Residential Irrigation System Rainfall Shutoff Devices[1]

Michael D. Dukes and Dorota Z. Haman[2]

Rain sensors—also called rain shut-off devices—are designed to interrupt the cycle of an automatic irrigation system controller when a specific amount of rainfall has occurred. They are small devices wired to the irrigation system controller and mounted in an open area where they are exposed to rainfall.

Some of the new irrigation controllers have a special connection which allows a rain sensor to be attached directly. If such a shut-off device is not available, or the sensor doesn't work with a given controller, the sensor can always be "hard-wired" into the controller. This is done by wiring the rain sensor in series with the common wire. When a specific amount of rainfall has occurred, the rain sensor will interrupt the system's common wire, which disables the solenoid valves until the sensor dries.

Florida is one of just a few states with a rain sensor statute. The most recent version of this statute (2010) says the folllowing: "Any person who operates an automatic landscape irrigation system shall properly install, maintain, and operate technology that inhibits or interrupts operation of the system during periods of sufficient moisture." (Florida Statute 373.62). Thus, all automatic landscape irrigation systems require rain sensors, or other shut off devices such as soil moisture sensor irrigation controllers (see http://edis.ifas.ufl.edu/ae437). Rain sensors are available wherever irrigation supplies are sold, and a homeowner or irrigation professional can install them.

Advantages of a rain sensor:

- Conserves water -- prevents irrigation after recent rain events.
- Saves money -- reduces utility bills by interrupting the irrigation system after adequate rainfall.
- Reduces wear on the irrigation system because the system runs only when necessary.
- Reduces disease damage by eliminating unnecessary irrigation events.
- Helps protect surface and groundwater by reducing the runoff and deep percolation that carries pollutants, such as fertilizers, into storm drains and groundwater.

Types of Devices

Rain sensors operate by one of two methods. 1) Shut-off devices may either measure or weigh collected rainwater. Devices that collect water operate on two basic principles: water weight; or electrical conductivity of water. 2) Shut-off devices may measure proportional expansion of water-senstitive materials, such as cork disks.

Water weight -- When a preset weight of water is collected in a small dish, the connection to the automatic irrigation valve is interrupted until the dish is emptied or a portion of water evaporates reducing the weight below the critical level. A disadvantage of this device is that any other weight (debris, frogs, etc.) can turn off the irrigation system and it requires more maintenance (Figure 1).

Electrical conductivity of water -- A set of electrodes is used to detect the water level in a small collection dish. The

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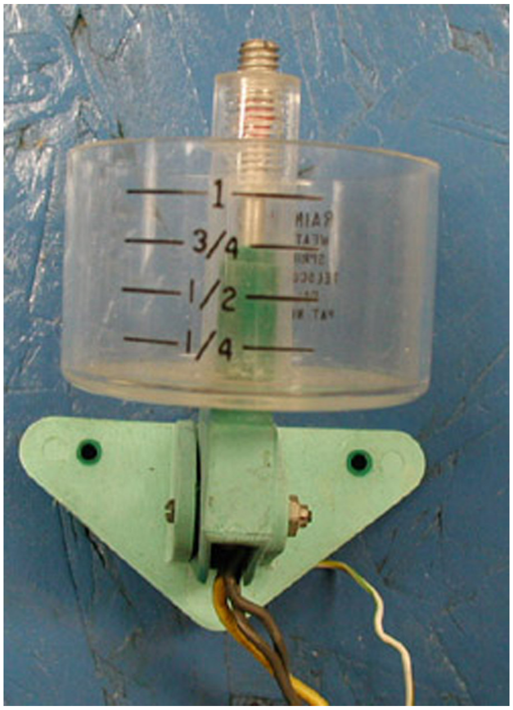

Figure 1. Weight-based rain shut-off device.

distance between the bottom of the collection dish and the electrodes can be adjusted so the irrigation system is not switched off by small rain events. Typically, the sensor is set to detect rain events larger that 1/2 inch. Similar to the previous type, water may have to be removed from the dish, and debris may create some problems (Figure 2).

Expansion disks -- This device is the most popular rain sensor due to high reliability and low maintenance. Expanding cork disks trigger a pressure switch. The expansion space can be easily adjusted by rotation of the disk cover to a predetermined amount of rain required to trigger the switch. The amount of rain that will interrupt the irrigation system is marked on the adjustment cap (Figure 3 and Figure 4).

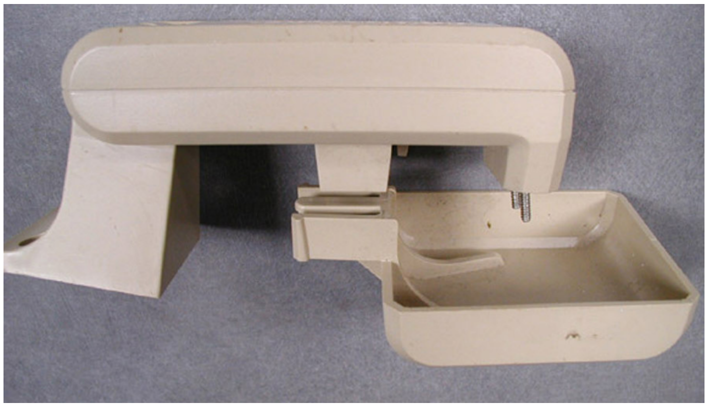

Figure 2. Rain shut-off device based on electrical conductivity.

Figure 3. Rain shut-off device with expanding material.

Figure 4. The expanding material of a shut-off device is visible in this photo of the cap removed from a device similar to the one in Figure 3.

Installing the Device

A rain sensor should be mounted where it will be exposed to unobstructed rainfall, but not in the path of sprinkler spray. It is typically installed near the roofline on the side of a building. However, it should not be mounted such that it comes into contact with water running directly off the roof. If vandalism is not a threat, it can be mounted lower on a fence post or deck railing. It is important that trees, overhangs, and awnings are not blocking direct rainfall onto the device.

The closer the sensor is to the controller, the shorter the wire and less chance for wire breaks. Mounting the sensor in a very sunny, southern end of a building may cause the water to dry out sooner than desired. Conversely, mounting on the northern end of a building with constant shade may keep it from drying soon enough, especially in Florida's humid climate. Some experimentation with adjustment of sensor level is strongly recommended for best results.

The controllers that are provided with a plug for a rain sensor require that the sensor be compatible with a given type of controller. The sensor can operate as "normally closed" or "normally open."

If a given sensor does not work with a controller that is already installed, it can always be "hard-wired" into the controller. If the sensor is purchased at the time of controller installation, it is a good idea to check for compatibility of both devices.

Testing

The device can be tested during normal rainfall events by setting out several containers with dimensions similar to those recommended for testing irrigation system uniformity (see How to Calibrate Your Sprinkler System). At least three containers should be located in the yard such that rainfall can accumulate freely in these containers. Measure the depth of water in each container with a ruler, and calculate the average of the measurements. When the containers average 1/2 inch of rainfall, set the rainfall sensor to 1/2 inch and manually initiate the irrigation system at the controller. The system should not operate. If this is the case, the rainfall sensor is adjusted properly. If the system runs, the rainfall sensor may have to be: 1) cleaned, 2) located so that rainfall will contact it, or 3) repaired or replaced. Sensors with electrodes (see Figure 2) may require cleaning of the electrodes and/or cleaning of the catch container. Sensors with a weighing dish or cup (see Figure 1) may require periodic cleaning of the container.

Potential Water and Cost Savings

The amount of water that can be saved using rain shut-off devices varies, but in a year with average rainfall, savings are usually substantial. There are several factors involved in determining how much a sensor can reduce water usage: how often it rains, whether or not the controller is left on for automatic operation, and the amount of water applied by the system per cycle. If the water costs and the amount of water applied per watering cycle by the whole system are known, it is easy to calculate how much money is being saved each time the sensor interrupts the watering cycle because of rainfall.

As an example, if a system irrigates 1/2 acre of turf and is set to run each zone so that 1/2 inch of water is applied per cycle, one can calculate that 13,576 gallons are being applied over the 1/2 acre of turf per cycle. Assuming water costs $2.00/thousand gallons, the savings will be $27.15 every time the sensor eliminates an irrigation event. What is even more important, 13,576 gallons that would be lost to deep percolation or runoff will be saved. If this amount is multiplied by the number of substantial rainfalls that occur in the area over one growing season, a significant amount of money and water can be saved.

Research Results and Recommendations

Dukes and Cardenas-Lailhacar (2008) showed that smaller set points led to the highest water savings. Thus, homeowners should use the smallest set point possible with 1/8" being the lowest on most devices. In any case, we recommend not exceeding a set point of 1/4". This same study estimated a payback period of less than a year.

References

How to Calibrate Your Sprinkler System (IFAS Publication ENH-61) (On the Web at: http://edis.ifas.ufl.edu/LH026)

Cardenas-Lailhacar, B. and M. D. Dukes. 2008. Expanding disk rain sensor performance and potential savings. *Journal of Irrigation and Drainage Engineering* 134(1):67-73. (Available at, http://www.abe.ufl.edu/mdukes/pdf/publications/RS/Cardenas-Dukes-RS-paper-JID.PDF).

Smart Irrigation Controllers: How Do Soil Moisture Sensor (SMS) Irrigation Controllers Work?[1]

Michael D. Dukes, Mary Shedd, and Bernard Cardenas-Lailhacar[2]

This article is part of a series on smart irrigation controllers. The rest of the series can be found at http://edis.ifas.ufl.edu/TOPIC_SERIES_Smart_Irrigation_Controllers.

Introduction

Water is required for the basic growth and maintenance of turfgrass and other landscape plants. When a sufficient amount of water is not present for plant needs, then stress can occur and ultimately lead to reduced quality or death. Irrigation is common in Florida landscapes because of sporadic rainfall and the low water holding capacity of sandy soil. This inability of many of Florida soils to hold substantial water can lead to plant stress after only a few days without rainfall or irrigation.

Water conservation is a growing issue in Florida due to increased demands from a growing population. One of the areas with the largest potential for reducing water consumption is residential outdoor water use, which accounts for up to half of publicly supplied drinking water. Most new homes built in Florida have automated irrigation systems. These irrigation systems use an irrigation timer to schedule irrigation (see *Irrigation System Controllers* http://edis.ifas.ufl.edu/ae077 for more information on timers). These automated irrigation systems have been shown to use 47% more water on average than sprinkler systems that are not automated (i.e. hose and sprinkler), which can be attributed largely to the tendency to set irrigation controllers and not readjust for varying weather conditions. Irrigation control technology that improves water application efficiency is now available. In particular, soil moisture sensors (SMS) can reduce the number of unnecessary irrigation events.

How Soil Moisture Sensor Systems Work

Most soil moisture sensors are designed to estimate soil volumetric water content based on the dielectric constant (soil bulk permittivity) of the soil. The dielectric constant can be thought of as the soil's ability to transmit electricity. The dielectric constant of soil increases as the water content of the soil increases. This response is due to the fact that the dielectric constant of water is much larger than the other soil components, including air. Thus, measurement of the dielectric constant gives a predictable estimation of water content. For more information on soil moisture sensors see, *Field Devices For Monitoring Soil Water Content* http://edis.ifas.ufl.edu/ae266.

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Bypass type soil moisture irrigation controllers use water content information from the sensor to either allow or bypass scheduled irrigation cycles on the irrigation timer (Figures 1 and 2). The SMS controller has an adjustable threshold setting and, if the soil water content exceeds that setting, the event is bypassed. The soil water content threshold is set by the user. Another type of control technique with SMS devices is "on-demand" where the controller initiates irrigation at a low threshold and terminates irrigation at a high threshold. The "on-demand" SMS controller concept is discussed in *What Makes an Irrigation Controller Smart?* http://www.edis.ifas.ufl.edu/ae442.

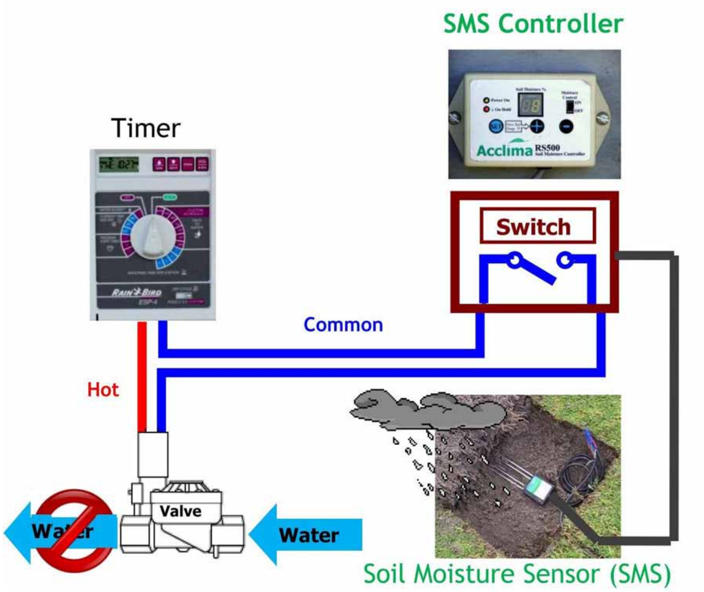

Figure 1. Simplified diagram showing how a soil moisture sensor (SMS) is typically connected to an automated irrigation system. The irrigation timer is connected to a solenoid valve through a hot and a common wire. The common wire is spliced with the SMS system (a controller that acts as a switch, and a sensor buried in the root zone that estimates the soil water content). The SMS takes a reading of the amount of water in the soil and the SMS controller uses that information to open or close the switch. If the soil water content is below the threshold established by the user, the controller will close the switch, allowing power from the timer to reach the irrigation valve and trigger irrigation. In this example the controller opens the switch, bypassing irrigation, because of rainfall wetting the soil around the soil moisture sensor.
Credits: Melissa Haley

Sensor Installation

A single sensor can be used to control the irrigation for many zones (where an irrigation zone is defined by a solenoid valve) or multiple sensors can be used to irrigate individual zones. In the case of one sensor for several zones, the zone that is normally the driest, or most in need of irrigation, is selected for placement of the sensor in order to ensure adequate irrigation in all zones.

