Water Management for Florida Sugarcane Production

T. A. Lang, S. H. Daroub, R. S. Lentini, and J. H. Bhadha

Florida sugarcane production requires substantial quantities of water to support the approximately 2 billion dollar economy it generates in Florida (Rice et al. 2013). Hence, irrigation water availability, drainage capabilities, and environmental factors are of major concern to Florida sugarcane producers within the Everglades Agricultural Area (EAA).

Florida sugarcane growers irrigate and drain their fields by subirrigation (seepage irrigation) and open ditch drainage. Subirrigation is defined as supplying water to the crop root zones by controlling the water table. A water table is established above an existing water table or above a restrictive (impermeable) soil layer by pumping water into open ditches. Drainage involves reversing the process. The ditch water levels are lowered allowing water to flow out of the soil profile back into the ditches. The effectiveness and efficiency of this type of system can vary widely depending upon site-specific conditions. South Florida lends itself to water table management because of its flat land, relatively high soil hydraulic conductivity underlain by a restrictive layer, and large quantities of available water.

Sugarcane production generally involves large farm sizes, due in part to the high cost of irrigation and drainage. Each individual grower must have both a surface water management permit and a consumptive use permit. The permits must be processed by the South Florida Water Management District (SFWMD) and the Florida Department of Environmental Regulation.

Subirrigation/Open Ditch Systems

Requirements for Effective Water Table Control

Subirrigation supplies water to crop root zones by controlling the water table. It is synonymous with “seepage irrigation.” Growers may or may not use mole drains to accelerate the lateral spreading of irrigation water.

The seepage system is a viable one if natural conditions are suitable and it is managed properly. However, precision water table adjustments are difficult to accomplish, but sugarcane is ideal for this type of system because it is a relatively flood and drought tolerant crop. Conditions in the soil that may prevent or impede the efficient use of the system are discussed under “Irregular Water Table Profiles.”

A major requirement for using seepage irrigation effectively is an impermeable or water restrictive layer in the soil profile. The layer must be deep enough to provide a soil thickness above it for storing water in addition to
a sufficiently thick root zone profile. At the same time, the layer must be shallow enough to allow the irrigator to supply adequate water to the root zone without having to pump extremely large amounts of water into the perched (unconfined) aquifer. The relative positions of the root zone, water table, perched aquifer or water storage profile, and impermeable layer, are shown in Figure 1. In the EAA, impermeable limestone lies beneath the soils and facilitates adequate water storage.

**Open Ditch Drainage**

The same conditions that are conducive to seepage irrigation can be detrimental to surface drainage efforts. Maintaining a high water table means there is little room in the soil profile for storing excessive rainfall. In fact, if the water table is being held at the optimum depth, any additional water could stress the crop. The root zone would fill rapidly during a heavy rainfall and could cause massive crop losses if water is not removed quickly.

The fact that an impermeable layer must exist at a depth relatively close to the ground surface may add additional complications to drainage. For example, if the impermeable layer were high, say only two feet from the ground surface, and ditches were spaced far apart, it might be difficult after a heavy rainfall to drain the soil rapidly enough to prevent crop damage.

Another system contradiction is the requirement for level field surfaces. Without land slopes, and with the ridges in the field that occur during cultivation, surface drainage is greatly impeded. This means the majority of the rainfall must infiltrate the soil profile and travel through the soil medium prior to exiting into the drainage ditches. This may cause unduly long periods of root zone saturation and possible crop damage. A delicate balance exists. Careful control of irrigation and drainage events is necessary to operate the system effectively and efficiently.

**Water Quality**

Water quality is another issue with seepage/open drain systems. When heavy rains fall on flat farmlands, water must pass through the soil profile. Nutrients and chemicals vital to crop growth are washed out of the root zone. This results in a loss of revenue for the growers as well as a degradation of the water in the sink where excess water is stored. On- or off-farm storage facilities could help alleviate this problem. Drainage water containing nutrients and chemicals could be stored and recycled for irrigation usage that would contribute to a partial recovery of leachates. This would increase both fertilizer and water-use efficiencies.

