AGR56

UNIVERSITY OF FLORIDA

IFAS EXTENSION

Water Management Best Management Practices for PhosphorusControl on Organic Soils: Minimizing Water Table Fluctuations [1]

Del Bottcher and Forrest Izuno[2]

This BMP series was written specifically to address the concern for phosphorus control in the Everglades Agricultural Area. The information contained in the series may be applied to any agricultural area composed primarily of organic soils or Histosols. However *please be aware that this information is not applicable to any other soil types*.

BACKGROUND

Minimizing downward water table fluctuations in vegetable and sugarcane fields could reduce phosphorus losses for individual farms from 0-50%, depending on existing conditions. This Best Management Practice relates primarily to stopping the over-drainage of organic soil. Preventing the water tables from dropping below an optimal level will limit the amount of phosphorus being mineralized. Some temporary upward fluctuation can be tolerated, however, after rainfall events to limit or prevent pumping.

Water table control relates both to the temporal (over time) variations of the water table at a given location on the farm as well as to the spatial (across farm) variations between different farm locations at any given time. Temporal variations can best be managed by improving the operational schedules for both drainage pumps and irrigation inputs, since pump scheduling can also influence phosphorus concentration. For example, the water at the beginning of a drainage event is often of better quality than the water discharged later in an event. Spatial variations can be managed most efficiently by having sufficient hydraulic capacity in the canal system and by using both flashboard culverts and laser leveling. Higher pump and conveyance system capacities may be needed to eliminate the practice of dropping water tables below optimum levels prior to storm events to assure adequate drainage capacity after the storm. Each of these water table management options and related crop management concerns will be discussed in this guide.

OPTIMAL WATER TABLE

Drainage and irrigation schedules should be focused on maintaining a water table which will provide optimal crop production while simultaneously minimizing water quality impacts. Suggested minimum rooting depths for various crops are provided in Table 1. For water quality control, the *minimum* rooting depths in Table 1 should also be considered the *maximum depth.* Ideally, the water would be maintained exactly at this depth at all times. Obviously, such water table control is impossible. Therefore a reasonable management scheme would be to minimize fluctuations away from the optimal water table depth.

ALLOWABLE WATER TABLE FLUCTUATIONS

Crop roots will adapt and grow to fill the aerated soil profile above the water table. Short-term downward fluctuations of the water table can create the situation where a larger volume of aerated soil exists than can be used by the crop roots while at the

1. This document is AGR56, 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 December 1992. Reviewed July 2002. Visit the EDIS Web Site at http://edis.ifas.ufl.edu.
2.

same time it is increasing the risk of water stress. In addition to the lower water table adversely impacting crop production, the additional aerated soil volume will increase soil mineralization rates and related nutrient releases. Downward water table fluctuations, therefore, should be prevented if at all possible.

Table 1. Minimum water table depths for maximum yields in the EAA (adapted from Snyder et al., 1978 and 1987, and Coale, 1988).

Crop	Water Table Depth cm.	in.
Snap Beans	45.7-61.0	18-24
Cabbage	45.7-61.0	18-24
Cauliflower	61.0	24
Celery	61.0-76.2	24-30
Sweet Corn	76.2-91.4	30-36
Lettuce	45.7-61.0	18-24
Onions	45.7-61.0	18-24
Peas	45.7-61.0	18-24
Potatoes	45.7-61.0	18-24
Tomatoes	45.7-61.0	18-24
Escarole	61.0-76.2 est.	24-30 est.
Endive	61.0-76.2 est.	24-30 est.
Radishes	35.6-40.6 est.	24-30 est.
Parsley	35.6-40.6 est.	24-30 est.
Sod	45.7-61.0 est.	18-24 est.
Sugarcane	61.0 est.	24 est.

Upward fluctuations of the water table, on the other hand, can saturate a portion of the root zone which will limit mineralization, but can also adversely impact crop growth. The impact of temporary root saturation on crop growth is a function of the crop, temperature, soil, crop maturity, as well as of the degree, frequency, and duration of saturation. Table 2 provides the relative maximum time to allow for the full drainage of the active root of major Everglades Agricultural Area crops after a rainfall event. The table reflects the most crop sensitive condition, so adjustments to the provided values should be made based on individual farming conditions, if known. As shown, vegetables are very sensitive to wet soil conditions, compared to sod and especially to sugarcane. Table 2 also reflects the potential urgency of dropping the water table based on the percent of the root zone saturated after a drainage event. Since a higher water table does have the advantage of reducing mineralization of the soil, the draw-down of an upward fluctuation should be delayed to the maximum allowable time in Table 2. This practice will also reduce pumping volumes. Obviously, knowledge of the actual water table location in the field will be needed for management. The use of water table wells, therefore, is highly recommended.

Table 2. Maximum allowable time (days), as a function of the percent of root zone saturated, to fully drain the root zone after a rainfall event[1]

Crop	100% Saturated	50% Saturated	25% Saturated
Vegetables	0	.5	1
Sod	2	4	8
Sugarcane	5	9	14

[1] Current data does not exist for these crops. The values were generated by the of the EAA Environmental Protection District and IFAS experts. They should be considered advisory only and should be used with caution.

We suggest that individual growers experiment on small plots to determine the saturation sensitivity for their individual crops because saturation sensitivity can vary significantly between farms due to the parameters indicated above. For experimental procedures, please contact your IFAS water extension specialist.

