Circular 769

Water Budgeting for High Water Table Soils[1]

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Introduction

Water budgeting is a practice which can be used beneficially to account for water stored, entering, and leaving a particular area of interest. It can be especially helpful in agriculture for scheduling irrigation and drainage events as well as for determining the volumes of water to be moved into or out of, a farm. The size of the area to budget water on, for agricultural purposes, may range from the large scale regional, state, or basin-wide levels to the smaller scale farm or field units.

In water budgeting, additions or depletions are added to, or subtracted from, the volume of water present in the area from the time budgeting or accounting begins. The discussion herein will be limited to farm and field level water budgeting. The purpose of this discussion is to illustrate what variables and factors must be considered, how a budget is kept, and how water budgeting can be used in water management decision making. Water budgeting can increase the confidence of the water manager with respect to knowing how much water is available for crop use and what the future needs might be.

The Hydrologic Cycle

The schematic representation of the hydrologic cycle in figure 1 illustrates the pathways by which water is exchanged between the earth's surface and the atmosphere. Precipitation in the forms of rain, snow, sleet, etc., adds water to the earth's surface. The water is stored as groundwater or in surface sinks such as ponds, lakes, streams, rivers, or oceans. Water falling on land areas moves over the ground surface in sheet flow or in small channels to surface water sinks. Alternatively it can percolate to the groundwater aquifer where it may either flow underground to the same sinks or remain stored beneath the earth's surface. Water returns to the atmosphere through evaporation from the surface water bodies or soil surface as well as through transpiration during plant growth.

Agricultural Water Budgets

The hydrologic cycle defines components that must be considered in developing a farm or field level water budget. The water budget is based on the basic principle of mass conservation. In other words, it is assumed that water is neither created nor destroyed, thus opening the possibility of being able

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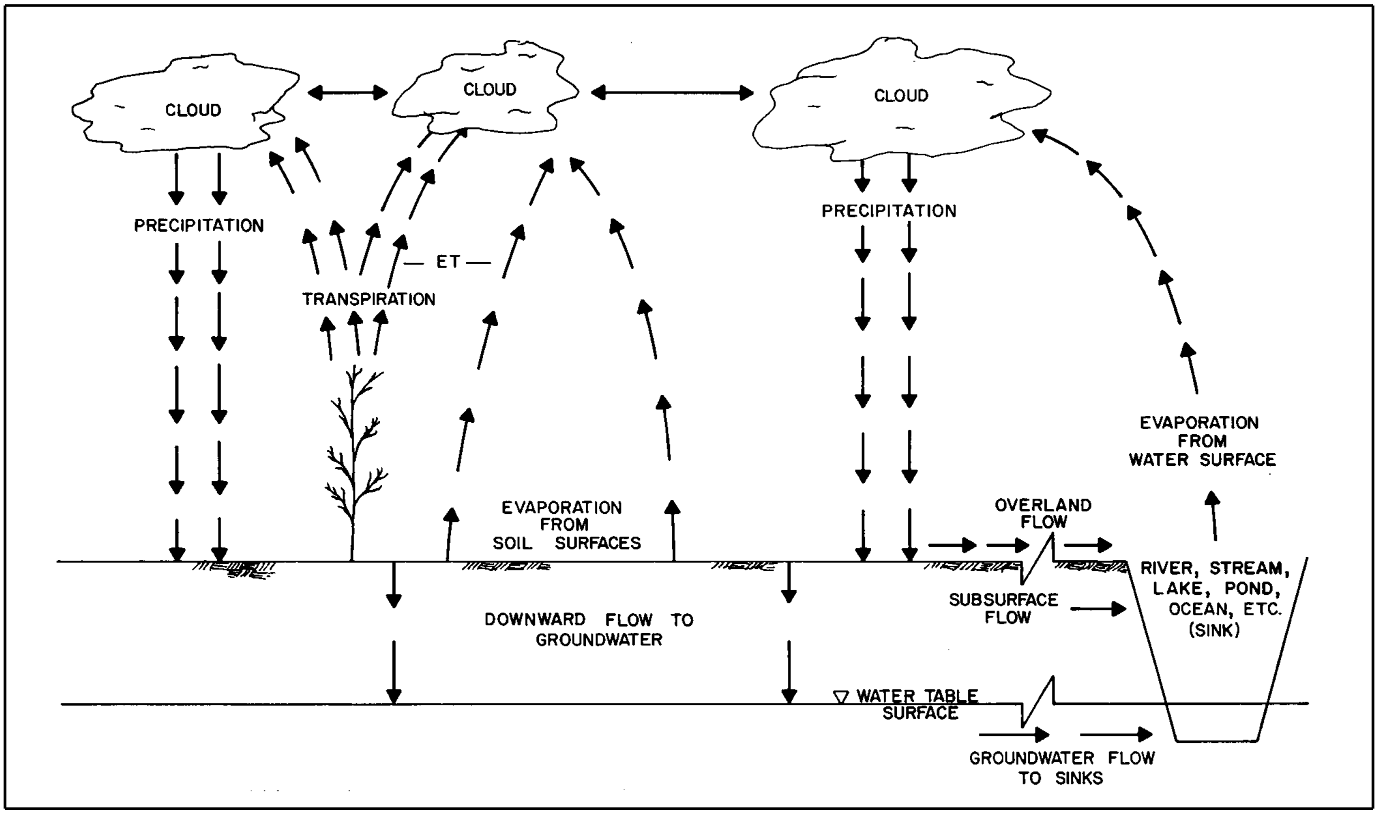

