Westlands Water District

WATER MANAGEMENT HANDBOOK

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Overview

Irrigation is both an art and a science. Science has provided many concepts and methods for measurement of the various processes involved in irrigation. However, your knowledge of your field and crop, along with your experience in applying this science to them, will remain of utmost importance in achieving effective, efficient irrigations.

EFFECTIVE irrigations produce the desired crop response.

EFFICIENT irrigations make the best use of available water. Irrigation efficiency does no good if it is not effective in producing a profitable crop. But increasing pressures on agriculture water supplies and legitimate concerns for water quality require that we be as efficient as possible.

Effective, efficient irrigations are the result of knowing WHEN to irrigate, HOW MUCH to irrigate, and HOW to irrigate.

WHEN to irrigate is an agronomic decision, based on how you want the crop to develop.

HOW MUCH to irrigate is the soil moisture deficit in the effective root zone. You must know how much water is needed to take the soil back to field capacity.

HOW to irrigate is not just knowing how to set a siphon tube or hook up a sprinkler pump. Knowing HOW to irrigate, is knowing how to apply water evenly (a high distribution uniformity) with control of the total application (a high irrigation efficiency).

This handbook is not meant to be a rigorous, scientific explanation of physical processes. For example, you will see descriptions of how soil "holds" water and the limits to this ability, field capacity, and permanent wilting point. Soil actually never retains an absolute amount of water. There is always internal drainage, however slow. And the actual measurements of field capacity and permanent wilting point will change with the soil condition, temperature, plant, and growth stage.

However, for the normal, everyday purposes of modern agricultural water management, the concepts you will see have been accepted and used quite successfully for many years.

In the past, scientists have been very successful in formulating recommendations for the fertilizer program. Modern managers utilize soil and plant analyses to plan what fertilizer, in what form, is to be applied by what method. "Numbers" have been put on the fertilizer program.

"Numbers" have also been put on the weed/pest control programs. Now growers think in terms of economic thresholds. Applicators have to follow label requirements exactly to ensure efficient and safe use of chemicals.

This handbook will help you to "put numbers" on the irrigation program.

This Handbook is an ongoing and evolving project and, as such, will be implemented in a progressive manner. The information presented here is intended to be of specific interest to water users in the District, but links will be provided to other resources on the Internet that may be of value. Peter Canessa, PE, has contributed significantly to the materials presented in this handbook.

Water Supply

Water Supply Planning

When analyzing on-farm systems and management, there are three distinct segments to identify; the primary water supply, the actual farm irrigation systems, and drainage. The successful farm has a sufficient, flexible, reasonably priced, and good quality water supply. Its irrigation system and farm management can apply water effectively and efficiently. Finally, sufficient drainage is available to allow maintenance of a salt balance and good soil structure.

This chapter will provide methods for analyzing seasonal water requirements. It is the foundation of the crop year to determine how much and when water supplies are going to be needed. When compared to available water, this will tell you if your water supply is sufficient. If not, the crop rotations must be modified. The simple budgeting methods introduced in this chapter will assist in planning for the farm water requirement for any month or for any field.

Three levels of planning will be introduced. First will be the Farm Water Budget. This budget identifies the total seasonal water needs in distinct periods of two water years, March thru February while the crop year is generally planned on an October thru September time period, which covers the main growing season.

The second level of planning will break down the seasonal requirements on a monthly basis. The monthly planned schedule can then be compared to the actual water deliveries to help see when water use, reported on the monthly water billing, is getting out of line with projections.

Finally, a technique for tracking the requirements and deliveries for any one field will be demonstrated. This will help to identify problem fields and also provide better profit/loss estimates for any one crop.

The District has an unreliable water supply at best. Many water users depend on ground-water to help meet the requirements of their desired crop rotations. Groundwater can be expensive and requires special management to prevent salinity problems. The District strongly encourages growers to use the techniques demonstrated here and in the Irrigation Scheduling chapter to best plan their irrigation programs.

Farm Water Budgeting

Westlands Water District's limited water supply is allocated to eligible land that applies for an annual water allocation. Water users may predict annual water requirements for various cropping patterns by completing this Farm Water Budget worksheet. This work-sheet can be saved on your computer to be used without being connected to the Internet. See the instructions on the lower part of the page.

This worksheet was designed to allow realistic planning for the overlap of crop, calendar, and water years. Water requirement planning utilizes two distance time periods, the upcoming water year requirements and requirements supplied by water delivered in the previous October-February period, from the previous water year.

The first period (March-September) covers the seasonal water needs of most crops grown in the District. To finish the water year, the period October-February is included. This period will allow users to plan pre-irrigations for the subsequent year.

The next section covers the October-February period of the previous water year. This allows you to account for water needs, such as preirrigations, taken care of by the previous year's water supply.

Typical values for ET, effective precipitation, and salinity control are included in the table on the bottom of the form page. These values are provided as a starting point, but you should use or adjust these values from actual experience for your location in the District.

A typical range of irrigation efficiencies for crops grown in the District is provided. The lower part of the range is generally related to furrow irrigation systems and the upper part of the range is generally related to micro-irrigation systems. Crops with shallower rootzones will generally have lower irrigation efficiencies, but improved irrigation systems such as micro-irrigation systems can be in the lower part of the range if not properly designed or maintained. A combination of sprinkler preirrigations and furrow for seasonal irrigation has proved very effective for cotton and is widely utilized. The average District efficiency over the last 20 years has been about 83%, with a low year of 73% and a high year of 93%.

Water Meter Installation & Maintenance

All water delivered within Westlands, for both agricultural and non-agricultural purposes, is currently accounted for through any one of approximately 3,700 meters. The use of meters to measure water delivery is a cornerstone of any water conservation program. Meters enable water managers to accurately allocate limited supplies and recoup true delivery costs. They also enable the farmer to precisely measure the amount of water delivered and calculate irrigation efficiency. Without a reliable meter-based delivery system, farmers are more likely to apply a safety factor to each irrigation to avoid crop yield reducing under irrigation.

Recognizing these benefits, District founders elected to install flow meters as each lateral was originally constructed. Each of the 3,075 original agricultural deliveries cost $1,400, in 1991 dollars, for a total of $4.3 million. District-wide meter accuracy is within plus or minus two percent as determined from calibration tests.

Westlands' Meter Shop, located at the District's Five Points Shop and Field Office, is among the states most modern. Meters are calibrated in the shop on a fixed schedule and repaired as needed. Description Meters that fail or are inaccurate are repaired and recalibrated immediately. To ensure accuracy, meters are placed on a four-year preventive maintenance cycle ensuring that each is over-hauled and recalibrated at least quadrennially. O&M Reserve funds are used for preventive maintenance during water-short years when funds are short.

In addition to testing approximately 1,000 District meters annually, the District also tests and calibrates an additional 250 meters installed by farmers on well discharges in conjunction with Westlands' Pumped Ground-water Exchange and Groundwater Integration Programs. These conjunctive use Programs maximize the use of the farmers' groundwater wells during drought periods. Operation and maintenance of all wells is the farmers' responsibility.

Under the present program, accurate metering allows both the farmers and the District to carefully manage and account for all water delivered. Other water conservation pro-grams, such as the Water Management Information System (WMIS), must be built on the foundation of a solid water metering program.

Meter Selection:

Many different manufacturers' water meters are in or have been in service within Westlands:

- McCrometer
- Water Specialties
- Brooks
- Hershey Sparling
- Rate-of-Flow
- Rockwell
- Badger

Kansas State Cooperative Extension has a pamphlet that discusses meter selection (http://www.ksre.ksu.edu/bookstore/pubs/L878.pdf) and University of Florida IFAS Extension discusses meter selection "Selection and Use of Water Meters for Irrigation Water Measurement" (http://edis.ifas.ufl.edu/ae106) on the internet.

Installation & Maintenance:

The vast majority of meters in use are of a propeller type. Brooks meters are a non-propeller type and were installed in the district because they provided head control, but they are being phased out due to the amount of maintenance required with age.

Installation specifications and maintenance requirements are specific to the type and manufacturer of the meter. A manual for McCrometer propeller flowmeters (Propeller

Flowmeter (All Models) #24517-11), as well as information for other equipment that they manufacture) is available for download (http://www.mccrometer.com/library/Default.aspx) on the Internet from the manufacturer's online library. McCrometer suggests that simple observations can tell you when maintenance is required:

- Meters operate very quietly. Any grinding or growling noises that can be detected are the first signs that mechanical failure is near.
- A once steady rate-of-flow indicator that has become erratic is usually indicative of something beginning to fail.
- Fogging seen through the lens would suggest a leak, either from the bearing assembly, or from an external seal.

Accurate measurement requires that the manufacturer's specifications be followed. Propeller meters generally require a certain distance of straight pipe ahead and behind a meter for a proper installation. The above mentioned manual for McCrometer presents their specifications.

Pumps and Pumping Costs

Introduction

Many times, Growers think in terms of unit costs. They know about how many dollars per acre to cultivate, how many dollars per acre to harvest, how many tons per acre of production to expect (hopefully), etc. It is also good to know unit-costs for water pressure. That is, the costs to pump one acre-foot of water through a sprinkler system, or back up a tailwater reuse system.

A handy unit-cost is the money required to pressure water to 10 pounds-per-square-inch (PSI). (This is only the direct power costs. Capital costs for the engine/motor and maintenance are not considered.) Since we are talking about unit costs, we already know how much water we have to move, one acre-foot.

There are only three (four if using diesels) additional numbers needed to calculate the cost to pump it. For electric-powered pumping plants these are the amount of pressure you need, the pump efficiency, and the unit cost of electric power. The equation to use for electric power is . .

$$UC = 2.36 * H * UCE / PE$$

where:

UC = unit pumping cost, $/acre-foot

H = pumping head, pounds per square inch

UCE = unit electric power costs, $/KWH (this is an average cost based on power and demand charges).

PE = pumping plant efficiency, a decimal normally in the .5 to .7 range

For example, to determine an example 10 psi unit-cost, assume that the average electric power cost is $.07/KWH. The pumping plant efficiency is estimated at .6. Thus, . . .

UC = 2.36 * H * UCE / PE

UC = 2.36 * 10 * .07 / .6 = $2.75

10 PSI = $2.75/AF

10 PSI is the unit-cost to pressure one AF of water 10 PSI.

10 PSI Electric Unit Cost /AF			
KWH Cost	50% Eff.	60% Eff.	70% Eff.
$.05	$2.36	$1.97	$1.69
$.10	$4.72	$3.93	$3.37
$.15	$7.08	$5.90	$5.06

If you were thinking about a field sprinkler system that required about 70 psi, just multiply the unit cost by 70 PSI /10. . .

COST = 70 PSI/10 * $2.75/AF

10 PSI COST = $19.25/AF

At 70 PSI, each AF pumped costs $19.25 for power alone.

Determining pumping costs for diesel engines requires one more number, which indicates how efficient the engine is in converting diesel fuel into energy. It has been called the "energy-conversion constant" and for modern turbocharged diesels is around 15-17 brake-horsepower hours/gallon of diesel burned. The equation for diesel engines is . . .

UC = 3.16 * H * UCD / (EC * PE)

where:
UC = the unit power costs.
H = pumping head, in PSI.
UCD = the unit cost of diesel fuel (delivered to the engine) in $/gallon.
EC = the energy conversion constant, brake-horsepower hours per gallon of fuel burned.
PE = pumping plant efficiency, a decimal normally in the .5 to .7 range.

For example, figuring the unit cost to pressure water to 10 PSI, assume that diesel fuel is about $.65/gallon delivered to the pump. The engine is relatively old and the EC is only 15 BHP-hours/gallon. Then, the cost of pressuring water to 10 PSI is,

$$UC = 3.16 * H * UCD / (EC * PE)$$

$$UC = 3.16 * 10 * .65/(15 * .60)$$

$$UC = \$2.28/AF$$

The unit-cost for pressuring one-acre foot of water to 10 PSI is $2.28 with a diesel engine and fuel costing $.65/gallon delivered.

10 PSI Diesel Unit Cost / AF			
Cost/Gallon	50% Eff.	60% Eff.	70% Eff.
$ .60	$2.37	$1.98	$1.69
$ .80	$3.16	$2.63	$2.26
$1.00	$3.95	$3.29	$2.82
$1.20	$4.74	$3.95	$3.39
Note: Assumes 16 BHP-hours/gallon			

Note that diesel prices have been much higher in past years. Doubling the price of diesel would double the unit pumping cost.

Important!!! The unit-costs developed above do not consider annual maintenance or the capital costs of the pumping plant. They are only the direct power costs.

Required Pumping Power

Questions that come up many times in field situations are "How big a pump, and what type, is needed?" They are critical questions because one pump might throw enough water, but not at the right pressure. And another pump might build up enough pressure, but not enough flow. And, if using electricity as the power source, you may or may not have enough power where you need the pump.

Here is an easy equation to use in answering the power question . . .

$$HP = (FLOW * HEAD) / (1714 * PE)$$

where:
HP = gross horsepower rating of the pump.
FLOW = flow of water from the pump in gallons per minute (GPM).
HEAD = pressure built up by the pump in pounds per square inch.
PE = is the pumping efficiency of the unit.
1714 is what is known as a conversion constant, it matches up the various measurement units.

For example, assume that you are thinking about going to sprinklers for a pre-irrigation. You usually take a 4 cubic-feet-second (CFS) head of water (flow from the delivery). You also know that the sprinklers need to run at about 50 PSI. The field is relatively smooth ground and sits next to the canal. Thus, there are no large elevation changes and you don't have to pump the water for long distances.

Four CFS is about 1800 GPM (1 CFS = about 450 GPM). We need to add about 15 PSI for pipe friction, thus, we need about 65 PSI total pumping pressure. Assuming a 65 percent pumping efficiency, the equation then says that . .

$$HP = (FLOW * HEAD) / (1714 * PE)$$

$$HP = (1800 * 65) / (1714 * .65)$$

$$HP = 105 \text{ horsepower}$$

Pumps do not operate at the same efficiency at every combination of flow/pressure. For example, a sprinkler pump may operate at 70 percent efficiency when pumping 1400 gpm at 80 PSI. It may operate at only 60 percent efficiency when pumping 1100 gpm at 100 PSI. That drop of 10 percent is money out of your pocket. (60 percent efficiency means that 60 percent of the power delivered to the pumping plant, power that you paid for, is used to pump the 1100 gpm of water at 100 psi).

The other 40 percent is used up in overcoming friction within the pump and motor. Always consult an experienced pump engineer when buying or rebuilding a pump. Match the pump design and type to the job. Also, make sure you follow a regular maintenance schedule to keep your pumps working at top efficiency. If using electricity for power, consider a design that will allow using the off-peak power rates offered by PG&E.

For an additional source on energy use and conservation (http://www.irrigationtoolbox.com/NEH/Part652_NationalIrrigationGuide/ch12.pdf).

Standard Guidelines for Design and Proper Construction of a Water Well

By Roy F. Senior, Jr.[1]

Site Selection

Site selection should be made with consideration being given to probable water quality and volume, followed by location of a power source and then transportation of water to the desired area.

Available driller and electric logs of the surrounding area should be obtained, including oil and gas logs. (The probability of locating a successful, deep well below the Corcoran Clay may often be as high as 90%, based on research and review of existing logs.)

After the site location has been determined, specifications that follow accepted industry standards should he obtained and used as a basis for the well contract and construction. (Specifications are available from many sources, such as the Bureau of Reclamation, various governmental agencies, and geologist or engineering firms. All employ similar industry standard procedures that have- been developed and proven successful over the years.)

Pilot Hole (Test Hole)

Pilot holes should always be drilled and water samples collected and analyzed if water quality is of a questionable nature.

A pilot hole should be drilled, samples of drill cuttings taken at 10' intervals (or at formation changes) and sieve analysis performed on the sands. An electric log of the pilot hole should then be performed to identify footage and characteristics of the producing sands with some indication of water quality. Based on a review of this information, a proper well design can be achieved.

After sands and electric log analysis, the pilot hole should be properly abandoned, if the pilot hole indicates the formation will not support a well of sufficient capacity or water quality.

A word about shallow pilot holes…. It may be necessary to drill a shallow pilot hole, analyze sands and the electric log of the proposed well site above the Corcoran Clay to determine water quality and production capacity. Water samples may be taken above the Corcoran Clay in a standard rotary test hole by installing a small diameter, 2" pipe, and pumping water samples from the target zone.

[1] These remarks were presented by the author at a District workshop in 1992. Roy can be reached at (559) 233-6131. Last updated January 2001.

Pre-Construction Criteria

The factors that should be considered for shallow and deep well selection design are:

1. Amount of water desired
2. Pumping cost analysis
3. Life expectancy of the well
4. Effects on land value created by a usable ground water supply.

Producing Water from below the Corcoran Clay

Proper depth selection of a well will greatly affect producing capacity over the life of the well by as much as 1000 gpm to 1200 gpm. For instance, using an approximate value of 10 gpm water production for each one foot of producing sands below the Corcoran Clay, you can determine how many feet of producing sands should be incorporated into the final well depth, thereby constructing a well of maximum capacity, efficiency and longevity.

Therefore, for every 100' of producing sands added to the well depth, they additional productivity could be as high as 4 acre feet per day. Thus, the added footage of producing sands incorporated into the final well design may be equated as usable "water-in-the-water-bank" or "money-in-the-bank." At this point in the pre-construction decisions, consideration should be given as to how much of the potential producing sands should be incorporated into the well design, remembering that every foot of saturated sand adds value to the land.

For example, a 1200' well may initially produce a sufficient amount of water to be economically feasible. However, if there are producing sands below 1200' that can be incorporated into the well, the well would produce at a higher specific- capacity, lower pumping cost and would be able to tap more usable water. This means longer usable well life, more efficient pumping cost, and increased land value.

During the initial planning stages and continuing through the well construction, as you gain more information, is the proper time to determine well depth. If a 1200' well is completed today and at a later date a 2000' well is needed, it will be necessary to either drill a new well or go to a much greater expense to deepen the existing 1200' well.

