

IRRIGATION SCHEDULING

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INTRODUCTION

It is said many times in this handbook, the keys to efficient, effective irrigations are knowing WHEN to irrigate, HOW MUCH to irrigate, and HOW to irrigate. This chapter will discuss the irrigation scheduling process. Irrigation scheduling is a generic term, covering a variety of techniques. They all objectively attempt to answer the questions, WHEN and HOW MUCH to irrigate.

All methods of irrigation scheduling will start with some form of the water-budget equation. The water-budget equation is a simplified,

mathematical model of water going into and out of the effective root zone.

A key element of irrigation scheduling will depend in large part on your experience. What is the effective root zone? That is, where do you want to control soil moisture? And how dry will you let the root zone get?

The measure of how dry the root zone is before an irrigation is the ALLOWABLE DEPLETION. The choice of AD depends on the crop, the growth stage, and how you want the crop to develop. Sometimes there are detailed recommendations available to help. The leaf pressure chamber readings recommended by UC Extension for cotton are an example. Other times it is your experience alone that will decide.

Water going into the root zone is irrigation, rainfall, or upwards movement of groundwater from a shallow water table. Water coming out of the root zone is crop water use (ET_c), or deep percolation. The deep percolation may be a result of excessive irrigation or rainfall.

The water budget equation will be introduced as . . .

$$SMD_{end} = SMD_{start} - IRR - PPT - GW + ET_c + DEEP$$

where: SMD_{start} = soil moisture depletion at the start of a time period

IRR = any irrigation during that time period

PPT = any rainfall infiltrating during that time period

GW = any upwards movement of groundwater from a shallow water table into the root zone during the time period

ET_c = crop water use during the time period

DEEP = deep percolation from excess irrigation or rainfall during the time period

SMD_{end} = soil moisture depletion at the end of the time period

The information needs for, and different methods of using the water-budget equation will be discussed.

The help that is available to you will be identified. These include the weekly and daily [Crop Water Use Guide](http://www.westlandswater.org/wwd/wtrcon/irrguide.asp?title=Irrigation%20Guide&cwide=1024), (http://www.westlandswater.org/wwd/wtrcon/irrguide.asp?title=Irrigation%20Guide&cwide=1024) the Crop Data Sheets, and the [Irrigation Scheduling Charts](#). These were all developed by the District's Water Conservation Program.

IMPORTANT! Irrigation scheduling can be an important tool in increasing irrigation efficiencies. As you will see, it can help to decide the best time to irrigate as well as provide an estimate of how much water to apply. **However, it does little to improve the actual application of water in the field.** That important factor will be discussed in the "System Management" sections.

Also, in many cases, the traditional water-budget irrigation scheduling is used as an early-warning device. It can alert you that a field is getting close to the allowable depletion so that you can begin looking at it closer. It is never recommended that a water-budget irrigation scheduling system be the sole ruler of when to irrigate. However, water-budget irrigation scheduling will always provide an estimate of how much water to put back into the soil.

One other reason for using some type of irrigation scheduling system is repeatability.

If something goes right, if above-average yields are achieved one year, you would like to do the same things next year. Not exactly the same things because Mother Nature is not always the same. But you would like to react in the same manner. Objective methods of irrigation scheduling usually create a record of what happened and when. At the end of a year you can look at this record to see what went wrong and what went right.

Additional related materials are also available from an online [training manual](http://www.fao.org/docrep/T7202E/t7202e00.htm) (http://www.fao.org/docrep/T7202E/t7202e00.htm) provided by the United Nations FAO. Be advised that this publication uses metric measurements. Also, the USBR has supported the creation of the [WaterRight](http://www.wateright.org/) (http://www.wateright.org/) site which provides an additional source of irrigation scheduling information.

A REVIEW OF SOIL-WATER-PLANT RELATIONSHIPS

In the previous chapter you were introduced to some key concepts of soil-water-plant relationships.

- Soil will hold water against the pull of gravity, available for crop use.
- There are limits to this ability, field capacity (upper limit) and permanent wilting point (lower limit).
- The water-holding forces generated by the soil will increase as the soil moisture level goes down. Thus as soil moisture decreases, it becomes harder and harder for the plant to extract water from the soil at the rate it wants to.
- We are generally only interested in soil moisture in the effective root zone, which may or may not be the

actual extent of active plant roots. The effective root zone is where you want to control soil moisture.