Figure 1. Schematic representation of the hydrologic cycle.

to account for all water that is stored, enters, or leaves a particular area.

A water budget may be developed and used in four basic steps:

1. Select the size and boundaries of the area of concern.
2. Determine what additions and depletions of water will occur in the area.
3. Determine the reference amount of water from which to add or subtract changes.
4. Continuously track the total amount of water and use the results to schedule irrigation and drainage timings and amounts.

For the purpose of explaining water budgeting, the checkbook analogy will be used as an example. The initial balance on the day when records begin is money in the bank, or for agricultural purposes, water available for crop use. In any budgeting or accounting procedure, a balance or an amount is carried over to the next time period.

The balance is the most important aspect of checkbook records since it indicates whether, and how much, money is available. For agriculture, water stored in, or directly available to, the plant root zone is the most significant component since it determines whether a crop will have adequate water and aeration for maximum non-water-limited yields, or whether too much or too little water will cause crop damage. Therefore, in agricultural water budgeting where deep soil profiles exist, the water stored in the root zone (WS) is usually considered to be the "checkbook balance".

Using the checkbook analogy, as checks are written or deposits made, the balance is adjusted to reflect increasing or decreasing amounts of money in the bank. Each day that transactions occur, the items and amounts are entered and the balance adjusted. Generally, payments are delayed or deposits are made to ensure that the balance does not fall below a predetermined level that the owner is comfortable with or that the bank requires. On the other hand, if the balance gets very large, withdrawals are made so that the money can be used to purchase goods or to invest in higher yielding future returns. If either too little remains or too much accumulates in the account, the account holder pays a penalty in the form of a service charge or a loss of possible interest earnings. This analogy can, and has been used for budgeting agricultural water by farmers to assure themselves that the water resources are used in an optimum fashion, with the least amount of energy expenditure.

The basic water budgeting equation, including all possible components, can be written as:

$$[delta]WS = R + I + S_{in} + F_{si} + C - ET - E_s - S_{out} - DP - F_{so} - D$$

(1)

where

$[delta]WS$ = The change in water stored in the root zone during a given time period, usually one day;

R = Rainfall or other forms of precipitation that fall on the area;

I = Irrigation water added to the area;

S_{in} = Lateral underground or subsurface seepage into the area;

F_{si} = Overland or surface flow into the area;

C = Capillary flow upwards from a water table into the root zone;

ET = Evapotranspiration (crop water use);

E_s = Evaporation from surface storage or conveyance structures if they are considered to be a part of the budgeted area;

S_{out} = Lateral underground or subsurface seepage out of the area;

DP = Deep percolation or water movement out of the bottom of the root zone;

F_{so} = Overland or surface flow out of the area; and

D = Drainage water removed from the area.