Gravel Pack

Appropriate gravel pack MUST be used and placed correctly to obtain maximum well efficiency and production. In the University of California Bulletin No. 1889, titled "Water Well and Pumps: Their Design, Construction & Maintenance," the following information is referenced:

1. Grain size distribution curves are drawn for material in each water-producing zone.
2. Grain size distribution curves are used to identify the aquifer with the finest material.

3. The 70% retained size of the finest aquifer material is selected as a basis for design. The gravel pack to retain 70% of the aquifer material should be 4 to 6 times larger than the aquifer material. For uniform fine material, the factor should be four (4); for non-uniform coarser material, five (5); and for highly non-uniform material including fines, six (6).

The selection of gravel roundness is extremely important because it allows the use of the proper graduation to fit the finer formations and retain the maximum porosity and permeability of the gravel pack to achieve maximum well efficiency. Two suppliers who come close to meeting the roundness criteria are "Colorado Silica" and "Heart of Texas." Both are expensive compared to less suitable gravel (due to availability and freight), but their use will pay back the added cost may times over during the life of a well.

Casing & Screen

Casing and screen diameter must be adequate to allow the desired amount of water to pass without friction loss. The pump chamber casing must be large enough to allow the required size column pipe and bowl assembly to be installed freely in the well to the point of anticipated future needs.

Screen opening design should retain 80% to 90% of the gravel pack. The most commonly used perforations are louvered and continuous V slot wire-wound casing. Both are resistant to gravel pack plugging and perform efficiently with most gravel pack installations.

Millslot perforation is also frequent used, but a much higher percentage of plugging by the gravel pack occurs with millslot because the perforations are straight rather than louvered or "V" shaped. Millslot can be used in some areas, but in most instances it is unwise to use it.

Although additional slot openings can be added to compensate for plugging, millslot casing is not considered as efficient as louvered or wire-wound. A word of caution….if millslot is used exclusively in a well; it will generally result in lower well efficiency, and create greater drawdown, thereby causing higher pumping cost for the entire life of the well. However, if a combination of millslot in the lesser producing areas and continuous "V" slot wire-wound in the more productive areas is used, the combination can prove satisfactory.

Cutting & Settlement Pits

The drill cutting and settlement pit must be excavated to dimensions adequate to permit sufficient time for fine sands to drop out of the viscous fluid as the cuttings are discharged into the pit and to pass the full length of the pit before returning to the well bore.

If fine sands (fines) are not settled out (or removed mechanically by a de-sander) they will return to the well bore and deposit fines on the walls of the well, plugging the water passages and creating irreparable damage.

In Ground Water and Wells, published by Johnson Filtration Systems, Inc., the author suggests that a reverse rotary pit system should be three times the volume of the hole in order to properly settle solids from the drilling fluid.

EXAMPLE: A 28" diameter well bore that is 1200' deep will hold about 38,000 gallons of water. Using "Johnson's" formula a pit large enough to accommodate about 115,000 gallons is needed. A pit 70' long x 10' wide x 8' deep will hold about 42,000 gallons of water. Using two pits of this dimension will process approximately 84,000 gallons of water. The cuttings laden water will travel 70' across one pit and 70' back through the other pit before returning to the well bore. This distance allows considerable settlement time, and in most cases, will settle out fine sand.

To prevent drill hole walls from plugging, the fluid system must be maintained with a sand content of below 2% at all times. This type of plugging is often caused by less qualified contractors using poor drilling procedures or conventional rotary drilling methods. Then to compensate for this, they use a gravel pack many times coarser than the formation demands resulting in void areas between these coarse sand or gravel particles, not only large enough to pass the sand deposited on the wall into the production water, but also to large to sufficiently stabilize the sands on the drill hole wall., thereby continually passing producing fines into the water. This creates what is commonly known as a "sand pumper."

Pits of sufficient size, proper construction methods and the correct selection of gravel pack size is vital to the efficiency of a well and cannot be over emphasized.

Conventional Rotary vs. Reverse Rotary Drilling Method

In conventional mud rotary drilling, damages due to formation plugging will occur without fail because the sand laden fluids must pass by the walls to reach the surface and therefore will irreversibly plug some of the production zones, even under the best of conditions.

Knowing this, one can make the assumption that wells should be drilled by the reverse rotary method, because the efficiency of the wells drilled by the conventional rotary method usually cannot approach the efficiency of wells drilled properly by the reverse rotary method. Even though installation costs may be less expensive, it will cost much more during the entire life of the well due to the increased pumping cost.

Sand Production

Sand production can easily be maintained at 5-parts per million or below, if proper design and construction methods are performed. This amount of sand production will not noticeably affect pump bowl bearing life and should be the goal of all gravel packed wells. However, some agencies permit 10-parts per million, which will noticeably affect pump bowl bearing life. Therefore, a well that produces 10-part per million sand is of lesser value than a well that produces 5-parts per million sand.

Drilling Fluid (Mud)

Commercial drilling mud is necessary much of the time to control the Corcoran Clay, although it increases the difficulty of keeping the sand content in the drilling fluid returning to the well bore below the 2% level.

Slope Test

Deep well contracts should require an EASTMAN or TOTCO slope test to be run every 100' to the deepest anticipated pump setting depth. The well bore should not be allowed to drift more than one half degree at any point above the pump setting depth. If drift occurs, the contractor should correct it back to half a degree maximum before further advancement of the well bore.

This correction will prevent “doglegs” in the well bore and is a reasonable requirement that will greatly extend pump-bearing life, and prevent well casing breaks caused by stress created by the "doglegs." Many casing failures can be attributed to "doglegs" in the well bore.

Drill Hole Diameter

Drill hole diameter should be at least 8" larger than the screen diameter, but not over 12" larger than the screen diameter. Drill holes can be too large, creating a gravel pack so thick that development procedures cannot reach the drill hole wall to clean it.

Again, it is pointed out that at no stage of the drilling procedure should the fluid returning to the well be allowed to contain a sand content above 2%. If the sand content goes above 2%, sand will redeposit itself on the drill hole wall and be trapped by the gravel pack (when proper size gravel pack is used) and be impossible to remove during the development process, thereby creating permanent well damage, resulting in lower well efficiencies. And, as stated above, when proper gravel pack design is used to compensate for an improperly constructed well, the result is a sand pumper.

Gravel Installation

Gravel may be successfully poured slowly from the ground surface into the well annulus only on shallow wells completed above the Corcoran Clay. However, any gravel pack installed below the Corcoran Clay should be pumped through a treme pipe set to a depth at the bottom of the screen before starting gravel installation, and slowly withdrawn as gravel is pumped and fills the annulus. The gravel treme pipe should be removed one joint as a time in order to monitor gravel filling level and ensure that all areas are completely filled with the gravel.

A circulation pipe should be installed inside the well casing/screen to the bottom of the perforations, and circulation of 250 gpm of water should commence prior to gravel installation and continue during the entire gravel packing process. The fluid used to pump the gravel should be clean water because this method transports the silts and clays that are removed from the well by the scouring action of the gravel going into place. These silts and clays then enter the well

screen and are pumped to the surface and settle out in the settling pit, leaving the gravel pack relatively clean and ready for the development process.

Airlift/Swabbing

Following the completion of the gravel pack procedure, the well should be airlift pumped to remove the remaining drilling fluid from the annulus in the producing zones until the water is relatively clean.

The circulation pipe should then be removed from the well and two close fitting swaps (about 5' to 6' apart with sufficient intake holes between the swaps) installed on the circulation pipe.

While the airlift pump is operating, the swabs should then be lowered and raised as fast as possible for about 30 minutes per joint of casing, starting at the top of the screen and adding a joint each 30 minutes until the bottom of the well is reached. The bottom joint should then be swabbed until the pumped water is relatively clean and this should be continued, removing one joint at a time and repeating this procedure until each joint is swabbed to the top of the screen and the final water produced is relatively clear.

The walls will then be clean enough to produce, and ready for final development by pumping and surging the well at high rates. The mechanical swabbing will clean the thin sand layers of sand from the well bore wall that will produce small amounts of water when mechanically swabbed clean. But will remain unproductive for the entire life of the well if not mechanically swabbed clean. In most cases pump development alone will leave the weaker areas undeveloped and unproductive.

Often times, a combination of many small zones properly swabbed clean can increase the well production and efficiency (if they have not been damaged during well construction and are correctly cleaned during initial well development).

A word of caution….if only pump development is performed, these fines can remain sealed against the well bore walls for the life of the well and the thin sand layers that could have had some low flow production rates has they been properly swabbed and pumped would now make no contribution.

Pump Development

The high capacity pump and surge development process should follow the airlift/swabbing and be started at 750 gpm to 1,500 gpm on large capacity wells, pumping at one rate until the water being pumped is relatively clear. The pumping level should be monitored during all pumping.

When the pumped water is relatively clear, the pumping rate should be raised in increments of approximately 500 gpm and the process continued at each rate until the pumped water is again relatively clear.

This procedure should be continued in 500 gpm increments until the top rate of the pumping equipment, or the top rate of well capacity is reached and the water is relatively clear and the specific capacity (gpm per foot of drawdown) stabilized.

The pump surging process is performed next, but should not begin until the pumped water is relatively clear, because surging with dirty water can permanently damage the well.

During the pump surging process the pump should be stopped, the water allowed to flow back into the well, and then the pump restarted again, and the water pumped until it is again relatively clear. This procedure should be continued until the water no longer is dirty looking. When the water is clear the well should then be surged several times (possibly five), just bringing the water to the ground surface, then pumped until again relatively clear.

This process is continued slowly, increasing the number of back surges each time until the water remains clear after surging and the pumping level is stabilized. The well is then fully developed at that particular pumping rate, and when the specific capacity stabilizes. Many times, a well developed at 4000 gpm is capable of further development and higher capacities if higher pumping rates can be achieved. However, the special equipment required to perform higher capacity rates is often not readily available.

Pump Testing

The procedure for pump testing for pump design is as follows:

1. After the well has set idle 8 to 12 hours following development, the step test should be performed by pumping at a minimum of there (3), and preferably four (4) rates, with the pumping time being three hours minimum at each rate. The highest rate should usually be at the highest rate at which the well was developed, with drawdown and flow rates recorded at minimum 5-minute intervals during the first 30 minutes of each pumping rate, and at least 30-minute intervals for the remainder of each rate. Recovery readings should be taken at minimum 5-minute intervals for the first 30 minutes after pump shutdown, and at least 30-minute intervals for four (4) to eight (8) hours.
2. After the step test is complete, a 24-hour pump test should be run at the rate calculated for the well based on the results of the step test. It is very important that a knowledgeable individual perform the calculations to accurately project sustainable yield.

It is in the best interest of the owner to employ a capable experienced firm that is able to design and monitor the construction, the material installation, well development, and the pump testing and pump design. This should be someone independent of the well construction contractor and pump supplier, in order to provide the owner with an unbiased and impartial overseer.

Well Efficiency Effects on Pumping Costs

If proper construction procedures are used, a well efficiency as high as 94% can reasonably be expected. (There is a case history of a well that is 95% efficient at 2250 gpm with a 46' drawdown.)

Based on case histories, we can assume that many new wells in the area have efficiencies near 50%. Using a 50% effective rate as a basis for comparison, a well with a 87.4' drawdown at 2250 gpm would have an additional 41.4' drawdown penalty for inefficient construction of the well.

Assuming a power rate of .075 KWH and a pumping plant efficiency of 68%, the inefficiency in the drilled well would cost $4.641 per acre foot pumped, which would be $9,299.03 for a well pumped 200 days, or $13,948.66 for a well pumped 300 days, and this additional cost occurs every year for the life of the well.

These figures do not assume any interest expense or inflation in energy costs over the 30-year life of the well, although one must assume that interest expense and inflation would greatly increase the penalty on an inefficiently constructed well.

Appraisal

If you assume a water table decline of 10' per year, you can roughly project the total acre feet that can be pumped from a well (assuming and estimated value for recharge.) The test of a well should be determined by several things. Some of the most important are:

1. desired life expectancy of the well
2. appraisal value of the land
3. power cost (power/fuel cost)
4. water quality

Future Economic Considerations

In designing a well consideration should be given concerning the use of top/bottom water. You can only use the bottom water if you have the original well deep enough. The water below the depth of the well has a much less value when it is not tapped by the original well; whereas, if that same water is tapped by the original well, (although possibly not immediately being pumped) has much value in the future. Although the water is available, if it is not tapped by the original well, it has no value to that particular well.

The decision on how much of the available producing aquifer to incorporate into any given well design should be based on expected well life and the effect on land appraisal value. The shallow well can be looked at as a band-aid solution; the deeper wells would be a valuable investment in that particular property.

Most shallow wells can be considered as short term and a temporary “fix” solution to a long term problem. However, in some instances and conditions they make the most economic sense (i.e.

getting through a drought, providing water quality is usable.) Unfortunately, in some areas such as the Westlands Water District, long term supplies are more important.

The previously discussed water sample tests taken from test holes should be one of the deciding factors in determining whether the shallow waters above the Corcoran Clay should be considered.

Drought Water Management

Overview

Westlands' farmers deal with a limited water supply on a continuing basis. Even in above normal rainfall years since 1996, the surface water supply (http://www.westlandswater.org/resources/watersupply/supply.asp?title=Annual%20Water%20Use%20and%20Supply&cwide=1680) delivered under our contract was not 100%. From the District's point of view in 2000, a long term water supply of 50% of our contract amount seems to be a normal condition. Drought conditions for Westlands' farmers relate to water shortage that severely curtail cropping plans.

Westlands' farmers are very efficient with the water supplies made available to them (Water Management Plan; http://www.westlandswater.org/long/201002/WMP_2007.pdf?title=Water%20Management%20Plan&cwide=1680). Economic farming decisions in Westlands related to water generally fall in to two categories:

1. Produce at maximum yield levels.
2. Don't produce at all.

Lands will be fallowed to aggregate enough water to produce at maximum yields with the available water. The higher value crops grow in Westlands, to justify higher cost water, respond unfavorably to water stress. Lower value crops must be produced at maximum yield levels to justify higher cost water. Even though these crops may be able to withstand moderate water stress, these too must be grown at maximum yields to justify the decision to plant these crops, unless there is a necessity in the crop rotation for these crops to sustain agricultural production in the long term.

District Specific Resources

- Supplemental Water Supply – Annually the District acquire additional water supply when available (see Notice 392, under 2012/-13 Supplemental Water; http://www.westlandswater.org/short/201304/notice392.pdf?title=4/5/2013).
- Irrigation Management for Almond Trees Under Drought Conditions (http://cesanjoaquin.ucanr.edu/files/35491.pdf)
- Snow Conditions (http://cdec.water.ca.gov/snow/)

Related Links

- UC Cooperative Extension Drought Tips (http://lawr.ucdavis.edu/ce_irrigation_tips.htm)
- USDA National Agricultural Library "Drought and Weather" (http://wqic.nal.usda.gov/water-availability/drought-and-weather)
- DWR Drought Information Page (http://www.water.ca.gov/waterconditions/drought/)
- National Drought Mitgation Center--The Basics of Drought Planning (http://drought.unl.edu/portals/0/docs/10StepProcess.pdf)
- USDA Drought Portal (http://www.drought.gov/drought/content/resources)
- NRCS, Defending Against Drought (http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/newsroom/features/?&cid=nrcs143_023349)
- US Drought Monitor (http://droughtmonitor.unl.edu/)

This section of the Water Management Handbook is intended as a source of information for District water users who must make decisions under extremely severe water shortages.

Irrigation Planning

Soil, Water and Plant Relationships

This chapter will introduce you to the basics of what scientists call "soil-water-plant" relationships. The ideas form a model system of how water enters the soil, moves through the soil, into the plant root system, and back to the atmosphere. More important they identify the important components of the system and provide standards of measurement so that we can control this movement.

Major ideas presented are . . .

- Soil "holds" water against the pull of gravity, retaining it for crop use. There are limits to this ability. The upper limit is called FIELD CAPACITY. The lower is called PERMANENT WILTING POINT.
- You can add water to soil above FIELD CAPACITY. It will not hold this additional water. It will drain below the effective root zone to become deep percolation.
- Between field capacity and permanent wilting point is the soil's AVAILABLE WATER HOLDING CAPACITY (AWHC). This is the amount of water that the soil will hold that is available for the crop to use.
- As the crop pulls water from the soil, the soil holds onto the remaining water harder and harder, putting more and more stress on the crop. You will see the crop wilt during the hottest parts of the day. Sooner or later, if the stress gets big enough, the crop will permanently wilt. The soil moisture is at PERMANENT WILTING POINT.
- Soil water can be measured in two ways . . .

  a) *volumetrically* the actual amount of water in the soil.
  b) *tension* a measure of the water-holding forces in the soil.

- The crop doesn't care how much water is physically in the soil, only how hard it is to get out. Thus, although a volumetric measurement will tell us how much water is in the soil and, therefore, how much to irrigate, the tension measurement is more important in terms of preventing crop stress.
- The volumetric standard of measurement is inches of water held per foot of soil or just inches/foot. Available water holding capacities vary from 1 to 2.5 inch/foot.
- The tension standard of measurement is pressure, usually centibars.
- The rate at which crops extract water from the soil is called EVAPO-TRANSPIRATION, ET_c. ET_c is the combination of soil surface evaporation and plant transpiration and is measured in terms of inches of water per day. Normal ET_c rates for cotton are around .05 in/day as seedlings to .35 in/day as a full-grown plant.
- ET_c varies with the plant, the climate, the level of soil moisture, and plant condition (fertilizer/pest/disease stress). ETc can be measured and predicted.