- The combination of soil evaporation and plant transpiration is called evapotranspiration, ETc.
- There are standards of measurement for soil moisture (inches of water held per foot of soil) and ETc (inches of water use per day, or per season.)

EFFECTIVE ROOT ZONE AND THE SOIL MOISTURE RESERVOIR

The available water holding capacity of the soil measured over the depth of the effective root zone results in a [soil moisture reservoir](#) .

This reservoir is available for the crop to use. It's as if the plant was pulling from a pan of water, with a specific depth of water in the pan.

Some soils, because of their higher available water-holding capacity, will provide a deeper pan than others. And, some plants will provide a deeper pan because of their deeper rooting systems.

A key idea is that we cannot let the plant use up all the water in the soil moisture reservoir. Remember that the bottom limit of available soil moisture is the permanent wilting point. If we let the plant use water up to the permanent wilting point, then it dies. In fact, past a certain level of soil moisture depletion, the plant comes under more and more stress as it becomes harder and harder for it to extract water from the soil. This stress can reduce yields and/or quality.

ALLOWABLE DEPLETION

A term in wide use by water management professionals is "allowable depletion". (You may also see it called "management allowable depletion" or "MAD" in other writings.) This is the amount of available soil moisture that is allowed to be used by the plant between irrigations.

Allowable depletions can be described as a percentage or as total inches of water use. Thus, we might say . . . "the allowable depletion for this field is 45 percent of the available water holding capacity". We are saying that we will allow the crop to use 45 percent of the available water in the effective root zone between irrigations. Or, we might say . . . "the allowable depletion for the field is 3.5 inches". We are now saying that we will allow the crop to use 3.5 inches between irrigations. Put another way, the soil moisture depletion (the moisture you want to replace with an irrigation) will be 3.5 inches before an irrigation.

The allowable depletion, AD, in inches of water use is equal to the allowable depletion percentage multiplied by the available water holding capacity, AWHC. For example, assume . . .

$$\begin{aligned} \text{AWHC} &= 5.5 \text{ inches} \\ \text{AD}\% &= 45\% \end{aligned}$$

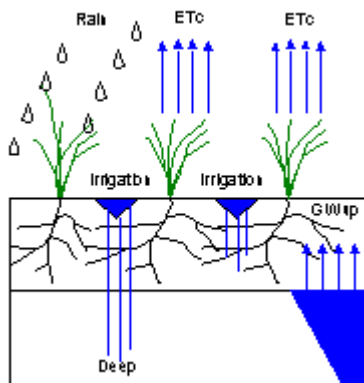
thus allowable depletion in total inches of water use is . . .

$$\begin{aligned} \text{AD}_{\text{inches}} &= \text{AWHC} \times \text{AD}\% / 100 \\ &= 5.5 \times 45 / 100 \\ &= 2.5 \text{ inches} \end{aligned}$$

WATER INTO AND OUT OF THE EFFECTIVE ROOT ZONE

Modern farm managers attempt to control all processes on the farm. When controlling the irrigation program, modern managers first look at the effective root zone (ERZ) as a "system". Then, they identify, measure and control the water going into and out of the system.

FIGURE-1 - schematic of root zone ins/outs



Referring to Figure-1, the primary sources of water going into the effective root zone are rain (RAIN), irrigation (IRR), and upwards movement of groundwater from a shallow water table (GW).

The primary losses of water are deep percolation (DEEP) from excess irrigation or rainfall and crop evapotranspiration (ETc).

All of the water going into and out of the effective root zone on a daily or seasonal basis can be measured in terms of a depth of water, usually inches . . .

- Rainfall is measured in inches.

- Irrigations are commonly measured as acre-inches/acre applied, or just inches.
- Upwards movement of groundwater (considered as irrigation) is measured in inches.
- Deep percolation is water soaked into the effective root zone in excess of the soil's field capacity. Since it is either excess irrigation or excess rainfall, it too is measured in inches.
- Finally, crop evapotranspiration (ETc) is measured in inches.

In addition to the water coming into and out of the effective root zone, the actual level of soil moisture at any time (which we've called the soil moisture reservoir) can be measured in inches. Thus all components of the system are measured in the same units, inches. This enabled scientists to develop the "water budget" equation and the water budget method of irrigation scheduling.