All of the terms in Equation 1 are usually expressed in units of volume per unit area (e.g. acre-inches/-acre or inches). Each of the components in Equation 1 is illustrated in figure 2. The terms on the right side of Equation 1 represents deposits to or withdrawals from the "water bank", and will cause an increase or decrease in water available for crop use. When all of the deposits and withdrawals are summed up for the day, the net change in water stored for that day is then represented by the term WS. The change in water stored ([delta]WS) can be either positive or negative depending on whether deposits are greater or less than withdrawals. The resulting daily [delta]WS is then added to the value of water stored (water in the "water bank", WS) from the preceding day to arrive at the new balance at the end of the present day, by using the following equation:

$$WS_i = WS_{i-1} + [delta]WS,$$

(2)

where WS_i = water stored at the end of the present day, and WS_{i-1} = water stored at the end of the previous day, remembering that [delta]WS can be either positive or negative.

Field Applications

The first step in budgeting water is to select the area to be considered as the unit area of the budget. Two obvious choices in agriculture are the farm and field units. Another alternative is to select an area for which inflows and outflows can be measured practically with an acceptable degree of accuracy. An example of this is to select an area that is served in its entirety by a single inlet/outlet structure (pump, gates, or a combination of both). In this case, however, flows into or out of the area in farm ditches must be measured using other water measurement structures or devices if water passes through the area in transit to other parts of the farm. In florida's seepage irrigated areas, budgets can be conducted for entire farm units served by a single pump station on a Water Management District canal. Alternatively , the area served by a relay pump within the farm may be selected. At the small scale, a water budget can be conducted on a single field. The important factors are that there must be a finite area selected and there must exist a reliable method of measuring inflows