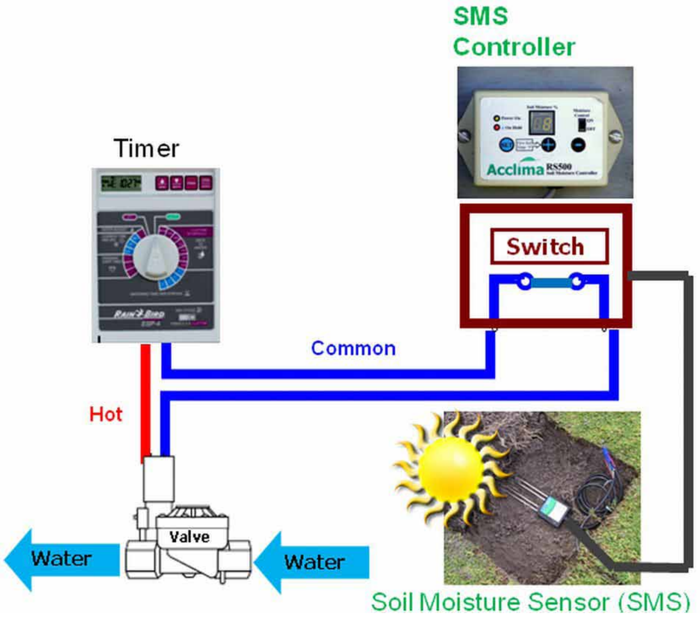

Figure 2. In this example the controller closes the switch allowing irrigation because of dry conditions in the soil around the soil moisture sensor.

Some general rules for the burial of the soil moisture sensor are:

- Soil in the area of burial should be representative of the entire irrigated area.
- Sensors should be buried in the root zone of the plants to be irrigated, because this is where plants will extract water. Burial in the root zone will help ensure adequate turf or landscape quality. For turfgrass, the sensor should typically be buried at about three inches deep.
- Sensors need to be in good contact with the soil after burial; there should be no air gaps surrounding the sensor. Soil should be packed firmly but not excessively around the sensor.
- If one sensor is used to control the entire irrigation system, it should be buried in the zone that requires water first, to ensure that all zones get adequate irrigation. Typically, this will be an area with full sun or the area with the most sun exposure.
- Sensors should be placed at least 5 feet from the home, property line, or an impervious surface (such as a driveway) and 3 feet from a planted bed area.
- Sensors should also be located at least 5 feet from irrigation heads and toward the center of an irrigation zone.

- Sensors should not be buried in high traffic areas to prevent excess compaction of the soil around the sensor.

Setting the Sensor Threshold

Once the sensor has been buried and the SMS controller has been connected to the irrigation system, the sensor needs to be calibrated and/or the soil water content threshold needs to be selected.

Based on the sandy soils in much of Florida, the following steps should be followed to calibrate or select a threshold for the soil moisture sensor controller:

Step 1. Apply water to the area where the sensor is buried. Either set the irrigation zone to apply at least 1 inch of water or use a 5-gallon bucket to apply directly over the buried sensor.

Step 2. Leave the area alone for 24 hours, and do not apply more water. If it rains during the 24 hours, the process should be started over.

Step 3. The water content after 24 hours is now the sensor threshold used to allow or bypass scheduled irrigation events. This threshold may be decreased slightly (~20%) to allow more storage for rainfall; however, the landscape will still need to be carefully monitored to ensure that adequate irrigation is being supplied.

The last step may vary slightly for each type of SMS controller. Generally, the manufacturer's instructions should be followed for the actual setup of the controller. These steps are provided mainly to direct how to establish the proper soil moisture content for the specific soil.

Examples of Step 3 for SMS systems commercially available in Florida:

- Acclima Digital TDT® RS500 (Acclima Inc., Meridian, ID) - This controller displays the water content in the soil as a percentage of the volume of the soil. The set point of the controller is the water content of the soil after the 24-hour waiting period. In research on fine sandy soil and St. Augustinegrass at the University of Florida, a set point of 10% (volumetric water content) was sufficient to ensure adequate turf quality while minimizing wasted irrigation water. In contrast, a set point of 7% was adequate for bermudagrass turf.

- AquaBlu® (Aquaspy, Inc., Santa Ana, CA) – The AquaBlu irrigation controller has a dial with relative set-point positions. The leftmost position represents a dryer soil water content and the rightmost position represents a wetter soil water condition. According to the manufacturer, the following procedure should be followed: With the AquaBlu turned "OFF," irrigate the area to the desired level. Turn the AquaBlu "ON," with the dial in the "Left Most" position. Rotate the AquaBlu dial very slowly to the right until the "RED" light goes out. The AquaBlu will now stop irrigation whenever moisture exceeds this value.

- Lawn Logic® LL1004 (Alpine Automation, Inc., Aurora, CO) - This controller uses relative calibration, meaning the controller has relative set points from #1 (dry) to #9 (wet). The calibration of the controller is performed after watering and waiting 24 hours. After calibration a set point from #1 to #9 is selected. To maintain both good turf quality and produce water savings, a set point after calibration of #5 is suggested by researchers at the University of Florida.

- Moisture Clik™ IL200-MC (Dynamax, Inc., Houston, TX) – After the 24-hour draining process, the water content is read off the controller with a digital voltmeter, and is considered to be the field capacity (FC) of the soil. This manufacturer recommends using a chart provided by the company to develop a threshold set point. This chart contains various values for maximum allowable depletion (MAD), which is the amount of water that plants are allowed to use from the soil, before irrigation is initiated. The user chosen MAD value is then correlated to the FC of the soil using the chart, and a set point for the controller is then recommended by the manufacturer. For more information about FC and MAD, visit *Basic Irrigation Scheduling in Florida* http://edis.ifas.ufl.edu/ae111. Testing is ongoing for this controller at the University of Florida.

- WaterTec™ S100 (Baseline, Meridian, ID) – The WaterTec S100 comes with an auto-calibration capability. After the soil has been saturated, the "+""-" and "Bypass" buttons must be held simultaneously for 3 seconds. The screen will flash between "CAL" "24H" and the current moisture reading. The 24 hour auto-calibration function is initiated. The "24H"will count down on the hour until the calibration is complete. Watering pauses during this time. It is important that the biSensor does not receive any water during calibration. If the calibration succeeds, the moisture threshold will be automatically set, and the system will allow watering when soil moisture drops below this threshold. Testing is ongoing for this controller at the University of Florida.

Programming the Irrigation Timer with a Soil Moisture Sensor System

Soil moisture control devices can reduce water use on the lawn by bypassing scheduled irrigation events, but is important to make sure the irrigation schedule is programmed into the irrigation timer correctly. Programming the irrigation timer correctly for the area to be irrigated can make the use of irrigation water more efficient. Before setting the irrigation schedule it is important to determine when the water will be applied and how much to apply with each irrigation event. In most areas of Florida the days per week in which irrigation is allowed is already limited by water restrictions. Irrigation run time is the amount of time an irrigation zone has to be turned on to apply the desired amount of water. It is affected by the water application rate of the irrigation sprinklers and the time of the year. See EDIS publication *How To Calibrate Your Sprinkler System* http://edis.ifas.ufl.edu/lh026, for information on how to determine the application rate of your system. For more information on setting the irrigation timer properly see *Operation of Residential Irrigation Controllers* http://edis.ifas.ufl.edu/AE220, which is also provided as a tool in the Florida Automated Weather Network (FAWN) urban irrigation scheduler (http://fawn.ifas.ufl.edu/tools/urban_irrigation/).

Extensive details on soil moisture sensor controller installation and programming can be found in the Field Guide to Soil Moisture Sensor Use in Florida http://www.sjrwmd.com/floridawaterstar/pdfs/SMS_field_guide.pdf.

References

Dukes, M. D., B. Cardenas-Lailhacar, B., and G.L. Miller. (2005, June). *Irrigation Research at UF/IFAS.* Retrieved June 27, 2008, from Institute of Food and Agricultural Sciences: http://irrigation.ifas.ufl.edu/SMS/pubs/June05_Resource_sensor_irrig.pdf.

Florida Department of Environmental Protection. 2002. Florida Water Conservation Initiative. Section 62-40.412(1), F.A.C. Available at http://www.dep.state.fl.us.

Dukes, M.D. and D.Z. Haman,. 2002. *Operation of Residential Irrigation Controllers. EDIS.* Retrieved July 7, 2008, from Institute of Food and Agricultural Sciences, University of Florida: http://edis.ifas.ufl.edu/AE220.

Haley, M.B., M.D. Dukes, S. Davis, M. Shedd and B. Cardenas-Lailhacar. 2008. *Energy Efficient Homes: The Irrigation System. EDIS.* Retrieved July 7, 2008, from Institute of Food and Agricultural Sciences, University of Florida: http://edis.ifas.ufl.edu/FY1043.

Mayer, P.W., W.B. DeOreo, E.M. Opitz, J.C. Kiefer, W.Y. Davis, B. Dziegielewski, and J.O. Nelson. 1999. *Residential End Uses of Water*. American Water Works Association Research Foundation. Denver, CO.

Muñoz-Carpena, R. 2004. *Field Devices for Monitoring Soil Water Content*. *EDIS*. Retrieved July 7, 2008, from Institute of Food and Agricultural Sciences, University of Florida: http://edis.ifas.ufl.edu/AE266.

Smajstrla, A.G., B.J. Boman, D.Z. Haman, F.T. Izuno, D.J. Pitts, and F.S. Zazueta. 1997. *Basic Irrigation Scheduling in Florida*. *EDIS.* Retrieved July 14, 2008, from Institute of Food and Agricultural Sciences, University of Florida: http://edis.ifas.ufl.edu/AE111.

Trenholm, L.E., J. Bryan Unruh, and J.L. Cisar. 1991. *How to Calibrate Your Sprinkler System. EDIS.* Retrieved July 14, 2008, from Institute of Food and Agricultural Sciences, University of Florida: http://edis.ifas.ufl.edu/LH026.

University of Florida Program for Resource Efficient Communities. 2007. *Field guide to proper installation, calibration and maintenance of soil moisture sensor control systems in residential Florida landscapes*. St. Johns River Water Management District: http://www.sjrwmd.com/floridawaterstar/pdfs/SMS_field_guide.pdf.

Smart Irrigation Controllers: What Makes an Irrigation Controller Smart?[1]

Michael D. Dukes[2]

This article is part of a series on smart irrigation controllers. The rest of the series can be found at http://edis.ifas.ufl.edu/TOPIC_SERIES_Smart_Irrigation_Controllers.

Introduction

So called "smart" irrigation controllers have appeared on the market for use in residential and commercial applications since the early 2000's. The Irrigation Association (www.irrigation.org) defines "smart controllers" as (controllers that reduce outdoor water use by monitoring and using information about site conditions (such as soil moisture, rain, wind, slope, soil, plant type, and more), and applying the right amount of water based on those factors". Essentially, these irrigation controllers receive feedback from the irrigated system and schedule or adjust irrigation duration and/or frequency accordingly. For example, they would reduce watering in the cooler months and increase watering in the hot and dry months. There are generally two types of smart controllers: climatologically-based controllers and soil moisture-based controllers.

Evapotranspiration Controllers

Climatologically based controllers are also known as evapotranspiration, or ET, controllers (Fig. 1). Generally, ET is the process of transpiration by plants combined with evaporation that occurs from plant and soil surfaces. More information on the ET concept and definitions can be found in the publication, *Evapotranspiration: Potential or Reference*? http://edis.ifas.ufl.edu/AE256. There are generally three types of ET controllers:

1. signal Based: Meteorological data are either collected from publicly available sources or from agreements with weather station networks. The ET value is calculated for a hypothetical grass surface for that site. Then, ET data are sent to surrounding controllers via wireless communication. In some cases, the ET values are adjusted to account for controllers that are not near the weather data collection site. The ET controller adjusts the irrigation run times or watering days according to climate throughout the year.

2. historical ET: This approach for ET controllers uses a pre-programmed crop water use curve for different regions. The curve may be modified by a sensor such as a temperature or solar radiation sensor that measures on-site weather conditions.

3. On-site Weather Measurement: This approach uses measured weather data at the controller to calculate ET continuously and adjust the irrigation times according to weather conditions.

Several bench scale studies have shown that ET controllers can adjust irrigation in response to plant needs, but few studies demonstrate the controllers in comparison to

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Figure 1. Photo of three brands of ET controllers undergoing testing at the University of Florida, Agricultural and Biological Engineering Department.
Credits: Stacia Davis.

controls such as actual homeowner irrigation or non-irrigated test plots. Results from two demonstration studies with ET controllers in California indicate that some irrigation savings is possible with these controllers, but that more detailed comparisons are needed. Testing of ET controllers in Florida is ongoing at the plot and homeowner scale. More information on ET controllers can be found at *Smart Irrigation Controllers: Operation of Evapotranspiration-Based Irrigation Controllers* http://edis.ifas.ufl.edu/AE446.

Soil Moisture Sensor Controllers

Two types of control strategies are employed with soil moisture sensor (SMS) controllers, "bypass" and "on-demand".

1. The bypass configuration is the most common for small sites including most residential sites. Typically, a bypass SMS controller has a soil moisture threshold adjustment from "dry" to "wet". This threshold can be used to lower and raise the point at which the irrigation system is allowed to water to suit specific plant, soil, and microclimate needs. This type of controller bypasses timed irrigation events if the current soil moisture content exceeds the adjustable threshold. The bypass mode of operation is very similar to that of a rain sensor (see EDIS publication *Residential Irrigation System Rainfall Shutoff Devices* http://edis.ifas.ufl.edu/ae221). Most of these types of SMS controller are added to an existing time clock (Fig. 2). Many of these systems only include one soil moisture sensor, in which case the sensor should be buried in the driest irrigation zone and the run times for the other zones should be adjusted to limit over-watering. Controllers that contain multiple sensors allow for the installation of a sensor in each irrigation zone.

2. An on-demand SMS controller initiates irrigation at a pre-programmed low soil moisture threshold and terminates irrigation at a high threshold. This type of controller is often used where a high level of customization or high level of control is needed such as commercial sites or other types of sites with many irrigation zones. Thus, this controller initiates and terminates irrigation events, whereas the bypass controller only allows irrigation events (i.e. day of the week, time of day, and run time) from a time clock. Therefore, it is critical to properly program a schedule into the time clock. Detailed information on soil moisture sensor controller programming and installation can be found at Smart Irrigation Controllers: *How do Soil Moisture Sensor Irrigation Controllers Work*? http://edis.ifas.ufl.edu/AE437.

Figure 2. Four brands of soil moisture sensor controllers with an electronic time clock.
Credits: Michael Dukes.

In summary, a Smart Controller is "smart" due to the feedback received from the irrigated system whether it be climate measurements or soil moisture measurements. This feedback is then used to adjust irrigation application to match plant needs. In contrast a "dumb" irrigation time clock simply applies water at the pre-programmed date and time.