THE WATER BUDGET EQUATION

Remember the different ways that soil moisture can be described volumetrically . . .

- Total moisture, the total amount of moisture in the soil.
- Available moisture, the amount of moisture in the soil above the permanent wilting point.
- Soil moisture depletion, the amount of moisture needed to take the soil up to field capacity. This would normally be the net amount of water you would apply at an irrigation.

Irrigation scheduling methods generally work with the last definition. This is because one of the questions that irrigation scheduling techniques try to answer is "how much to

irrigate?". How much to irrigate is the soil moisture depletion at irrigation.

"Water budget" irrigation scheduling is the day-to-day accounting of all water going into and out of the effective root zone. The basic process is to assume a starting point, the soil moisture depletion at the start of a day. Then, the soil moisture depletion at the end of the day is calculated using the water budget equation . . .

$$SMD_{end} = SMD_{start} + DEEP + ET_c - IRR - RAIN - GW_{up}$$

All this equation is saying is that if you start with a certain soil moisture depletion (SMD_{start})

- Any irrigation is going to reduce the depletion (- IRR).
- Any rainfall that soaks into the ground is going to reduce the depletion (- RAIN).
- Any groundwater moving up into the root zone from a shallow water-table will reduce the depletion (- GW_{up}).
- Any crop water use (evapotranspiration, ET_c) is going to add to the depletion (+ ET_c).
- And any irrigation or rainfall in excess of the field capacity will add to the depletion (+ DEEP).

For example, assume that you are starting the water budget on the day after a full irrigation. Thus the starting soil moisture depletion is 0, $SMD_{start} = 0$ inches. It didn't rain that day so $RAIN = 0$ inches. There was no irrigation because you just irrigated, so $IRR = 0$ inches. The crop water use (evapotranspiration, ET_c) for the day was estimated at .22 inches. And there is no shallow water-table, thus GW_{up} is 0. The water budget equation then says that . . .

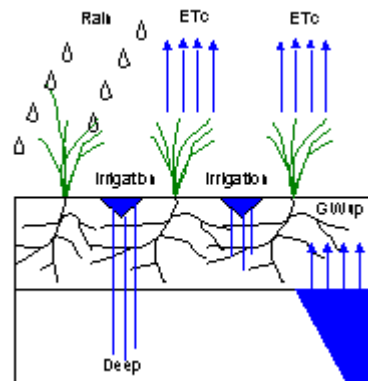
$$SMD_{end} = SMD_{start} + DEEP + ET_c - IRR - RAIN - GW_{up} = 0 + 0 + .22 - 0 - 0 - 0 = .22 \text{ inches}$$

At the end of the first day after irrigating, the soil moisture depletion is .22 inches.

As stated previously, the water budget equation is solved on a day-to-day basis. When SMD_{end} is calculated to be at or over the allowed depletion, an irrigation is scheduled. The amount of irrigation is the SMD_{end} (the soil moisture depletion at time of irrigation) plus any leaching requirements plus allowances for irrigation efficiency.

Effective, efficient irrigations are the result of knowing **WHEN** to irrigate, **HOW MUCH** to irrigate, and **HOW** to irrigate. **Water budget irrigation scheduling helps to identify two of the three keys . . .**

- **WHEN** to irrigate, when the soil moisture depletion is calculated to be more than the allowed depletion.
- **HOW MUCH** to irrigate, the calculated soil moisture depletion when you decide to irrigate. Detailed examples of water-budget scheduling are contained in the Appendix.



INFORMATION REQUIREMENTS FOR WATER-BUDGET IRRIGATION SCHEDULING

The actual water budget equation is simple, a starting soil moisture depletion and five numbers to add or subtract to determine the ending soil moisture depletion. The problems, and the costs, of water budget scheduling come with identifying those numbers. Accurate water budget irrigation scheduling requires knowledge of the following . . .

- The soil's available water holding capacity throughout the season.
- Agronomic factors that determine how much to stress the crop between irrigations, the choice of allowable depletions.
- Effective rainfall, that is, rain that actually soaks into the soil and is not runoff.
- Effective irrigation depths, how much water delivered to a field stays in the effective root zone, available to the crop.
- Upwards water movement from any shallow water-table.

Most people doing water budget scheduling will also take (or they should be taking) regular measurements of soil and/or plant moisture. This will make sure that the estimates of the numbers are accurate.