TEMPORAL WATER TABLE CONTROL

Temporal water table control means keeping the water table as close as possible to the optimal water table over time. Temporal variations can best be managed by improving the operational schedules for both drainage pumps and irrigation inputs. Operational schedules need to take into account the following parameters:

* predicted rainfall,

* actual rainfall (measured on farm),
* pump/irrigation capacities,
* crop susceptibility to water stress,
* hydraulic capacity of ditch/channel system,
* in-field as well as ditch-water levels, and
* seepage.

Pump operation schedules will need to vary according to these parameters in a sophisticated fashion. For example, high discharge rates may be necessary at the beginning of high discharge events, whereas in smaller storm events pump start-up may need to be delayed to determine if it is even necessary to pump. In all cases, it is critical that the operational schedule terminate drainage discharge before the water table is dropped below the optimal level.

Temporal water table control can best be achieved by developing relationships between farm inflow and outflow rates versus the water table response interior to a field. These water table response relationships can be determined by plotting pump and irrigation flow rates against water table levels recorded within the fields. Examples of typical response curves are provided in Figure 1. The most useful water table response relationships would be for the two extremes where there is either the maximum (wet and draining) or minimum (dry and irrigating) available water condition in the soil profile (defined later in this section). The early condition is depicted in Figure 1. Field ditch water levels can be used as rough estimates of in-field water tables, but using data from water table wells in the fields is strongly recommended. Additionally, placing several water table recorders throughout the farm will allow for the determination of the spatial variation of water table responses across a farm (see Spatial Water Table Control).

It is important to note here that the water table response curve for both drainage and irrigation will be significantly affected by seepage into a farm. In severe seepage problem areas, irrigation input may never be needed because irrigation demand can be met or exceeded by seepage (requiring pumpage during irrigation). During storm drainage, higher discharge rates must be used to compensate for the additional water. Similar water table response curves as those depicted in Figure 1 can be achieved for high seepage areas, but at a high water management cost.

Once the water table response relationships are known, a water budget accounting program for the in-field root zone should be developed. This budget must take into account the evapotranspiration (ET) and rainfall (actual and/or predicted), as well as the water table response to inflows or outflows. The water table movement (WT_m) in response to rainfall and ET can be roughly estimated by the following relationship (units are in inches):

Equation 1

$$WT_m = 7 \times (excess\ rainfall - excess\ ET)$$

Note: The 7-inch response coefficient can vary from 5 to 9, depending on the soil properties. Due to its relatively low sensitivity to water management control criteria, however, 7 should work well for most conditions.

This relationship would mean that one inch of rain could raise the water table approximately 7 inches. The key words here are "could raise" because a portion of the rainfall or ET could possibly be utilized to replace or remove available water in the aerated soil profile without displacing the water table. In other words, if the soil is very dry, then about .5 - 1.0 inch of rainfall may be needed to re-wet it before the water table will rise. Conversely, about .5 - 1.0 inch of ET may have to occur before the water table will drop. The amount of rainfall or ET "left over" after filling the needs of available water in the soil profile is called "excess" rainfall or ET. The standard irrigation "accounting method" can be used to keep track of the available water in the soil profile.

The accounting method uses the following relationship (units are in inches):