**Ideal Water Table Profiles**

In the idealized cases for both sand and muck soils in Florida, three water table shapes may occur where seepage irrigation and open drainage are practiced. An ideal field
can be defined as one where both the ground surface and the impermeable boundary are parallel and relatively flat (Figure 1). This figure shows the water table in equilibrium. There is no recharge or depletion occurring. Such a condition is extremely rare under natural conditions because it requires a perfectly impermeable layer and no inflows or outflows from the soil profile.

Figure 2 depicts a situation with a crop depleting the aquifer through evapotranspiration. This causes the lowering of the water table. This can occur in areas with shallow soils where roots are close to the bedrock. When irrigation is applied by raising the water levels in the ditch to replenish the water used by the plants, a concave water table surface results. Only a few points in the field will be at the average water table level at any given time. Additionally, the water table profile varies with time at any point in the field as evapotranspiration varies and rainfall and irrigation events occur. The average water table for the field is, therefore, an average over space as well as time.

Figure 3 illustrates an idealized field under drainage after a rainfall. The water levels in the ditches have been pulled down and flow occurs from the aquifer into the ditches, forming a convex water table surface (drainage crown). Note that flow occurs into the ditches through both the common boundary between the aquifer and the ditch water level as well as through a “seepage face.” In this case again, the water table will be at the average depth only at a few points in the field during certain time periods of the growing season. Therefore, the root zone will usually be wetter or drier than average over time and space.

Irregular Water Table Profiles
It would be a less difficult task to maintain desired water table levels in the field under ideal geologic conditions. In the sugarcane growing area of south Florida, however, there are often cracks and solution holes in the caprock or bedrock. In addition, the restrictive layer is frequently uneven.

DECLINING GRADIENTS AND STORAGE CAPACITY
In the EAA, irrigation canals, main farm canals and a few field ditches have been dug into bedrock, opening channels of flow to and from the limestone aquifer beneath the root zone. To further complicate matters, subsidence has been occurring in the muck soils. This reduces the root zone thickness, leaving a continuously declining hydraulic gradient for drainage as well as a declining storage capacity. Both these factors, along with the requirement of high water tables for reducing subsidence, make agricultural drainage in the EAA a complicated endeavor.

Continuously declining hydraulic gradients for drainage make lowering of the water table in the field to the desired level more difficult. As soil profiles decline, drainage operations will take more time to remove the same amounts of water. At the same time, the storage capacity of the soil profile also decreases. Management operations relative to water table position have to become more timely and precise since the safety margin for holding excess rainfall on a field, represented by deep soil profiles, is shrinking.
**LEAKY AQUIFER**

If a field has enough cracks and solution holes that allow movement of water upwards through the bedrock, a continuous recharge of the root zone may occur (Figure 4). In field situations where a particularly large crack or solution hole exists, conditions much like a spring would exist. Leaky aquifers of this type would cause the grower to require large amounts of nearly continuous drainage pumping to maintain suitable root zones. On the other hand, if the main water table falls below the leaky bedrock and irrigation water is applied, the grower would have to pump considerable amounts of water into the field to fill both the limestone aquifer as well as the water table aquifer in the root zone (Figure 5).

**IMPERMEABLE SHALLOW BEDROCK**

As mentioned earlier, in an instance where the impermeable layer (bedrock) is very high, no matter how deep the ditches penetrate the bedrock, drainage capacity will not increase once water levels in the ditches can be maintained below this layer. This could result in a slower drainage than desired and a long period of excess moisture around the root zone possibly causing crop damage (Figure 6).

**UNEVEN BEDROCK FORMATION**

Uneven bedrock may form concave “pockets” that cannot be drained using the open drains (Figure 7). Likewise, if irrigation is desired in these pockets, the entire profile between the high points in the bedrock formation and the ditches must be saturated above the level of the formation before filling of the pocket occurs. This would result in excessive water use.
SLOPING IMPERMEABLE LAYER
The impermeable layer may slope either crossfield, downfield or combined and may vary in depth from near the surface to several feet (Figure 8). A sloping impermeable layer may create several extremely uneven drainage and irrigation situations depending upon the degree of the slope and how the slope is positioned in relation to the open ditches.

PROBLEMS IN FLATWOOD SANDS
Similar drainage and irrigation problems occur in the flatwood sands. However, the impermeable boundary supporting the water table in the root zone is generally a compacted spodic layer, rather than rock (Bhadha et al. 2010).