- The INFILTRATION RATE, measured in inches/hour, is a measure of how fast water is soaking into the ground. Infiltration rates will decrease during an irrigation.
- The APPLICATION RATE, also measured in inches/hour, is a measure of fast we are applying water. Knowing the application rate of sprinkler systems is especially important. They usually run from .1 to .5 inches/hour.
- If the application rate is higher than the infiltration rate, runoff occurs. There should not be excessive runoff with a trickle or sprinkler irrigation system.
- There are several methods available for measurement of soil moisture both for volumetric (the neutron probe, gravimetric, "feel") and tension (tensiometers, gypsum blocks, leaf pressure chambers). They all have their strengths and weaknesses.
- Very high or out-of-balance salts will modify many of the measurements and results of different measurements (high or low). Refer to the chapter on salinity for further information.

The Soil's Available Water Holding Capacity

Soil "holds" water available for crop use, retaining it against the pull of gravity. This is one of the most important physical facts for agriculture. If the soil did not hold water, if water was free to flow downward with the pull of gravity as in a river or canal, we would have to constantly irrigate, or hope that it rained every two or three days. There would be no reason to pre-irrigate. And there would be no such thing as dry land farming.

The soil's ability to hold water depends on both the soil texture and structure. Texture describes the relative percentages of sand, silt, and clay particles. The finer the soil texture (higher percentage of silt and clay), the more water soil can hold.

Gravity is always working to pull water downwards below the plant's root zone. To counteract the pull of gravity, soil is able to generate its own forces, commonly called "matric forces" ("matric" because of the soil "matrix" structure that forms the basis for the forces).

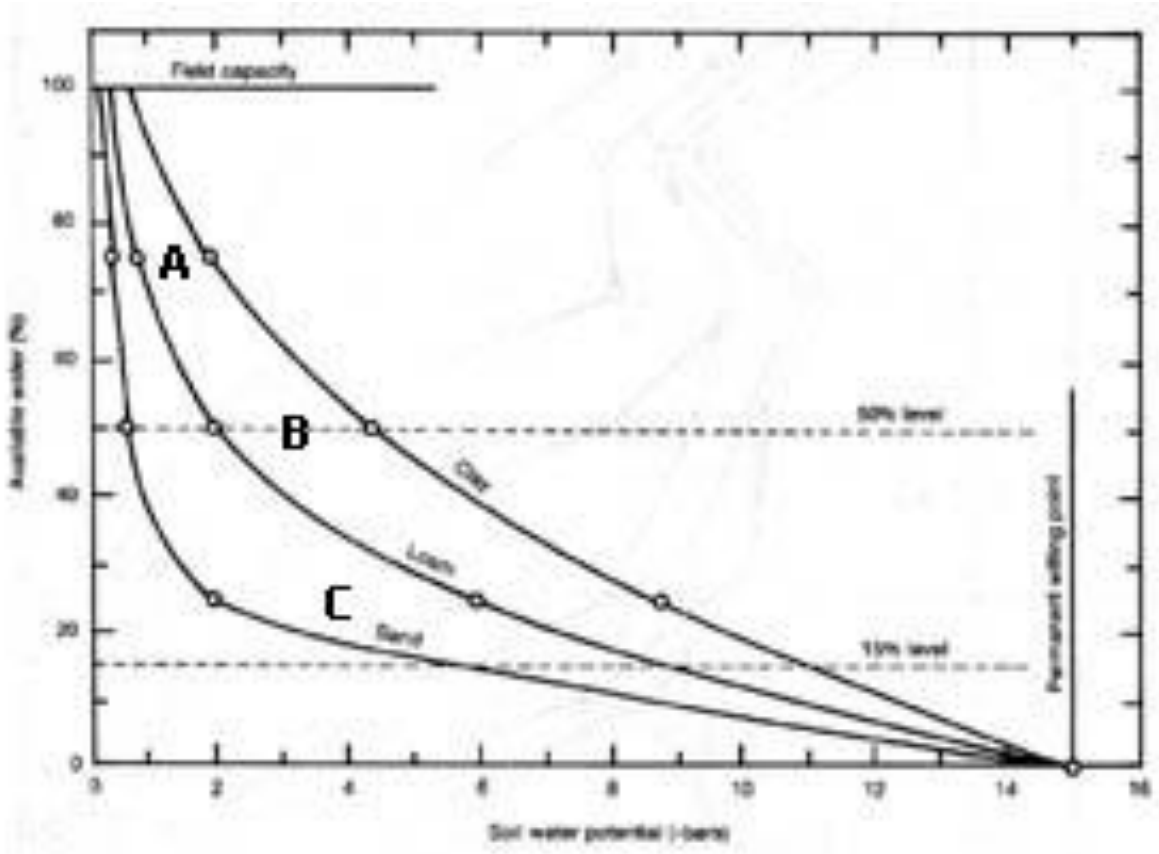
An important fact about the soil's water-holding forces is that as the level of soil moisture goes down, the soil generates more force. This is the reason that some water will move up into the root zone from a shallow ground water table. As the plant extracts water in the root zone, the soil pulls water up from the area with more water to the area with less.

As you would expect, the rate at which the water-holding forces go up with decreasing soil moisture is different for different soils. In a coarse soil, they will go up slowly. This means that plants can extract a great amount of water from coarse soils before they stress. In contrast, these forces rise quickly in finer soils.

Graphically, the relationship can be described by the Figure 1. Looking at the lowest line for a coarse soil. You can see that at A, the soil moisture level is very high and the water-holding forces are low. This means that the plant can extract water easily from the soil. At B, the soil moisture level is lower but the water-holding forces haven't gone up that much. The plant can

still extract water easily. However at C, the soil moisture level is very low and the water-holding forces have increased greatly. The plant cannot extract water easily and will be stressed.

FIGURE 1: Soil Moisture Level (Depletion, %) vs. Soil Moisture Tension (Bars).



Looking at the top line for a finer soil. At A, as with the coarse soil, the water-holding forces are low when the soil moisture level is high. However, at B, the soil moisture level has dropped somewhat but the water-holding forces have gone up greatly. And at C, where the soil moisture level is low, the water-holding forces have gone up very high.

We will be coming back to this idea of <u>increasing</u> soil water-holding forces with <u>decreasing</u> soil moisture many times.

<u>Available Water and the Effective Root Zone</u>

The water held by the soil between field capacity and permanent wilting point is termed the "available water holding capacity" of the soil. It is water that is "available" for the plant to use. Water added to the soil in excess of field capacity will drain down, below the active root system. Water held by the soil that is below the permanent wilting point is of no use, the plant has died.

As a crop manager you are concerned with the soil moisture throughout the depth of the plant's active root system, the "effective root zone". The effective root zone is that depth of soil where you want to control soil moisture (just as you control fertility and weed/pest pressures). The effective root zone may or may not be the actual depth of all active roots. It may be shallower because of concerns for crop quality or development (as with many vegetable crops). For a preirrigation though, you may want to consider the maximum potential root zone as the effective root zone for that irrigation.

For example, with cotton you may estimate the effective root zone as 6 feet for a preirrigation, 2 feet for the first seasonal irrigation, 4 feet for the second seasonal, and 6 feet thereafter. For an almond orchard, you may estimate the effective root zone as four feet for the entire season. With onions, the major concern is with the top 2 feet.

Table-1 shows some estimates for effective root zones healthy crops grown on deep well-drained soils.

Table 1. Normal Crop Rooting Depths (feet).

Alfalfa	5-10	Grain	3-4
Asparagus	6-10	Grass	2-4
Beans	3-4	Lettuce	1-1.5
Beets(sugar)	4-6	Melons	6
Broccoli	2	Onions	1
Cabbage	2	Peas	3-4
Carrots	2-3	Peppers	2-3
Cauliflower	2	Potatoes	3-4
Celery	3	Spinach	2
Citrus	4-6	Squash	3
Corn(sweet)	3	Strawberry	3-4
Corn(field)	4-5	Tomatoes	6-10
Cotton	6-8	Walnuts	12
Deciduous tree	6-8		
Grapes	4-6		

Note the wide range in some of the root zones in the table above. This is an example of irrigation as both an art and a science. There are scientific ideas like "effective root zones" and "field capacity" that provide a way to think about water management. But it is up to you, the

grower, to apply these ideas, to pick the effective root zone, to estimate the field capacity and permanent wilting points

.

Measurement Standards for Soil Water

To make use of the ideas of available soil moisture and effective root zones, we need standards of measurement (as the "foot" is a standard of measurement for length or a "gallon" is a standard for volume). The standard of measurement for effective root zones is depth, either inches or more commonly, feet. But how do we measure soil moisture?

First consider a cubic foot of soil that has just been taken from a field. Soil is not completely solid. It has mineral solids held in a matrix-type structure intermixed with open spaces, pores. Assume we were somehow able to compress the soil so that all the solids were together. We would have a depth of solids (mineral and organic particles), a depth of water that had been held by the soil, and a depth of air that had also been within the soil pores. See figure-2. We measure soil moisture in terms of that depth of water held by a depth of soil.

Commonly this is inches of water per foot of soil, or just "inches/foot". For example, we might say . . . "the field capacity of this soil is 2.0 inches/ft.". This means that the most water this soil will hold is 2.0 inches per foot. We might say . . . "the current soil moisture is 1.7 inches/foot".

Figure 2

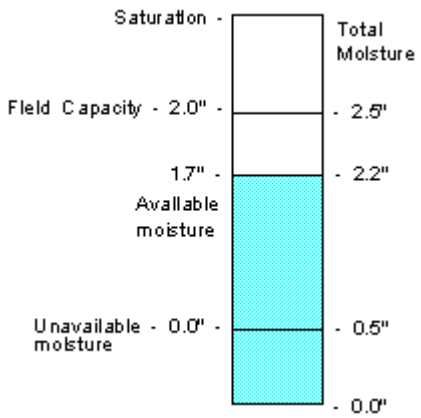


Table 2. Representative Available Water Holding Capacities

Soil Class	Range/Average in/ft
VeryCoarse to Coarse Sand	0.50-1.25/.90
Moderately Coarse Sandy Loams	1.25-1.75/1.50
Medium Loams	1.50-2.30/1.90
Clays and Clay Loams	1.60-2.50/2.10
Peats and Mucks	2.00-3.00/2.50

The numbers in Table-2 are ranges of normal available water holding capacities. The Reference chapter of this handbook contains specific numbers for common soils of the District. The maximum depth of water available to the plant in the effective root zone can be determined by adding the available water holding capacity for each foot of soil in the effective root zone.

For example, assume you have an effective root zone that is four feet deep. The first two feet are Medium Loam, the third foot is a Sandy Loam, and the last foot is a Coarse Sand. The estimated maximum available water (using the example numbers from Table -2) is . . .

Medium Loam - 1-2 ft (2 x 1.9)	=3.8 inches
Sandy Loam - 2-3 ft	=1.5
Coarse Sand - 3-4 ft	=0.9
Maximum AWHC	=6.2 inches

If the soil in the entire four-foot effective root zone was at field capacity, there would be 6.2 inches of water available to the crop to use. It's as if there was a 6 inch deep pan of water that the crop was growing in.

Plant Evapotranspiration

Water is extracted from the soil by evaporation at the soil and plant surfaces (crop transpiration). The combination of the two is termed "crop evapotranspiration", or ETc. (It has also been termed "consumptive use" or "crop water use".)

ETc is affected by many factors. ETc will vary with the type of plant and growth stage. Some plants just use less water than others. And obviously, a seedling is going to extract less water than a full grown plant.

ETc varies with the climate. Up to a certain point, increasing temperature and wind will increase ETc. (There is usually a maximum ETc rate for any plant, beyond which it just stops transpiring due to stress). Increasing humidity and cloud cover will decrease ETc.

ETc varies with the amount of soil moisture in the effective root zone. Remember that the soil's water-holding forces increase as the soil moisture decreases. Thus, as the plant uses up soil moisture, it becomes harder and harder to extract more. Past a certain point, which depends on

the plant, the soil's texture and structure, and the root zone salinity, the ETc rate will decrease. Below-normal ETc rates will place stress on the crop. Depending on the crop and growth stage, more or less stress is desirable. Knowing the acceptable level of stress and knowing what level of soil moisture will cause this stress is an important function of modern crop management. The Reference chapter of this Handbook contains information sheets for all major crops describing critical growth stages, ETc rates throughout the season, and desirable water management.

The standard for measurement of ETc is inches of water use per day or "inches/day". You may see ETc described in terms of inches of water use per season if someone is talking of seasonal ETc. Table-3 contains approximate ETc's of common crops. The reference section of this handbook contains full information on ETc for most common crops grown in the District.

Table 3. Approximate ETc at maturity of some crops at Five Points (mid-July)

CROP	ETc (inches/day)
Alfalfa	.12 - .30
Almond	.27
Corn	.35
Cotton	.28
Melon	.20
Onion	.20
Tomato	.30
Sugar beet	.30

Movement of Water Into and Through the Soil

During an irrigation or rain, water soaks into the soil at a rate dependent on the soil type/structure, the soil/water chemistry, and the current soil moisture. Usually, the soil's "infiltration rate" will decrease with time during an irrigation or rain. This is graphically illustrated in Figure-3.

Figure 3: Soil Infiltration Curves, Rate (in/hr) vs. Time.

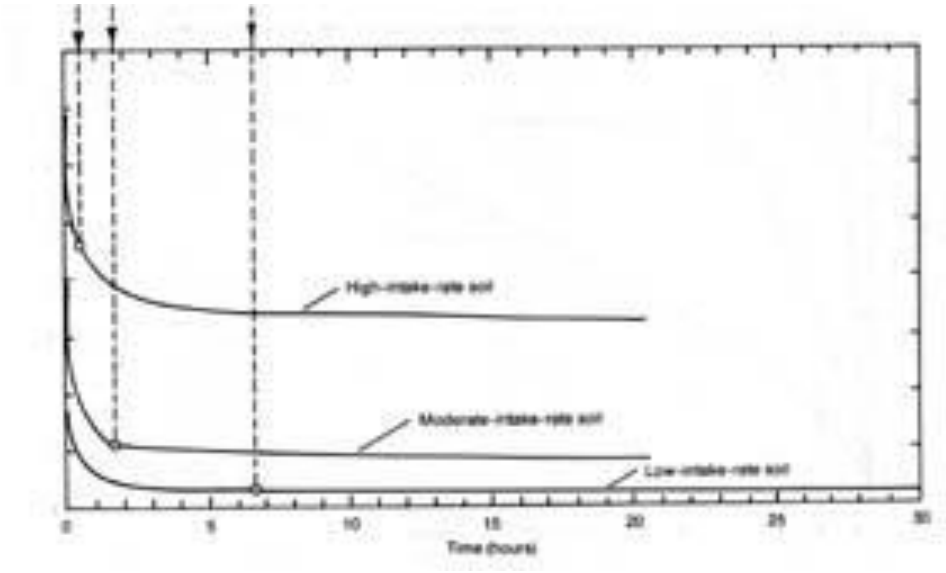


Figure-3 is a graph of the infiltration rate at the head of a furrow during an irrigation. At the left the irrigation has just started (elapsed time = 0) and the infiltration rate is high. The water is taking in water very quickly. But 20 hours into the irrigation, the infiltration rate has dropped dramatically.

Water movement into and through soil is very much influenced by the soil/water chemistry and soil structure. A “sodic” soil will usually have an imbalance in salts that reduces the permeability of the soil. More is said about salts and managing their effects in the Salts and Drainage section.

Water moves through the soil due to a combination of gravitational and matrix forces. Water always tends to move down. However, as described previously, soil water-holding forces are higher in areas with low soil moisture. Thus, water will also tend to move from soil with high soil moisture to areas of less. This is why water can move up into the root zone from a shallow ground water table. As the plant's root system extracts water in the immediate vicinity of the root, water from the wetter surrounding soil will move towards the drier area around the root. As the soil moisture goes down, less and less water will move towards the root and that water surrounding the root is held tighter. Thus, the root can extract less and less water and stress is put on the plant as the soil dries.

Runoff and the Irrigation System Application Rate versus the Soil’s Infiltration Rate

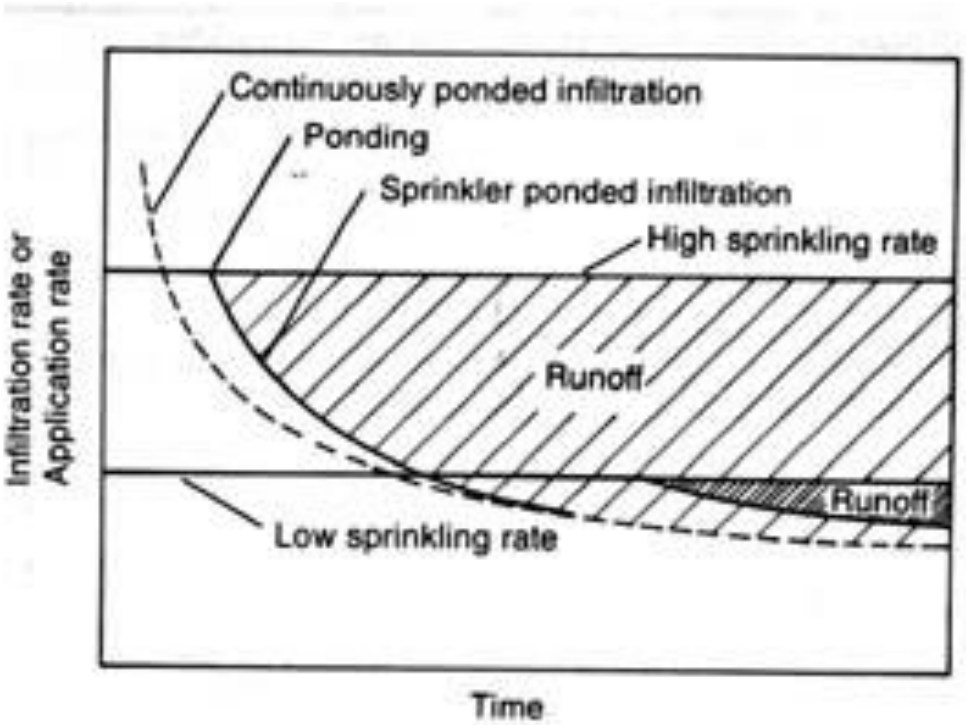
The rate at which water soaks into the soil is called the "infiltration rate". The rate at which we apply water through irrigation, or the rate that water falls during a rain storm is called the “application rate”. Surface runoff occurs when the application rate of the irrigation/rainfall is greater than the infiltration rate of the soil.