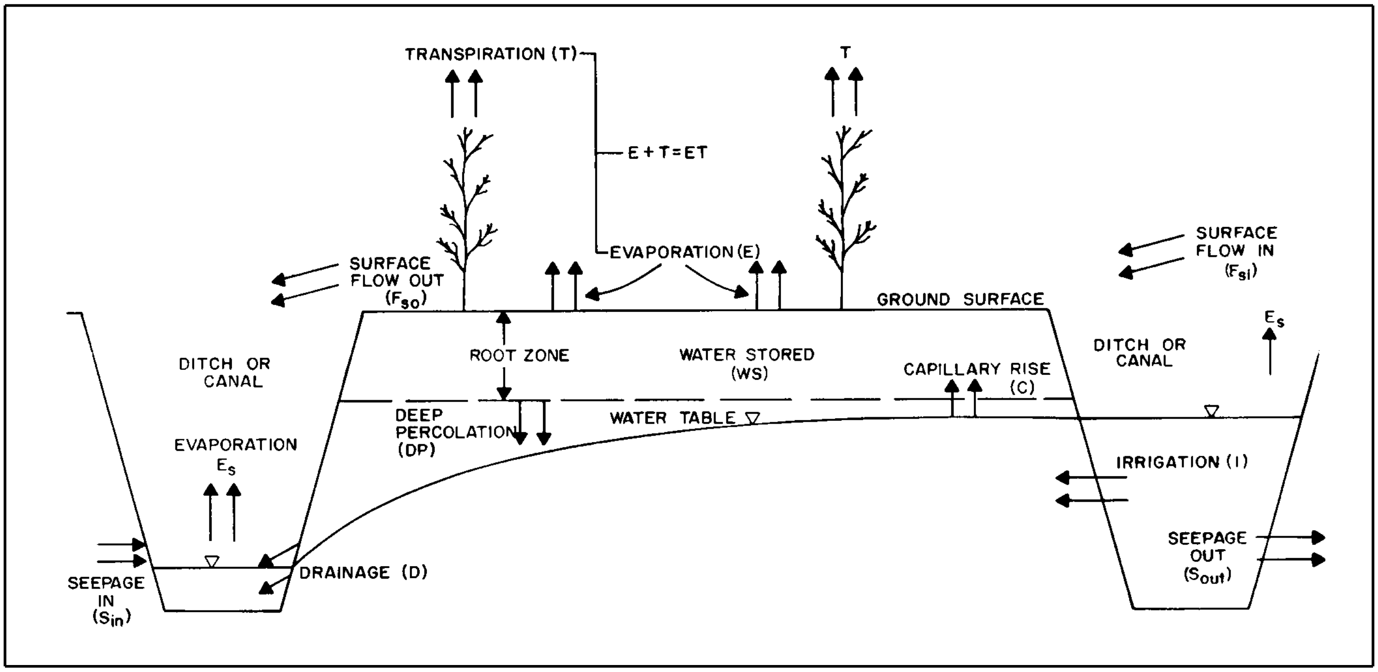

Figure 2. Possible components of an agricultural water budget.

and outflows in the ditch network. The other consideration is that the area be large enough so that effects on the budget by expected errors made in measuring, estimating, or ignoring budget components, will not greatly affect the budget results. Of importance here are the surface and subsurface flows that will occur through the area boundaries.

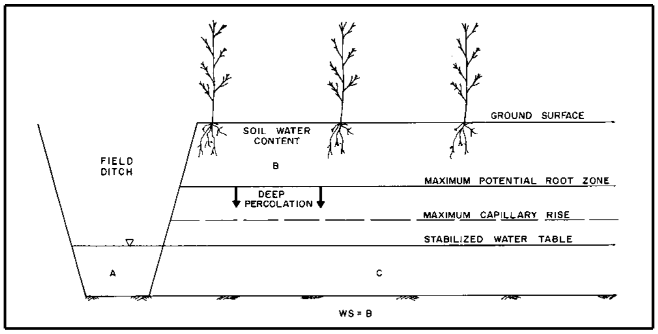

Figure 3. Situation requiring that only the soil water content need be included in WS.

After the unit area is selected, the terms in Equation 1 must be screened to determine which are applicable, which can be measured accurately, and which must be estimated. It must be stressed that not all the terms in Equation 1 will apply in every case. Some components of the budget may be excluded based on nonapplicability or insignificance. Consequently, the terms to consider will change with existing conditions of the area, the size of the area, and at the discretion of the water budgeter.

Generally, in areas where water tables are deep and do not contribute water to plant growth, WS can be defined as the water in the root zone (Figure 3). In this case, water is usually applied to the field surface for irrigations. However, in theory, the water table could be raised into the root zone for a period of time before being lowered, thus accomplishing an irrigation by moving the water table into the root zone and by capillary rise above the water table. Capillary rise would not contribute to crop water needs on a continual basis. The amount of water added during the irrigation could be measured by soil water content determinations. Deep percolation would also have to be accounted for and could be quantified by taking soil water content measurements before and after the rainfall or irrigation event.

In the high water table areas of Florida, additional factors must be considered in defining WS. A portion of the water table aquifer generally resides in the potential crop root zone. In other words, rooting depths may be limited by the water table (Figure 4). Capillary water from the water table continually rises into the root zone above. Beneath the water table aquifer is a shallow impermeable boundary.

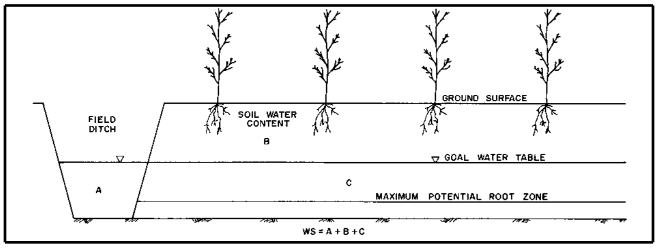

Figure 4. Situation requiring that the water table aquifer and ditch water level be included in WS.

When a rainfall occurs, Water percolates through the root zone and enters the water table aquifer, thereby raising the water table into the root zone. This water cannot be called deep percolation since it is in the water table aquifer which has been temporarily raised into the crop root zone, and hence, could be available in its entirety for crop use as long as the impermeable layer doesn't leak. The water remains available until it is removed by drainage, crop use, evaporation, or lateral seepage.