SOLUTIONS
It is obvious that other conditions in the soil profiles exist. A field that has a drainage problem may not necessarily have an irrigation problem. Also, the conditions described here may occur in combinations. The common element in the area seems to be the need to develop methods to drain areas with restricted, non-uniform root zone profiles after a heavy rainfall. Definitive answers are not presently available for all possible naturally existing conditions. Possibilities, however, have been tried and discussed. These include breaking up the spodic layer in the flatwood sands, farming around wet spots in both sands and mucks, closer open drain spacings, tile or mole drains and alternative land forming practices.

On-Farm Systems
Mains and Sub-Mains
The typical farm layout is relatively simple, using a network of open ditches that run parallel to section boundaries. Typically, a main farm ditch, excavated into rock, runs from the farm pump station on a South Florida Water Management District or Special Drainage District canal to the far reaches of the farm. The farm size served by a pump station varies greatly, and in some cases requires a main farm ditch over 5 miles long. Sub-mains or farm laterals branch off the main ditch at right angles, generally on 1/2 mile spacings, on section and half section boundaries. These ditches are most often excavated into rock to obtain the flow capacity required. Lateral ditches are generally around 6 ft. wide with slopes no flatter than 0.5 to 1, and are often nearly vertical. Bottom slopes of 3 inches/mile are generally used.

Field Ditches
Emanating at right angles from the farm laterals are equally spaced field ditches, generally excavated to limerock. The field ditches are generally 3 ft. wide on slopes of 3 inches/mile. Side slopes are no flatter than 0.5 to 1, again approaching the vertical. The ditches are parallel and subdivide the farm into rectangular field units with nominal dimensions of 660 ft. by 2,640 ft. These 40 acre blocks are the basic water management units considered by growers. There are cases where either the length and/or width of the blocks are halved. The closer ditch spacings are used when soils cannot be adequately drained by the wider ditch spacings. Although closer ditch spacings would provide more responsive water control, in practice, economics plays a large part in dictating open ditch layouts.

The Soil Conservation Service recommends that open drain side slopes be 0 to 0.5 horizontal to 1 vertical and that the drains should be at least 36 to 48 inches deep on 330 or 660 ft. spacings for sugarcane.

Most of the rainfall occurring in the fields must flow through the soil profile in transit to the field ditches since the ground surface slopes are virtually level. Some surface runoff to the ditches can be seen during high intensity rains, or when rain volumes are such that fields become flooded. Water will also pass into the bedrock when solution holes or fissures are present. Once in the rock layer, flow can occur long distances to area canals.

Pump Stations
The general opinion among sugarcane growers is that a pump facility should be able to remove 1 inch of rain per
hour in 24 hours. Because of the relatively flat farms, water movement to the pump station depends heavily on the drawdown created by pumping. The surface water slope and the barely perceptible 3 inch per mile ditch slopes are the only factors allowing flow to the pump stations to occur. The pump stations are generally made up of one or more low head, high capacity pumps, capable of moving water at over 20,000 gallons per minute with lifts between 3 and 5 feet.

The most common type of pump in use is the axial flow propeller pump. This type of pump consists of a screw propeller submerged in the drainage intake sump pit and connected by a pump shaft held in the pump barrel with supports and bearings. The pump is driven by either a diesel or electric motor, usually coupled to the pump shaft using belts. It is common to find more than one pump, mounted in parallel, at the main station. The units are usually housed in a galvanized metal building on a concrete platform and will discharge either directly to a public works or drainage district canal, or to a discharge pit which has a short channel to a major canal. Back up diesel motors are often in place to protect against power outages where electric motors serve as the main drive units.

Portable pumps, either driven by tractor PTO shafts or portable diesel motors, are used at points around farms when additional pumping is needed for either irrigation, flooding fallow, or drainage. These are generally used for specialty operations such as flooding fields, or in cases where a small block of fields requires a different water table than the surrounding areas. Permanent relay pumps are also used in many cases. They are placed at junctions between farm main ditches and submains or laterals to hasten flow to or from particular areas of the farm.

Farm Water Control Structures
Flashboard riser culverts are generally placed at the inlets to each field ditch. These may also be found on lateral ditches and are used to help distribute water more evenly throughout the farm. If less flow is desired in a particular ditch, for either irrigation or drainage, the board height in the riser is simply increased. In some instances, these control structures are in place, but are left open to flow under all conditions except when maintaining a flood.

