip code, a longitudinal coordinate, a latitudinal coordinate, and a map code.

9. The irrigation control unit of claim **1** wherein the signals received at the at least one input correspond to current values of the one or more of the plurality of variables for a geographic region local to the irrigation control unit.

10. The irrigation control unit of claim **1** further comprising:

a first housing containing the irrigation control unit and an irrigation controller coupled to and controlling operation of flow control devices.

11. The irrigation control unit of claim **1** further comprising:

a first housing containing the irrigation control unit, the first housing adapted to be coupled to a second housing containing an irrigation controller coupled to and controlling operation of flow control devices.

12. The irrigation control unit of claim **1** wherein the processor is adapted to determine, based on the plant water requirements, adjustments to a programmed watering schedule.

13. The irrigation control unit of claim **12** wherein the processor is adapted to generate signaling to cause the adjustments to the programmed watering schedule.

14. The irrigation control unit of claim **1** wherein the processor is adapted to determine a watering schedule in order to meet the plant water requirements.

15. The irrigation control unit of claim **1** wherein the stored historical values are stored in the memory prior to the irrigation control unit being sold.

16. The irrigation control unit of claim **1** wherein the processor is adapted to determine the plant water requirements at least in part using the current value for at least one of the plurality of variables and the stored historical value for at least one of the plurality of variables.

17. A processor implemented method for use in irrigation control comprising:

determining, for each of a plurality of variables used at least in part to determine plant water requirements, whether a current value is available; and

determining the plant water requirements at least in part using, for each of the plurality of variables on a variable by variable basis, the current value in the event the current value is available and at least in part using, for each of the plurality of variables, a stored historical value in the event the current value is not available.

18. The method of claim **17** wherein the determining the plant water requirements step comprises determining an evapotranspiration (ET) value.

19. The method of claim **17** wherein the plurality of variables comprises two or more parameters selected from a group consisting of: temperature, solar radiation, humidity, wind speed, and an amount of rainfall.

20. The method of claim **17** further comprising:

receiving, for each of one or more of the plurality of variables, the current value from a sensor.

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