Although the concept of Smart Controllers reducing inefficient water use while maintaining landscape quality seems to have potential, little information has been available until recently.

Smart Controller Water Conservation Potential

Since these Smart Controllers are relatively new to the irrigation industry, a group of researchers at the University of Florida have been testing various Smart Controller technologies under field plot conditions and on cooperating homes in Florida. To date, the water conservation potential of these technologies ranges depending on weather conditions and site conditions such as soil and microclimate to name a few. Generally, irrigation savings can be as high as 30-40% during dry conditions and up to 70-90% during normal Florida rainfall conditions for properly installed and programmed Smart Controllers. The research publications are available at the following website, http://abe.ufl.edu/mdukes/.

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AE445

Smart Irrigation Controllers: Programming Guidelines for Evapotranspiration-Based Irrigation Controllers[1]

Michael D. Dukes, Mary L. Shedd, and Stacia L. Davis[2]

This article is part of a series on smart irrigation controllers. The rest of the series can be found at http://edis.ifas.ufl.edu/TOPIC_SERIES_Smart_Irrigation_Controllers.

Introduction

Irrigation systems are installed to provide water as a supplement to rainfall for maintaining plant health and aesthetics. Typically in Florida, irrigation is applied with an automated, in-ground system utilizing an irrigation timer programmed with user-defined irrigation schedules. However, homeowners who use these systems may apply more water for landscape irrigation than homeowners without automatic irrigation systems due to a "set it and forget it" mentality regardless of seasonal fluctuations in plant water needs.

"Smart" technologies for irrigation have been developed to apply irrigation to the landscape based on plant water needs while conserving our increasingly limited water resources. An overview of Smart Irrigation Controllers can be found in *What Makes an Irrigation Controller Smart* http://edis.ifas.ufl.edu/AE442. Ideally, these technologies will conserve water while helping to maintain landscapes of acceptable quality to consumers. *Operation of Evapotranspiration-Based Irrigation Controllers* http://edis.ifas.ufl.edu/AE446 presents general operating principles associated with ET controllers.

This publication will present programming guidelines for several examples of ET controllers available in Florida.

Controller Inputs

ET controllers vary according to the way they receive data, as described in *Operation of Evapotranspiration-Based Irrigation Controllers* http://edis.ifas.ufl.edu/AE446, but can also vary based on the types of programmed inputs used for irrigation scheduling. Depending on the manufacturer, each controller can typically be programmed with various conditions specific to the irrigation system and landscape.

Irrigation System Inputs

Irrigation systems have parameters specific to their design and installation. Some common parameters include application rate and efficiency. Both application rate and efficiency factors are determined by the type of irrigation emitters such as sprinklers, spray heads, and drip irrigation.

Irrigation Type – The type of sprinkler used for the irrigation system affects the rate that water is applied to the irrigated area and the efficiency of water application. This input can generally be selected from a set of choices available in the ET controller (Table 1).

Application Rate – Rates of water application vary depending on the brand, type and installation details of sprinklers. Typically, the application rates of rotors are lower than

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1. This document is AE445, one of a series of the Agricultural and Biological Engineering Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Original publication date January 2009. Reviewed January 2012. Visit the EDIS website at http://edis.ifas.ufl.edu.

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spray nozzles. This rate has units of depth per time (such as inches/hour) and can be used to calculate the irrigation runtime from the depth found using the soil water balance (*Operation of Evapotranspiration-Based Irrigation Controllers* http://edis.ifas.ufl.edu/AE446). The rate of application can be located in the manufacturer's specifications or determined by performing a distribution uniformity test. See LH026, "How To Calibrate Your Sprinkler System", for information on how to determine the application rate of your system.

Efficiency – Irrigation efficiency is discussed in Efficiencies of Florida Agricultural Irrigation Systems http://edis.ifas.ufl.edu/AE110. Generally, landscape sprinkler systems are considered to be inefficient. For scheduling purposes in the ET controller instead of using low quarter distribution uniformity (DUlq), it is recommended that the low half distribution uniformity (DUlh) be used. In absence of uniformity testing information the following efficiencies may used as an estimate: rotary or impact sprinklers, 70-80%; spray heads, 60-80%; drip or other microirrigation emitters, 80-90%. The concept of irrigation efficiency and uniformity can be found in Understanding the Concepts of Uniformity and Efficiency in Irrigation http://edis.ifas.ufl.edu/AE364. The lower the efficiency number input to the controller, the more water that will be applied because the controller will compensate for lower efficiency (i.e. more losses) by applying more water. It is best to use as high an efficiency value as possible to limit over-watering.

Landscape Inputs

Landscape conditions typically included as inputs to the controllers are soil type, plant type, slope, sun, and shade. The controllers generally have options available for each condition. Examples of inputs to an ET controller and inputs typically applicable to Florida are listed in Table 1.

Soil Type - Choosing the correct soil type can be extremely important to the soil water balance. Soil type affects the amount of water that can be held in the root zone and the infiltration rate of water into the root zone. Sand generally has high infiltration rates with low soil water holding capacity while clay has a very low infiltration rate, but holds water extremely well (Operation of Evapotranspiration-Based Irrigation Controllers http://edis.ifas.ufl.edu/AE446). Also, soil type affects the amount of runoff that can occur and is determined from the infiltration rate. If the infiltration rate is too low, most of the water will be lost to runoff and will not enter the root zone. Most soils in peninsular Florida can be classified as "sand" while those in the panhandle can be classified as "sandy loam". Fill soils may also be classified as "sand". However, site specific conditions need to assessed and appropriate soil type selected. On some construction sites, substantial compaction limits infiltration and root growth. For these sites, the top soil should be tilled to ameliorate compaction.

Plant Type – The type of plant in a landscape affects the irrigation required. Plant types are selected for the purpose of defining the appropriate crop coefficient and possibly defining an appropriate root depth. Crop coefficients and plant water requirements are described in Operation of Evapotranspiration-Based Irrigation Controllers http://edis.ifas.ufl.edu/AE446 and Basic Irrigation Scheduling in Florida http://edis.ifas.ufl.edu/AE111. Deeper root systems allow for longer periods between irrigation events. Some controllers allow you to choose custom crop coefficients and root depths that will override the default values given for the plant type option.

Slope – ET controllers may use the slope of an irrigated area to create multiple irrigation start times with shorter durations for each irrigation event. This will reduce runoff allowing water to infiltrate into the soil after each event.

Microclimate –The percentage of the irrigated area covered with shade may be used by the ET controller to adjust the amount of water applied. Evapotranspiration (ET) in a shaded area will be lower than ET in an area with full sun.

Weather Conditions

ET controllers may have several options limiting irrigation during windy or rainy conditions. As wind speeds increase, the ability for the irrigation system to apply water efficiently decreases and evaporative loss of water increases. Also, irrigation should be reduced or suspended during periods with adequate rainfall.

Rain Sensors – An ET controller may include a rain sensor in the system such as the Weathermatic Smartline Series (see AE221, Residential Irrigation System Rainfall shutoff Devices http://edis.ifas.ufl.edu/AE221 for details on rain sensors). Rain sensors bypass irrigation events when a specific amount of rainfall has occurred. Some ET controllers will refill the soil water after a rain event is sensed by the rain sensor whereas other controllers will only pause irrigation until the rain sensor is dry. Unless a controller measures rainfall on site, a supplemental rain sensor should be used due to frequent and site specific rainfall experienced in Florida. It is important that the rain sensor be connected to a "sensor" port if available on the ET controller so that irrigation bypass events are accounted for properly in the controller.

Rainfall Service – Some signal-based ET controllers receive an input of rain depth from the weather signal. Irrigation may be paused for a preset number of days as a response to the amount of rainfall measured at the weather station. It is possible for the user to program the response to a rainfall event manually. Instead of pausing irrigation, other controllers account for rainfall measured in the weather network as an input to the plant and soil system and the irrigation schedule may be adjusted accordingly.

Challenges

ET controllers can be very useful tools for improving irrigation water application because they allow the homeowner to “set it and forget it”. Most of these controllers calculate irrigation run times and cycles based on the user inputs and weather conditions (Table 1). However, these controllers cannot fix a poorly designed or poorly maintained irrigation system. Thus, it is important to have the irrigation system inspected regularly and to have necessary maintenance performed in a timely manner.

The various controllers operate differently to reduce irrigation water use depending on whether they are add-on devices that bypass fixed events or complete units that calculate run time of irrigation events themselves. While these controllers can be programmed once and left alone, they need maintenance to ensure that the signal is not lost and they are working properly.

Confusion may arise with these controllers when dealing with the programming aspect. The various commercially available ET controllers have different programming terms, inputs, and procedures; there is no standardized model (Tables 2 and 3). Manufacturers design the controllers to be installed by knowledgeable contractors who understand the various inputs. Programming the controller correctly for each unique landscape is critical to the ability of the controller to reduce water use and maintain good landscape aesthetics.

References

Mayer, P. W., W. B. DeOreo, E. M. Opitz, J. C. Kiefer, W. Y. Davis, B. Dziegielewski, and J. O. Nelson. 1999. Residential End Uses of Water. AWWA Research Foundation and American Water Works Association. Denver, Colorado.

Table 1. Common settings that are programmable in ET controllers to properly schedule irrigation.

Category	Common Settings	Parameter Effected by Setting	Common Florida Inputs	More Information
Irrigation Type	Spray head Rotor Impact Bubblers Drip emitters	Application Rate Uniformity/Efficiency	Spray Rotor	CIR825
Soil Type	Sandy Sandy Loam Loam Clay Loam Clay	Infiltration Rate Water Holding Capacity	Sandy Sandy Loam	SS169
Plant Type	Warm Season Grass Cool Season Grass Combined Grass Flowers Trees Shrubs Mixed Trees Native Grasses	Crop Coefficient (Kc)	Warm Season GrassMixedShrubs	ENH860
Microclimate	Sunny all day Sunny most of the day Shady most of the day Shady all day	ET Adjustments	Site Specific	EES43
Slope	0-5% 6-8% 9-12% 13-20% >20%	Cycle/Soak	Site Specific	

Table 2. Program settings for four commercially available ET controllers irrigating a full sun St. Augustinegrass lawn on a sandy soil and using spray heads.

Setting	Toro Intelli-sense	Weathermatic Smartline	ET Water Smart Controller 100	Rain Bird ET Manager
Sprinkler Type	Spray Head	Spray	Spray Head	Fixed Spray
Application Rate[1]	1.7 in/hr	1.0 in/hr	1.5 in/hr	User-defined[2]
Soil Type	Sand	Sand	Sand	Sand
Plant Type	Warm Season Turf	Wturf	Lawn - Warm Season	Warm Season Turf
Microclimate	Sunny All Day	NA[3]	Sunny All Day	NA
Slope	0% - 5%	1% - 5%	0% - 5%	0% - 3%
Efficiency/ Uniformity[4]	80%	NA	80%	80%
Zip Code[5]	NA	32611	NA	NA

[1] Application rates are default controller values for the spray head program setting. Site-specific information based on catch can testing should be used if available.

[2] The application rate can be found using on-site catch-can testing or, after choosing the sprinkler type in the scheduling software, the ET Manager lists various sprinkler manufacturers and corresponding models of the sprinkler category to determine the application rate from the technical specifications.

[3] NA refers to settings that do not apply to the controller program settings.

[4] This factor should be based on a catch can uniformity measurement and the calculated low half distribution uniformity value. The values here are merely guidelines in the absence of site-specific information. In addition, these values presume coverage of the irrigated area by 2-3 overlapping heads.

[5] Zip codes should be updated for location of controller.

Table 3. Program settings for four commercially available ET controllers irrigating shrubs on a sandy soil and using microsprinkler irrigation.

Setting	Toro Intelli-sense	Weathermatic Smartline	ET Water Smart Controller 100	Rain Bird ET Manager
Sprinkler Type	Spray Head	Spray	Spray Head	Micro Spray
Application Rate[1]	User-defined	User-defined	User-defined	User-defined[2]
Soil Type	Sand	Sand	Sandy	Sand
Plant Type	Shrubs – Med Water Use	Shrubs	Shrubs	Shrubs
Microclimate	Sunny All Day	NA[3]	Sunny All Day	NA
Slope	0% - 5%	1% - 5%	0% - 5%	0% - 3%
Efficiency/ Uniformity[4]	90%	NA	90%	90%
Zip Code[5]	NA	32611	NA	NA

[1] Application rates should be determined for microsprinkler by measurement since default values do not exist for these controllers. If a value for "drip" irrigation is available in the controller it could be used; however, it may need adjustment over time to provide adequate water to the plant material.

[2] The application rate can be found using on-site catch-can testing or, after choosing the sprinkler type in the scheduling software, the ET Manager lists various sprinkler manufacturers and corresponding models of the sprinkler category to determine the application rate from the technical specifications.

[3] NA refers to settings that do not apply to the controller program settings.

[4] Uniformity of microsprinkler assumes that the sprays are targeted to the root zone of the shrubs.

[5] Zip codes should be updated for location of controller.

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Smart Irrigation Controllers: Operation of Evapotranspiration-Based Controllers[1]

Michael D. Dukes, Mary L. Shedd, and Stacia L. Davis[2]

This article is part of a series on smart irrigation controllers. The rest of the series can be found at http://edis.ifas.ufl.edu/TOPIC_SERIES_Smart_Irrigation_Controllers.

Introduction

Florida has sandy soils in many areas of the state resulting in poor water retention to meet plant water needs. During dry periods, there may not be enough rainfall to maintain acceptable landscape quality. Also, rainy periods have infrequent, high intensity rain events causing only a small portion of water to infiltrate and remain in the root zone while the rest is lost to deep percolation and runoff. Drought conditions can occur in as little as a few days without rain. Previous research has shown that homeowners using in-ground, automatic irrigation systems, typical in Florida, apply 47% more water for landscape irrigation than homeowners without automatic irrigation systems. This over-irrigation is largely due to a “set it and forget it” mentality despite seasonal fluctuations in plant water needs (Mayer et al., 1999).

“Smart Irrigation Control” technologies for irrigation have been developed to apply irrigation to the landscape based on plant water needs while conserving increasingly limited water resources. One type of technology is an evapotranspiration-based irrigation controller, or ET controller. General information on ET controllers and other smart irrigation technologies can be found in *What Makes an Irrigation Controller Smart* http://edis.ifas.ufl.edu/AE442, and these technologies in energy efficient housing are described in *Energy Efficient Homes: The Irrigation System* http://edis.ifas.ufl.edu/FY1043.

This publication will present the operational techniques of several commercially available ET controllers that are being studied at the University of Florida.