Mole Drains
To hasten drainage or the spreading of irrigation water beneath the crop root zone, some growers use mole drains. The process entails pulling a 6 inch diameter bullet shaped plug through the soil profile at the desired depth. Naturally, the shank that attaches the plug to the tractor or crawler must cut through the entire soil profile to the desired depth. As the plug is pulled through the soil, it forms an approximately 4 inch diameter cylindrical channel with compacted sides. Care must be taken when installing the drains so that back pressure behind the plug does not collapse the channel behind the plug. These drains will hold their shape for an undetermined amount of time, often less than 1 or 2 years.

Mole drains are spaced from 5 to 20 ft apart with 10 feet on center being common. Drain depths observed are from 30 to 46 inches below the ground surface. It is generally considered impractical to mole drain soils less than 3 feet deep. This can be attributed to the propensity of the drains to collapse at shallower depths, the fact that subsurface limerock outcroppings would cause drain interruptions thereby making shallower depths inappropriate, or the inability to drain the land sufficiently with only 3 feet of soil over impermeable bedrock.

The effectiveness of mole drains in the organic soils is debatable, especially in the shallower areas. Obviously, with heavy machinery traversing the mole drained fields, collapse of the drains is quite possible, if not imminent. Moles must be redug as often as possible to be effective water management tools. Unfortunately, the deterioration of the drains is not the only criterion used as the determining factor for redigging. Growers must wait until a field is fallow to dig mole drains, which can be as long as four or more years in the case of sugarcane.

Water Table Management
Sophistication of water table control techniques vary widely. Some attempt has been made towards automation of pumping systems and towards water table monitoring. Pump automation centers primarily on automatic shut off controls to avoid bringing ditch water levels too low and causing damage to pumps. Water table monitoring in fields is being practiced to some extent using observation well levels to determine whether irrigation is needed. This is in contrast to the most common method of judging field water table levels by those seen in ditches. Growers desire to attain a higher level of control over water tables.

All growers must maintain similar water tables on their farms for optimum water levels to be held. In other words, if one grower maintains a high water table and his neighbor maintains a low one, seepage from the high to the low will occur and will cause the grower with the high water table to pump inordinate amounts of water from area canals to maintain his water levels.
Subsidence Control
The water table height issue dictates that two conflicting parameters be optimized. The growers need to be concerned with both subsidence of the soil which could severely limit the productive longevity of their lands, and maintaining yields sufficient to generate income in the present. Subsidence control requires flooding the soils. Some oxidation retardation can occur with high water tables. However, high water tables can have significant negative impacts on yield. The growers must find a balance that will yield the maximum future life of agriculture in the region, as well as optimum profits in the present.

In 1981 a technique called “land forming” was suggested to prolong the life of organic soils by reducing subsidence. The technique called for leveling or smoothing the land surface to enhance uniform wetting of the crop root zone. There would be no low spots in the field requiring a lower water table than necessary in order to drain the low spots, and no high spots to expose too much of the soil to aeration when water tables are at normal levels. Those suggesting “land forming” predicted it would add 10 years to the life of the soil.

Target Water Table Levels
It has been shown that crops are much more tolerant to excessively low water tables than excessively high water tables, except in cases of extreme drought. Growers will consequently maintain water tables that are below the maximum possible levels to protect themselves from heavy rains. During rainy periods, at or near harvest, and during fallow periods, the growers may even cease to maintain water tables and will let them decline to the limerock.

Water table levels deeper than 24 inches are usually maintained for sugarcane. At times, the water table is allowed to fall to 30 to 36 inches to enhance sugarcane growth and sugar quality. This practice is prevalent primarily in areas where the soil is raw, fibrous peat that holds excessive water in the plant root zone under conventional water table management. A seven year study at the EREC showed that 30 inches to the water table was optimum for sugarcane on the basis of tonnage per acre. Production dropped only 5% with a 15 inch water table depth. It should be noted that these studies were conducted under precise water table control in lysimeters where the normal hazards of inundation following heavy rains was not a factor.