Equation 2

$$Available\ Water = Rainfall - ET$$

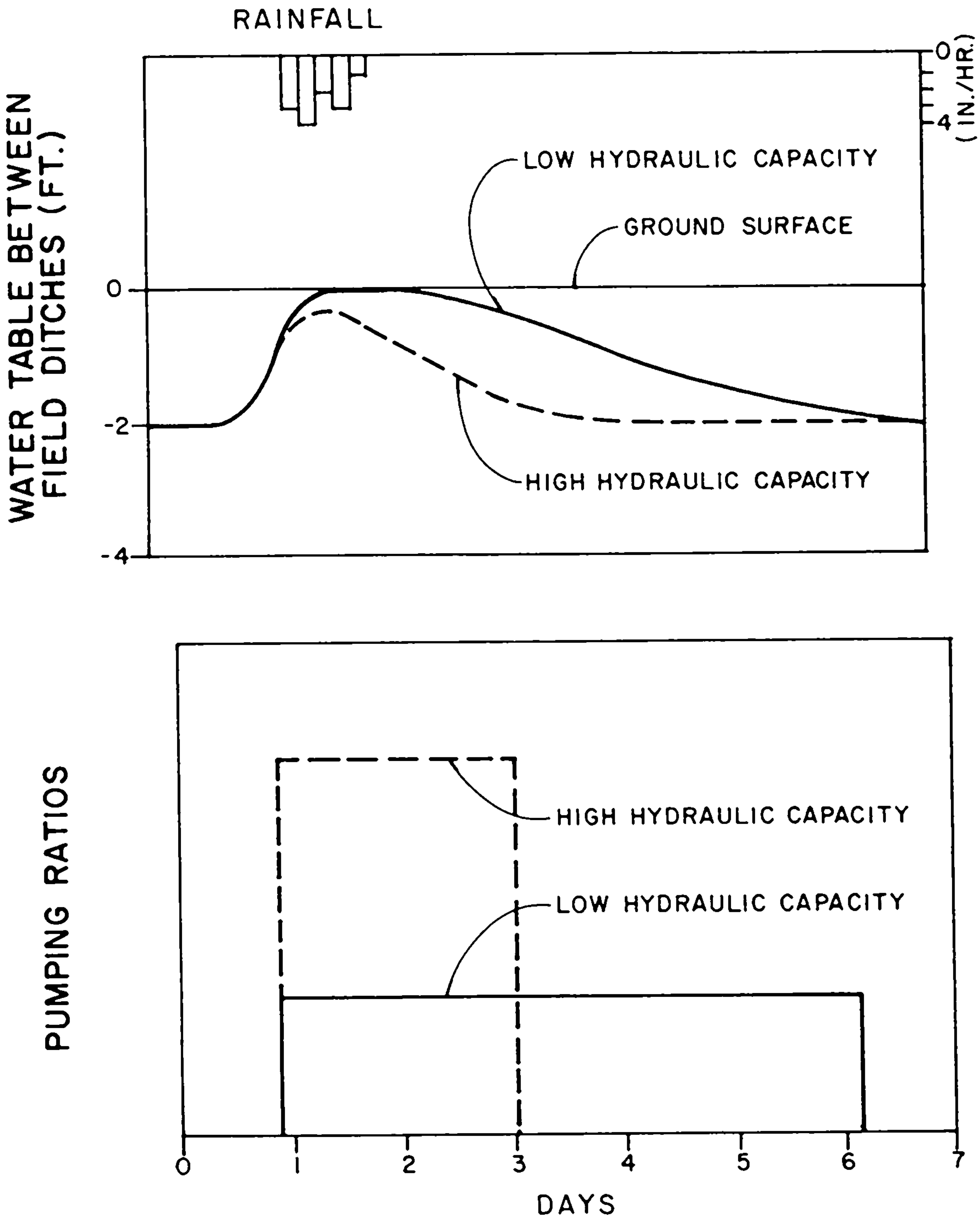


Figure 1. Typical response relationship between the farm level inflow and outflow to the in-field water table

The total available water is approximately equal to the difference between the field capacity and the wilting point of the soil multiplied by the depth of the aerated soil.

Using the above water budget information, irrigation and pump scheduling decisions can then be optimized for water table control. Irrigation scheduling, drainage/pump operations or predicted vs observed rainfall should be used.

Irrigation Scheduling

Irrigation scheduling should be based on setting inflow rates to match farm-wide ET rates once available water has been exhausted. This could be done operationally by observing the in-field water table levels and "accounting" for the currently available water. Then, using Equation 2, an estimate can be made of the time when the excess available water will become depleted. Taking the estimated time to depletion in conjunction with the water table response curve (Figure 1), the correct time to initiate irrigation can be calculated.

The rate of farm level irrigation inflow can be roughly estimated by predicted ET rates. Continuous fine tuning based upon observed in-field water table levels, however, will be the best procedure for maintaining optimal water tables after irrigation has been initiated.

During irrigation, the available water in the soil profile is normally at its lowest level. The soil, therefore, will have the capacity to store about .5-1.0 inches of rainfall before excess water will cause the water table to rise (Malaika and Bottcher, 1988). However, since the roots will now have this additional available water to use, continuing irrigation will cause water tables to rise. Irrigation, therefore, should be immediately terminated after any significant rainfalls (less than .2 inches) in order to prevent upward water table fluctuations which could result in additional future pumping demands. The time until re-initiating irrigation can be calculated by the same procedure described above.

Drainage or Pump Operations

Drainage or pump operations to remove excess rainfall can be scheduled in a similar fashion to irrigation. Now, however, the potential rise in the water table due to measured or predicted rainfall must be considered in the scheduling of the pump(s). Due to the time delays between pump start-up and water table response in the field (Figure 1), it is normally not practical to use only the observed in-field water table levels as control guides. The actual or predicted rainfall, therefore, should be employed to estimate the water table rise by using Equation 1. Once again, the amount of available soil water storage, as determined by the "accounting method" described above, must be subtracted from the rainfall before use in Equation 1. The predicted water table rise can then be compared to the water response curve (Figure 1), the crop saturation tolerance (Table 2), and the predicted ET for the allowable saturation period. This comparison should be made in the following fashion:

Step 1. Obtain the predicted water table level from Equation 1 using the excess rainfall (predicted or observed) and use it in Table 2 to estimate the allowable time needed to return the water table to optimal levels.

Step 2. Determine the volume of ET that will occur before the crop experiences saturated water stress by multiplying the estimated ET rate -- based on crop and season (See Jones, et al., 1988) -- by the allowable recovery time obtained in step 1. If the ET volume exceeds the excess rain, pumps should not be turned on and estimates for future irrigation scheduling should be made. If the ET volume is less than the excess rainfall, pumping should be initiated immediately and run only as long as needed to remove the difference between the excess rainfall and the ET volume calculated. Removing this water as quickly as possible by using full pump capacity will typically provide for lower phosphorus concentrations in the discharged water.

Step 3. Repeated calculations will be needed because of the variability of rainfall. Each adjustment will require the repetition of steps 1 and 2 with a continuous tracking of allowable root saturation. By this point it has become apparent that these continuous and frequent adjustments will become very complicated over short time periods. It is recommended, therefore, that a portable computer be programmed with the appropriate algorithms. Such a program is not currently available, but is presently being developed by the Institute of Food and Agricultural Sciences and should be available soon.

Check with your Cooperative Extension Specialist on its availability.