Irrigation Scheduling

Irrigation scheduling is detailed in *Basic Irrigation Scheduling in Florida* http://edis.ifas.ufl.edu/AE111; however, this section will briefly review basic irrigation scheduling concepts.

The water requirement of plants can be determined from a balance of water inputs and outputs to the root zone and is called a soil water balance (Figure 1). Rainfall and irrigation enter the root zone as inputs. A shallow water table could also provide water for plant needs through capillary action. Water exits the soil and plant system from runoff, deep percolation, evaporation, and transpiration; these are considered outputs from the soil water balance. Evaporation is the loss of water to the atmosphere from the soil surface and transpiration is the loss of water from respiration of the plants (Allen et al., 1998). When calculating the soil water balance, evaporation and transpiration are combined into one term called evapotranspiration (ET).

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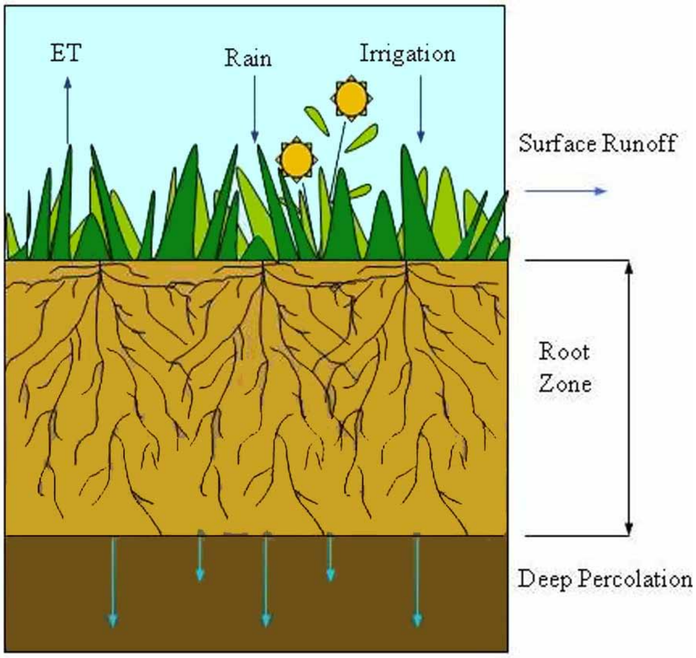


Figure 1. Water-based inputs and outputs occur in the root zone of a plant assuming well drained conditions without a shallow water table.
Credits: Mary L. Shedd

$$\Delta S = R - ET_C + I - D - RO$$

ΔS = Change in soil water storage (in)
R = Rainfall (in)
ET_C = Crop evapotranspiration (in)
I = Net irrigation (in)
D = Deep percolation (in)
RO = Surface runoff (in)

Figure 2. This equation is used to balance the change in soil water storage in the root zone of a plant, also termed the soil water balance equation.

Equation 1 is used for calculating the change in soil water in the root zone (Irrigation Association [IA], 2005). Generally, on sandy soils common in Florida, unless there is excessive compaction or other properties that decrease infiltration of water, it can be assumed that there is negligible surface runoff. Also, irrigation is scheduled so that, ideally, there are negligible losses. Deep percolation is minimized by irrigation events that do not exceed the soil water holding capacity while surface runoff is minimized by using irrigation events just long enough to infiltrate the soil but not runoff (i.e. cycle/soak). The change in storage is typically very small in Florida's sandy soils between necessary irrigation events. These assumptions reduce equation 1 to an equation used to calculate the irrigation depth required:

$$I = ET_C - R_E$$

I = Net irrigation (in)
ET_C = Crop evapotranspiration (in)
R_E = Effective rainfall (in)

Figure 3. This formula is a simplified version of Equation 1 used to calculate net irrigation depth required by assuming negligible drainage, runoff, and change in storage.

Equation 2: This formula is a simplified version of Equation 1 used to calculate net irrigation depth required by assuming negligible drainage, runoff, and change in storage.

Effective rainfall refers to the amount of rainfall that is stored in the root zone (IA, 2005). The ability of the soil to retain water is the soil water holding capacity (IA, 2005). Rainfall that is greater than the soil water holding capacity of the root zone is assumed to drain or run off and is no longer useful to the plant. So how much water can your soil hold?

Calculating Soil Water Content

The root zone of a plant is the depth of soil from the surface that can be used by the plants to obtain water for physiological processes. The amount of water that can be stored in the root zone is a function of the type of soil texture. Soil texture is discussed in detail in *Soil Texture* http://edis.ifas.ufl.edu/SS169. The permanent wilting point (PWP) of the soil is defined as the depth or percentage of water in the root zone causing plants to wilt permanently without recovery (IA, 2005; Figure 2). Alternately, field capacity (FC) is defined as the water level when the rate of downward movement in the root zone due to gravity has substantially decreased after saturation (IA, 2005). Theoretically, irrigation should be applied before reaching PWP and filled to FC. Both PWP and FC vary with soil texture where the more sandy a soil the less water that can be stored and the more clayey a soil, the more water that can be stored. Water holding capacity as it relates to soil texture is discussed in *Soil Plant Water Relationships* http://edis.ifas.ufl.edu/AE021.

Based on the above definitions, the amount of water available for use by the plant falls between FC and PWP and is termed available water, AW (IA, 2005; Equation 3). To prevent plant stress, AW should not be allowed to reach the PWP before irrigation is scheduled; irrigation should be applied when the available water level drops by a percentage known as the maximum allowable depletion, MAD (IA, 2005). *Basic Irrigation Scheduling in Florida* http://edis.ifas.ufl.edu/AE111 gives details on MAD selection but

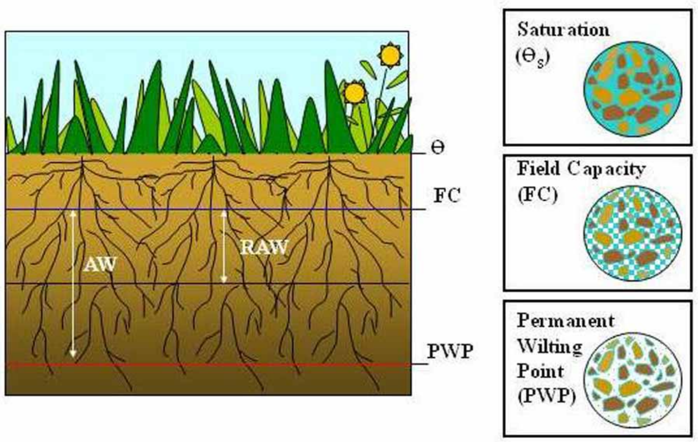
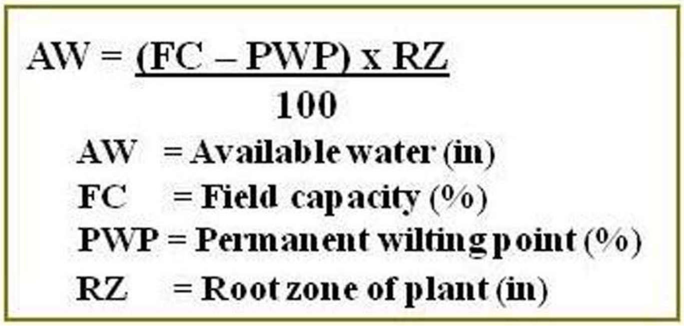


Figure 4. Diagram of water content in the root zone including: saturation where all soil pore space is filled with water, field capacity is the water remaining in soil pores after gravitational drainage has ceased, permanent wilting point is only thin films of water remaining that is not available to plants. Available water (AW) is the total amount of water held by the soil for plant use, and readily available water (RAW) is the amount of water available for plant use before stress. Credits: Mary L. Shedd

50% is often a rule of thumb in absence of more specific information. The amount of water allowed to be used before irrigation is required is called readily available water, RAW (IA, 2005; Equation 4). As time passes, water is lost from the root zone through ET_C. Daily values of ET_C are added cumulatively, taking into account effective rainfall, until it equals or is greater than RAW. Once the RAW is depleted, irrigation should occur to fill the soil water store to field capacity.



$$AW = \frac{(FC - PWP) \times RZ}{100}$$

AW = Available water (in)
FC = Field capacity (%)
PWP = Permanent wilting point (%)
RZ = Root zone of plant (in)

Figure 5. Formulas used to calculate the available water in the root zone.

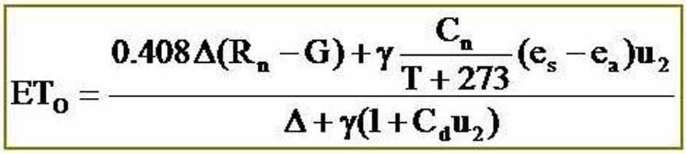
$$RAW = MAD \times AW$$

RAW = Readily available water (in)
MAD = Maximum allowable depletion

Figure 6. Formula used to calculate the readily available water in a root zone where MAD is a fraction from 0 to 1.

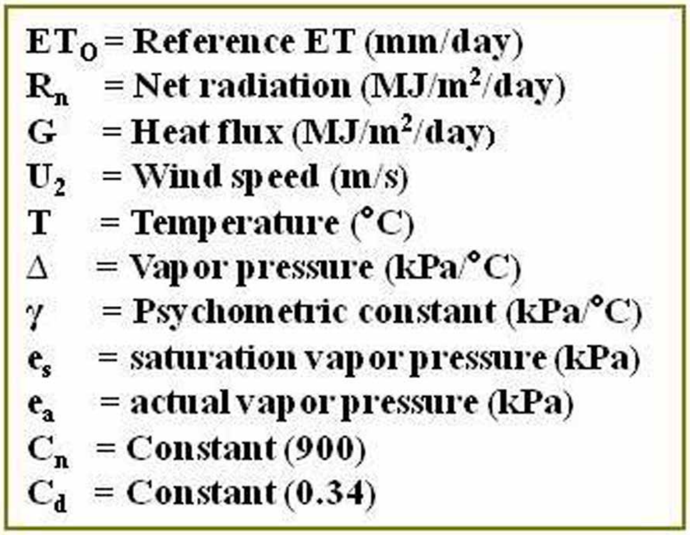
Calculating Evapotranspiration

Reference evapotranspiration (ET_O) is defined as ET from a reference surface using grass at a 0.12 m height that is adequately-watered, actively growing, completely covering the soil, and with a fixed surface resistance (Allen et al., 2005). The ASCE standardized reference evapotranspiration equation is considered the standard for ET calculations and is commonly used to calculate ET_O as seen in Equation 5. This equation is used for daily ET_O calculations and is based on wind speed, temperature, relative humidity, and solar radiation (Figure 3). More information on this method and calculation details can be found at http://www.kimberly.uidaho.edu/water/asceewri/.



$$ET_O = \frac{0.408\Delta(R_n - G) + \gamma \frac{C_n}{T + 273}(e_s - e_a)u_2}{\Delta + \gamma(1 + C_d u_2)}$$

Figure 7. ASCE standardized reference evapotranspiration equation (Allen et al., 2005).



ET_O = Reference ET (mm/day)
R_n = Net radiation ($MJ/m^2/day$)
G = Heat flux ($MJ/m^2/day$)
U_2 = Wind speed (m/s)
T = Temperature (°C)
Δ = Vapor pressure (kPa/°C)
γ = Psychometric constant (kPa/°C)
e_s = saturation vapor pressure (kPa)
e_a = actual vapor pressure (kPa)
C_n = Constant (900)
C_d = Constant (0.34)

Figure 8. The variables used in the ASCE standardized reference evapotranspiration equation (Allen et al., 2005). Note that 1 inch/day = 25.4 mm/day.

Plant ET (ET_C) is defined as ET applicable to a specific plant other than the reference crop. ET_C can be calculated for a specific plant material by applying a crop coefficient (K_C), using the following equation:

Crop coefficients can be found in a number of references depending on the specific crop, horticultural practices, and geographical location. Sources of crop coefficient data can be found in *Basic Irrigation Scheduling in Florida* http://edis.ifas.ufl.edu/AE111.

$$ET_C = K_C \times ET_O$$

ET_C = Crop evapotranspiration (in/day)

K_C = Crop coefficient

Figure 9. This equation is used to calculate ET loss for a specific crop or plant from reference ET using a crop coefficient.

ET Controllers

ET controllers are irrigation scheduling devices that use the principles of the soil water balance to schedule irrigation amounts and timing. The basic operation of ET controllers is described in *What Makes an Irrigation Controller Smart* http://edis.ifas.ufl.edu/AE442.

Signal-Based Controllers

These controllers utilize wired (phone) or wireless (cellular or paging) communication to receive ET_O data. Weather information is gathered from publicly available or dedicated weather stations near the controller location. Some manufacturers gather the climatic information from the weather stations, calculate a daily value for ET_O, and then broadcast the value directly to the controller each day. Other manufacturers may broadcast weather data from weather stations and the controller then calculates ET_O. ET_C is calculated from the ET_O and crop coefficients depending on the plant type selected. The advantage of these controllers is that they adjust in response to actual weather conditions. However, the disadvantage to this approach is that the weather conditions at the weather station data source may not be representative of conditions at the controller location. In particular, Florida site-specific rainfall is very important since rainfall can satisfy much of the plant water requirement. An adequate signal is also important for ensuring accurate soil water balance calculations. Some ET controllers utilize historical data until the signal to the controller is regained; others use the last broadcasted ET_O value for each day the controller is not in communication. Signal-based controllers generally have the option of adding an external antenna if the built in antenna is insufficient. Three examples of signal-based ET controllers available being studied in Florida are shown in Figure 4.

Standalone Controllers

These controllers utilize sensors installed on-site to measure weather conditions and then calculate real-time ET_O based on the data collected. The sensors collect readings at intervals anywhere from every second to every fifteen minutes and then a daily ET_O is calculated from those values. On-site sensors could include: temperature, solar radiation, or even a full weather station (Riley, 2005). However, installing weather stations at every home is not practical or economically feasible; therefore, simplified ET estimation methods are typically used. For example, the Weathermatic Smartline controller (Figure 5) uses Hargreaves equation instead of the ASCE standardized ET_O equation. Hargreaves equation is temperature dependent allowing the sensor to measure only temperature (Jensen et al., 1990). The advantage of this approach is that ET is measured on-site and signal fees are not required. The disadvantage is that simplified methods are not accurate across a wide range of climate conditions (Jensen et al., 1990).