Infiltration rates and application rates are both measured in terms of inches of water applied per hour, or “inches per hour”.

For example, a standard field sprinkler system using 7/64" nozzles and running at 50 psi applies water at about .2 inches of water per hour. (That is, for every hour the system runs, an equivalent depth of about .2 inches of water is sprayed onto the ground). If the soil's infiltration rate is greater than .2 inches/hour, then all water applied by the sprinkler system will soak in. If it is less, then you will see water standing on the surface or running off.

Figure-4 is a graph of infiltration rate versus time during an irrigation. The infiltration rate at the start of the irrigation(the left side) is very high, while at near the end of the irrigation(the right side) it has dropped greatly. The straight horizontal line represents the application rate of a sprinkler system that could have been used during the irrigation, high and low rate. It is straight because the application rate of the sprinkler system doesn't change. It pumps out the same amount of water all through the irrigation.

Figure-4: Sprinkler Infiltration Rates



The infiltration rate is higher than the application rate at the start of the irrigation. Thus, all water applied by the sprinklers soaks into the soil. However, by the end of the irrigation, the infiltration rate has dropped below the application rate. Now the sprinkler system is applying more water than the soil can soak in. You will see standing water or runoff occur.

If you see excess surface runoff with sprinkler (or trickle) systems, then either the system is being run too long per set or the design of the system is not matched to the soil (it applies water too fast). Note that sprinkler systems do not spray water on all parts of the field at equal rates. Because of this you may see standing water close to sprinkler heads and not further away during an irrigation. If this occurs continually check your spacing's or the length of your sets.

Also see this link to a United Nations soil and water training manual (http://www.fao.org/docrep/R4082E/r4082e03.htm) that covers this same material, but describes things in metric units. Another link to material on this topic is the NRCS National Engineering Handbook, part 652 (http://www.irrigationtoolbox.com/NEH/Part652_NationalIrrigationGuide/ch2.pdf).

Irrigation Scheduling

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:

SDM_{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=1680) 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 Irrigation Water Management: Irrigation Scheduling (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 WateRight (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, ET_c.
- There are standards of measurement for soil moisture (inches of water held per foot of soil) and ET_c (inches of water use per day, or per season.).

Effective Root Zone and the oil 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. If 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 . . .

$$AWHC = 5.5 \text{ inches}$$

$$AD\% = 45\%$$

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

$$AD_{inches} = AWHC \times AD\% / 100$$

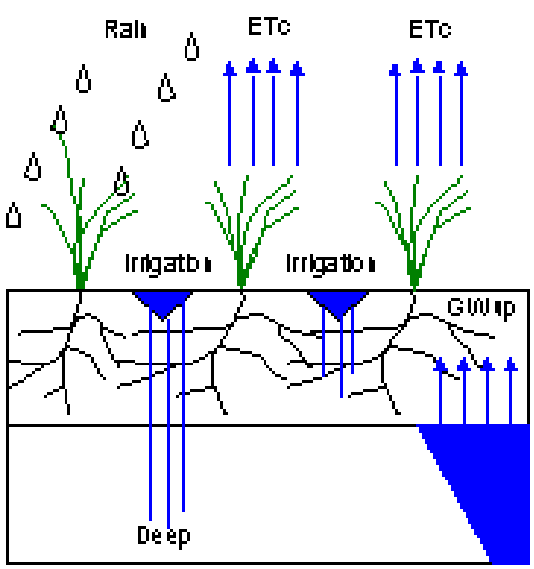
$$AD_{inches} = 5.5 \times 45 / 100$$

$$AD_{inches} = 2.5 \text{ inches}$$

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 (ET_c).

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 (ET_c) 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 . . .

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

$$SMD_{end} = 0 + 0 + .22 - 0 - 0 – 0$$

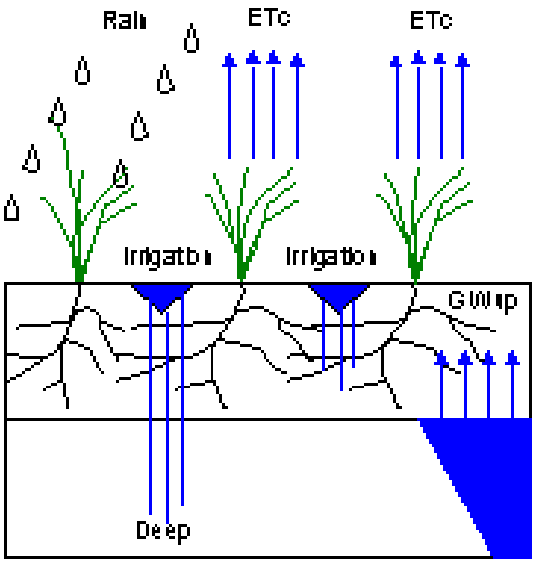
$$SMD_{end} = .22 \text{ inches}$$

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=1680) 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 root zone, 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 root zone then the current depletion is zero, and falls out of the equation. If the amount of water applied by, say, a hand-move 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 root zone 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 root zone 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 root zone 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 root zone 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 root zone. It will give a good estimate of the current depletion of the active root zone and in the process allow you to see where the moisture is being removed from, which tells you what the active root zone 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 furrow irrigation is generally about ¾ 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 appeals 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" x 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."

Salinity and Drainage

Without sufficient drainage (http://www.fao.org/docrep/r4082e/r4082e07.htm), a salt balance cannot be maintained. Yields will decline, you will have to grow less salt-sensitive (usually less profitable crops), and in the long run, land will go out of production.

The basic problem is that all irrigation waters contain salts. Applying water to the soil adds both salts and water. But the crops will extract mostly pure water, leaving the salts behind.

Salts in agriculture can be both good and bad. Many fertilizers are salts. However, excessive salts in the soil (http://www.fao.org/docrep/r4082e/r4082e08.htm) is one of the most serious problems facing irrigated agriculture in the San Joaquin Valley.

There are many different types of salts such as sulfates, chlorides, and bicarbonates of sodium, calcium, magnesium, and potassium. Sometimes the problem is just the high level of salts in the soil and/or water (although in some areas a common problem is too little salts in the water); sometimes it is a problem of imbalance between the types of salts.

Excessive or imbalanced salts in soil and water cause four types of problems for agriculture . . .

1. General yield decline - This is the result of excessive total salts in the soil. The yield decline varies with the crop and management. Some crops are more salt-tolerant than others. And, there are certain techniques that can be used to minimize salt damage.

2. Poor soil structure and reduced water infiltration - This is a result of an imbalance of salt types. The extent of the problem depends on the imbalance, the amount of salts in the water, and also the clay content and type of clay in the soil.
3. Specific crop toxicities (direct action to stunt or kill the plant) - Boron is the most recognized toxic salt by Growers, especially in almonds.
4. Miscellaneous problems with quality (taste or appearance)

With some very poor quality water, damage to components (corrosion, encrustation) of the irrigation system becomes important. The problem of salts can be very obvious or very subtle. Most Growers will recognize a salt problem if they see white crusts in a field or have problems with getting water into the soil. However there could be significant crop yield reductions for years without realizing the problem.

Sources and Measurement of Salinity

There are three main sources of salts in agricultural soils, irrigation water, fertilizer, and naturally occurring salts in the soil that may be dissolved under irrigation. (Most of the time, the amount of salts dissolving from the soil is balanced by those salts precipitating out of solution).

The water supply for Westlands includes both Grower-owned deep wells and Project contract water from the San Luis Aqueduct. Most of the deep well water in the District is of very poor quality. And, although the Project water is relatively good, it still adds about 500 pounds of salt to the soil for every acre-foot (AF) applied.

One measure of the level of salts in soil or water is in terms of a concentration, typically parts of salt per million parts of water. You may see salt levels described as “200 parts per million total dissolved solids” or, “200 ppm TDS” (about the level of salts in Aqueduct water). An AF of water weighs about 2,700,000 pounds. And at 200 ppm TDS, there are 200 pounds of salt per million pounds of water. Thus, every AF of this water contains about 540 pounds of salt. And if you apply three foot of water per acre per year, then you are putting 1620 pounds of salt on that acre.

A more common measure of salts in the soil and water for agriculture scientists is electrical conductivity. This is a measure of how much electric current will flow through water at a specific voltage. The more salts in water, the more current will flow through that water. You will see water described as having an “electrical conductivity of 1.5 dS/m”, or simply EC_w = 1.5 dS/m (dS/m stands for deci-Siemens of electrical conductivity per meter of water).

An approximate conversion between concentration and electrical conductivity is that 640 ppm TDS (parts per million total dissolved solids) = 1 dS/m. A comparison of some water qualities is seen below . . .

- Aqueduct-200-320 ppm TDS or .3 to .5 dS/m
- Friant-Kern Canal - 50 ppm TDS
- Rainwater - Near Zero
- Average deep well in the District, Sub-Corcoran:

    - East of Aqueduct - <1,300 ppm TDS
    - West of Aqueduct-Varies < 2,600 ppm TDS
- Sea-water - 35,000 ppm TDS
- Colorado River - 1000+ ppm TDS at the Mexican border

You may see the symbol "EC" followed by one of several letters. If you see "EC_w" then it is usually describing the electrical conductivity of the irrigation water. If "EC_e" it is usually the electrical conductivity of the saturated soil moisture extract. (Here, the laboratory has made a paste by saturating a soil sample with pure water, then drawn off the excess water and measured the electrical conductivity). "EC_d" is usually used when measuring drainage water.

Suitability Standards for Water Use

The suitability of water (http://www.fao.org/docrep/t0667e/t0667e07.htm) for irrigation is judged on measurement standards that indicate the potential for causing one or more of the four classes of problems. For general yield declines and the necessity for leaching, the standard would be total dissolved solids or the electrical conductivity. For soil structure problems scientists are interested in the sodium absorption ratio (SAR) in conjunction with the total dissolved solids. For specific toxicities, they look at the relative levels of specific salts.

Table-1 is the well-accepted Guidelines for Use of Irrigation Water (from FAO 29A, by Ayers/Westcott). Note that the suitability for use is reported in terms of None, Increasing, and Severe problems to be expected with continual use of the water. For example, a TDS reading of 450-2000 ppm is going to indicate an increasing potential problem while with water over 2000 ppm TDS the problem is likely to be severe.

Also, be aware of some of the assumptions that were made in developing the Guidelines. For example, looking at the notes under Site Conditions . . . "Drainage is assumed to be good, with no uncontrolled shallow water table present within 2 meters of the surface." Obviously in some areas of the District this is not true.

Remember, water quality is only one factor in judging the extent of, or potential for, a problem. Depending on the situation, crop selection, soil type, and soil/water management all affect crop yields and quality.

Table-1: Guidelines For Salinity, ppm TDS

	No Problem	Increasing Problems	Severe Problems
Salinity	< 450	450 - 2000	> 2000

Saline Soils and General Yield Declines

As was seen above, there are two ways in which to measure the level of salts. There are also several ways to describe the type of problem, “saline soils”, “sodic (or alkali) soils”, and “saline-sodic soils”.

Saline soils have an excessive level of salts and are associated with poor yields. However they usually have sufficient permeability (water moves freely through the soil). Saline soils can be improved and/or yields maintained if a fairly good quality water supply and sufficient internal drainage are available.

To explain how salts can cause yield declines, remember that previous sections of the Handbook described that soil can hold water. The lower the soil water content, the harder soil holds the remaining water and the harder it is for the plant to extract this water. Thus, lower water levels in the soil put stress on the plant, reducing yields and if allowed to continue, killing the plant.

The water-holding forces of the soil are called “matric forces”. But there is another force at work to reduce the amount of water that can be extracted by the plant, “osmotic forces”. These osmotic forces increase with an increase in salts. Osmotic forces also act to restrict water extraction by crop roots.

The salts may also interfere with the plant's ability to take up nutrients from the soil. They can do this by affecting some of the chemical reactions inside/outside the plant.

The two forces, osmotic from excess salts and matric from the soil structure, are additive. Thus, in a saline soil, even if it appears wet, the plant can have trouble extracting the amount of water it needs.

For example, use a scale of 1 - 10, with 10 being the highest force for the plant to overcome, to describe the level of osmotic and matric forces. Assume that you are using a furrow irrigation system on a normal soil. The total force working against the plant may peak at . . .

Sodic Soils and Soil Structure Problems

Sodic or alkali soils have a salt imbalance. Typically the ratio of sodium to calcium and magnesium is too high. A measure of this potential imbalance is the “sodium absorption ratio”. The potential for a problem is also dependent on the amount and type of clay in the soil.

It is a highly technical process to explain but in the wrong situation, excess sodium “attaches” itself to clay particles and weakens the soil structure. This leads to “dispersion” (commonly called puddling) of the soil, which can clog soil pores. The permeability is lowered and it becomes harder to get water into the soil.

Some clays/clay-loams are more susceptible than others. Many people will use the term “a shrinking/swelling" type of clay or clay-loam soil. These types of clay soils have the most potential for structural problems (montmorillite, 2:1).

Sodic soils are improved by changing the chemistry of the soil. Commonly a chemical amendment, such as gypsum, is applied. The gypsum may be broadcast or mixed with irrigation water. The calcium that is in the gypsum will replace the sodium that has attached to the soil. Improving sodic soils can take some time as the infiltration rate has been reduced. This makes it harder to get the improving amendment into the soil. (It seems strange to say but when fixing a permeability problem; some Growers will purposely add salts to the water as saltier water will penetrate faster).

Sulfuric acid can be used if there is already sufficient calcium in the soil. Acids work quicker than gypsum but must be carefully handled.

Always consult a qualified soil scientist when working with sodic soils. Take several samples of the field at different depths and have them analyzed to determine the proper amending chemical and required application rates.

Saline-Sodic Soils

Saline-sodic soils have both excess salts and the imbalance problem. They are improved by first treating the structural problem (the "sodic" problem) with chemical amendments. With the soil structure, and thus, infiltration rates, improved, the soil than can be reclaimed with leaching to remove the excess salts. Leaching requirements when treating salt-affected soils or maintaining a salt balance, two things are required, a fairly good quality and sufficient water supply, and sufficient internal drainage. The only way to maintain yields with a salty water supply is to continually leach the excess salts applied with the irrigation water through the root zone. That is, a certain amount of applied water is meant to drain through the root zone. This internal drainage will carry excess salts out of the root zone.

There are two equations used to determine how much leaching water is required. The derivation of the first is somewhat technical and depends on some assumptions about water extraction patterns by plants from different depths in the root zone. The one presented here is in widespread use. It says that . . .

$$(1)\ LR = EC_w / 5 * EC_e - EC_w$$

where:

LR is the decimal fraction of irrigation water that must be leaching water in order to maintain the root zone salinity at the desired level EC_e.

EC_w is the electrical conductivity of the irrigation water.

ECe is the average electrical conductivity in the root zone that will result in a satisfactory yield.

EC_e, a measure of the average root zone salinity, is a management-chosen salinity level that will result in a satisfactory yield. You choose the EC_e you want to maintain. In most normal situations this would be an EC_e that allows 100% yields **with the most salt-sensitive crop in the rotation**.

This is an important point. Cotton is more salt-tolerant than fresh vegetables. The EC_e could be higher when growing cotton than green peppers. However, if you operated the irrigation system on a field to maintain an EC_e for cotton, and then decided to grow peppers in that field, the EC_e would be too high for maximum tomato yields. *Soil salinities must be managed for the most salt-sensitive crop in the rotation, "manage the soil, not the crop".*

With the leaching requirement determined, the depth of water to apply can be calculated by . . .

$$(2)\ AW = ET_c / (1 - LR)$$

where:

AW = total net irrigation requirements (you will need to factor in your application efficiency to calculate the gross amount of water to apply).

ETc = net crop evapotranspiration.

LR = the leaching requirement as determined above.

Recommendations for annual leaching requirements are contained in the Management Techniques section below (Table 6-2). Always check with qualified agronomists when designing salt management programs.

Drainage

There are two things needed to maintain a salt balance. One is a sufficient, good-quality water supply. But there must also be sufficient internal drainage. There has to be some place for the necessary deep percolation to go.

Problems occur, and are occurring in large portions of the District, when there is no place for this leaching water to go. Unfortunately, much of the District is underlain by what is known as the "Corcoran" clay. This is a geologic formation consisting of a relatively impermeable layer of clay that lies from 50 to 200 feet below ground. What has happened over a number of years is that excess water applications, including the deep percolation required for maintaining a salt balance in the soil (and thus, maintaining production), has "perched" on this clay layer until the saturated zone has moved back up into the root zone. Thus, a high water table is formed.

This causes several problems. The perched water table is usually of poor quality and salts are drawn up into the root zone from this table, thus, increasing the salinity of the soil. Root pruning occurs as the water table reduces the effective root zone. And obviously, there is no place for the required deep percolation to maintain the salt balance.

Normally, in these situations, artificial drainage (tile drains) are installed. The excess deep percolation is drawn off the field by the drains and pumped out of the ground. The resulting water table would be drawn down near the drains and thus would cause the water table to be drawn down between the drains. The drains are laid at such a depth and spacing to produce the

minimum required root zone at the mid-point between the drains while providing enough drainage to carry off the deep percolation.

The problem then becomes of disposing of the pumped tile drainage. Unfortunately, this tile drainage is of very poor quality and requires the presence of a “salt sink” somewhere to put the salty drain water without harming anyone. In the Imperial Valley, which has many of the same problems as the District (additionally having to use Colorado River Water at some 1000 ppm+ TDS), that salt sink is the Salton Sea. To the north of Westlands many Districts drain to the San Joaquin River and thus, eventually to the Ocean. Westlands Water District has no such outlet. However, with very careful irrigation management, it has been seen that enough water will percolate through the restraining clay layer to allow continued successful production. [say something else about the District programs?] This careful management consists of restricting deep percolation to the absolute minimum needed to maintain a salt balance and choosing a crop rotation and cultural management regime that minimizes the required percolation.