The above procedure will require significant training of staff and on-farm experience before it will become fully functional. In the interim period, it is suggested that at least automatic "cut-off" controls be placed on all farm pumps to assure that over-drainage is reduced to a minimum. A "cut-off" float can be installed at a water level in the main farm canal no more than 0-6 inches below optimal in-field water table levels. Automatic "on" switches can also be used to initiate or re-initiate pumpage. Such automated systems will primarily serve to protect against pump operators failing to turn off pumps before significant over-drainage has occurred. Note that float control systems are prone to failure without regular maintenance and should not be considered a replacement for assigning an operator the job of periodically checking the pump.

An optimally designed drainage system would not require multiple pump cycles to remove excess rainfall. Multiple pump cycling is an indication of insufficient hydraulic capacity, e.g. water level gradients needed to move water to the pump station would be excessive. Data have shown that water pumped early in a storm is typically of better quality than water pumped later in the storm process. Therefore, getting the excess rainfall out as quickly as possible without over-draining the fields is important. Obtaining sufficient hydraulic capacity is further discussed in a later section.

Use of Predicted vs Observed Rainfall

Use of predicted vs observed rainfall needs to be understood in terms of when to use one over the other. Observed rainfall should always be used whenever possible because it obviously represents the real situation. However, it may become necessary to initiate pumping based on *predicted* rainfall if the crop's water saturation stress sensitivity is such that a delay in gaining water table control through use of observed data could cause crop damage. Typically, predicted storms of less than 1 inch of rainfall require *no prepumping* for any crops. Storms between 1-3 inches will only impact vegetables while storms greater than 3 inches could potentially impact all crops. The procedure described earlier, however, should be used to determine the potential for the occurrence of a detrimental impact. It is important to note that the sensitivity of the water table varies seasonally due to crop rotations and different growth periods. Fallow periods, for example, have no saturation limitations, except for land preparation needs.

SPATIAL WATER TABLE CONTROL

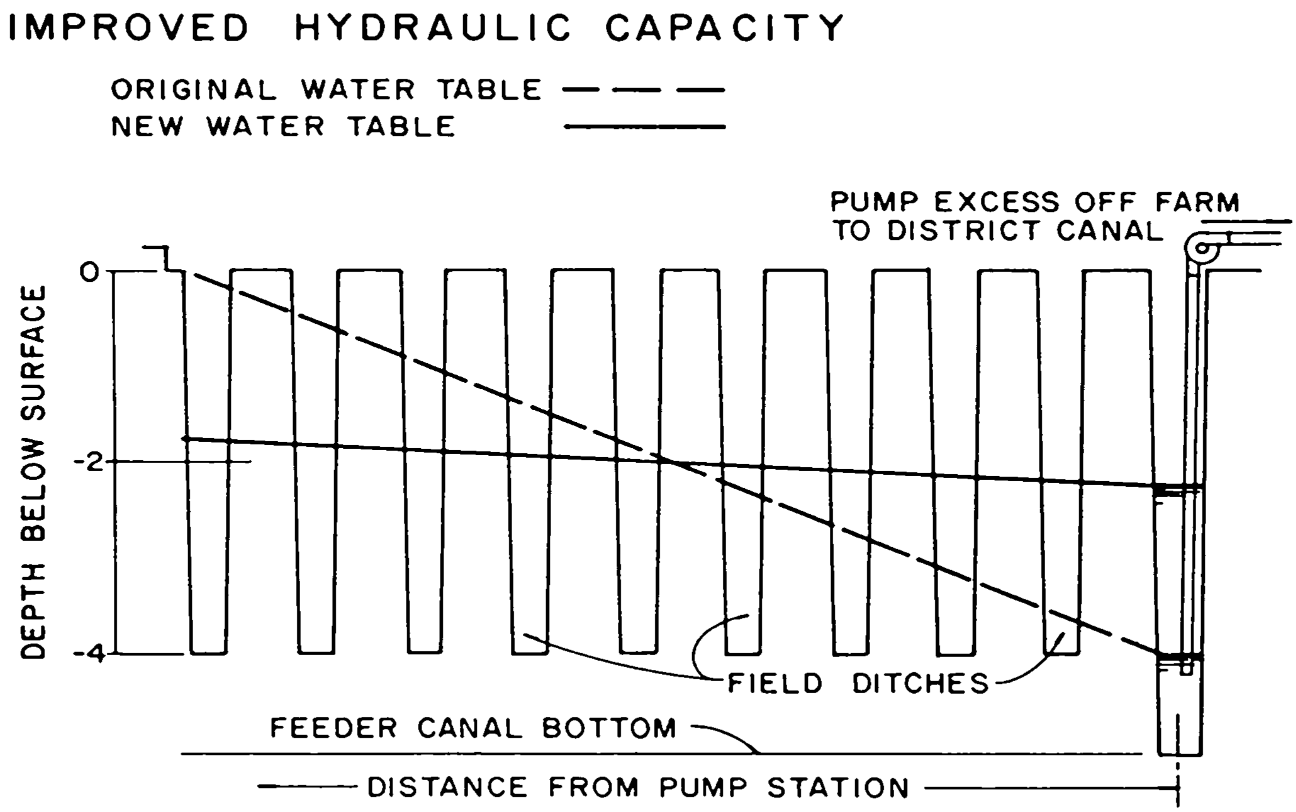
Spatial water table control implies keeping the water table throughout the farm as uniform as possible at any given time. Variable water tables across a farm are typically the result of an uneven ground surface, inadequate hydraulic capacity of the primary farm canal system and field ditches, and/or poor culvert maintenance and/or management. All of these conditions can cause excessive soil mineralization and related phosphorus releases.