Add-on ET Controllers

Some ET controllers, such as the Rain Bird ET Manager, are add-on devices to automatic timers and are not equipped with the ability to calculate runtimes. Instead, they use the soil water balance to determine if an irrigation event will occur. The Rain Bird ET Manager has a software program to help develop an appropriate irrigation schedule based on site-specific conditions. The schedule is input into the timer and the depth of water per irrigation event calculated by the software is input into the ET Manager. The ET Manager uses the depth input, combined with rainfall and daily ET, to decide when to bypass irrigation events.

Conclusion

Detailed programming recommendations for several controllers in Florida conditions can be found in *Programming Guidelines for Evapotranspiration-Based Irrigation Controllers* http://edis.ifas.ufl.edu/AE445.

Note that the University of Florida does not endorse any particular brand but that the information contained here is for illustrative purposes only.

References

Allen, R.G., L.S. Pereira, D. Raes, and M. Smith. 1998. Crop evapotranspiration – Guidelines for computing crop water requirements. FAO Irrigation and drainage paper 56. Available at: http://www.fao.org/docrep/X0490E/x0490e00.htm. Accessed January 12, 2007.

Allen, R.G., I.A. Walter, R. Elliot, T. Howell, D. Itenfisu, and M. Jensen (eds). 2005. The ASCE Standardized Reference Evapotranspiration Equation. American Society of Civil Engineers Environmental and Water Resource Institute (ASCE-EWRI). 59 pp.

Irrigation Association [IA]. 2005. Landscape Irrigation Scheduling and Water Management. Available at: http://www.irrigation.org/gov/pdf/IA_LISWM_MARCH_2005.pdf. Accessed January 12, 2007.

Jenson, M.E., R.D. Burman, and R.G. Allen. 1990. Evapotranspiration and Irrigation Water Requirements. ASCE Manuals and Reports on Engineering Practices No. 70. American Society of Civil Engineers. New York, New York.

Mayer, P. W., W. B. DeOreo, E. M. Opitz, J. C. Kiefer, W. Y. Davis, B. Dziegielewski, and J. O. Nelson. 1999. Residential End Uses of Water. AWWA Research Foundation and American Water Works Association. Denver, Colorado.

Riley, M. (2005). The cutting edge of residential smart irrigation technology. *California Landscaping*. July/August pp 19-26.

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AE472

Frequency of Residential Irrigation Maintenance Problems[1]

Thomas R. Olmsted and Michael D. Dukes[2]

Introduction

An improperly functioning residential in-ground irrigation system may result in some areas of the landscape showing stress while other areas are well watered. Alternatively, the poorly functioning irrigation system may be applying excess water, resulting in damage to landscape plants and loss of nutrients from the soil. The causes of the poorly functioning irrigation system may be from an inefficient design, improper installation and/or inadequate system maintenance over time.

A poorly designed irrigation system or one installed improperly may not have head-to-head sprinkler spacing, matched application rates of rotor sprinkler nozzles, or spray heads in the same zone. It could also have plants with different water requirements located in the same irrigation zone (Smith 1997). Improper maintenance issues may include clogged or leaking sprinklers, sprinklers obstructed by plant material, and misadjusted sprinklers that over-spray onto sidewalks or streets (*Basic Repairs and Maintenance for Home Landscape Irrigation Systems* found at http://edis.ifas.ufl.edu/ae451).

Irrigation system audits or inspections provide a method of determining the condition of the components and the application uniformity of coverage. In Florida, a fleet of Mobile Irrigation Labs (MILs) provide auditing services to analyze irrigation systems and educate property owners on how to improve water use and promote conservation. The MILs give recommendations on the improvement of existing irrigation systems and equipment, and educate their customers and the general public on water conservation, irrigation planning, and irrigation management. Originally developed for agricultural purposes, now Urban Mobile Irrigation Labs (UMILs) perform the same service for residential clients. The service areas covered by an MIL or UMIL in Florida can be located from the Florida Department of Agriculture and Consumer Services' website at: http://www.floridaagwaterpolicy.com/MobileIrrigationLabs.html.

An UMIL has three levels of evaluation (Palm Beach Soil & Water Conservation District 2008):

1. visual inspection
2. pressure and flow check
3. catch can test (optional)

First, visual inspections are conducted to determine if the system is in disrepair (leaks, broken sprinkler heads, etc.) or has poor coverage. If the system is found to be in poor condition, the other levels of evaluation are not carried out until the repairs are made. Pressure and flow checks on individual sprinkler heads or emitters are carried out next. Catch can tests can be used to measure irrigation

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uniformity and the application rate (how fast the sprinklers apply water) of an irrigation zone. In the urban setting, the catch can test for distribution uniformity is rarely done by the auditors because it is very time consuming. In a typical residential irrigation system with 4 zones, it would take a significant amount of time to complete the steps for the test (laying out the small cans in each zone, running the irrigation for the set amount of time, and then recording all the volumes). Experienced auditors can visually assess poor distribution caused by maintenance issues or inadequate irrigation design. Another way the auditors calculate the application rate of an irrigation zone is to run the zone for a set time and record the volume observed from the water meter converted to depth over the zone's irrigated area.

Under the visual inspection, the technician has a list of 34 codes to describe the problems seen in the irrigation system as shown in Table 1 (the same codes are used for agricultural audits). Any one residence may have multiple problem codes.

Analyzing the frequency or number of times an irrigation maintenance problem occurs will provide a list of the most common irrigation maintenance problems in the residential irrigation system. Knowing the most common problems should increase awareness, which will lead to prevention or corrective action of these problem areas and help reduce water wasted with in-ground irrigation systems.

Procedure

Urban Mobile Irrigation Lab audit information was obtained from the Florida Department of Agriculture and Consumer Services. It consisted of the problem codes per UMIL audits from about 2003 to 2007. After removal of incomplete and corrupted data, the problem codes of 3,416 audits of urban irrigation systems remained.

The frequency of occurrence of each code in all 3,416 audits was tabulated and then the codes were ranked from the most frequent occurrence to the least.

The UMIL audits were concentrated mainly in south Florida.

Results

In the sample of 3,416 residential irrigation systems evaluated by the Florida UMILs, the quantity of problems per audit (or home) ranged from 1 to 18. There were no homes that did not have at least one problem. The first eleven most frequent problem areas represent 80% of all the problems recorded and are listed in Table 2.

Five problem areas represent half of all recorded problems. They are as follows:

1. Turf and landscape area irrigated in the same zone
2. Mixed sprinkler/emitter sizes & unmatched application rates in the same zone
3. Stream of water blocked by vegetation
4. Operating time too frequent
5. Operating time too long

Turf and landscape area irrigated in the same zone

In 70% of the residential systems evaluated, the turf and landscape (ornamental beds) areas were irrigated by the same zone. This means that ornamentals and turfgrass are irrigated simultaneously because an irrigation zone covers both types of plant material (Figure 1). In most cases, ornamentals need less frequent irrigation than turfgrass. If the zone is programmed with a run-time for the water requirement of the turfgrass, the result could be over-irrigation of the ornamentals.

Figure 1. Ornamentals and turfgrass being irrigated from the same irrigation zone. Note: the spray head in the background is irrigating the ornamentals and the rotary sprinkler is irrigating the turfgrass in the foreground (photo by Michael Gutierrez).

How this is "fixed" depends on the severity of overlap. A few nozzles hitting the ornamentals will probably not justify changing the system. However, if there are rotor sprinklers or spray heads designed for turf irrigation irrigating ornamentals beds instead, they probably should be replaced with a lower flow-rate sprinkler or removed altogether.

On newly installed irrigation systems, this overlapping of two different plant materials should be avoided. The irrigation contractor should have the landscape plans and install the irrigation system zones according to plant type. Correcting this problem has a potential to save water, depending on how many spray heads or rotor sprinklers are removed (Table 3).

Mixed sprinkler/emitter sizes & unmatched application rates in the same zone

Mixing sprinkler types with different flow rates or application rates in the same zone was found to be the next most frequently occurring problem (Figure 2). For pictures of the different sprinkler types see *Operation of Residential Irrigation Controllers* at http://edis.ifas.ufl.edu/ae220. The result of this problem could be either over- or under-irrigation of part of the zone. If the rotor or spray head has a higher application rate than designed, the plant may not effectively use the excess water. If the application rate of an individual rotor sprinkler or spray head is less than designed, the homeowner may see that area is drier than the rest of the zone and increase the run-time to compensate, over- irrigating the other areas of the zone.

Figure 2. Mixed sprinkler types. Note: rotary sprinkler in foreground and spray heads in background (photo by Bernard Cardenas).

Unmatched application rate rotor sprinklers or spray heads can easily be fixed by changing out the incorrect nozzle and installing the correct one. The size of the mismatch will determine the quantity of water saved. Changing out the nozzles should involve only a moderate investment of time and money (Table 3).

Stream of water blocked by vegetation

The next most often occurring problem is the water stream from the sprinkler is deflected or blocked by vegetation (Figure 3). When the water hits vegetation close to the sprinkler, it is concentrated in certain areas and prevents spray uniformity. In older homes, either the vegetation could have grown substantially since the irrigation system installation or the system was installed without the proper risers to clear the vegetation. If the stream of water is being blocked, then the plant material on the other side is not receiving the water the system was designed to deliver. This could stress the plant material or possibly result in an ill-advised decision to increase run-times to try to compensate for the lack of water in those areas.

Figure 3. Blocked water spray (photo by Bernard Cardenas).

If vegetation is blocking a stream of water from a nozzle, the options to fix it include cutting or trimming the vegetation, installing a new sprinkler with a higher riser, moving or removing the offending sprinkler or spray head, or replacing vegetation in the area not receiving water with drought-tolerant plants. Any water savings after fixing the problem may be minimal and depend on the area being blocked and the type of vegetation not receiving the full coverage. If the water blockage is causing turf stress, then one of the repair options should be considered (Table 3).

Operating time too frequent and Operating time too long

Two issues occurring in about 50% of the homes audited dealt with the irrigation timer. Either the timer was set to run (irrigate) too frequently and/or too long (longer than necessary run-time per zone). These homes were probably not following the days of the week watering restrictions set by the water management district or the local water utility. Given the same run-times, irrigating 3, 5, or 7 days a week will result in more water usage and over-irrigation than irrigating with the same run-time 1 or 2 days a week. When the irrigation timers are set for a longer duration or run-time per zone than necessary the irrigation water will probably exceed the water-holding capacity of the soil. The excess water will either runoff or be lost to deep drainage.

These problems can easily be changed by re-programming the irrigation time clock. A properly set irrigation time clock can reduce irrigation water use by 30% (Haley et al. 2007). This change has the potential to quickly save a significant amount of water. Instructions on programming the irrigation time clock can be found in *Operation of Residential Irrigation Controllers* at http://edis.ifas.ufl.edu/ae220. Changing the time clock settings may be the most cost-effective change to save irrigation water (Table 3).

Smart irrigation controllers

To lessen the need for homeowners to worry about the settings on their irrigation controller/timer, the irrigation industry has developed “smart” irrigation controllers. The two types are as follows:

- evapotranspiration-based controllers
- soil moisture sensor controllers

(For more information on the application of these “smart” controllers in the residential irrigation system see: *Smart Irrigation Controllers: What Makes an Irrigation Controller Smart?* found at http://edis.ifas.ufl.edu/ae442.)

The evapotranspiration-based controllers operate using weather data and site specific inputs such as sprinkler and plant type. The controllers calculate the water requirement of the plants during a time period and adjust or operate the irrigation system to replenish the water lost by the plant (evapotranspiration). See: *Smart Irrigation Controllers: Operation of Evapotranspiration-Based Controllers* found at http://edis.ifas.ufl.edu/ae446.

Soil moisture sensor controllers measure the actual soil moisture where plant roots are located. When the soil moisture goes below a certain value (measured by how dry the soil is) the irrigation system is allowed to irrigate. Conversely, if the soil moisture is above that value, then there is sufficient moisture in the soil for plant growth and the irrigation system will not be allowed to irrigate. See: *Smart Irrigation Controllers: How Do Soil Moisture Sensor (SMS) Irrigation Controllers Work?* found at http://edis.ifas.ufl.edu/ae437.

Both of these types of “smart” irrigation controllers can save water over conventional irrigation time clocks with no control device. Once set up properly these controllers can relieve the burden of changing the irrigation controller/timer to match the changing landscape water needs (*Energy Efficient Homes: The Irrigation System* found at http://edis.ifas.ufl.edu/fy1043).

Conclusion

The majority of Florida in-ground irrigation systems have some type of maintenance problem that could be causing excessive water use. Inspections should be done on a regular basis. The Florida UMILs are qualified to do these inspections and will provide them free of charge. Homeowners not in a UMIL service area but who would like to have their irrigation system inspected should call their local water utility. They may offer a similar program or can recommend some qualified irrigation contractors.

Acknowledgement

Appreciation goes to Camilo Gaitan with the Florida Department of Agriculture and Consumer Services for supplying the UMIL data.

References

Dukes, M.D., and D.Z. Haman (2008, December). Operation of residential irrigation controllers. Institute of Food and Agricultural Sciences EDIS Document AE220. Retrieved June 1, 2010 from http://edis.ifas.ufl.edu/ae220

Dukes, M.D., M. L. Shedd, and S. L. Davis (2009, February). Smart irrigation controllers: operation of evapotranspiration-based controllers. Institute of Food and Agricultural Sciences EDIS Document AE446). Retrieved June 1, 2010 from http://edis.ifas.ufl.edu/ae446

Dukes, M.D., M. Shedd, and B. Cardenas-Lailhacar (2009, February). Smart irrigation controllers: how do soil moisture sensor (SMS) irrigation controllers work? Institute of Food and Agricultural Sciences EDIS Document AE437. Retrieved June 1, 2010 from http://edis.ifas.ufl.edu/ae437

Dukes, M.D. (2009, February). Smart irrigation controllers: What makes an irrigation controller smart? Institute of Food and Agricultural Sciences EDIS Document AE442. Retrieved June 1, 2010 from http://edis.ifas.ufl.edu/ae442

Haley, M.B., M.D. Dukes, S. Davis, M. Shedd, and B. Cardenas-Lailhacar (2008, June). Energy efficient homes: the irrigation system. Institute of Food and Agricultural Sciences EDIS Document FY1043. Retrieved June 1, 2010 from http://edis.ifas.ufl.edu/fy1043

Haley, M.B., M. D. Dukes and G.L. Miller (2007). Residential irrigation water use in Central Florida. *Journal of Irrigation and Drainage Engineering*, 133, 427-434.