Management Techniques

Salinity problems can frequently be managed to minimize reductions in crop yield with proper crop selection and irrigation management. The following management techniques deal with existing salinity problems and conditions. Always consult a qualified agricultural scientist when analyzing and treating salinity problems.

Salinity Testing - The extent and severity of a salinity problem must be determined before proper farm management decisions can be made. The salinity problem can be identified by testing soil samples for various salinity related factors. General guidelines for collecting soil samples can be given but conditions vary and individual situations must be consider when interpreting test results.

Possible salt affected areas are generally identified by plants that appear stressed or have low production. Several sampling sites should be selected for each problem area. Soil samples should be taken from the entire effective root zone. Sampling intervals may range from one- to two-foot increments in depth and extend down six or more feet. The salinity level in the top three inches of the seed bed is critical for germination and seedling development. Sampling the field outside the problem area need not be extensive, but is necessary for comparison purposes and to see if the problem is spreading.

General salinity estimates of the field can be made by sampling 20-acre blocks, if conditions are similar over the entire area. Additional sampling sites may be necessary in fields with several different soil types or layers.

When designing a testing program be aware of the effects of irrigation distribution uniformity on salt distribution in fields. If the lower end of a field is continually under-watered, there will not be as much leaching water applied in that area and salts may build up.

Westlands Water Conservation and Management Personnel will determine the EC of the saturated extract of soil samples brought to the District's Five Points Shop and Field Office by

Westlands' water users. The EC of water samples taken from perched water tables or drains will also be determined. The sample must be identified as follows: (1) water user, (2) sampler, (3) date, and (4) location.

Other measurements that would be needed to identify salt-based problems would be . . .

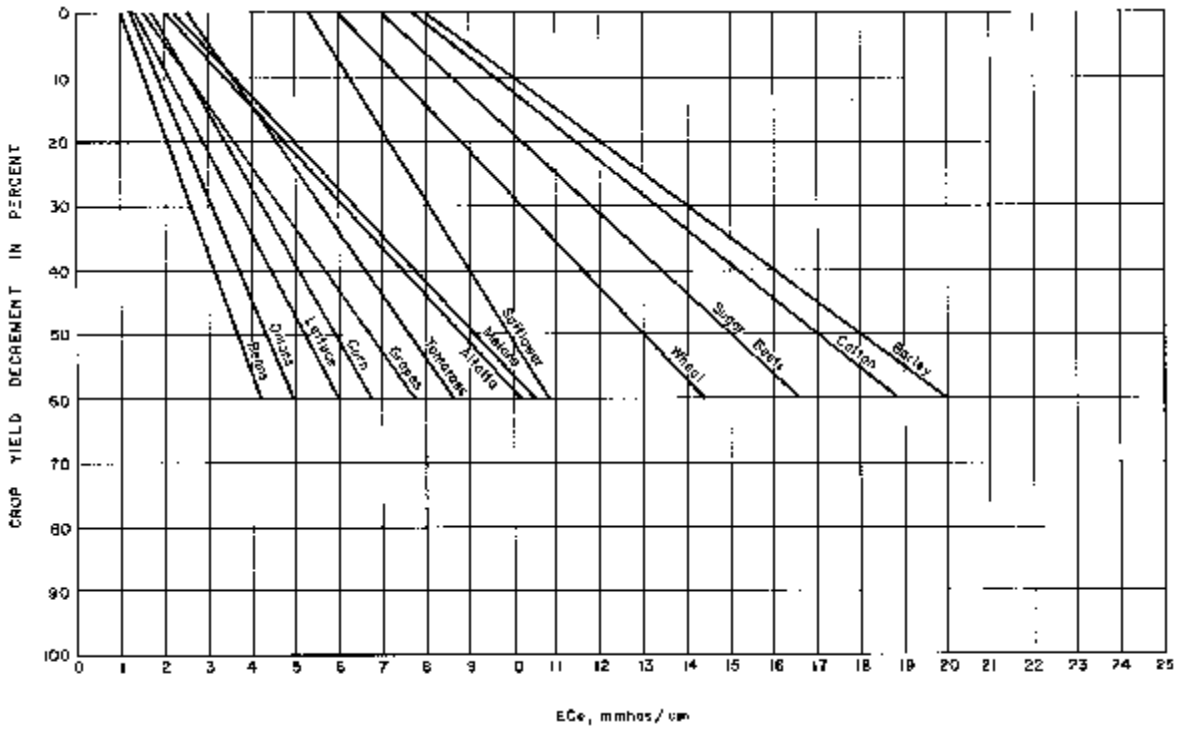
- Measurements of the individual salts present (how much calcium, how much magnesium, etc.).
- Measurements of the different forms of fertilizer salts present (nitrate and ammonium nitrogen, phosphate phosphorous, and potassium).
- Boron.
- pH.
- SAR, sodium absorption ratio, (calculated from the individual measurements of sodium, calcium, and magnesium salts).

Crop Selection - Crop selection is a major management decision. Some crops, such as barley and cotton, can be grown on salty soil without large yield reductions. Other crops, such as almonds and onions, will have significant yield reductions when grown on soils with fairly low salt concentrations. Figure-1 indicates the average EC_e of the root zone that will cause yield reductions due to soil salinity for selected crops. If your soil tests indicate EC_e's over those indicating substantial yield declines in Figure-1 for the crop you would like to grow, consider some other until you can reduce the salt concentrations in that field.

Salts can be managed by crop rotation so that they do not concentrate in the upper portion of the root zone. It can be difficult to apply additional water for leaching during the growing season for crops which have high ET requirements, such as cotton or alfalfa. Thus, some salts may start to accumulate in the root zone when growing these crops. However, additional water for leaching can be applied when winter crops with a low ET are grown in the rotation. The excess deep percolation will drive the salts below the effective root zone.

Crops can be used to manage salinity. Some crops, such as cotton, can use upwards flow of water from a shallow water table, even very poor quality water. This will lower the perched water table and make room for water used to leach salts from the upper portion of the soil profile allowing a more salt-sensitive crop such as tomatoes to the planted.

Figure-1: Crop Sensitivity



Seed Germination - Average salinity through the root zone is not a useful measure when trying to anticipate germination problems. Salts may be excessive in the surface soil area surrounding the germinating seed.

Rainfall and pre-plant irrigations will move salts away from the seed zone if the rains are adequate or pre-plant irrigations are carefully managed. Sufficient rain, sprinkling, or other pre-plant irrigations applied to flat fields should easily control salts in the seed zone. However, listed fields, when irrigated through furrows, often have excessive salt buildup in the top or high point of the bed which may reduce or stop germination.

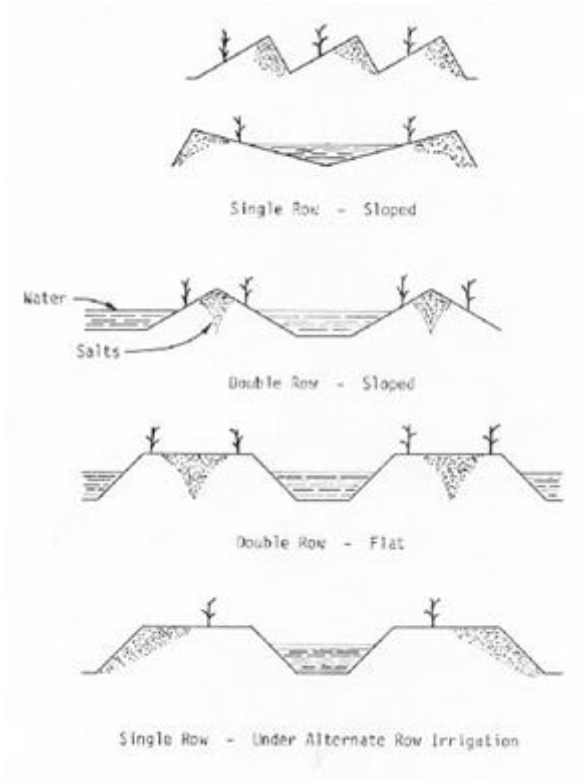
The salinity of the seed zone during germination must be minimized. If there is any question about the salinity, have representative seed zone soil samples tested. An EC_e of 3 or 4 mmhos/cm is about maximum for seed germination of sensitive crops. Once the developing roots reach a low salt area, the effects of salts near the seed become less of a factor in the health of the plants.

Seed placement can be adjusted to reduce the effects of salt on seed germination and plant development. Figure-2 shows the shapes of seed beds that will reduce salt in the seed area when irrigating by the furrow method.

Salts tend to concentrate at the center of a flatbed which has irrigation furrows on either side. Sloping the bed will allow salts to accumulate at the highest point (see Figure-2, top). Seed planted on the slope far below the top of the bed will be less likely to suffer salt damage. Single and double rows of seed can be planted on sloping beds. Double rows of seeds can be planted on

a wide flatbed since the salts tend to concentrate at the center of the bed away from the seed (see Figure-2, second).

FIGURE-2, Seed Beds/Seed Placement



Irrigating alternate furrows can flush salts away from properly placed seed. Salts will move away from the irrigated furrow to the opposite side of the bed or into the dry furrow (see Figure-2, fifth). However, alternate furrow irrigation should not be used with double-seeded rows. If the salt isn't driven far enough, it may end up in one of the seed rows.

Salt-sensitive crops have a greater chance of germinating if planted after pre-irrigation. Pre-irrigation will decrease the concentration of salts in the bed by leaching salts from the top of the root zone giving the seedlings a better chance to survive. Increased seeding rates may improve the plant population in salt-affected areas.

Infiltration - Infiltration problems are related to an imbalance in the ratio of sodium to calcium and magnesium in the soil. Soil can seal up, either from swelling or dispersion (puddling), reducing the water infiltration rate. Soil crusting, compaction, water-logging, poor aeration, poor germination, excessive weeds, and diseases are problems that may be related to excessive sodium.

Chemical soil amendments, such as gypsum can be used to manage infiltration problems when the soil profile has good drainage. Gypsum is mixed into the soil or irrigation water. The sodium attached to the soil is replaced by the calcium from the gypsum. The sodium is then removed from the soil profile by leaching. This practice may require annual or semi-annual applications of gypsum over a number of years to effectively increase the infiltration rate to an acceptable level.

Sulfuric acid can also be used on alkali soil where there is already sufficient calcium present in the soil. Acid can improve soil properties quickly but requires extremely careful handling.

Agricultural laboratories can advise you on the proper soil amendment, application rate, and application method.

Organic residues incorporated into the soil surface also will increase water infiltration. Stubble mulches, such as cotton stalks or cover crops, can be disced into the soil. Animal manure can also be used, but it contains salts which could create additional problems when applied in large quantities.

Cultivation and deep tillage, such as plowing or chiseling, are often used to temporarily correct infiltration problems. These practices create rough, cloddy furrows which also cause water to infiltrate more readily. However, the benefit is greatly reduced after one or two irrigations. (Also, rough cloddy furrows can result in extreme over-irrigation). Although deep tillage can improve penetration in compacted soil, it may bring salts from the lower portion of the soil profile to the surface, which also reduces the benefits of tillage.

The amount of water infiltrated into the soil may be increased by lengthening the duration of irrigations. Reducing the flow into a furrow slows the rate of advance down the furrow to provide a longer infiltration period. This method works best for preirrigations, when standing water will not affect seeds or plants. Collecting and recalculating water with a tailwater return system also will allow water to be on the field for longer durations.

The slope of the field can be decreased to reduce the rate of advance of the water which provides more time for penetration into the soil. This may require land grading or a change in the direction of the furrows to reduce the slope. However, changing the direction of slope may be difficult when fields are uneven or irrigation systems are inflexible.

Irrigation systems that can apply water at the same rate as it enters the soil help solve infiltration problems. The application rate of sprinkler systems can be changed by altering operating pressures or nozzle sizes. However, the change in distribution uniformity must be considered as well. The application rate of a linear move sprinkler system can be adjusted by altering the systems' speed across the field. Sprinkler systems, as well as drip systems, can be turned off when ponding or runoff occurs and the irrigation interval adjusted accordingly.

Irrigation - Crop yields may be maintained by reducing the allowable depletion, since normal depletions can cause crop stress under saline conditions.

To further explain this technique, remember that there are both matric forces (the soil's water-holding force) and osmotic forces (from salts) at work. With a furrow irrigation system, where water is applied infrequently, the matric forces will increase substantially between irrigations. Thus, as an example . . .

$$\text{Force}_{\text{total}} = \text{Force}_{\text{matric}} + \text{Force}_{\text{salt}}$$

$$\text{Force}_{\text{total}} = 10 + 4$$

$$\text{Force}_{\text{total}} = 14$$

Now, using a system that can apply water frequently (such as trickle), the matrix forces can be held very low, since with high frequency irrigations the soil moisture is consistently high. And . . .

$$\text{Force}_{\text{total}} = \text{Force}_{\text{matric}} + \text{Force}_{\text{salt}}$$

$$\text{Force}_{\text{total}} = 3 + 4$$

$$\text{Force}_{\text{total}} = 7$$

The osmotic forces have not been affected. You've done nothing to reduce the amount of salts in the soil moisture. But since the soil moisture is kept at a high level, the crop can do better.

Frequent irrigations can decrease salt concentration in the root zone between applications. However, frequent irrigations from inefficient systems will waste water, can cause a rise in the water table, and may result in killing some plants.

Flood or furrow irrigation methods are not suitable for frequent irrigations. These methods can usually apply a large quantity of water efficiently, but irrigation timing and amounts are often difficult to alter, making frequent irrigation inefficient and impractical.

Within limits, sprinkler systems can apply small amounts of water frequently and efficiently. Frequent irrigations reduced salt concentrations in the upper portion of the root zone by moving salts downward. Sprinklers also reduce soil crusting problems and improve germination by keeping the soil surface wet. But unless it is a solid-set system, labor costs will go up because of the more frequent moves.

Drip irrigation systems apply small amounts of water frequently. The entire soil profile is not wetted, but water is applied to a small area which moves the salts away from the roots. Frequent irrigations are necessary when drip systems are used in a saline environment because salts quickly concentrate in the restricted root zone. Daily application probably will be required during periods of high crop water use. A sprinkler irrigation or heavy rainfall on a drip irrigated crop might move salts into the root zone, causing damage to the crop. A leaching irrigation may

be required prior to planting a crop to be grown under drip to reduce salinity in the root zone or to allow germination.

Toxicity - Excessive amounts of boron or chloride are toxic to plants. Crops vary in their tolerance to these elements and toxicities may occur when total salinity is low.

Certain symptoms may indicate toxicity to these elements. However, each may cause specific/general symptoms. Plant nutritional problems and chemical damage may cause symptoms similar to those caused by boron and chloride toxicity. Soil or foliar samples should be tested by an agricultural laboratory to determine the cause of the problem.

The first symptoms of boron toxicity include yellowing, spotting and/or drying of tissue at the tips and edges of older leaves. The yellowed or spotted areas may dry up and spread from the tip along the edges of the leaf, eventually going all the way to the mid-rib of the leaf. Seriously affected tress, such as almond, may discharge gummy substance.

Chlorides are most toxic to trees and vines. The first symptom is the drying of tissue at the tip of the older leaves, spreading along the leaf edge. Extreme toxicity may lead to leaf drop.

Sodium can also cause toxic symptoms.

Toxic salts can be leached out of the root zone as with the total salt load. Boron is more difficult to leach than chloride.

The choice of fertilizer and application methods can affect salt concentrations in the soil. Fertilizers high in salts, such as ammonium nitrate should be applied in split applications to reduce the salt concentration around the seed or plant.

Water Table - A perched water table containing a high concentration of salt aggravates the salinity problem when it rises into the crop root zone. Perched water containing low concentrations of salt and toxic elements can be used by the crops. However, salt concentration in the perched water table (http://www.fao.org/docrep/w7224e/w7224e00.htm) will increase over a period of time. A program of monitoring the EC of the perched water table and the soil profile can warn of developing problems.

Crop root extension will be restricted when they are not able to penetrate into poor quality perched water. This restricted root zone must be considered in irrigation management. Over-irrigation can cause the salty perched water table to rise into the active root zone. Small frequent irrigations leach salts downward into the lower portion of the root zone and tend to keep the water table lower.

Water should not be over-applied where drainage is restricted. Excessive irrigation can only be removed by natural or artificial drainage, or crop water use of the high water table. The application efficiency needs to be very high on land which has a perched water table.

Maintaining Salinity Levels - Normal irrigation practices usually include adequate water to satisfy the maintenance leaching requirement. However, care should be taken in planning for soil salinity maintenance as irrigation systems and management practices become more efficient. Leaching that moves salts below the root zone usually occurs during pre-irrigation or early season irrigations. Irrigations during the growing season move salts from the upper portion to the lower portion of the root zone, since the entire root zone usually cannot be refilled with water at that time.

The EC_w of Project water is about .3 to .4 mmhos/cm. One AF of Project water contains about 500 pounds of salts. This salt will build up to concentrations which can reduce yields if it is not leached. As discussed previously a maintenance leaching program removes salts from the root zone which are supplied in irrigation water and maintains a long-term salt balance in the soil profile.

Table-2 shows the minimum leaching requirement selected crops to maintain a salt balance in the root zone and an acceptable production level. The calculated leaching requirement of the seasonal ET for crops irrigated with Project water.

Table-2 Maintenance Leaching Requirements

CROP	FT	CROP	FT
Alfalfa	0.2	Lettuce	0.05
Almonds	0.2	Melons	0.05
Beans	0.2	Onions	0.1
Corn	0.1	Safflower	0.05
Cotton	0.05	Sugarbeet	0.05
Grape	0.1	Tomatoes	0.05

The leaching requirement must be increased to maintain production if salt concentrations increase in the root zone. When using only a maintenance leaching requirement, irrigation intervals should be short or salt will concentrate to harmful levels in the upper portion of the root zone.

Groundwater may contain boron or other toxic salts and should be tested prior to use.