This looks like a lot of information and it is. But there are many sources available to you. Also, scheduling consultants will develop the required numbers as part of their service.

Looking at the help available to you in finding the information needed (by category):

SOILS - the Reference section of this handbook describes important properties of most important soils in the District. The UC Extension specialists also will have information, including Extension pamphlet #21463, "Holding Capacities of California Soils".

Knowledge of the soil will provide estimates of field capacities and permanent wilting points as well as any restrictions to root zone development and salt levels.

A very fine point of irrigation scheduling concerns the estimate of available water holding capacity, AWHC. We've said that AWHC is equal to the field capacity minus the permanent wilting point. And we've also said that it does no good to soak water into a soil already at field capacity as it will just drain through the root zone. However, depending on the soil and the depth of the root zone, it may take 2 or more days for this excess water to soak through. In this time the crop can be using some of the excess. In real terms, the AWHC may be somewhat more than the accepted value of field capacity minus permanent wilting point.

The effect of this slow drainage in increasing the practical soil moisture reservoir vary with the soil. The effect will be greater on finer soils and deeper root zones than on coarse soils and shallower root zones.

ROOT ZONES - it can be very difficult to set effective root zones and may take a couple of years of experience, especially with annual crops. Your UC Cooperative Extension specialist or consulting agronomist will have information for you.

Make sure you consider any restrictions on the root zones due to hard pans or high water tables. The root zone of an annual is going to change constantly up to plant maturity. But

the effective root zone does not have to be the full depth of the rooting system. For example, in cotton it is common to choose an effective root zone of 4 feet. This is done even though the full system might go to 6 foot or more. Remember, the effective root zone is where you want to control soil moisture.

ALLOWABLE DEPLETIONS - AD's are a measure of how much stress is to be applied to a crop. AD's may change with the season. With cotton it was common (although not recommended with newer varieties) to put heavy water stress on early and then go to a more regular routine once the plant was fruiting. Be aware of the different growth stages of your crops and how they should be manipulated during these stages.

Also, if you have fields with high salinity, the AD is likely to be lower than normal (keeping more moisture in the root zone). The Crop Data Sheets in the Reference chapter contain recommended water stress levels for the different growth stages of most important District crops.

Many times, allowable depletions are "backed-in to" when first starting irrigation scheduling. The Grower is checking a field and finally decides to irrigate. The irrigation scheduling system is checked for the soil moisture depletion at the time of the irrigation. This is then converted to an allowable depletion for future use.

For example, the maximum soil moisture reservoir (SMR_{max}) of a field is calculated to be 5 inches. The Grower has decided that the crop is ready for irrigation. The irrigation schedule calculates that 2 inches of water have been used by the crop since the last irrigation (with no rainfall occurring). Thus the soil moisture depletion is at 2 inches at the time of irrigation. Now . . .

$$AD\% = 100 * (SMD / SMR_{max})$$

$$AD\% = 100 * (2 / 5)$$

$$AD\% = 40\%$$

The Grower is letting the crop use 40 percent of the soil moisture reservoir between irrigations and this 40 percent allowable depletion will be used to schedule the next irrigation.

EVAPOTRANSPIRATION, ET_c - the District publishes the printed [Irrigation Guide](http://www.westlandswater.org/wwd/wtrcon/irrguide.asp?title=Irrigation%20Guide&cwide=1024) (<http://www.westlandswater.org/wwd/wtrcon/irrguide.asp?title=Irrigation%20Guide&cwide=1024>) on a weekly basis, daily on the web site, with three editions for the North, Central, and South regions. All the major crops in the District, with several planting dates for many, are covered in the Guide. It includes a summation of the past 7 and 14 days and seasonal water use plus a predicted water use in the next 7 and 10 days.

The Irrigation Guide provides information making it easier to schedule irrigations. It can also help in using the WWD Irrigation [Scheduling Chart](#) . The Scheduling Chart is used to calculate the next irrigation date.

The District's Irrigation Guide is easy to use and contains direct estimates of crop water use. However, some consultants will develop their own estimates using a reference ET and crop coefficients. Although more time-consuming and subject to the same errors as the District's Guide, it does allow a field/crop specific approach to scheduling. An explanation of using reference ET and crop coefficients is contained in the Appendix.