It has been suggested that the target water table level for sugarcane be between 23 and 30 inches. Studies have shown both plant and ratoone sugarcane crops produced high yields at an average water table of 22 inches. Water tables varied during the study from a field average low of 39 inches to a high of surface ponding. The variation in water table level around the average illustrates the problem with managing farm water using annual average water table values.

Flooding Soils
Field flooding is done for a variety of reasons including disease, weed, and insect control, improvement of soil tilth, and the reduction of soil subsidence. Most flooding occurs during the summer rainy season. Procedures entail the building of temporary dikes around the field blocks to be flooded. Earth is simply pushed to the edges of the fields. Temporary pumps mounted on trailers are generally used. The pumps operate off transportable diesel motors or tractor PTO shafts.

Although most of the sugarcane growing area is underlain with nearly impermeable layers, maintaining a flood can be an expensive proposition in terms of energy usage for pumping. Seepage is such that water readily flows back to the ditch that is being pumped to maintain the flood. In places where the limerock is cracked or has large solution holes, flow can also occur through the limerock enroute to a sink with a lower hydraulic head. The cost of maintaining a flood dictates that floods be kept no longer than absolutely necessary. Commonly, a fallow field is flooded for 3 weeks. This is followed by 1 to 2 weeks during which the standing water is allowed to evaporate and drain naturally. Following that period of natural water table subsidence, another 3 week flood is applied. Depths of flooding are generally 4 to 16 inches above the ground surface.

Evapotranspiration Requirements
One of the prime needs relative to the water quantity and quality issues in south Florida is to determine how much water a crop requires for optimum growth, and how little a grower can use and suffer major economic losses. The issue becomes extremely important with the limitations placed on back pumping to Lake Okeechobee for storage because of water quality issues and the lack of a definite adequate alternate supply plan.

Most of the studies relative to crop water requirements have been conducted in lysimeters using procedures that did not always reflect actual field conditions. Lysimeters allow for the careful maintenance of a water table and hence do not accurately reflect the fluctuations that occur under natural field conditions. Since water can be drained from lysimeters faster than in a field situation, not only does the crop have
less chance to suffer from flooding, but it also has less chance to use water that would be stored in the root zone due to the water table receding more slowly under field conditions. Additionally, water tables that are maintained at a constant level throughout the season do not take advantage of the ability of sugarcane to withstand higher or lower water tables at different stages in its growth cycle.

The earliest reported lysimeter work examining sugarcane water requirements (ET rates) averaged about 46.8 inches per year at a 1.5 foot water table level. From this work, it was estimated that ET under actual field conditions would be between 42 and 45 inches per year since water tables were lower in the field.

**Water Table Monitoring**

Water table monitoring is essential for the optimum management of irrigation and drainage systems for sugarcane production. It takes on even more importance with current public interest directed toward water managers' responsibilities of protecting water quantity and quality. Water table monitoring can provide the water manager with important information regarding the relationships between rainfall, irrigation, drainage and water table responses. This will help bring consistency and uniformity to irrigation and drainage decision making.

Presently, many of the irrigation and drainage decisions are based on rainfall amounts and drive-by scanning of water levels in ditches (ditch-riding). Pumping decisions are based on past experience or the verbal passing of anecdotal information. This method, although inexact, can sometimes work depending on how and for how long the experience was developed. The practice, however, may not be adequate to achieve the high level of control necessary in the present environment. Growers are pressured to maintain as much water on their farms as possible to minimize pumping for both irrigation and drainage. More water on the farms means higher water tables during the wet season, shorter response times, and less margin for error in conducting water management activities.

Water table management and its effective incorporation into a farm water management program requires that four distinct activities be carried out. First, observation wells must be constructed and installed at strategic locations around the area to be monitored. Second, the water levels in the wells must be read and recorded diligently on a regular basis. Third, the resulting data must be analyzed and reduced to a form that is readily useful to water managers. Finally, the resulting information must be incorporated into daily activities associated with irrigation and drainage events.

**Observation Wells**

The primary structure required for the monitoring of water table levels is the observation well. An observation well is no more than a cased vertical hole in the ground with ports in a casing to allow for unrestricted water entry. The casing prevents wall sloughing and the subsequent filling of the well. Typically, the well casing is a length of Schedule 40 PVC pipe, 4 to 12 inches in diameter (Figure 9). It is recommended the well casing be screened around the perforated area to prohibit the entry of large soil particles into the well bore. In south Florida, observation wells are generally no more than five feet deep and usually go down to the water restrictive layer or rock. For more information about observation wells, see IFAS Bulletin 251, “Water Table Monitoring.”