Recirculating Drainage Water – Recirculating tile drainage water is a short term solution and does not solve a drainage problem. The leached salts are only returned to the soil profile with the irrigation water. Some drainage water contains a toxic level of boron and should be used cautiously even though recent research has indicated that foliar symptoms due to boron appear on cotton before yield is affected.

Soil with a relatively low EC_e will maintain crop production longer than soil with a higher EC_e when drainage water is recirculated. It would be expected that the increase in the EC_e of a four-foot soil profile for a slightly saline soil (EC_e = 2.65 mmhos/cm), and moderately saline soil (EC_e = 6.0 mmhos.cm) would stay in production longer. If you assume that the increase in the EC_e is based on the application of 2.5 AF of Project water applied annually, the slightly saline soil is projected to have an EC_e of 8 after water is recirculated for 12 years while the moderately saline soil is projected to have an EC_e of 8 in only 5 years.

Blending water - In times of drought, District growers will use deep wells. Well water is usually of very poor quality and can quickly cause problems, especially if the SAR (sodium absorption ratio, a measure of potential infiltration/soil structure problems) is high.

Blending of deep well and Project water may or may not physically be feasible on an individual field. Blending can reduce the infiltration problem potential since it will change the ratio of sodium, calcium and magnesium salts in the water. It will not change the total salt loading of the water. If you have 1 foot of Project water available (500 pounds of salt) and 1 foot of well water with 1500 pounds of salt, you are going to apply 2000 pounds of salts. It would not matter if you applied the Project water first, then the well water, or mixed them together.

But usually you would alternate the use of the good quality Project water and wells. Use the good quality Project water early for germination and seedling growth, then switch to the well water.

Please follow this link for an additional source of information on this topic (http://www.irrigationtoolbox.com/NEH/Part652_NationalIrrigationGuide/ch13.pdf) in the NRCS National Engineering Handbook, part 652.

Soil Moisture Status & Instrumentation

Content vs. Depletion vs. Tension

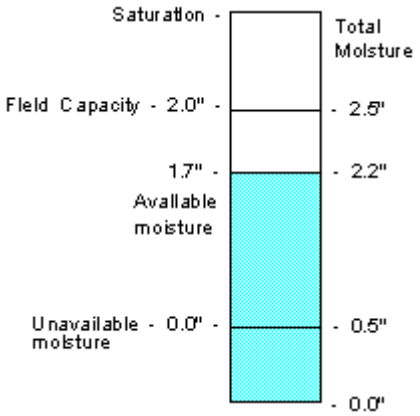
Descriptions of soil moisture can often times be confusing. Sometimes soil moisture is described in terms of actual or total soil moisture content. That is, how much total water is actually in the soil? Other times, soil moisture will be described in terms of available water. This is soil moisture that is above the permanent wilting point, available to the crop.

Another way to describe soil moisture is to talk in terms of the “soil moisture depletion” or “soil moisture deficit”. Remember that the upper limit of available soil moisture is field capacity. Adding water to the soil in excess of field capacity will just result in deep percolation. The

amount of water required to take the soil from its current soil moisture to field capacity is termed the soil moisture depletion (or deficit), the SMD.

The figures below will help to explain. For example, assume that a soil has a field capacity of 2.0 inches/foot. The permanent wilting point is at .5 inches/foot. The current soil moisture reading is 1.7 inches/foot total water. Thus, . . .

There is 1.7 inches/foot total water in the soil. There is 1.2 inches/foot available water in the soil, 1.7 minus the .5 inches below permanent wilting point which won't be used by the crop. The soil moisture deficit is .3 inches/foot, that is, adding .3 inches/foot to the current 1.7 inches/foot will take the soil to its 2.0 inches/foot field capacity.



All of the above describe soil moisture "volumetrically". They are "volumetric" measurements of soil water. The measure the actual soil water content (or what it takes to refill the soil to field capacity). The measurement standard of "inches of water held per foot of soil" is a standard for volumetric measure.

There is another way to describe soil moisture. This is in terms of the soil's water-holding forces, termed "soil moisture tension."

Soil Moisture Tension

We have been talking of soil moisture in volumetric terms. That is, how much water is physically in the soil, the inches of water held per foot of soil?

However, the plant doesn't really care about the actual amount of water in the soil. It cares about the soil's water-holding forces, how hard the soil is holding on to that water. For example, a clay loam may have an available water content of 1.2 inches/foot. And a sandy loam may have the same available water content of 1.2 inches/foot. A plant in the clay loam is probably feeling much more stress than the plant in the sandy loam. Finer soils will hold more water than coarse soils. But they will also hold on to it much tighter for any given water level.

The term used for describing the water-holding force is “soil moisture tension”. Soil (or plant) moisture “tension” is another way that moisture can be measured and described.

Soil/plant moisture tension is measured in terms of pressure, most commonly as centibars (1 bar = 100 centibars = 1 atmosphere = 14.7 PSI for agricultural work.

To a plant, all other things being equal, it doesn’t care if it is growing in beach sand or black clay. If the moisture tension is equal, it feels the same amount of stress, regardless of the actual amount of water present. And it will develop at the same rate.

Methods of Measuring Soil Moisture

There are three main ways of measuring soil moisture volumetrically, that is, in terms of inches/foot. One well-known method is the neutron probe. The neutron probe consists of a small cylinder, usually about 2" x 8" that is connected to a control box by 6-8 feet of electrical cable. The radioactive material (the source of the neutrons) is contained in the cylinder. When not in use the cylinder is stored within the control box, which is lined with paraffin wax and lead for safety.

Access holes are drilled and PVC or aluminum pipe inserted at appropriate places in a field. To measure soil water the neutron probe cylinder is lowered into the hole to pre-determined depths (dependent on the crop and soil). When turned on, the source within the cylinder will emit fast, low-energy neutron particles in about a 6" ball around it. When these fast-moving particles strike a hydrogen molecule (present in water, H2O) they are slowed down. The instrument detects and counts these slowed particles. The total number of slowed particles is calibrated to read out in terms of total soil moisture.

The neutron probe is an expensive instrument (although costs, size, and weight are coming down) and requires special training, licensing, and storage procedures. Also, the required access tubes and time to take a reading realistically restrict its use to one or two spots in a field. Usually it is used by scientists, consultants, and larger farms.

Another way to measure soil moisture is to take a soil sample of a known volume, weigh it, dry it thoroughly and then weigh it again. The difference in weight between the wet and dry soil is the total water content. This method, known as the “gravimetric” method, is slow and not used in production agriculture except to calibrate other methods.

Measuring Soil Moisture by Hand Probing, the “Feel” Method

One of the easiest, cheapest, and most flexible methods is by “feel”. That is, using a soil sampler or soil auger to take samples of soil from varying depths of the root zone and judging the water content by the feel and appearance of the sample. It is easy because anyone can do it. It is cheap because all it takes is an inexpensive soil sampler (see the Additional Resources section of the Appendix for places to obtain soil samplers). And it is flexible because you can go any place in the field, at any time.

This flexibility is one of its great strengths. With neutron probes, tensiometers, and gypsum blocks, you can only measure soil water at the point of installation of the access tube or instrument. If using tools like leaf pressure chambers or infrared thermometers, you are restricted as to time of day (and in the case of the infrared "gun", whether it is cloudy or not, and windy or not).

With practice, it is easy to become fairly accurate. The University of Nebraska – Lincoln document can help relate the feel and appearance of soil samples to the water content, the "feel method." It has some good color photos and presents the depletion in percentage.

http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=2194&context=extensionhist

Additionally, NRCS has similar information.

Probing is cheap enough that it can be used both before and after an irrigation. Use it before an irrigation to both time the irrigation and estimate the correct amount of water to apply. Sample the soil after an irrigation to make sure that you got enough water into the root zone. If the after-irrigation sampling indicates too much or too little water in, adjust the next irrigation's management as required.

Measuring Soil/Plant Moisture Tension

Measuring water volumetrically, that is, in terms of actual water content is important. It gives us an idea of how much water to replace at an irrigation. Remember though, the plant does not care how much water is actually in the soil. It only cares how hard that water is being held by the soil. Thus, to prevent stress you would like to be able to measure this water-holding force, the soil moisture tension.

The most well-known methods are the tensiometer and gypsum blocks. Both are in wide-spread use. They are relatively inexpensive and easy to use. However, like a neutron probe access tube, once installed they can only measure soil moisture tension at that one spot. Care must be taken in choosing the measuring site and the depths of installation.

Also, for complete water management there should be a way to relate a relative soil moisture tension reading to the soil moisture depletion to allow for efficient irrigations.

This is a very important point. The measurement of soil moisture tension provides an indicator for WHEN to irrigate. We want to irrigate before excessive stress on the plant, to provide for optimum plant development. The measurement of soil moisture content provides the estimate of HOW MUCH to irrigate. This is how much water to apply when we do irrigate.

The tensiometer tries to mimic the root as closely as possible. There are three main parts to the instrument, illustrated in link below. They are a water-filled tube (of varying lengths depending on what depth of soil is to be measured), a vacuum gauge on the above ground end of the tube, and a porous, ceramic tip on the other.

The tensiometer is inserted into the soil to the desired depth. As the soil moisture level decreases at that depth, the soil will try to draw water out of the tube through the porous tip. This creates a vacuum in the tube which is read on the gauge. It is a direct reading on the stress that the plant roots must overcome. If irrigation (or rain) water is added, the vacuum in the tube will draw water back into the tube, decreasing the vacuum and reducing the gauge reading.

Tensiometers will generally read a range of from 0 to 70-80 centibars. Above 70-80 centibars, the water flow between the soil and the ceramic tip breaks and suction (and thus, the vacuum in the tube) is lost. The reading will go to zero.

This is an important point, especially with deep tensiometers. A zero reading on a tensiometer can either mean a very wet soil, or a very dry soil.

"Gypsum block" is a generic term. Modern blocks may be made of fiberglass and other porous materials. They consist of a cylinder of porous material, about 1 inch in diameter and two inches long, with two wires embedded in it but not touching.

The block is buried at the desired depth with the electric leads extending above ground. When measuring tension, an electric voltage is sent through the wires. The resulting current flow is read with a sensitive instrument. The porous block will contain more or less water as the soil dries or wets. The wetter the block, the more current will flow. Instruments used are commonly calibrated so that the current flow is read as centibars.

An advantage of gypsum blocks are that they can be used to read very high soil moisture tensions.

Another instrument that may be called a gypsum block (because they are very much alike in appearance) is the thermal dissipation sensor. Wires are again embedded in a porous ceramic block. When wet, the block will dissipate (throw off) heat rapidly. When dry it dissipates heat much slower. An electric circuit is used to quantify this change as the soil wets or dries.

With a neutron probe, the access tube allows you to measure at any depth or depths desired. But once buried, the gypsum block or tensiometer is in one place. Thus, tensiometers and any form of "gypsum block" are usually used in "banks". That is, two or more of the instruments will be installed at the same field site but at different depths.

Measuring Plant Moisture Tension

Measurements of moisture tension can be soil-based or plant-based. Soil-based measurements measure the tension in the soil, as with a tensiometer or gypsum block. This is a direct reading on the tension that the plant must overcome. There is an instrument that measures the moisture tension within the plant directly, the plant leaf pressure chamber (also called the "pressure bomb").

This device consists of a pressure chamber with a special removable cover, pressure gauge, and pressure source. When using the pressure chamber, a leaf/petiole sample is cut. The petiole is

inserted through a self-sealing hole in the pressure chamber cover. The cover is then screwed on the chamber with the leaf inside the chamber and the cut end of the petiole left out. Then pressure is slowly introduced to the chamber. At some point, sap will be seen to bubble from the petiole. The pressure gauge is read in centibars of pressure. The reading is a direct measurement of the plant moisture tension and thus, the stress in the plant.

Leaf chambers have been very effective in scheduling irrigations (particularly the first seasonal) for cotton. The UC Extension has done much testing to develop specific recommendations. They can suggest desirable pressure readings at the first seasonal and following irrigations in different varieties.

Pressure chambers are flexible in that you can go anywhere in the field to cut petiole samples. However they are restricted to 2-3 hours of sampling time a day, usually around solar noon (when the sun is highest).

Again, tension measurements are essential to prevent stress from lack of soil moisture. However there must still be some way of knowing how much water to apply during irrigation. Effective, efficient irrigation management combines tension measurements with volumetric soil moisture measurements.

The Thermal Infrared Thermometer

Another instrument in use is the thermal infrared thermometer (sometimes called the "infrared gun" because of its appearance). This instrument is a thermometer that measures temperature by reading infrared radiation. The instrument is aimed at whatever you wish to measure the temperature of.

In use the thermometer is aimed at the crop canopy so that the average temperature of the crop's leaf surfaces is measured. At the same time a measurement of the ambient air temperature is taken. The difference between the two temperatures indicates the amount of stress on the crop. The basic theory being that if ET_c is normal, the leaf temperatures will be lower (as water evaporates through the surfaces).

The thermometer is very fast and easy to use. You can point it anywhere in the field. However, it should be used at about the same time every day, it should be used on a full canopy (so that bare soil is not read), and also in low wind.

One of the keys for effective use of any form of soil or plant moisture measurement is picking the correct field site and depth in the root zone to sample. Do you want to irrigate to the driest part of the field, or the wettest? Do you irrigate to the sand streak, or the rest of the field. This is again an example of the art and science of irrigation management. Science has provided the tools for measuring soil moisture. You have to decide where best to measure and interpret the results.

Salt and Irrigated Agriculture

All of the ideas discussed in this chapter are affected by the amount and relative balance of salts in the soil and water. High or out of balanced salts in the soil can reduce effective available water holding capacities, restrict water infiltration, require more irrigations, and/or alter soil moisture tension readings, among other effects. Westlands Water District is affected by high water tables in some areas and by high salts in groundwater in most areas. Please read the chapter on Salts and Drainage or see this link to a United Nations soil and water training manual (http://www.fao.org/docrep/R4082E/r4082e08.htm) that covers this same material, but describes things in metric units.

Summary

In summary, there is a body of science that has created a model of how water moves into the soil, through the soil, into the plant, and back out into the atmosphere.

We know that soil will only hold so much water; it does no good to irrigate over this maximum field capacity. We know that the water-holding forces in the soil go up as the level of soil moisture goes down. This leads to two ways of describing soil moisture- in terms of the actual water content (inches of water held per foot of soil), and in terms of the water-holding forces (centibars of tension).

We act in terms of the actual water content (inches of water per foot of soil); we need to know how much water to replace at an irrigation. The crop doesn't care how much water is in the soil. It cares how hard that water is being held by the soil (the soil moisture tension in centibars). Crops extract water at a measurable and predictable rate, evapotranspiration, ET_c, measured in terms of inches/day. We do not let the crop use all the available water in the soil. As the soil moisture goes down, the forces holding water in the soil go up. It becomes harder for the plant to extract the water it needs.

We can describe the rate at which water enters the soil as an infiltration rate, measured in inches/hour. We can also describe the rate at which we apply water during an irrigation, the application rate, also measured in terms of inches/hour. If the application rate is greater than the infiltration rate, runoff will occur.

There are many ways of measuring water, both in terms of volume and in terms on tension. Each has its own strengths and weaknesses. Which is chosen depends on the specific situation.

The available water holding capacity of soils, the rate at which water soaks into and through soil, the level of stress on a plant at any soil moisture level, are all affected by excessive or imbalance salts in the soil. See other pages on Salinity for further information on these effects.

On-Farm Irrigation System Management

Furrow Irrigation Systems

In another section you saw the importance of planning for the primary water supply. Assuming that you have the water supply committed, the next step is to use it. The goal is effective, efficient irrigations.

- Effective irrigations produce the desired crop response.
- Efficient irrigations make the best use of available water.

Effective, efficient irrigations are the result of knowing WHEN to irrigate, HOW MUCH to irrigate, and HOW to irrigate.

WHEN to irrigate is an agronomic decision, based on how you want the crop to develop.

HOW MUCH to irrigate is the Soil Moisture Deficit, SMD, in the current effective root zone. You must know how much water is needed to take the soil back to field capacity.

HOW to irrigate is not just knowing how to set a siphon tube or hook up a sprinkler pump. Knowing HOW to irrigate is knowing how to apply water evenly (a high distribution uniformity) with control of the total application (a high irrigation efficiency).

This section will look at three aspects of furrow irrigation systems. . .

1. The important operational characteristics of each system will be described.
2. How to apply water evenly (and get good distribution uniformity) with each system will be explained.
3. How to control the total amount of water applied (and get good irrigation efficiency) with each system will be explained.

The two measures of irrigation performance are distribution uniformity (DU) and irrigation efficiency (IE). DU is a measure of how evenly water is applied. You must be able to apply water evenly before you can have high efficiencies. IE is a measure of how much applied water ends up in the effective root zone available for crop use (or is beneficial in maintaining a salt balance).

With furrows there are three aspects to good DU, down-row uniformity, cross-row uniformity, and general soils variability.

- Good down-row uniformity is the result of getting water to the end of a furrow quickly. Recommendations are that water should get to the end of a furrow in 1/3 to 1/2 the set time for medium loams and 1/4 to 1/3 with coarse soils. For very heavy, cracking clays, up to 2/3 of the set time may be okay.

- Cross-row uniformity is a problem of differential compaction of the furrows by tractor traffic. The infiltration rates are changed thus, some furrows take water faster than others. You may want to irrigate the field in two sets, one in the wheel-rows, one in the off-rows.
- You can't do much about general soils variability. Surge irrigation may be helpful to get water across a field that is streaked badly.

Tailwater reuse systems are highly recommended. They make it easy to manage the fast advance needed for high down-row uniformity.

Preplanning an irrigation is always a good practice. Know the soil moisture depletion and then compare how much water is to be delivered (the furrow flow rate times the set time divided by the furrow area).

Distribution Uniformity and Irrigation Efficiency

Distribution uniformity, DU, is a measure of how evenly water infiltrates across a field. If twice as much water infiltrates in one part of the field as in another that is bad DU. DU's are expressed as a percentage. 100 percent DU is impossible but means that the same amount of water was infiltrated all across the field.