Water moves freely from the water table aquifer into the root zone through capillary action as crops deplete the storage in the unsaturated portion of the soil profile. Capillary rise occurs continuously and in different amounts to different levels depending on the water table depth. Additionally, water in the open ditches is directly connected to the water in the water table aquifer and therefore to the water in the crop root zone. In fact, free exchange of water occurs between the three. As plants draw water from the root zone, water from the field water table aquifer replenishes the soil water deficit, and ditch water replenishes the water table aquifer as area-wide water tables are constantly moving to be in equilibrium. Like-wise, during a rainfall event, water percolates through the plant root zone, into the water table aquifer, and out into the ditches. There is no way, or reason, to practically stop ditch water from interacting with the water table aquifer and the soil water in the root zone. Consequently, it is virtually impossible to isolate and quantify capillary rise contributions to the root zone and deep percolation losses without involving a study of corresponding water table and ditch level changes.

A way to eliminate the need to deal with the DP and C terms independently is to include the soil water, water table aquifer, and the ditch water as parts of the total water available to the crop, and therefore, a part of WS. In many Florida cases, where the water table aquifer is bounded below by a shallow, virtually impermeable layer, this is a legitimate and simplifying technique. This assumes that all water above the shallow impermeable layer is potentially available to the crop.

It is extremely important to be able to identify how much water is on the farm when field water tables are at the ideal or goal level. This value is the goal WS term. Then it is important to be able to determine how much water is on the farm when field water tables are at both the highest and lowest levels desired. The manager must also determine how long the highest and lowest water tables can be allowed to remain in a particular critical field. The irrigation or drainage event can be scheduled when some percentage increase or decrease in the goal water volume occurs, considering how long it would take to see the effects of the irrigation or drainage activity at the critical field.

Farm Level Water Budgets

At the farm level in high water table areas where the water table aquifer occupies a portion of the potential crop root zone, WS represents the total water stored on the farm. This is the sum of the water in storage structures, conveyance ditches, the crop root zone, and the water table aquifer above the shallow impermeable layer. These volumes can be measured to a good degree of accuracy at any point in time. This total volume figure, on the day the budget begins, serves as the "checkbook" balance.

Rainfall, irrigation, and drainage can, and must, be measured accurately with proper measuring tools. Evaporation from surface water (E_s) and evapotranspiration (ET) can be estimated reasonably well using climatic data, prediction equations, evaporation plans, historical data, and scaling factors. Alternatively, ET in fields can be measured using lysimeters.

Overland surface inflows (F_{si}) and outflows (F_{so}) can generally be neglected since the budget is only concerned with them at the outer boundaries of the farm unit. Some flow could occur on or off the farm at the outer boundaries. However, in the high water table areas where water table control is practiced for irrigation and drainage, land slopes are flat and raised roads separate most areas, resulting in little opportunity for overland flow exchange between the farm and surrounding areas. All surface flows occurring within the system will not change the total volume stored on the farm. These flows will generally occur to ditches within the system after rainfalls and will be accounted for as rainfall, increases in storage, or as drainage through the pump station.

Underground seepage in (S_{in}) and out (S_{out}) of the farm unit may or may not be major factors. As with the overland flow components, the underground lateral seepage of concern is that which occurs at the farm boundaries. Generally, if the farm area is large enough, these terms can be assumed to cancel each other out or to be negligible when compared to the large volumes stored in the interior of the farm, rainfall, drainage pumping, irrigation, and evapotranspiration. This assumption is especially valid if the surrounding fields or farms are maintained at water table levels equal to the budgeted farm.

In high water table areas overlaying a shallow confining layer, deep percolation (DP) losses are not a factor since water simply percolates to the water table aquifer and raises the water table surface. This, along with capillary rise (C) from the water table neither adds to nor detracts from the overall budget since the water table aquifer is included in the WS volume. These to factors are simply redistributions of water within the system. Thus, for large farm unit water budgets, the change in water stored ([delta]WS) can be estimated as:

$$\text{[delta]WS} = R + I - ET - D - E_s$$

(3)

However, if lateral seepage in or out of the farm unit is determined to be a major factor affecting water on the farm at any time, the equation would be:

$$\text{[delta]WS} = R + I + S_{in} - ET - D - S_{out} - E_s$$

(4)

The value of [delta]WS (either positive or negative) would then be added to the value of WS for the preceding day according to Equation 2. The resulting value of WS could then be compared to the value of WS where water tables would be at the ideal or goal level and decisions regarding whether to irrigate or drain could be made. Using the water budget in this way makes it an important part of irrigation and drainage scheduling for farm units.