McCready, M.S., M. D. Dukes, and K. Migliaccio (2009, October). Basic repairs and maintenance for home landscape irrigation systems. Institute of Food and Agricultural Sciences EDIS Document AE451. Retrieved June 1, 2010 from http://edis.ifas.ufl.edu/ae451

Palm Beach Urban Mobile Irrigation Lab: Quarterly Report (2008, March). Palm Beach County Soil & Water Conservation District.

Smith, S. (1997). *Landscape irrigation* (1st ed.). New York, NY: John Wiley and Sons.

Table 1. UMIL Problem Codes (Palm Beach Soil & Water Conservation District 2008)

Code	Description of Problems
Pressure / Application Rate	
1	Under-sized pump for number and type of sprinkler heads or emitters
2	Pressure loss between pump and sprinklers/emitters due to inadequate pipe size
3	Higher pressure than manufacturer's specifications
4	Lower pressure than manufacturer's specifications
5	Low pressure due to water supply
6	Different pressure between manifolds
7	Small wetted area
8	Application rate > soil infiltration rate (ponding)
9	Air in pipelines
10	Turf and landscape area irrigated in the same zone
11	Pressure variation due to elevation differences
Emitters / Sprinklers	
20	Mixed sprinkler/emitter sizes & unmatched application rates in the same zone
21	Mixed sprinkler/emitter brands or types in the same zone
22	Poor emitter/sprinkler uniformity due to worn orifice
23	Poor overlap due to improper sprinkler/emitter alignment or spacing
24	Various riser heights in same zone
25	Emitter/sprinkler spacing varies in same zone
26	Missing/malfunctioning emitters or sprinklers
27	Missing/malfunctioning pressure gauge/regulator/filter
Maintenance - Irrigation System	
30	Leaks and broken valves, pipe, laterals lines (Poly-tubing), emitters, sprinklers
31	Clogged filter or filter screen
32	Sprinkler heads not properly adjusted, causing overflow on paved areas
33	Clogged emitters/nozzles (due to biological, chemical, or physical factors)
34	Leaning sprinklers/emitters causing non-uniform distribution
35	Malfunctioning valves
Maintenance – Landscape	
40	Stream of water blocked by vegetation
41	Variable crop spacing and stage of growth
42	Poor drainage, requiring water control
Operation / Management	
50	Operating time too long
51	Operating time too short
52	Operating time too frequent
53	No rain shut-off device
54	No soil moisture measuring device or rain gauge
55	No irrigation water management plan

Table 2. Eleven Most Frequent Problems in Residential Evaluations of 3,416 Homes.

Code/ Problem	Frequency of Occurrence	On Percent of Homes Evaluated	As a Percent of Total Problems	Cumulative Percent of Total
10/ Turf and landscape area irrigated in the same zone	2,419	70.8	11.7	11.7
20/ Mixed sprinkler/emitter sizes & unmatched application rates in the same zone	2,246	65.7	10.9	22.6
40/ Stream of water blocked by vegetation	2,029	59.4	9.8	32.5
52/ Operating time too frequent	1,827	53.5	8.9	41.3
50/ Operating time too long	1,773	51.9	8.6	49.9
32/ Sprinkler heads not properly adjusted, causing overflow on paved areas	1,333	39.0	6.5	56.4
21/ Mixed sprinkler/emitter brands or types in the same zone	1,252	36.7	6.1	62.4
53/ No rain shut-off device	1,076	31.5	5.2	67.7
30/ Leaks and broken valves, pipe, laterals lines (Poly-tubing), emitters, sprinklers	971	28.4	4.7	72.4
55/ No irrigation water management plan	782	22.9	3.8	76.2
23/ Poor overlap due to improper sprinkler/emitter alignment or spacing	729	21.3	3.5	79.7

Table 3. Estimated Effort, Cost, and Water Savings of the Top 5 UMIL Problem Areas.

Irrigation Problem	Effort Required to Repair	Average Cost to Repair	Expected Water Savings
Turf and landscape area irrigated in same zone	moderate	high	moderate
Mixed sprinkler sizes and unmatched application rates in the same zone	moderate	moderate	moderate
Stream of water blocked by vegetation	moderate	moderate	low
Operating time too frequent	low	low	high
Operating time too long	low	low	high

UNIVERSITY OF FLORIDA
IFAS EXTENSION

CIR832

Pumps for Florida Irrigation and Drainage Systems[1]

Dorota Z. Haman, Forrest T. Izuno and Allen G. Smajstrla[2]

The primary function of a pump is to transfer energy from a power source to a fluid, and as a result to create flow, lift, or greater pressure on the fluid. A pump can impart three types of hydraulic energy to a fluid: lift, pressure, and velocity. In irrigation and drainage systems, pumps are commonly used to lift water from a lower elevation to a higher elevation and/or add pressure to the water.

The classification of pumps used in this publication first defines the principle by which energy is added to the fluid, then identifies the means by which this principle is implemented, and finally, distinguishes among specific geometries commonly used. Under this system of classification, all pumps may be divided into two major categories: 1) dynamic pumps, where continuously added energy increases velocity of the fluid and later this velocity is changed to pressure, and 2) displacement pumps where periodically added energy directly increases pressure.

This publication will discuss only dynamic pumps which are commonly used for pumping water in agricultural applications such as irrigation and drainage. Displacement pumps have limited capacities and are not suitable for pumping large amounts of water required for irrigation or drainage. They are used mainly for chemical injection in agricultural irrigation systems. Displacement pumps are discussed in another publication.

Dynamic pumps described in this publication can be classified as one of several types of centrifugal pumps and a group of special effect pumps (Fig. 1).

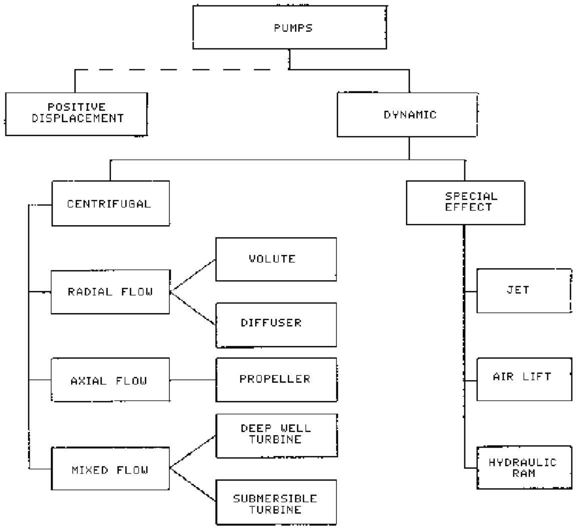

Fig. 1.

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[1] This document is CIR832, one of a series of the Agricultural and Biological Engineering Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Original publication date July 1989. Reviewed June 2003. Visit the EDIS Web Site at http://edis.ifas.ufl.edu.

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CENTRIFUGAL PUMPS

In centrifugal pumps, energy is imparted to a fluid by centrifugal action often combined with propeller or lifting action. Centrifugal pumps can be classified by impeller shape and characteristics. Impellers are grouped according to the major direction of flow with respect to the axis of rotation. A continuous range in impeller types can be found. They vary from the radial-flow type (which develops head mainly by the action of centrifugal force), through mixed-flow types, to the axial flow type (which develops most of its head by the propelling or lifting action of the vanes).

With respect to type of impeller, all centrifugal pumps can be classified into the three following groups:

- Radial-flow pumps
- Axial-flow pumps
- Mixed-flow pumps

In addition, a centrifugal pump can be classified in one of four major groups depending on its design and application (Figure 1):

- Volute pumps
- Diffuser pumps
- Turbine pumps
- Propeller pumps

Table 1 presents advantages and disadvantages of various centrifugal pumps. This comparison may be helpful in selecting a centrifugal pump for a particular application. (also see Table 3)

Further subclassification of centrifugal pumps distinguishes among the number of water inlets to the impeller. There are single suction impellers and double suction impellers.

Finally, the mechanical construction of the impeller itself provides an additional classification (Figure 2). The impeller can be:

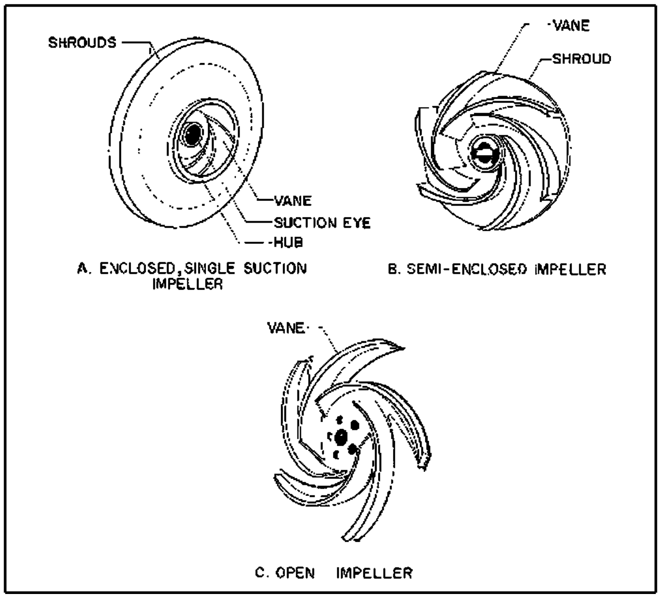

Fig. 2.

- Enclosed with shrouds or side walls
- Open with no shrouds
- Semi-open or semi-closed.

Most irrigation pumps use enclosed or semi-enclosed impellers. Pumps with open impellers are usually used for pumping liquids with large particles and may be advantageous in drainage or when animal waste is applied through an irrigation system. Open impellers require frequent adjustments since the clearance between the impeller and the housing is critical.

RADIAL-FLOW PUMPS

Basically, a centrifugal radial-flow pump has two main parts: 1) a rotating element (impeller and shaft) and 2) a stationary element (casing, stuffing box and bearings). Water enters the pump near the axis of the high-speed impeller, and by centrifugal force is thrown radially outward into the pump casing. The velocity head imparted to the fluid by the impeller is converted into pressure head by means of a volute (Figure 2) or by a set of stationary diffusion vanes (Figure 3) surrounding the impeller.

VOLUTE PUMPS

The centrifugal volute pump is the most common type of radial-flow centrifugal pump. It has an impeller housed in a progressively widening spiral

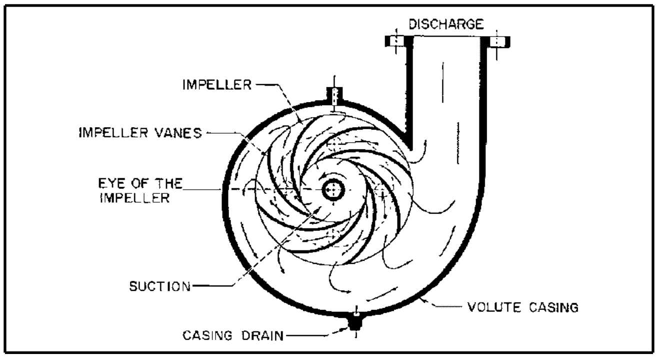

Fig. 3.

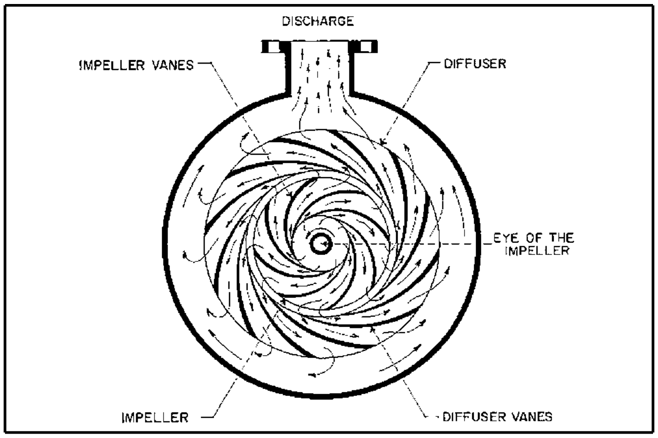

Fig. 4.

casing as shown in Figure 2 . Water enters the eye of the impeller and is thrown radially outward. This type of pump does not have diffuser vanes to reduce the velocity of the water. Instead, velocity is reduced by the shape of the volute itself. This design creates an unequal pressure distribution along the volute which may result in a heavy thrust load on the impeller, creating deflection of the shaft, and increasing the probability of its failure.

Volute pumps can be single-suction or double-suction pumps. A single-suction pump impeller is exposed to a large axial hydraulic thrust resulting from the unbalanced hydraulic pressures on the impeller. In a double-suction pump, water is fed from both sides of the impeller, significantly improving its hydraulic balance. As a result, double-suction volute pumps can produce higher pressures than single-suction pumps.

Volute pumps are commercially available as single-stage (single impeller) or multistage (multiple impellers) pumps. The main reason for the multistage configuration is to increase the head produced by the pump. If a multistage pump has single suction impellers, the impellers are usually arranged with equal numbers discharging in opposite directions to counteract the hydraulic imbalance on each of the impellers.

Volute pumps are used where irrigation water is obtained from depths generally less than 20 ft. The exact value of possible lift is determined by the net positive suction head required by the pump and other factors as discussed later in this publication.

DIFFUSER PUMPS

In a diffuser-type centrifugal pump, the impeller is surrounded by a ring of fixed diffuser vanes that provide enlarging passages in which the velocity of the water leaving the impeller is reduced, and as a result pressure is increased (Figure 4). The diffuser vanes provide a more controlled flow and allow a more efficient conversion of velocity into pressure than volute pumps. Shock losses are small since the change from velocity to pressure takes place gradually. Diffuser pumps, especially large ones, often have efficiencies over 90 percent. Diffuser pumps have the additional advantage of a balanced radial loading on the impeller, which reduces the chance of shaft failure due to fatigue.

Diffuser pumps are usually selected for high head applications (high pressure). As with volute pumps, diffuser pumps can be single or multistage depending on pressure requirements.

AXIAL-FLOW PUMPS

Axial-flow pumps, also called propeller pumps, produce flow by the lifting action of the propellers. Axial-flow pumps are designed for conditions where the capacity is relatively high and the head developed by the pump is low.

An axial pump does not produce high pressure or lift, but can have significant flow capacity if the pump is large enough. Most axial-flow pumps operate on installations where suction lift is not required. Generally, these pumps are mounted vertically or on an incline from vertical since it is necessary to submerge the impeller of an axial-flow pump. In some applications where high volumes of water are required and ample submergence above the pump is available, it is possible to mount an axial-flow pump in a horizontal position.

MIXED-FLOW PUMPS

Mixed-flow centrifugal pumps use both centrifugal force and some lifting action to move water. Water is discharged both radially and axially into a volute-type casing. The process is a combination of processes occurring in volute and axial-flow types of pumps. Mixed-flow impellers are often used in deep-well turbine and submersible turbine pumps.