![Figure 9. Typical observation well casings with water inlet ports.](image)

The placement of the wells is extremely important. Generally, they should be placed in the middle of the fields. Under subirrigation and open ditch drainage conditions, the field centers are the slowest to drain, slowest to irrigate, and fastest to rise during rainfalls.

At the farm level, fields to monitor should be selected according to their proximity to the pump station serving the area. One observation well near the station, one at the far reaches of the farm canal system, and one about midway between the two are the minimum recommended.
Additional wells may be required at sites with a history of irrigation or drainage problems.

**Common Monitoring Instruments**

Several different types of sensing and recording devices can be used in conjunction with the observation wells. There are water table monitoring instruments to fit the desires and budgets of all users. In general, the utility of the resulting data will increase with the intensity of monitoring. The cost of the instrumentation also increases with the monitoring intensity. The cost of the data manipulation, in terms of man-hours spent, will decrease with instrumentation costs.

**MANUAL MEASUREMENT INSTRUMENTS**

Manual water table monitoring can be accomplished using measuring tapes, yardsticks, pipes, or any graduated or ungraduated length of material that will remain rigid or hang straight in an observation well. They may include a bobbing float or sounding device. These types of measuring devices are obviously inexpensive, but are also of the least utility. Manual measuring methods require that a person check the water level in the well whenever a reading is desired. Readings taken on a daily basis will consume a great amount of time and will result in data that does not adequately define the fluctuations of the water table. The readings may be used to determine if an irrigation or drainage event is needed or the adequacy of irrigation or drainage on a point-in-time basis.

**STRIP CHART RECORDERS**

The most common method of monitoring water tables is to use strip chart recorders. These instruments employ float-counterweight-pulley assemblies to sense the water table level in an observation well and translate movements to pen traces on paper charts. The units require chart paper changes every 8 to 32 days. Charts will need to be read and the data manipulated to yield water table depths. If enough points on the charts are read, the result will be continuous water table traces which can then be compared to rainfall, irrigation, or drainage events. This data can be used to fine tune the ditch-riding procedures currently used to manage water. For more information about strip chart recorders, see IFAS Bulletin 253, “Strip Chart Water Table Recorders: Applications in On-Farm Water Management.”

**ELECTRONIC SENSORS AND RECORDERS**

The same type of float-pulley mechanism used with the strip chart recorders can be connected to a potentiometric sensor. The units require hardwiring to an electronic data logger which scans each sensor, supplies an excitation voltage, and records the return signal. The data can be downloaded directly to a computer for data analysis. The units can be left unattended, scanning each sensor on time intervals as short as one minute, for long periods of time. This greatly reduces the time required for data handling.

Pressure transducers can also be used to monitor water table elevations. They consist of an electronic bridge mounted on a silicone element which is housed and placed beneath the water surface. The resistance across the bridge changes as water pressure deforms the silicone element. The same type of recorders which are used with potentiometer based sensors can be used here. A wide variety of pressure transducers exist. Costs cover an extremely broad range which increase with sensitivity, ruggedness and accuracy.

For more information about electronic monitoring methods, see references.

**DATA ANALYSIS**

The number and types of data analyses that can be applied to the data collected vary widely. Also, the intensity of data removal will depend on the desired usage of the data. Although high intensity sampling is ideal, even sporadic manual water table readings taken prior to making decisions to irrigate or drain will increase the potential for efficient water management.

Average water tables are perhaps the most common types of information made available from the recorders. Yearly, seasonal, monthly, weekly or daily water table averages have various uses. Water table levels may be averaged over the wet and dry seasons to give an indication of how well irrigation and drainage events are being handled.

Water table fluctuations around the mean water table offer useful information to the grower. Fluctuations should be kept to a minimum to ensure a minimal chance of crop damage.

Water table data can be used to determine how quickly fields drain after a given rainfall intensity and volume. As more storm events are monitored, a database can be developed and used to answer questions pertaining to optimum pumping times for drainage given particular initial water table conditions and storm intensities and volumes.

**References**