RAIN - rainfalls are reported by radio, TV, and newspapers. Many times they get their information from weather stations at airports. Actual rainfall in your field can vary widely from reported. Rain gauges are cheap. Place

one near your fields to get an accurate measure of the actual rainfall.

Note also that the total rainfall may not have soaked into the ground. Depending on the storm's intensity and duration, along with pre-existing field surface and moisture conditions, there might be significant runoff. It is your experience that judges how much rainfall is EFFECTIVE rainfall, rainfall that actually soaked into your field.

Also, remember that soil at field capacity will still take in water. Rain may soak into the ground, but if the rain occurs just after a good irrigation, it may just be more deep percolation.

IRRIGATION - there are many different methods used to estimate the actual net irrigation. Some people will take a soil moisture measurement a day or two after an irrigation to see what went on. (Remember that the ["feel" method](#) is the cheapest, fastest, most flexible method available.) Some will assume that the irrigation is excessive (especially with surface irrigations) and that soil moisture depletions are taken to zero during an irrigation.

If using a sprinkle or trickle system, you should know what the application rate of the system is (refer to the System Management chapter of this handbook). Then, it is a simple matter of multiplying the application rate times the set time to estimate the irrigation.

In most irrigation scheduling systems, a gross irrigation is reported so that the total amount of water delivered to the field can be tracked. The net irrigation, used in the water budget equation, is determined by applying an efficiency factor. That is . . .

$$\text{NET IRR} = \text{GROSS IRR} \times \text{EFF}$$

The efficiency of an irrigation system can be estimated (See System Management and the Appendix). Many irrigation specialists offer this service. **It is a good idea to have your system evaluated for distribution uniformity and irrigation efficiency.**

PUTTING IT ALL TOGETHER TO CALL THE NEXT IRRIGATION

The water budget equation begins with the starting conditions to allow you to calculate the conditions at another future point in time. You want to project the next irrigation date so that you can plan to have the required resources available when you decide to begin the irrigation. These resources include water supply, labor, and irrigation equipment. Other cultural practices must also be scheduled for the field. Irrigation scheduling will allow the irrigation manager to plan ahead to avoid yield reductions caused by water stress while managing all cultural practices for a crop.

The water balance equation is nothing more than a bank account approach to the active soil moisture reservoir that is available to the crop rootzone, now and at the time of the next irrigation. Crop ET is a withdrawal from available moisture. The other components of the water balance also are deposits and withdrawals from the account. You want to avoid the penalties from an over drawn account and you want to minimize the irrigation costs for a field.

There are five pieces of information required to use the water balance equation to project the next irrigation date and amount.

1. Soil Type
2. Allowable Depletion
3. Current Depletion

4. Active Root Zone
5. Forecast Daily Crop Water Use

THE SIMPLEST EXAMPLE

The simplest example of projecting the next irrigation date could be using the last irrigation date to project the next date. If the last irrigation date refilled the active rootzone then the current depletion is zero, and falls out of the equation. If the amount of water applied by, say, a handmove sprinkler system or drip/micro irrigation system is less than the allowable depletion calculated for the crop, you will irrigate before any water stress might occur, so, the soil type, active rootzone and the crop determined allowable depletion are all within the criteria, and fall out of the equation. All that is needed is to sum the daily crop water use until you reach the allowable depletion. The amount of water required to refill the rootzone is the current depletion. When the current depletion equals the allowable depletion is time to irrigate.

The allowable depletion is sometime known as the management allowed depletion. If you have an allowable depletion of 3.0 inches and the crop ET from the Irrigation Guide is expected to be .25 inches per day, then you would expect to want to irrigate again 12 days after the last irrigation. If your system was 80 percent efficient you would expect to apply 3.75 inches to refill the rootzone for the average of the driest quarter of the field.

In this case the allowable depletion is determined by the desire to refill the active rootzone with a fixed amount of water and not by any other criteria. If the irrigation is too early deep percolation will be the result. If the irrigation is delayed there crop effects should considered, but the seasonal irrigation strategy must be reconsidered, which may call for the next irrigation to be scheduled earlier to refill the active root zone.

Drip and sprinkler irrigation systems allow for close management of the depth of water applied, but surface irrigation systems, like furrow are less certain of the amount of water applied. Drip systems will allow the irrigation manager to apply frequent smaller amounts of water with high efficiency, if the amount applied is matched to the current depletion, which is the sum of the withdrawals from the bank account (active root zone) over a period of time.