Field Level Water Budgets

At the field level in high water table areas of Florida, where water table aquifers reside in the potential crop root zone, WS should represent the summation of the water stored in the crop root zone, the water in the water table aquifer above the restrictive layer, and the water in the field ditch for reasons discussed earlier (figure 4). A root zone depth must be selected, related to the depth of the "goal" water table.

Since water in the field ditch serving the field must also be included in the WS volume, this raises an important issue of how a field should be defined for water budgeting purposes. Since each field ditch or lateral influences the soil water content in half of each field on either side of it, assuming ditch water levels are nearly the same, a field can be defined as a central field ditch plus half of the fields on either side of the ditch. This greatly facilitates measurements. The field layout is shown in Figure 5. This field definition facilitates budgeting by selecting a field unit with identifiable and measurable hydraulic boundaries.

The value of WS would be allowed to rise or fall within predetermined levels before drainage or irrigation occurs. The water budget equation for [delta]WS would be tracked in the same way that it was for the farm level with the exception that different budget components may be involved. Rainfall, irrigation, and drainage would again be measured as the total inflow into the central field ditch. Alternatively, it can be measured as the total increase in soil water content in the root zone, including the rise in water table level, plus ET that occurs during the irrigation, plus the change in volume stored in the field ditch. Drainage would be measured as the amount of water leaving the central field ditch or as the sum of the decrease in soil water content including the lowering of the water table,