Uneven Ground Surfaces

Uneven ground surfaces can be responsible for variable soil moisture conditions and related high P losses across a farm or within a field, even if a uniform water table is maintained throughout the canal/ditch system. Laser leveling is the best way to eliminate these soil surface undulations. However, if your farm has a significant elevation change from one side of the property to the other, then control culverts will be needed to separate the land into an appropriate number of large blocks within which the soil can be economically laser-leveled. Booster pumps will be needed to move water in the upslope direction between each of the blocks. Since irrigation flowrate requirements are less than for drainage, it is usually most economical to have the land sloping toward the main drainage pump station so that only irrigation would have to be handled by the booster pumps. It is possible in some situations to release the irrigation water directly into the farm's highest elevation block and to in this way eliminate any internal booster pumps. To do this, however the canal, pump, and culvert system must be designed with sufficient flow capacity.

Inadequate Hydraulic Capacity

Inadequate hydraulic capacity can cause non-uniform drainage and, to a lesser degree, irrigation across a farm. Typically, under-drainage (poor) occurs in areas located further away from the pump station, while areas nearer the pump become over-drained as depicted in Figure 2. This over-drainage



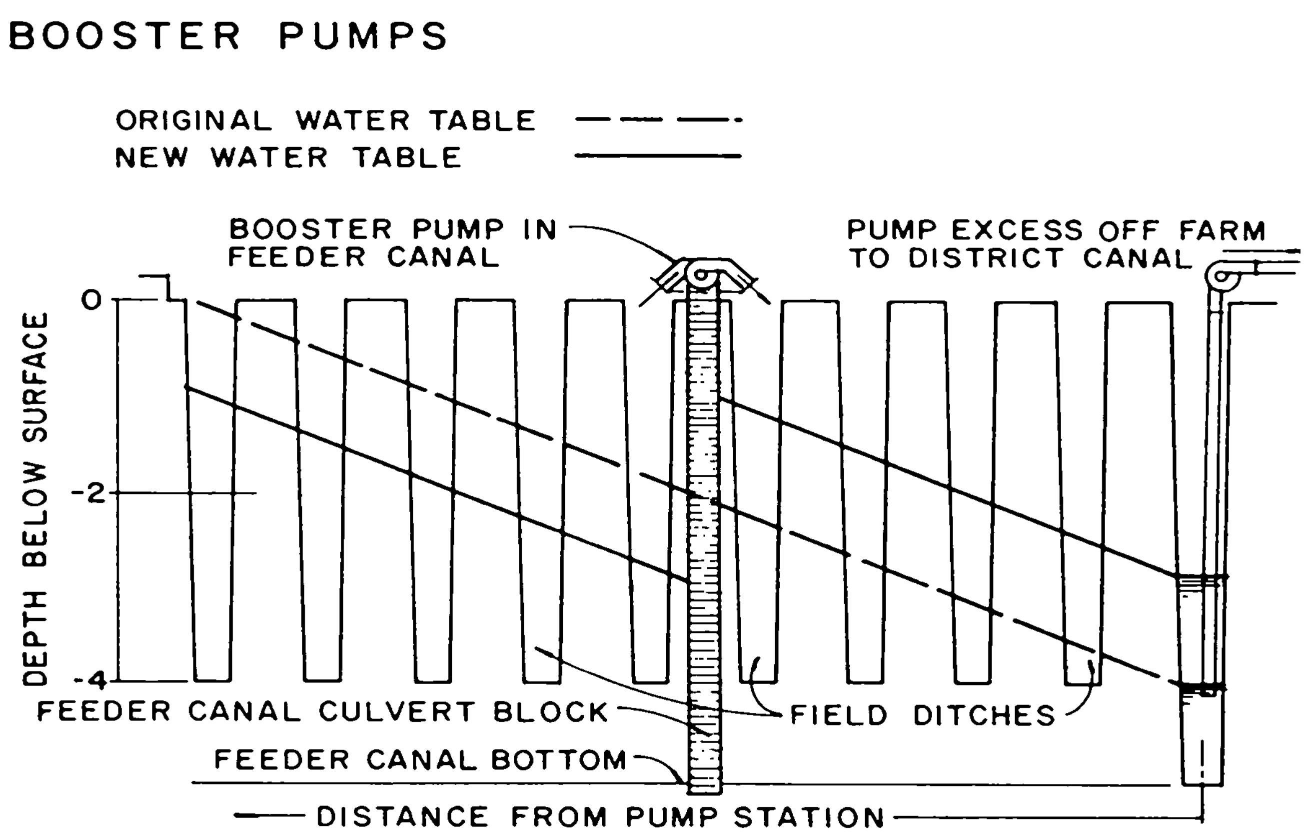


Figure 2. Two corrective techniques for poor water table uniformity across a farm due to inadequate hydraulic capacity of farm canals

of areas can result in excessive soil mineralization and related phosphorus losses. Inadequate hydraulic capacity can also result in a slower, "pulsing" type of water table drawdown which can produce higher phosphorus concentrations in the drainage water. Variability of the water tables across a farm can be managed by designing sufficient flow capacity in the farm canal/ditch system and maintaining and managing flashboard culverts in feeder/field ditches.