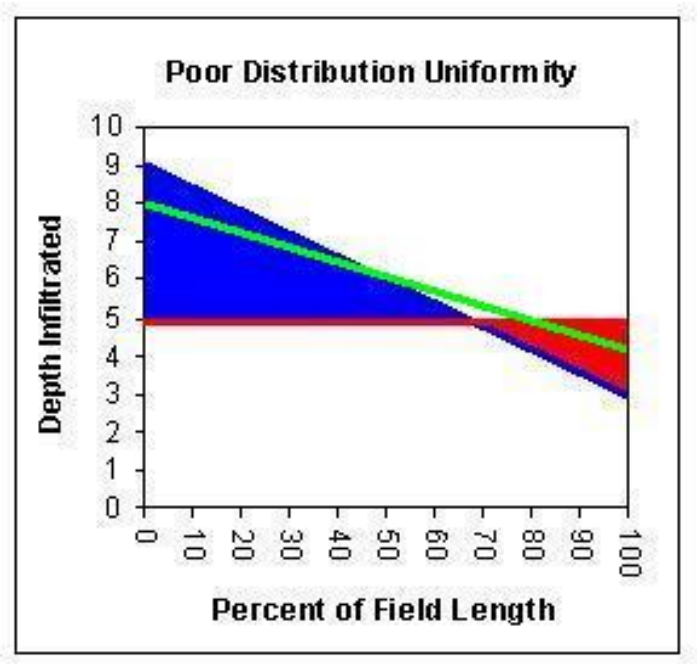
HOW to irrigate also means controlling the total amount of water applied. Irrigation efficiency, IE, is a measure of how much water allocated to a field ends up in the effective root zone, available for crop use. ("Allocated" water is all water delivered except surface runoff that is used on another field.) Irrigation efficiencies are also expressed as a percent.

A 100 percent IE would mean that all water that was delivered to a field and was not saved runoff, soaked into the soil and stayed in the effective root zone.

A 50 percent IE means that only half of the water that was delivered and not saved runoff, soaked into the ground and stayed in the effective root zone. The other half was deep percolation or tailwater that was not saved for reuse.

Again, distribution uniformity is a measure of how evenly irrigation water soaks into the soil. Irrigation efficiency is a measure of how much water that is applied to a field, and does not become saved tailwater, ends up in the effective root zone.

There are two relationships between DU and IE, explained in figures below. In the figures, the thick red line depicts the depth of the actual soil moisture deficit at irrigation. The blue line depicts the actual depth of irrigation at various points in the field. The blue area depicts deep percolation. The red area depicts under irrigation. The green line shows the infiltration of water with a 75% DU rather that the blue line with a 62% DU, when both applied the same average depth of water.



You must have good Distribution Uniformity before good Irrigation Efficiency. The figures above show that without good DU you will either cause excessive deep percolation (the blue area) or under-irrigate part of your field (the red area). Note that if you could have applied about 0.5" less, with the improved DU, and still have less deep percolation, less under-irrigation and a higher efficiency. Under-irrigation may result in a higher IE, but it is not an effective way of growing.

There are two important relationships between DU and IE. The first was demonstrated above. You need to have good DU before you can have good IE. You have to be able to apply water evenly before you can apply it efficiently. But good distribution uniformity is no guarantee of good irrigation efficiency. As seen in the figure above, a good DU allows a good IE, but you still must control the total amount applied.

Sprinkler and drip systems usually provide good DU. However, they are not automatically efficient. You could have a 100 percent DU, that is, apply the same amount of water all over the field, but apply twice as much water as needed, all over the field.

Furrow Irrigation Systems

An important characteristic of furrow systems is that the amount of water soaking into the soil during an irrigation is dependent on two factors, the “infiltration rate” of the soil and the “opportunity time” at any point in the field. Opportunity time is the time that water is on the soil surface soaking in, the time that the soil has the "opportunity" to infiltrate water.

The soil's infiltration rate is a measure of how fast water is soaking into the soil. Infiltration rates are described in terms of “inches per hour”. An infiltration rate of 1 inch/hour means that if you

ponded a one-inch depth of water on a soil with that IR, it would take 1 hour for it to soak in completely. Infiltration rates change constantly during an irrigation.

Remembering the relationship between DU and IE (http://www.wateright.org/), you have to get good DU first. With furrow irrigation systems, there are three factors to consider for achieving high distribution uniformities . . .

- Down-row uniformity is a measure of uniformity from the top to the bottom of any one furrow. If 8 inches of water soaks in at the top of the furrow and only 4 inches at the bottom, that is bad down-row uniformity. Given a homogenous soil (no streaking), down-row uniformity depends on the difference in opportunity time from the top to the bottom of the furrow. Land leveling is very important to achieving high down-row uniformity.
- Cross-row uniformity is a measure of uniformity between adjacent furrows. Extending the example of down-row uniformity, assume that the next furrow soaked in six inches of water at the top and only three inches at the bottom. That would be bad down-row uniformity AND bad cross-row uniformity (as the first furrow infiltrated eight and four inches top to bottom). Cross-row uniformity depends on the difference in opportunity times between furrows and also the different infiltration rates in furrows due to tractor traffic.
- General soils variability is a measure of uniformity due to different soil types in the field. Some fields are laid out over old stream channels or are just naturally variable. Thus, just due to the different soils and their different infiltration rates, different amounts of water will soak in to different parts of the field.

Infiltration Rates and Down-Row Uniformity

When you turn water into the top of the furrow, it takes time to reach the bottom of the furrow. (This is in contrast to sprinkler systems where you turn the valve on and the entire lateral is spraying water almost immediately). When you turn water off in a furrow, it is essentially gone immediately. (Obviously, if you are blocking your furrow ends, this must be modified somewhat).

The time that it takes for water to run off of a furrow is usually very small in relation to the total set time (for example 15 minutes out of a 24 hour set). Thus, we just say water is gone immediately after it is turned off. Blocking furrows will increase the opportunity time at the bottom of a furrow.

Blocking may or may not increase DU depending on the increase in opportunity time and length of furrow affected. Blocking does not usually increase DU as much as other techniques discussed further on. For example, you are running a 24 hour set. It takes 16 hours for water to run from the top of the furrow to the bottom. Thus, the opportunity time at the top of the furrow is 24 hours- at the bottom, only 8 hours.

More water will soak in at the head of the furrow than at the bottom. Having a large difference in opportunity time from top to bottom of a furrow doesn't necessarily mean that there will be a large difference in total water soaked in at the top versus the bottom.

As you saw in the “Soil, Water and Plant” section, infiltration rates decrease with time. Thus, 12 hours of opportunity time doesn't mean twice as much water soaked in as for 6 hours of opportunity time. But the rate of decrease is different for different soils. The table below gives example depths of water infiltrated with 12 hours and 24 hours of soaking time in different soils.

You can see that the difference in infiltration will be greatest for the coarse soil in the table below:

SOIL TYPE	12 hrs SOAKING	24 hrs SOAKING
Coarse	3.0"	5.5"
Medium	2.5"	4.0"
Fine	2.0"	3.0"

Note also that the depth infiltrated in 24 hours IS NOT twice as much as that infiltrated in 12 hours. This is because infiltration rates generally decrease with time. Soils do not soak in water at a constant rate at all times during an irrigation.

It is important to see that the infiltration rate of the coarse soil does not decrease as fast as the finer soils. In the example table there was 2.5 inches more water soaked in over 24 hours in the coarse soil, but only 1 inch more in the fine soil.

Thus, a coarse soil will give the greatest difference in depth infiltrated for a given difference in opportunity time. This means that you need to get water to the end of a furrow faster in a coarse soil than in a fine soil.

In summary, we know that there is a built-in problem with down-row uniformity in furrows due to the fact you can’t get water on the full furrow immediately. But we also just saw that there is not a direct relationship between the time water is soaking into the furrow at any one point and the amount that soaks in. So . . .

GENERALLY, THE FASTER YOU RUN WATER DOWN A FURROW, THE BETTER YOUR DOWN-ROW DISTRIBUTION UNIFORMITY.

Advance Ratios and Down-Row Uniformity

Because set times differ for each irrigation it is easier to describe (and recommend) how fast water gets to the bottom of a furrow in terms of an ADVANCE RATIO. Advance ratios can be defined two ways.

One way is to view the advance ratio as the ratio of the time it takes to get water to the bottom of a furrow to the total set time. Thus, if it took 8 hours out of a 24-hour set to get water to the end of a furrow, the advance ratio would be 1/3 (8/24). If it took 12 hours out of the 24-hour set, the advance ratio would be 1/2 (12/24).

The other way, and the one that will be used in this handbook is to define advance ratios as the total set time divided by the time of advance. Thus, for a 24 hour set and an eight hour advance time, the advance ratio is three. For a 24 hour set and a six hour advance time, the advance ratio is 4.

The higher the advance ratio, the faster the advance. An advance ratio of from 3 to 4 is recommended in coarse soils (with an advance ratio of 4 used only with the coarsest soils). Water should get to the end of a furrow in about 1/4 to 1/3 of the total set time with coarse soils.

Remember that infiltration rates in coarse soils do not slow as fast as in fine soils. Thus, you need to cover the furrow faster to get good distribution uniformity. For example, if you were planning a 24-hour set on a coarse sandy loam you should get the water to the end of the furrow in 6 to 8 hours. This would be 1/4 to 1/3 of the total 24.

For finer soils, an advance ratio of from 2 to 3 is recommended. That is, you should get water to the end of the furrow in about 1/3 to 1/2 of the total set time with fine soils. For example, if you were planning a 24-hour set on a fine clay loam you should get the water to the end of the furrow in 8 to 12 hours (1/3 to 1/2 of the total 24 hours).

Some options for getting water to the bottom of a furrow faster and achieving acceptable advance ratios are . . .

- Using larger stream sizes (keeping in mind erosion).
- Reducing the length of the furrow (this could be a permanent change or temporary). Some growers will use gated or flexible PVC pipe laid across the middle of the furrow for the pre-irrigation only).
- Using torpedoes (weighted 6-10 inch diameter pipes dragged in the furrow after cultivators) to break up clods and leave a smooth open channel to allow faster water flow.
- Driving tractors so the wheels are in the un-compacted rows (lowers the soil infiltration rates thus, providing faster water flow).
- Other practices to firm furrows. (http://www.ianr.unl.edu/pubs/irrigation/g1340.htm)
- Using "surge irrigation techniques" (http://www.ianr.unl.edu/pubs/irrigation/nf176.htm), alternate wet/dry cycles during irrigation of any one furrow.

There may or may not be objections to using any of the above options. But recognize that without an acceptable advance ratio, you will not achieve high down-row distribution uniformity. And without high DU, you cannot achieve a high irrigation efficiency.

Runoff Reuse Systems

The faster you get water to the end of a furrow, the faster you are going to have to deal with tailwater. This is not to say that tailwater is bad. The potential for significant tailwater in furrows is a natural result of achieving acceptable advance ratios.

Options for dealing with tailwater are . . .

- Letting the tailwater runoff your farm, which is not allowed in Westlands.
- Blocking the ends of the furrows.
- Cutting back furrow streams as they reach the end of the furrow so as to just keep the furrow wet.
- Installing a tailwater return (reuse, recycle) system to gather and use the tailwater.

Whenever a stream is cutback, the excess flow must be used in another furrow. With constant cutbacks, many sets may be running at once, complicating the irrigation management.

Tailwater systems lead to simpler management of furrows than cutback streams. Tailwater return systems require some land set aside for a sump and the cost of a pump and return pipeline/ditch.

Important decisions for tailwater systems include sump size and where to put it, pump size, return piping size and placement, and power source. You should also have a fair idea of the amount of tailwater to expect and how you plan to use it. Pump sizing is important. If the pump is too small in relation to the sump size and expected tailwater flows, you run the risk of not keeping up with the incoming tailwater. If it is too large, you run the risk of excessive cycling.

Tailwater systems that reuse tailwater immediately (without going through a regulating reservoir) will almost always run into the cycling problem. Thus, you are almost forced to use either gated pipe or sprinklers for the return flow.

Sufficient screening of the tailwater must be in place to prevent blockage of the gates or sprinklers by field trash. If your farm is not laid out in a single block or you are leasing separate fields, a small, temporary sump may be useful. A trailer-mounted diesel or PTO-powered pump can be used to supply either one or two sprinkler lines or aluminum (or possibly flexible PVC) gated-pipe.

Sump placement affects another important decision, what to do with the tailwater. You should not pump tailwater back into the same set that produced it if you have an alternative use. When you pump tailwater directly back into the set that produced it you do not get the full use of the power used by the pump. The infiltration rate of the soil has decreased and you get into a constant recycling situation.

A small sump can be used at the bottom of a field pumping back to a large reservoir at the top of the farm. This will allow a gravity supply to the farm. If the farm is contiguous, one or more large sumps can be placed at the low side of the farm and used only to irrigate the fields adjacent

to the sumps. If you are designing a multi-field tailwater system, it may help to consult a qualified agricultural engineer.

Cross-Row Uniformity

The compaction caused by tractor/implement wheels causes different infiltration rates in adjacent furrows. Thus, not only do you have to deal with the built-in problems with down-row uniformity, but also the furrow-to-furrow differences due to different compactions, the cross-row uniformity. There are three types of strategy for dealing with the differences in infiltration rates between wheel and non-wheel rows.

1. You could use the irrigation labor to manually check depths infiltrated/advance ratios in each furrow, changing stream sizes and moving water as it became necessary. This can be time-consuming and requires excellent irrigators.
2. You could try to even up the compaction in the furrows by running an empty tractor in the "off" rows. In doing this, make sure you run the tractor with enough moisture in the soil to achieve the compaction desired. This can be a risky strategy as you may reduce infiltration rates so low that you cannot get enough water into the soil.
3. Or, you could run water in two passes across the field. The first sets (with smaller streams and longer set times due to the lower infiltration rates) could be in the wheel rows. The second time through water would be run in the non-wheel rows (with larger stream sizes and shorter set times because of the higher infiltration rates). Obviously, this doubles some of the labor requirements but makes the management of any set much easier.

Again, what strategy you use depends on your situation.

General Soils Variability

"Streaked" fields (fields with different types of soils running through them) are always tough to manage for irrigation efficiency and uniform crop development. If the streaking is bad enough and the economics warrant, many growers will just use sprinklers.

If the streaking is well-defined and is primarily down the rows, you may be able to adjust the stream-sizes and set timing as you change sets across the different soils. Thus, one set might be in the lighter streak, with larger stream-sizes and shorter set times, while the next set would be in the heavier streak, with a smaller stream-size and a longer set time.

Efficiencies of fields that are streaked across the furrows may be improved by using "surge irrigation". Surge acts to reduce infiltration rates very rapidly. Depending on the mix of Usoils, this rapid decrease may result in infiltration rates that are close to equal across the soil streaks. The surge irrigation technique consists of several cycles of wetting and drying the furrow during an irrigation. The goal is to rapidly decrease the soil infiltration rates by sealing over the soil surface and allow faster water advance.

Many growers will recognize the surging technique. One common name for it was “bumping” water. The major operational problem with surging is the labor involved in creating the wet/dry cycles. Modern surge techniques may involve six or more cycles in an irrigation. That means labor has to start/stop water six times in each furrow during an irrigation.

Irrigation equipment manufacturers have created specialized surge irrigation valves for use with gated pipe that can do this automatically. They consist of a familiar looking TEE-fitting for gated pipe with a timer-controlled, automatic butterfly valve inside. The butterfly can be set to direct all the water to one side or the other of the TEE. Or, it can be set to split the flow to both sides. Some of these valves are quite elaborate with solar-powered controllers that will automatically operate the valve to surge water down one side of the valve or the other.

A common management technique is to install the valve in the field with a set of gated pipe running from each side. The valve is first set to first direct all water to the gates on one side of the valve, then the other on a varying time schedule. Then, for the last part of the irrigation, water is directed to both sides.

An example would be to force 30 gpm streams down the furrows during the cycling portion of the irrigation. The first cycle might be 2 hours on-2 hours off, then 4 hours on-4 hours off, then 6 hours on-6 hours off. During the last portion of the irrigation, after the furrow has been completely wetted, the TEE valve is set to split the water evenly so that 15 gpm streams are used. The switch from 30 to 15 gpm provides an automatic cutback stream.

Surge has not been shown to be effective in all cases. A lot depends on the type of soil and its reaction to wet/dry cycling. If the wheel/non-wheel row situation results in very uneven advance rates without surge, you should try the surge technique in alternate rows first.

Some tests have shown surge to worsen an uneven advance situation in adjacent furrows because the infiltration rates in the un-compacted row are reduced much less than those in the compacted rows.

Irrigation Efficiency with Furrows

With good advance ratios and strategies for handling cross-row variances and soil streaking you get good DU. But what about controlling the total amount of water applied? Since the soil's infiltration rate can be very hard to predict, controlling the total infiltration can be very difficult.

It is important to react to the results of the first set. When irrigating, usually the top of the root zone will become almost saturated. The depth of soil to where water has reached during an irrigation is called the “wetting front”. As the irrigation is stopped, the water in the saturated zone will drain downwards (remember that soil will not hold water above its field capacity).

A soil probe can be used to judge where the wetting front is during an irrigation as it can only be pushed into soil with a significant water content.

You should stop irrigating before the wetting front reaches the total root zone depth you are trying to wet. If you are trying to irrigate to 4 feet, change sets when the wetting front hits about 2.5 - 3 feet. This is because the excess water in the 2.5-3 feet will redistribute into the full 4 foot soil profile.

Come back in one or two days and use the probe again to see how far down water redistributed. With experience you will know how far down the wetting front must be to soak the desired root zone depth.

Also, using the probe at the top, middle, and bottom of the furrow one to two days after an irrigation can give you an idea of the distribution uniformity. If the DU was high, the probe will go in to about the same depth at all points in the different furrows. If the probe goes in to a depth of five feet at the top of the furrow and only two feet at the bottom, you know that something didn't go right.