DEEP-WELL TURBINE PUMPS

Under this category are grouped all types of pumps that are suspended by the discharge column within which the drive shaft is located (Figure 5). The name, deep-well turbine pump, is applied only to pumps operating on the centrifugal principle and having diffuser vanes within the bowl or case. They can be single-stage or multistaged for higher pressure applications. Pump bowls which contain impellers and diffusers are located below the water surface, and they should be submerged under pumping conditions. The drive shaft is located in the center of a discharge pipe and it can be either oil or water lubricated.

SUBMERSIBLE TURBINE PUMPS

A submersible turbine pump is a turbine pump that is close-coupled to a submersible motor which is attached to the lower end of the pump (Figure 6). This eliminates the long shaft required for deep-well turbine pumps. Submersible pumps are primarily deep-well pumps; however, they are sometimes used under conditions where the depth of water changes significantly during the season and may drop below the level required for the centrifugal volute or diffuser pump.

IMPORTANT CONCEPTS FOR CENTRIFUGAL PUMPS

Important concepts associated with the operation of centrifugal pumps include pump efficiency, net positive suction head, specific speed, affinity laws, cavitation, and priming. Good design, efficient operation, and proper maintenance require understanding of these concepts.

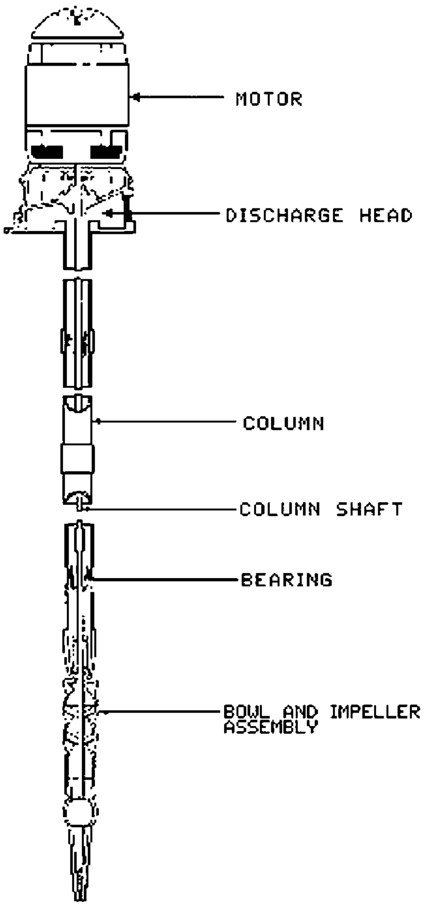

Fig. 5.

Pump Efficiency

The efficiency of a pump is a measure of its hydraulic and mechanical performance. It is defined as the ratio of the useful power delivered by the pump (water horsepower) to the power supplied to the pump shaft (brake horsepower). The efficiency of the pump is expressed in percent and can be calculated using Equation 1: To calculate water horsepower the flow rate in gpm and the total dynamic head (TDH) in feet must be known. Water horsepower can be calculated using Equation 2 : The efficiency of a pump is determined by actual test. All parameters required for the determination of water horsepower are recorded while brake horsepower is measured. Then, equations (1) and (2) are used to calculate the efficiency of the pump. The efficiency range to be expected varies with the pump size, type and design. However, it is normally between 65 and 80 percent. A pump should be selected for a given application so

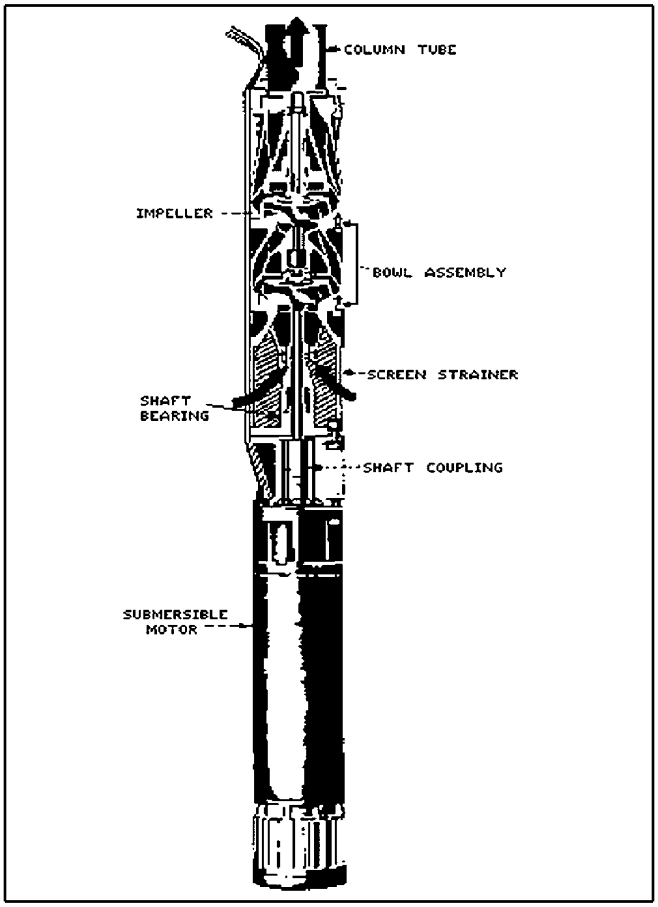

Fig. 6.

that it will operate close to its point of maximum efficiency.

$$E = \frac{whp}{bhp} \times 100\%$$

where:

whp = water horsepower

bhp = brake horsepower

Equation 1.

$$whp = \frac{gpm \times TDH}{3960}$$

Equation 2.

Suction Lift

The absolute pressure on the water at the water source is the driving force for the water moving into the eye of the impeller. Theoretically, if a pump could create a perfect vacuum at the eye of the impeller, and if it were operating at sea level, the atmospheric pressure of approximately 14.5 psi would be the driving force pushing water into the eye of the impeller. This pressure could lift water a distance of 34 ft. (1 psi = 2.31 ft. of water). In practice, this lift is much smaller due to lack of perfect vacuum in the impeller and friction losses in the intake pipe. The practical value of maximum lift differs between pumps, but it is usually no greater than 20 ft. If the pump is submerged under water, static water pressure is an additional driving force pushing water into the eye of the impeller and it must be added to the atmospheric pressure. Each foot of water above the eye of the impeller will add 0.43 psi of pressure to the driving force.

Net Positive Suction Head

Net positive suction head available (NPSHa) is the absolute pressure of the water at the eye of the impeller. It is atmospheric pressure minus the sum of vapor pressure of the water, friction losses in the intake pipe, and suction head or lift. Since any variation of these four factors will change the NPSHa, NPSHa should be calculated using Equation 3: Suction head (SH) must be added instead of subtracted if the water source is located above the eye of the pump impeller (submerged pump). An accurate determination of NPSHa is critical for any centrifugal pump application.

$$NPSHa = BP - SH - FL - VP$$

where:

BP = barometric pressure (ft)

SH = suction head or lift (ft)

FL = friction losses in the intake pipe (ft)

VP = water vapor pressure at a given temperature (ft)

Equation 3.

The NPSHr (Net Positive Suction Head required) is a measure of the head necessary to transfer water into the impeller vanes efficiently and without cavitation (see the discussion of cavitation in a later section of this publication). The NPSHr required by a specific centrifugal pump depends on the pump design and flow rate. It is constant for a given head, flow, rotational speed and impeller diameter. However, it changes with wear and different liquids since it depends, respectively, on the impeller geometry and on the density and viscosity of the fluid. For a given pump NPSHr increases with increases in pump speed, flow rate, and water temperature.

The value of NPSHr is provided by the manufacturer for each specific pump model and it is normally shown as a separate curve on a set of pump characteristic curves. To avoid cavitation NPSHa must be always equal to or greater than NPSHr.

Specific Speed

Two pumps are geometrically similar when the ratios of corresponding dimensions in one pump are equal to the same ratios of the other pump. Specific speed is a constant for any geometrically similar pump. It is an index number correlating pump flow, head and speed at the optimum efficiency point which classifies pump impellers with respect to their geometric similarity. Specific speed is usually expressed as shown in Equation 4: It should be noted that for a double suction impeller the flow (Q) is taken as half of the total flow.

$$N_s = \frac{N\sqrt{Q}}{H^{3/4}}$$

where:

N_s = pump specific speed
N = rotational speed of pump at optimum efficiency (rpm)
Q = flow at optimum efficiency (gpm)
H = head at optimum efficiency (ft)

Equation 4.

The specific speed is an index which is used when selecting impellers to meet different conditions of head, capacity, and speed. Knowing this index is very helpful in the determination of the maximum permissible suction lift, or minimum suction head, which is necessary to avoid cavitation under different capacities, heads and pump speeds. For a given head and capacity, suction lift is greater for a pump with lower specific speed.

The calculation of specific speed allows for determination of the pump type required for a given set of conditions to be determined. Usually high head impellers have low specific speeds and low head impellers have high specific speeds. (see Table 2)

There is often an advantage in using pumps with high specific speeds since, for a given set of conditions, their operating speed is higher, and the pump is therefore smaller and less expensive. However, there is also some trade-off since pumps operating at higher speeds will wear faster.

Affinity Laws

A set of formulas called **affinity laws** governs the performance of a given pump and the performance of geometrically similar pumps. Basically, affinity laws state that for a given pump, the capacity will vary directly with a change in speed, the head will vary as the square of speed, and the required horsepower will vary as the cube of speed or, mathematically, as shown in Equation 5: Assuming that impeller diameter is held constant, the mathematical relationships between these variables can be expressed as shown in Equation 6: Basically, the above relationships mean that an increase in pump speed will produce more water at a higher head but will require considerably more power to drive the pump. These calculated values are very close to actual test results, provided pump efficiency does not change significantly. However, when conditions are changed by speed adjustment, usually there is no appreciable change in efficiency within the range of normal pump operation speeds (6).

$$Q \propto N$$
$$H \propto N^2$$
$$BHP \propto N^3$$

where:

Q = pump capacity in gpm
H = pump head in feet
BHP = required brake horsepower
N = rotational speed of pump

Equation 5.

Law 1a:

$$\frac{Q_1}{Q_2} = \frac{N_1}{N_2}$$

Law 2a:

$$\frac{H_1}{H_2} = \left[\frac{N_1}{N_2}\right]^2$$

Law 3a:

$$\frac{BHP_1}{BHP_2} = \left[\frac{N_1}{N_2}\right]^3$$

where:

Q_1, H_1, BHP_1 are determined at speed N_1 (rpm)
and
Q_2, H_2, BHP_2 are determined at speed N_2 (rpm)

Equation 6.

For increase in pump speed the NPSHr increases but it cannot be determined from the affinity laws. Also the laws do not say anything about how the efficiency of the pump will change with speed, but generally this is not a significant change. NPSHr and efficiency changes must be obtained from the pump manufacturer's data (pump characteristic curves).

The above equations assume that the diameter of the pump impeller is constant. In some cases the size of the impeller can be changed. Often a pump is very precisely matched to a specific application by trimming the impeller. It is not feasible to increase impeller diameter.

There is a second set of affinity laws (Equation 7), which describes the relationships between the same variables when the impeller size is changed under constant speed conditions. These laws relate the impact of impeller diameter changes to changes in pump performance. Since change of impeller diameter changes other design relationships in a pump, therefore, this second set of affinity laws does not yield the accurate results of the first three laws discussed above and must be applied with caution.

Law 1b:

$$\frac{Q_1}{Q_2} = \frac{D_1}{D_2}$$

Law 2b:

$$\frac{H_1}{H_2} = \left[\frac{D_1}{D_2}\right]^2$$

Law 3b:

$$\frac{BHP_1}{BHP_2} = \left[\frac{D_1}{D_2}\right]^3$$

where:

D_1 = **initial diameter of impeller**

D_2 = **diameter of impeller after trimming**

Equation 7.

This second set of affinity laws strictly applies only to radial-flow pumps. They are only approximate for mixed-flow impellers. In addition, these equations only hold for small changes in impeller diameter. Calculations for a trim of more than 10 percent of the original diameter can be significantly in error.

Cavitation

Pump cavitation is defined as the formation of cavities on the back surface of an impeller and the resulting loss of contact between the impeller and the water being pumped (Walker, 1972). These cavities are zones of partial vacuum which fill with water vapor as the surrounding water boils due to the reduced pressure in the cavities. The cavities are displaced with the flowing water along the pump impeller surfaces toward the outer circumference of the impellers. As they move toward the circumference, the pressure in the surrounding water increases, and the cavities collapse against the impellers with considerable force. The force created by the collapse of the cavities often causes erosion and rapid wear of the pump impellers as well as a characteristic noise during pump operation.

The process of cavitation is caused by the reduction in pressure behind the impellers to the point that the water vaporizes (boils). Thus, it can be caused by any combination of factors which allow pressure to drop to that point, including inadequate submergence or excessive suction lift so that little pressure is available to move water into the pump, high impeller speeds which cause extremely low pressures to be generated behind the impellers, restricted pump intake lines which prevent water from moving readily into the pump, and high water temperatures which decrease the pressure at which water vaporizes.

Cavitation can occur in all types of pumps and it can create a serious problem. In some cases of mild cavitation, the only problem may be a slight drop in efficiency. On the other hand, severe cavitation may be quite destructive to the pump and result in pitting of impeller vanes. Since any pump can be made to cavitate, care should be taken in selecting the pump for a given system and planning its installation.

Pump manufacturers specify the Net Positive Suction Head required (NPSHr) for the operation of a pump without cavitation. Pump cavitation can be avoided by assuring that the net positive suction head available (NPSHa) is always greater than that required (NPSHr) by the pump.

Cavitation in Radial Flow and Mixed Flow Pumps

In radial-flow and mixed-flow types of centrifugal pump, when the water enters the eye of the impeller, an increase in velocity takes place. As a result of this velocity increase, water pressure is reduced as the water flows from the inlet of the pump to the entrance to the impeller vanes resulting in cavitation.

A concentrated transfer of energy during cavitation creates local forces capable of destroying metal surfaces. The more brittle the material which the impeller is constructed of, the greater the damage. In addition to causing severe mechanical damage, cavitation causes a loss of head, reduces pump efficiency, and results in noisy pump operation.

If cavitation is to be prevented, volute or diffuser pumps must be provided with water under absolute pressure which exceeds the NPSHr. The following conditions should be avoided in volute and diffuser pump installations:

- Heads much lower than head at peak efficiency of pump.
- Capacity much higher than capacity at peak efficiency of pump.
- Suction lift higher or submergence head lower than recommended by manufacturer of the pump.
- Water temperature higher than that for which the system was originally designed.
- Speeds higher than manufacturer's recommendation.