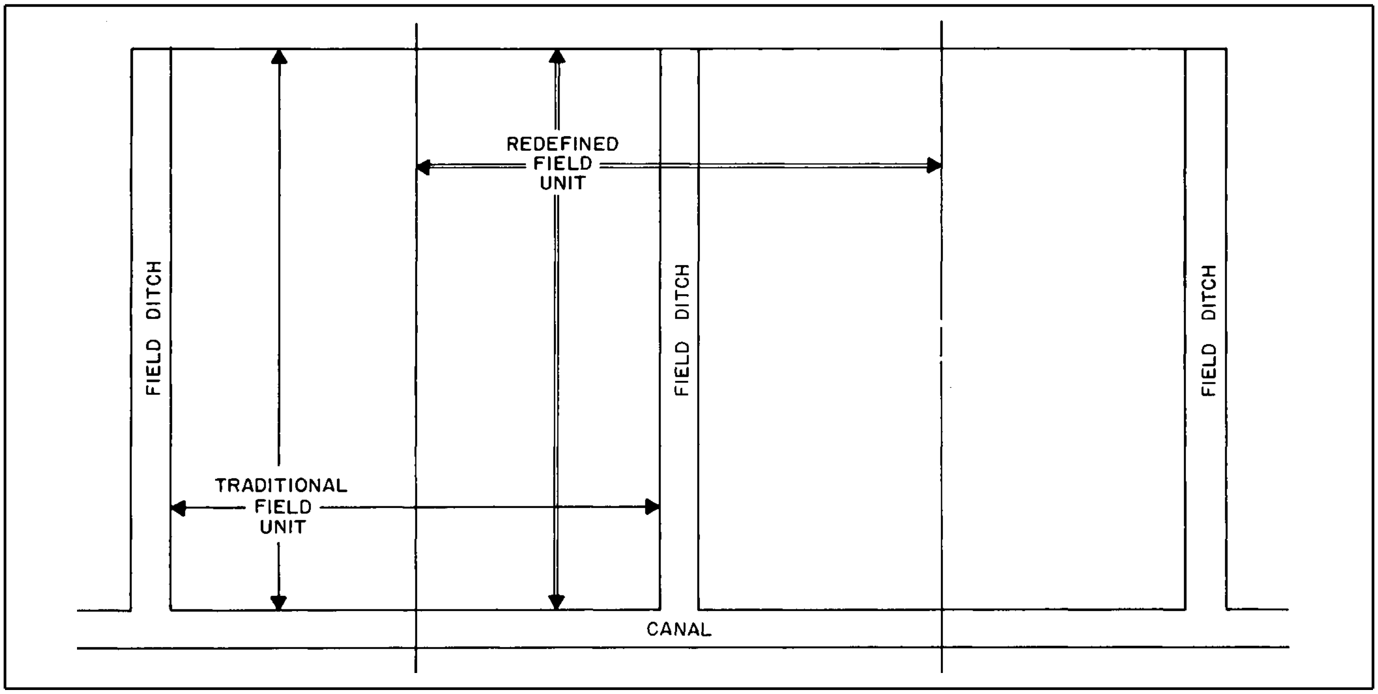

Figure 5. Definition of field unit for water budgeting in high water table seepage systems.

plus the decrease in the ditch water level, plus surface runoff into the ditch, minus the amount of ET occurring during drainage. Evapotranspiration would be measured, estimated, or calculated as was done in the farm level budget.

The overland surface flow terms F_{si} and F_{so} could be negligible since it may be the case that the majority of the excess rainfall must pass through the soil profile on the way into or out of the field, providing that negligible field slopes exist. The seepage terms S_{in} and S_{out} could present more of a problem. Water may be lost from, or gained in, the field unit if hydraulic gradients are such that flow occurs underground between field units. This volume may need to be included in a field level budget since other water volumes may not be large enough to mask the effects and since the total length of field boundaries with adjacent fields is significant when dealing with smaller land areas. Surface water evaporation must be measured to account for changes in the ditch water level not associated with irrigation, drainage, or crop use. If the shallow impermeable layer does not leak, the DP can again be ignored. Also, the C term can be ignored if the water table is in the root zone. Equation 4 can be used for calculating field level water budget changes. It is advisable to select fields where S_{in} and S_{out} do not greatly affect the water budget since these terms are difficult to quantify. Such a case would exist where water tables in all surrounding fields are maintained at the same level as the budgeted field. Then, [delta]WS can be calculated using Equation 3.

Judgments will need to be made to determine which terms would be insignificant in any particular situation. In particular, the seepage terms are difficult to measure or estimate, but may be negligible if hydraulic conditions are similar in surrounding fields.

Benefits of Water Budgeting

As is money in the bank, water in the "bank" is an asset that should be managed as any valuable resource. Good management cannot be determined or undeniably claimed without knowledge of how much water is available and how it is to be used. Keeping a water budget is not an easy task and requires certain measurements, calculations, and assumptions to be made. A computer program is desirable to keep the budget on a daily basis. The program can be run day by day or for weeks in advance based on predicted conditions to schedule irrigation and drainage events. A water budgeting model can also be used at any time to predict the effects on the volume of water stored in a field or on a farm as a result of a storm or drought event, without having to actually be experiencing the situation. Additionally, it can be determined how much pumping is necessary after a rain such that only that water which is absolutely necessary is removed. Such exercises would enable water managers to develop strategies and schedule activities to use water and energy in the most beneficial manner. Budgets can, in this manner assure managers that water resources are being utilized in the best possible way.

Water budgets can be kept manually. While this method may be tedious for long-term strategy development, it still can be a helpful tool to water managers. By keeping an eye on water in the "bank" and daily deposits and withdrawals, water needs for farms and areas of farms can be projected and scheduled. Water budgeting can eliminate much of the guesswork involved in water management activities.

Summary

Water budgets at the farm and field levels have been discussed. The possible components of water budget have been identified. It was shown how different types of budgets can be kept for different conditions. Additionally, it was shown how a budget can be tailored to specific situations by making assumptions as to the applicability or significance of individual terms. Water budgets can be used to predict irrigation and drainage needs as well as to develop water management strategies. Although a computer model is very useful in keeping budgets and projecting strategies for possible events, budgets can be useful when kept manually.

References

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