Inadequate field ditch spacing as depicted in Figure 3 and 4 can be another hydraulic limitation. If the soil is "tight" due to a low hydraulic conductivity, significant water table variations between the field ditches can occur for long periods of time after a storm. The only ways to increase the mid-field water table drawdown is to drop the field ditches very lowor to shorten the distance between ditches. The dropping of the field ditch water levels is not advised because of the severe over-drainage which will occur near the ditches before the mid-field levels drop. It is recommended, therefore, that the ditch spacing be set appropriately to assure sufficient drainage. The rate of water table drop at mid-field as a function of ditch spacing can be calculated by using one of several drainage equations or computer models. An agricultural or drainage engineering expert should be consulted to complete a drainage spacing analysis.

Adequate hydraulic capacity of the primary canal/ditch system can be determined by either a computer hydraulic analysis of the system or by field measurements of water levels across the farm during a pump event. Because irrigation flow rates are about one third of drainage flow rates, only drainage need be considered for sizing the canal/ditch system.

The canal system should be designed to provide minimally sufficient drainage for the field at the furthest flow distance from the farm pump without dropping the water tables in the fields nearest the pump by more than a few inches. The drainage response relationship procedure described in a previous section of this document will provide the necessary assessment information for drainage capacity.

Inadequate flow capacity in a canal system can be corrected by increasing the size of the canals/ditches and/or by using booster pumps at specific locations throughout the system. Figure 2 shows how the increased canal capacity and booster pump arrangement would enhance water table uniformity across the farm. The location and number of booster pumps and the sizing of canals/ditches will require an engineering analysis of the canal system which is beyond the scope of this guide.

In-field water table non-uniformity can be partially compensated for without increasing canal system capacity by restricting the flow from field ditches. This can best be accomplished by using culverts with flashboard risers. The boards in the culverts closest to the pump station should not be pulled below a few inches of the optimal water table during a drainage event. This allows the main feeder canals to drop significantly without rapidly draining the fields nearest the pump. Experience will have to be obtained for each individual farm system in order to determine the appropriate board settings throughout the farm that will provide the most consistent uniformity. This procedure is more labor intensive and provides less water table control than other procedures which increase the hydraulic capacity of the drainage system. Therefore, this is not the ideal way to gain uniformity, but it can be useful when the flashboard culverts are already in place. This is, however, only a temporary measure to be used until more appropriate control measures can be implemented.

Irrigation Uniformity

Irrigation uniformity can be best controlled by the appropriate use of flashboard culverts and/or laser leveling. It is essential that the ground surface be as uniform as possible to maintain optimal water tables throughout a farm. There are no water management practices that can correct for variable ground surfaces within a water management unit or control block.

Irrigation inflows must exactly match the farm ET losses or else the water tables will either begin to rise or fall. The dynamic changes of ET demands over relatively short time periods create the need for continuous control of inflows. Optimal water levels are typically managed either by regulating the inflow rates by automatic inflow control or by using flashboard culverts and a re-cycling canal system as depicted in Figure 5. Regulated inflow control offers the lowest labor cost and the lowest potential water discharges from the farm. It does, however, require a very level farm with sufficient hydraulic ditch capacity to assure no more than a few inches of water table variation across a farm or a farm block.