Cavitation in Axial-Flow Pumps

In axial-flow pumps cavitation cannot be explained in the same way as for radial-flow and mixed-flow pumps. The water enters an axial-flow pump in a large bell-mouth inlet and is guided to the smallest section, called the throat, immediately ahead of the propeller (Figure 7). The capacity at this point should be sufficient to fill the ports between the propeller blades. When the head is increased beyond a safe limit, the capacity is reduced to a quantity insufficient to fill up the space between the propeller vanes, creating cavities of almost a perfect vacuum. When these cavities collapse the water hits the propeller vane with a force sufficient to pit the surface of the vane. The first two cavitation prevention rules listed for volute and diffuser pump are different for an axial-flow pump. Avoid:

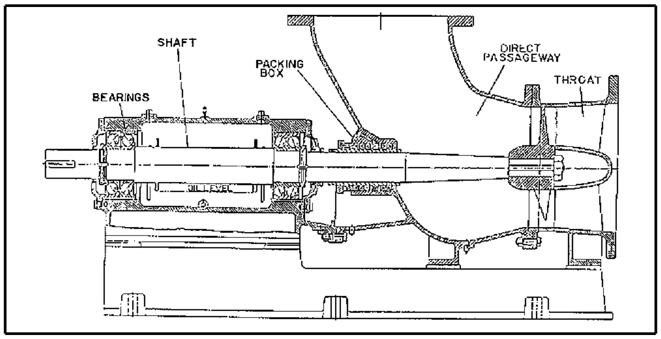

Fig. 7.

- Heads much higher than head at peak efficiency of pump.
- Capacity much lower than capacity at peak efficiency of pump.

The last three rules are the same for all centrifugal pumps.

Priming of Centrifugal Pumps

All centrifugal pumps must be primed by filling them with water before they can operate. The objective of priming is to remove a sufficient amount of air from the pump and suction line to permit atmospheric pressure and submergence pressure to cause water to flow into the pump when pressure at the eye of the impeller is reduced below atmospheric as the impeller rotates.

When axial-flow and mixed-flow pumps are mounted with the propellers submerged, there is normally no problem with repriming of these pumps because the submergence pressure causes water to refill the pumps as long as air can readily be displaced. On the other hand, radial-flow pumps are often located above the water source, and they can lose prime. Often, loss of prime occurs due to an air leak on the suction side of the pump. Volute or diffuser pumps may lose prime when water contains even small amounts of air or vapor. Prime will not be lost in a radial-flow pump if the water source is above the eye of the impeller and flow of water into the pump is unrestricted.

In some cases pumps are primed by manually displacing the air in them with water every time the pump is restarted. Often, by using a foot valve or a check valve at the entrance to the suction pipe, pumps can be kept full of water and primed when not operating. If prime is lost, the water must be replaced manually, or a vacuum pump can be used to remove air and draw water into the pump.

A self-priming pump is one that will clear its passages of air and resume delivery of liquid without outside attention. Centrifugal pumps are not truly self-priming. So called self-priming centrifugal pumps are provided with an air separator in the form of a large chamber or reservoir on the discharge side of the pump. This separator allows the air to escape from the pump discharge and entraps the residual liquid necessary during repriming. Automatic priming of a pump is achieved by the use of a recirculation chamber which recycles water through the impeller until the pump is primed, or by the use of a small positive displacement pump which supplies water to the impeller.

SPECIAL EFFECT PUMPS

Jet Pumps

A jet pump is a combination of a volute centrifugal pump and a nozzle-venturi arrangement. The driving force lifting the water in this type of pump is provided by a high pressure nozzle which creates a low pressure region in a mixing chamber. This low pressure causes water to flow into the pump (Figure 8a and Figure 8b). A diffuser following the mixing chamber slows down the water and converts velocity head into pressure head. The jet nozzle is installed in the pipe conveying the water. For a shallow well the nozzle is frequently located outside the well next to the centrifugal pump (Figure 8a). However, for a deep well, the nozzle can be placed inside the well in the intake line (Figure 8b). This location increases the jet pump lift capability considerably beyond that which is practical for the volute centrifugal pump. The role of the centrifugal pump in a jet pump is to produce the flow to the nozzle and maintain the combined flow through the intake pipe beyond this point.

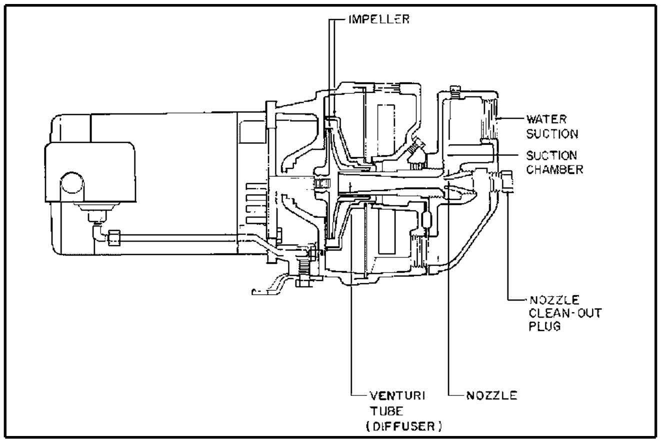

Fig. 8a.

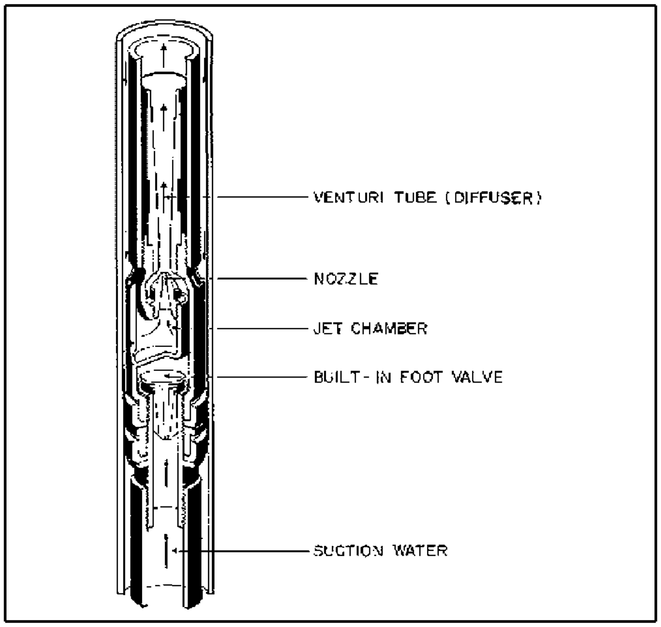

Fig. 8b.

Jet pumps are self-priming, have no moving parts and do not require lubrication. Their efficiency is typically low (on average about 40%) and they provide low flows at high pressure. Because of this characteristic, they are not suitable for large scale irrigation. However, they are frequently used for home water supplies and irrigation of lawns and gardens.

Air-Lift Pumps

Air-lift pumps operate on the principle that a mixture of air and water will rise in a pipe surrounded by water. An air-lift pump basically consists of a vertical pipe partially submerged in water and an air supply tube allowing compressed air to be fed into the pipe at a considerable distance below the static water surface. The mixture of water and air is lighter than the water outside the pipe and it rises in the pipe (Figure 9). The head which can be produced depends on the depth of submergence of the air tube.

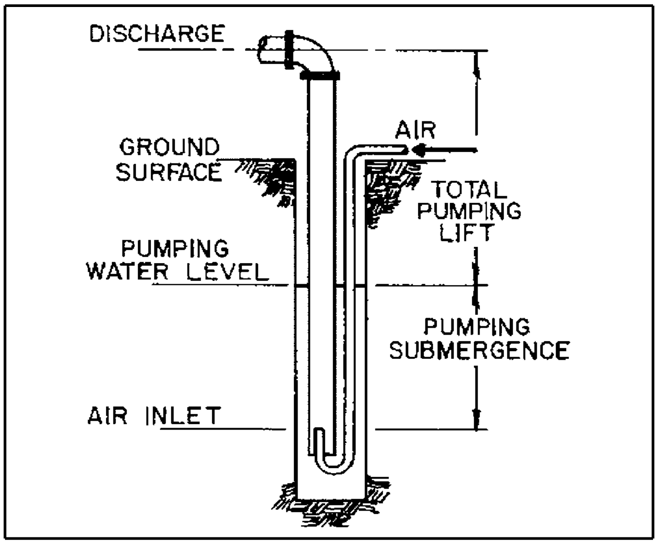

Fig. 9.

Air-lift pumps are relatively inefficient. Typical efficiencies range between 30 and 50 percent. Generally, air-lift pumping is most efficient when the static water level is high, the casing diameter is relatively small, and the well depth is not excessive in relation to the pressure capability of the compressor.

The volume of air needed to lift the water depends on the total pumping lift, the submergence, the length of air line, and the casing length and diameter. A useful rule of thumb for determining the proper compressor capacity for air-lift pumping is to provide about 3/4 cfm (cubic feet per minute) of air for each 1 gpm of water at the anticipated pumping rate.

Air-lift pumps have some advantages over the other pumps discussed above. They do not have any moving parts, can be used in a corrosive environment, and are easy to use in irregularly shaped wells where other deep well pumps cannot fit. Air-lift pumps are not available from suppliers, but they are very simple to build. The main disadvantages of air-lift pumps are their low efficiencies and requirement of a very large submergence as compared to other pumps.

Hydraulic Ram Pumps

A hydraulic ram pump is a motorless low flow rate pump. It uses the energy of flowing water to operate (Figure 10). It is suitable for use where a large flow rate is not required. The flow rate of typical commercially available units is limited to approximately 14 gallons per minute or 20,000 gallons per day. The head produced by the pump depends on quantity and velocity of water flow at the pumping source. Water can be lifted up to 400 feet depending upon the quantity and velocity of water flow in the delivery pipe. Hydraulic ram pumps can be used for domestic water supply or livestock watering. Usually, their flow rates are too small to consider them for other applications, such as irrigation. For more information on operation and selection of hydraulic ram pumps see Agricultural Engineering Fact Sheet AE-19.

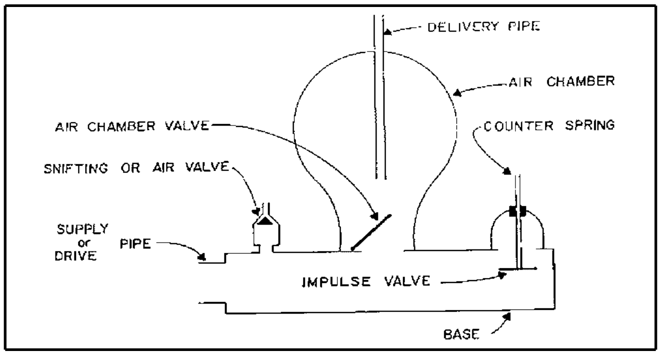

Fig. 10.

REFERENCES

Driscoll, F.G. 1986. *Groundwater and Wells*. Johnson Division, St. Paul, MN.

Harrison, D.S. 1980. *Hydraulic Ram Pumps*. Agricultural Engineering Department. Fact Sheet AE-19, IFAS, University of Florida, Gainesville, FL 32611.

Holland, F.A. and F.S. Chapman. 1966. *Pumping of Liquids*. Reinhold Publishing Corporation, New York.

Hydraulic Handbook. 1979. Colt Industries, Fairbanks Morse Pump Division, 3601 Fairbanks Avenue, Kansas City, KS 66110.

Jensen, M.E. 1980. *Design and Operation of Farm Irrigation Systems*. American Society of Agricultural Engineers, St. Joseph, MI 49085.

Karassik, I.J., W.C. Krutzsch, W.H. Fraser and J.P. Messina. 1976. *Pump Handbook*. McGraw-Hill Book Company, New York.

Peerless Pump Technical Data. 1987. A Sterling Company, P.O. Box 7026, Indianapolis, IN 46206.

Walker, R. 1975. *Pump Selection - A Consulting Engineer's Manual*. Ann Arbor Science Publishers Inc. P.O. Box 1425, Ann Arbor, MI.

Table 1.

Table 1. Advantages and Disadvantages of Various Centrifugal Pumps[*]

ADVANTAGES	Volute Pumps	Diffuser Pumps	Turbine Pumps	Propeller Pumps
Available in a wide range of sizes	X	X	X	X
Simple construction	X			X
Relatively quiet operation	X	X	X	X
Robust with a long life	X	X		X
Available in a wide variety of materials	X	X		X
Can handle liquids containing solids	X	X		X
Can handle liquids with a high proportion of vapor			X	
Self-priming			X	
Variable speed drive units not required to adjust the capacity	X	X	X	X
Pressure and power developed are limited at shutoff	X	X	X	X
DISADVANTAGES				
Unsuitable for pumping high viscosity liquids	X	X	X	X
Heads developed are limited	X	X	X	X
Close clearances			X	

[*] After Holland and Chapman, 1966.

Table 2.

Table 2.

Specific Speed Range	Pump Type
Below 5,000	Radial Flow Pumps
4,000 - 10,000	Mixed Flow Pumps
9,000 - 15,000	Axial Flow Pumps

Table 3.

Table 3. Problems in Centrifugal Pump Operation

Problem	Possible Causes
No Liquid Delivered	- Pump not primed
	- Insufficient available NPSH
	- Suction line strainer clogged
	- End of suction line not in water
	- System total head higher than pump total head at zero capacity.
Pump Delivers Less Than Rated Capacity	- Air leak in suction line or pump seal
	- Insufficient available NPSH
	- Suction line strainer partially clogged or of insufficient area
	- System total head higher than calculated
	- Partially clogged impeller
	- Impeller rotates in wrong direction
	- Suction or discharge valves partially closed
	- Impeller speed too low
	- Impeller installed in reverse direction.
Loss of Prime While Pump is Operating	- Water level falls below the suction line intake
	- Air leak develops in pump or seal
	- Air leak develops in suction line
	- Water vaporizes in suction line.
Pump is Noisy	- Cavitation
	- Misalignment
	- Foreign material inside pump
	- Bent shaft

Table 3.

Table 3. Problems in Centrifugal Pump Operation

Problem	Possible Causes
	- Impeller touching casing.
Pump Takes Too Much Power	- Impeller speed too high
	- Shaft packing too light
	- Misalignment
	- Impeller touching casing
	- System total head too low causing the pump to deliver too much liquid
	- Impeller rotates
	- Impeller installed in wrong direction.