A MORE COMMON EXAMPLE

In a more common example, monitoring is necessary for surface irrigation systems because of the uncertainty in soil moisture holding characteristics or in knowing the depth of water applied, which varies during the season and the practical minimum depth that can be applied with the system. See the section of this handbook on [soil moisture monitoring](#) for options available.

Hand-probing is a practical method to check the soil moisture status of the active rootzone. It will give a good estimate of the current depletion of the active rootzone and in the process allow you to see where the moisture is being removed from, which tells you what the active rootzone is currently and by actually seeing the roots in the soil. Irrigation scheduling in this situation needs the remainder of the factors mentioned above.

Where the monitored depletion is beginning depletion, which is not the full profile after the irrigation and the soil type and crop characteristics become important. Hand-probing is usually accomplished at least a week prior to the next irrigation to validate the assumption that the last irrigation refilled the profile. If it did not refill the profile(say, low wheel row infiltration) then the next irrigation date will need to be pushed up

earlier or if the available soil moisture to the crop was higher than estimated (say, higher water holding capacity of the soil or larger active root zone depth) the date will need to be slipped.

Another important aspect to monitoring is the choice of monitoring site. Does the site give information that will allow for the best management. For example, the least amount of water infiltrated during a furrow irrigation is generally about $\frac{3}{4}$ the way down a furrow. This will be the first place in the field to suffer the effects of water stress and would be the place that you would want to monitor. The remainder of the field will not be stressed if the monitoring site is not stressed.

CALCULATING A DATE

With the information in hand, all that is left is to do the arithmetic. You might use a calculator, but with practice you can do it in your head.

In case neither of these appeal to you, we have developed a graphical aid to do the calculations. In the appendix there are irrigation scheduling charts that allow you to find the next irrigation date graphically, without arithmetic. Enter the chart at the appropriate point and move to the number of days till the next irrigation. There even is a pocket size graph that could be used in the field:

1. Pick the graph that applies to the soil type for the monitoring site, Coarse.
2. Enter the graph on the lower left edge of the page at the current depletion, say 30%.
3. Move vertically up the page to the appropriate allowable depletion line, say 60% for cotton.
4. Move horizontally across to the right to the expected daily crop water use

line, say .15"/day, from the Irrigation Guide.

5. Move vertically down to the number of Days to Irrigation.
6. Read 6 days to irrigation on the scale for a root zone of 3 feet.
7. Determine the amount to be replaced in the soil profile by multiplying the Available Moisture in Inches value for the Days to Irrigation used, in the lower right corner, by the allowable, $3.0" \times 60\% = 1.8"$.
8. Determine the amount of irrigation water required to be applied by dividing the amount to be replaced by the irrigation efficiency, $1.8" / 75\% = 2.4"$

FIELDMAN SCHEDULING SHEET

A second alternative to doing the arithmetic is to use the Fieldman Scheduling Sheet that is available daily on the District web site. These sheets are calculated using the water use information for a particular crop from the Irrigation Guide and values believed to be typical to the District for crop development active root zone depth and water holding capacity. While these values may not correspond exactly to your specific situation, determining the next irrigation date is very easy and it can be used for both of the examples presented earlier using the previous irrigation date or a depletion using the "feel method."

The sheet has irrigation dates down the left margin and projected depletions across the top. If you know the previous irrigation date when the profile was refilled, enter on the left at that date and move along the line to the right until you reach the desired allowable depletion, in inches. Move up to the top of the column to the estimate irrigation date.

The corresponding percent depletion is just below the depletion in inches.

To use the sheet with hand-probed depletion on a particular date, move across the top to the date of the depletion. Move down the column to the row with the measured depletion, percent or inches. Move across the row to the right to the allowable depletion and then up to the date of the next irrigation.

In either situation the next applied irrigation amount can be found by dividing the depletion at the time of the irrigation by the irrigation efficiency. **Again, these sheets are calculated using average or typical conditions and so will not apply exactly to your particular field, but they are very easy to use.**

There are also two UC publications that contain detailed examples and in-depth discussions of all of the above. They are numbers 21419, "The Water Budget Method - Irrigation Scheduling for Southern San Joaquin Valley Deciduous Orchards" and 21454 "Irrigation Scheduling - A Guide for Efficient On-Farm Water Management"