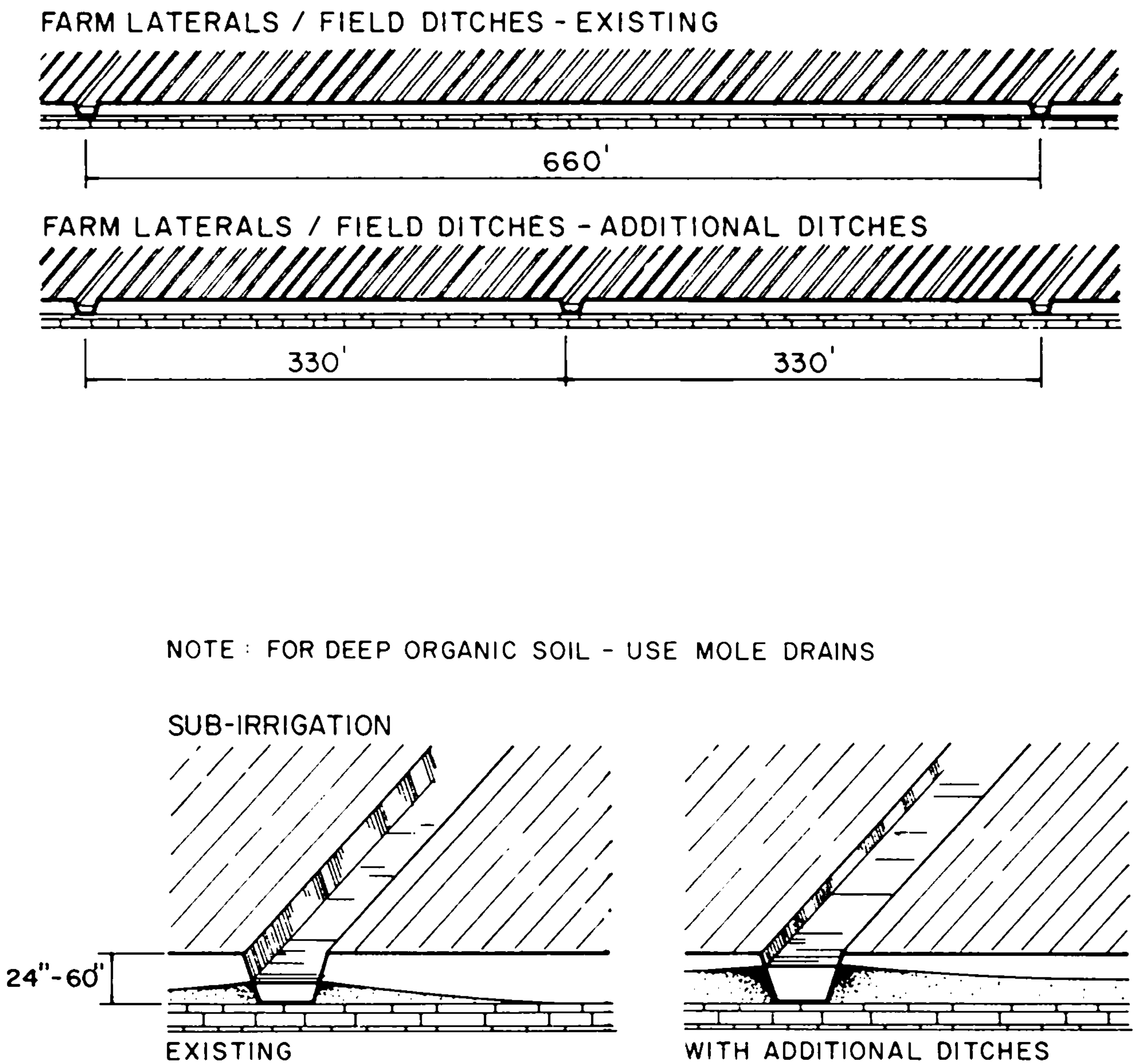


Figure 3. Influence of additional ditches for drainage control.

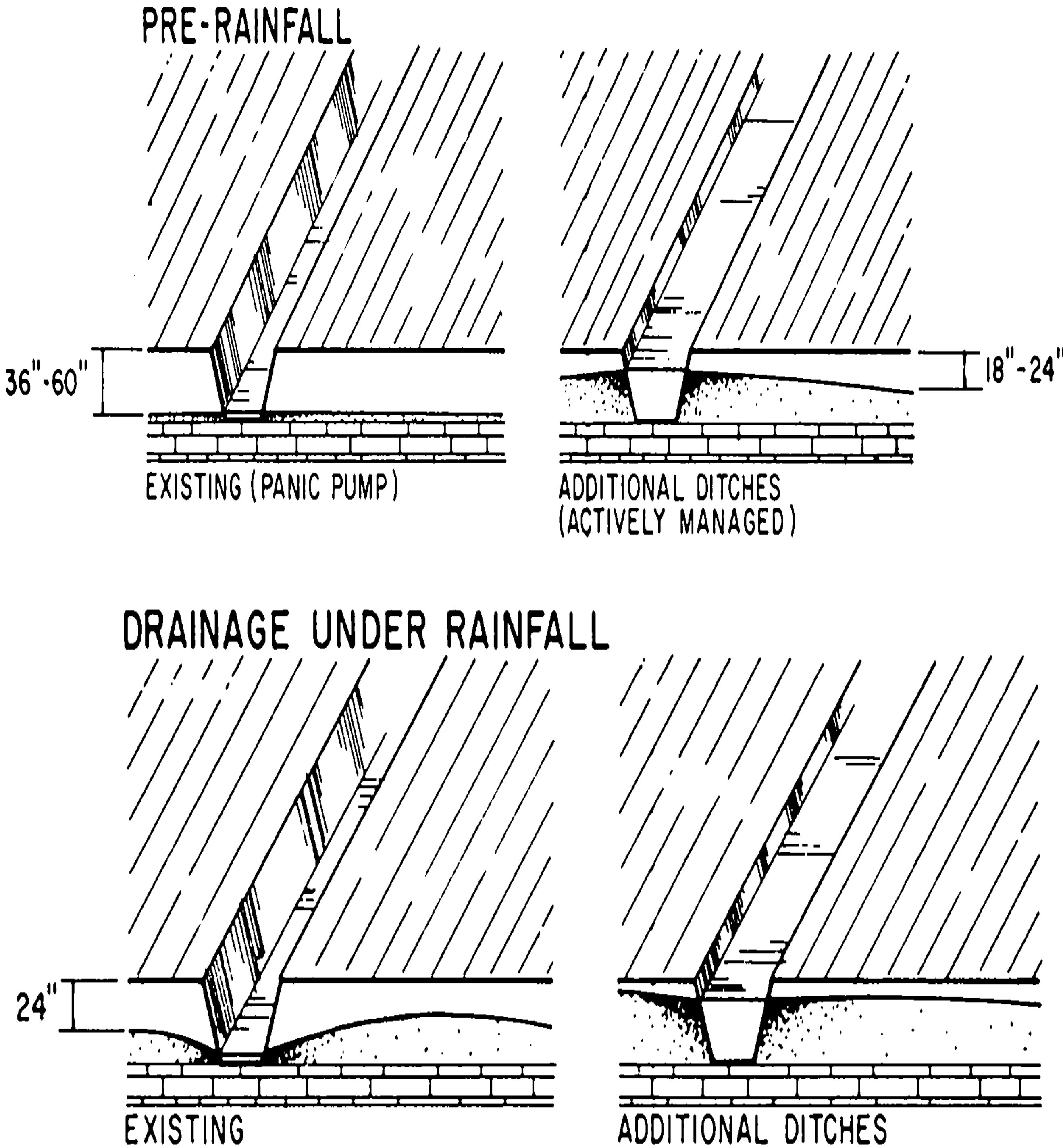


Figure 4. Influence of additional ditches for drainage control.

Regulated inflows for water table maintenance can be achieved by using automatically controlled gate structures or pumps. Both gates and pumps would utilize a float control system to activate them. For optimal management, a "smart" controller -- programmable for variably regulating flow rate based on main canal water levels -- can be employed. The use of a pump manager is normally insufficient to properly control pump operations for the regulated inflow procedure.

When farm slope uniformity and/or automated inflow control are not available, flashboard culverts can be used. These flashboard culverts can be operated at the field ditch level or at a larger block level. A recycling irrigation system is depicted in Figure 6. Water is fed (typically by gravity, but sometimes pumped) into the feed end of the field canal/ditch and spills over the flashboards at the other end of the ditch. This allows the flow rate into the feeder canal/ditch to remain relatively constant while the flow over the boards varies according to the ET demand in the field.

The management concern with this system is the problem of dealing with the return flow into the collector ditch. This can be easily handled by a fairly small pump which maintains the collector ditch's water level below the flashboard elevation. The pass-through water is most readily managed by being pumped off the farm. It can later be used again by anyone along the canal system. However, to prevent this irrigation through-flow water from being credited against your drainage discharge, you should pump it into the inlet basin of the main irrigation inlet structure. This procedure will assure that the through-flow water returns to your farm. Monitoring of its discharge, thus, may not be necessary.

Flashboard culverts will obviously restrict water flow during drainage events unless the boards are removed. Boards would not have to be removed if adequate hydraulic capacity exists in the feed side canal/ditch. This, however, would require a larger canal/ditch.

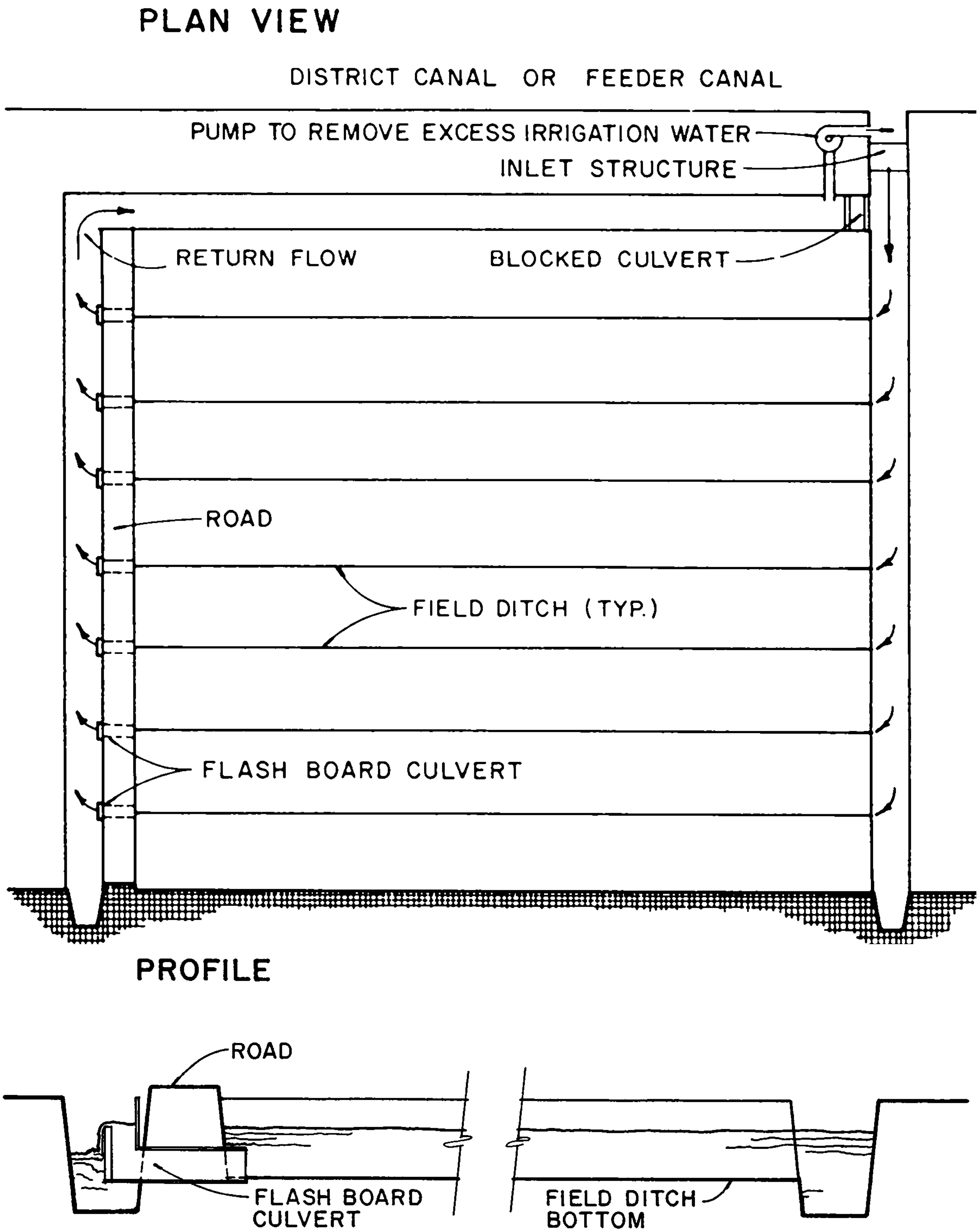


Figure 5. Irrigation water table control system using flashboard culverts and a return system.