Preplanning an Irrigation

There should be some preplanning to a furrow irrigation (http://cwi.csufresno.edu/wateright/furrow.asp). You will have to react to the first set but it is a good idea to know what the limits of the irrigation might be. A recommended approach to furrow irrigation is . . .

1. Determine the Soil Moisture Deficit. The fastest, cheapest, and most flexible way to do this is with a soil sampler and the feel method in the "Soil-Water-Plant Relationships" section.
2. Use the following equation to estimate the gross depth applied . . .

   (1) GROSS APPLIED = GPM x HOURS x 96.3 / AREA

   where:
   GROSS APPLIED is the inches of water applied to the AREA.
   GPM is the furrow flow in gallons per minute.
   HOURS is the total set time in hours.
   AREA is the area covered by the GPM in square feet and if wetting each furrow, AREA = furrow spacing x furrow length if wetting every other furrow, AREA = 2 x furrow spacing x furrow length.

3. Subtract the percentage of GROSS APPLIED you think you can recover in surface runoff. That is, determine how much water that you apply will run off the field and be used. Then, subtract this from the depth applied. Use the following equation . . .

   (2) NET APPLIED = (1-SAVED RO /100) x GROSS APPLIED

   where:
   NET APPLIED is the net depth of water infiltrated in the furrow in inches.
   SAVED RO is the percentage of GROSS APPLIED that you think will be saved as surface runoff

GROSS APPLIED is the gross applied as previously calculated.

4. Ask yourself, "With the GPM (furrow stream size) planned, will I get an acceptable ADVANCE RATIO". (That is, are you going to get water to the end of the furrow in an acceptably short time?) If not, change a factor in the irrigation and go back to step 2.

5. Then, determine the POTENTIAL IRRIGATION EFFICIENCY . . .

(3) POTENTIAL IE = 100 x IN ROOT / NET APPLIED

where:
POTENTIAL IE is the best irrigation efficiency you could hope for. This assumes that all NET APPLIED remains in the effective root zone
IN ROOT is water infiltrated that remains in the effective root zone in inches.
If NET APPLIED is greater than the soil moisture deficit at irrigation, then
IN ROOT = SMD
NET APPLIED is the net applied previously calculated

6. If the POTENTIAL IE is below 75 percent, see if you can change a parameter in the irrigation. You would like to see 75 percent or above. Furrow irrigations have been measured at 90 percent IE when using fast advance ratios and tailwater reuse systems.

Options are . . .

- Try another combination of GPM and HOURS (faster flow for fewer hours).
- Consider every-other row irrigation if the situation warrants (this will double the AREA).
- Consider surge irrigation, compaction, use of torpedoes, shorter furrows or some other method to achieve an acceptable advance ratio with a lower GPM.
- If not in place, consider installation of a tailwater return system or use of cutback streams (see below for calculating GROSS APPLIED with cutback streams). Sometimes there is nothing you can do. Putting on very low applications with furrows, especially on steeper grades, is hard to do efficiently.

As an example of preplanning, assume the following . . .

- 1320 foot furrow on 3.3 foot spacing.
- Soil moisture deficit at irrigation of 3.5 inches.
- A planned 24 hour set.
- A planned 20 gpm furrow stream.
- Desired advance ratio of 2 (furrow advance in 12 hours out of the total 24 hour set).

- Every furrow wet.

Remember, an important assumption is that the planned 20 gpm furrow stream will give you the 2 advance ratio.

Using equation (1) the GROSS APPLIED is . . .

GROSS APPLIED = GPM x HOURS x 96.3 / AREA

GROSS APPLIED= 20 x 24 x 96.3 / (3.3 x 1320)

GROSS APPLIED= 10.5 inches

Estimate that you will save 30 percent of this as runoff.

Using equation (2) to calculate the NET APPLIED . . .

NET APPLIED = (1 - SAVED RO/100) x GROS APPLIED

NET APPLIED = (1 - 30/100) x 10.5

NET APPLIED = 7.4 inches

Using equation (3), the POTENTIAL IE is . . .

POTENTIAL IE=100 x IN ROOT /(NET APPLIED)

POTENTIAL IE= 100 x 3.5 / 7.4

POTENTIAL IE= 47 percent

Note that the soil moisture depletion is 3.5 inches. Thus, 3.5 inches is the most you could infiltrate into the effective root zone. The rest is going into deep percolation or runoff that is not saved.

47 percent is not good potential IE. You should be trying for a minimum 70 percent.

The first change considered is to use a larger furrow stream with a shorter set time. Assume that a 30 gpm stream will get out in 6 hours of a 12 hour set.

Now from equation (1) . . .

GROSS APPLIED = 30 x 12 x 96.3 / (3.3 x 1320)

GROSS APPLIED = 8.0 inches

and from equation (2) . . .

NET APPLIED = (1 - SAVED RO/100) x (GROSS APPLIED)

NET APPLIED = (1 - 30/100) x 8

NET APPLIED = 5.6 inches

and from equation (3) . . .

POTENTIAL IE = 100 x IN ROOT / NET APPLIED

POTENTIAL IE = 100 x 3.5 / 5.6

POTENTIAL IE = 63 percent

This is still not good IE.

Another planning option would be to irrigate every-other row with a slightly larger furrow stream than initially planned. Assume that a 25 gpm stream for 24 hours will give you the 2 advance ratio if irrigating every-other row (AREA = 6.6 x 1320).

Now from equation (1) . . .

GROSS APPLIED = 25 x 24 x 96.3 / (6.6 x 1320)

GROSS APPLIED = 6.6 inches

and from equation (2) . . .

NET APPLIED = (1 - SAVED RO/100) x GROSS APPLIED

NET APPLIED = (1 - 30/100) x 6.6

NET APPLIED = 4.6 inches

and from equation (3) . . .

POTENTIAL IE= 100 x IN ROOT / NET APPLIED

POTENTIAL IE= 100 x 3.5 / 4.6

POTENTIAL IE= 75%

This is acceptable irrigation efficiency.

Again, the key assumptions are that . . .

- 25 gpm will give you an acceptable 2 advance ratio.
- It won't harm the crop to irrigate every other row.
- You can save 30 percent of the applied water as tailwater.

The validity of these assumptions are your responsibility and depend on your experience.

If you were planning to use a cutback stream, the only change in the above calculations comes in the GROSS APPLIED.

Here you must add up the GROSS APPLIED's for each stream size . . .

GROSS APPLIED = ((GPM1xHOURS1) + (GPM2 x HOURS2) . .) x 96.3 / AREA

where:

GROSS APPLIED is the inches of water applied to the AREA GPM1, 2, 3 . . . are the furrow flows in gallons per minute for each cutback HOURS1, 2, 3 . . . are the total time in hours each cutback is run

AREA is the area covered by the GPM in square feet (if wetting each furrow AREA = spacing x length, if wetting every other furrow AREA = 2 x spacing x length)

For example, assume you were planning a 24 hour furrow irrigation with two cutbacks. The furrows are 1320 feet long on 3.3 foot centers. The irrigation would start at 10 AM with one cutback at 8 PM (just before dark) for a 10 hour initial runtime and the other at 6 AM the next morning (another 10 hours runtime). The initial stream size is 30 gpm with the first cutback to 15 gpm and the third to 7.5 gpm.

GROSS APPLIED is . . .

GROSS APPLIED = ((GPM1xHOURS1) + (GPM2 x HOURS2) . . .) x 96.3 / AREA

GROSS APPLIED = ((30 x 10) + (15 x 10) + (7.5 x 4)) x 96.3 / (1320 x 3.3)

GROSS APPLIED = 480 x 96.3/4356=10.6 in

As previously discussed, not only to you have to apply water evenly you must be able to control the total amount infiltrated. Most growers like to use 12, 24, or 48 hour sets because they match labor availability. Sometimes however, getting the highest efficiencies requires changing sets at odd times (like 3:00 AM). It is your decision as to if the economics justify using a night irrigator.

It Is Important to know that Westlands Water District will allow you to turn on and off at any time with proper notice.

Managing furrow irrigation systems for high irrigation efficiencies is a difficult task at best. What works for one irrigation may not work for the next because the furrow conditions are constantly changing. A used furrow reacts differently from a new furrow, the root zones may be increasing, you may have used well water on one irrigation and canal water on the next, etc.

Furrow System Evaluations and Recommendations

The District's Water Conservation Program has developed a simplified procedure to estimate the performance of furrow irrigations for those wishing to perform their own evaluations. While this is not a complete, detailed evaluation, it does provide a quick estimate of the system performance. Check with the District to see if a Mobile Lab program is in effect. Many consultants are also available to perform these evaluations.

Typical recommendations and expected results for furrow irrigation systems are presented below. Each recommendation is explained in relation to desired distribution uniformity and irrigation efficiency improvements:

- 1. *Increase the furrow flow rate* - This recommendation would be made if the down-row uniformity was too low. Water is advancing too slow and much more water is infiltrating at the top of the furrow than at the bottom.
- 2. *Reduce the set time* - The system DU may or may not be good but the sets are too long, producing too much deep percolation.
- 3. *Increase the set time* - The system DU may or may not be good but the sets are too short and much of the field is under-irrigated.
- 4. *Change the set configuration* - Sometimes it is advantageous to irrigate every other furrow, especially if trying to apply a small depth with a high intake rate soil (refer to the example on pre-planning above). Other times you may need to irrigate every furrow to help infiltrate enough water to satisfy the soil moisture depletion.
- 5. *Drag torpedoes in the furrow* - This is related to down-row uniformity. Torpedoes will break down clods and leave a smooth path, helping to speed water advance.
- 6. *Use socks to reduce erosion* - Socks placed over gated pipe outlets act to dissipate energy and prevent erosion at the top of the furrow.
- 7. *Tailwater management recommendations* - These will change depending on the field, farm configuration, and manager. Note points a. and g. it is always recommended to allow tailwater rather than blocking furrow ends.
- 8. *Shorten furrow lengths* - This is again related to down-row uniformity. The furrow is so long that there is no furrow flow that will get water to the end sufficiently quick enough. Sometimes it may be best to only temporarily shorten the furrow for the pre and first seasonal irrigations. As the furrow

intake rates drop with use, you can go back to the original length. Temporary shortening can be done with aluminum or flexible PVC gated pipe.

- 9. *Significant differences in intake rates between wheel and non-wheel rows* - This is related to cross-row uniformity. Here we are recommending that you run water first in the wheel rows, then come back and run water in the non-wheel rows. The sets in the wheel rows can be longer with smaller furrow flows (because of the lower intake rates) than in the non-wheel rows.
- 10. *Use deeper furrows* - This will allow larger stream flows, speeding advance and improving down-row uniformity.
- 11. *Use sprinklers rather than furrows* - This is usually recommended for a pre-irrigation when the field is extremely dry and has just been worked up. In this situation it can be hard to control the total application with furrows. Sprinklers provide control over the total application (however be aware of distribution uniformity problems due to wind).
- 12. *Use a soil probe to judge when to stop irrigating* - Soil fills to field capacity from the top down (see Figures 5-6a and 6b). During an irrigation, the top of the root zone will nearly saturate. As the irrigation stops, the excess water will redistribute downwards. Using a probe is a good indication of when to change sets.
- 13. *Reduce the furrow flow after water has reached the furrow end* - cutbacks may be advantageous where very large furrow flows are used to achieve sufficiently quick advance rates. If the cutback was not performed, excessive tailwater would result.
- 14. *Improve irrigators mobility* - It may be, especially if irrigating both wheel and non-wheel rows in the same set, that the irrigators need to adjust furrow flows continually. They may need to go back and forth between the top and bottom of the field many times to ensure uniform applications.
- 15. *Improve overall farm coordination* - The irrigation program needs to be meshed efficiently with the pest control/fertility/cultural operations programs.
- 16. *Use surge flow* - Surge flow can help in very high intake rate soils, long furrows, or fields that are streaked across the rows.
- 17. *There is a large difference in how the day sets are managed from the night sets (if the night sets are "managed" at all)* - This may only mean making them the same length. But there may be cutbacks being made during the day and not at night.
- 18. *There are specific soil problems in the field* - This could be a sand streak, saline portions, or even a weed outbreak. Something is reducing distribution uniformity.
- 19. *Supply Variations* - Depending on how water is distributed on the farm, irrigations in other fields may be changing the total flow to the field. Thus, the irrigator may set 20 gpm per furrow at the start, only to see it dip to 15 as flow is diverted to some other field.
- 20. *Communicate* - Get everyone together so that all understand the current problems and the strategy for correcting them.

Further reading,

FAO Irrigation Methods, IWTM 5 (http://www.fao.org/docrep/s8684e/s8684e00.htm).
National Engineering Handbook, Part 652, Chapter 9, for information on Irrigation Water Management,
(http://www.irrigationtoolbox.com/NEH/Part652_NationalIrrigationGuide/ch9.pdf).
National Engineering Handbook, Part 652, Chapter 5, for information on selecting an irrigation method (http://www.irrigationtoolbox.com/NEH/Part652_NationalIrrigationGuide/ch5.pdf).

Tailwater Reuse Systems

This section is an excerpt from the NRCS, National Engineering Handbook, Section 15, Chapter 5, Furrow Irrigation (2nd Edition).

Tailwater recovery or recirculating facilities collect irrigation runoff and return it to the same or adjacent field for irrigation use. Such systems can be classified according to the method of handling runoff or tailwater. If the water is returned to a field lying at a higher elevation, it is usually referred to as a return-flow system; if the water is applied to a lower lying field, this is termed sequence use. The components consist of tailwater ditches to collect the runoff, drainage-ways or waterways to convey water to a central collection area, a sump or reservoir for water storage, a pump, a power unit, and a pipeline or ditch to convey water for redistribution. Under certain conditions where gravity flow can be used, neither pump nor pipeline may be necessary.

A return-flow system provides for the temporary storage of a given amount of water and includes the pumping equipment and pipeline needed to deliver the water back into the application system. The sequence system generally has a pump and only enough pipe to convey the water to the head ditch of the next field. The farm often can be planned so that there is enough elevation difference between fields to apply the runoff water to a lower field in sequence by gravity. Recovery systems can also be classified according to whether they accumulate and store runoff water. Systems storing collected runoff water are referred to as reservoir systems. Systems that immediately return the runoff water require little storage capacity. They have automatically cycled pumping systems and are called cycling-sump systems. One or more types of systems may be applicable to a given farm. A sump is used where land value is high, water cannot be retained in a reservoir, or water ponding is undesirable. Dugouts or reservoirs are more common and are easily adapted to storage and planned recovery of irrigation tailwater.

A reservoir system collects enough water to be used as an independent supply or as a supplement to the original supply. The reservoir size depends on whether collected water is handled as an independent supply and, if not, on the rate water is pumped for reuse. A smaller reservoir is required if the system is used for cutback irrigation. Reservoirs should be at least 8.0 and preferably 10 feet deep to discourage growth of aquatic weeds. Side slopes should be 2 or 2.5

feet horizontal for each 1 foot vertical to prevent sloughing of the banks. Where dugouts may be a safety hazard, one end slope should be 5 to 1 or less to provide a way of escape in case of accidents. The reservoir should provide for an unused storage depth of at least 1.0 foot.

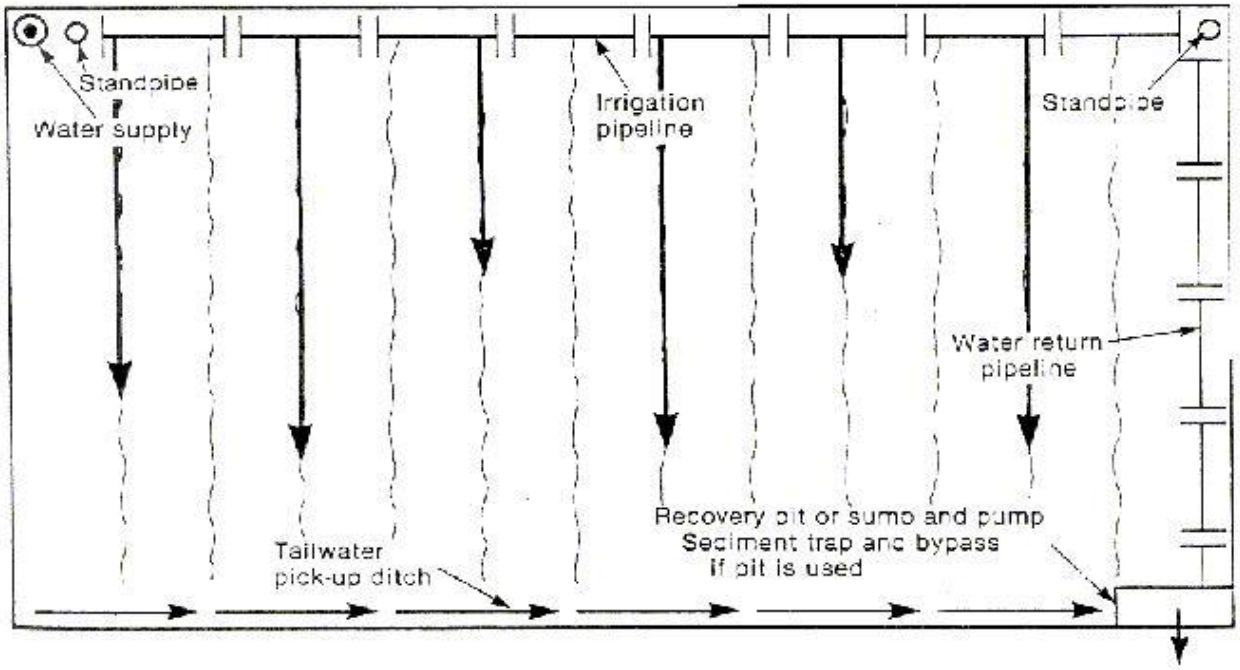
The cycling-sump system consists of a sump and a pump large enough to handle the expected rate of runoff that enters the sump. The sump is general a vertical concrete or steel tube with a concrete bottom. The tube is approximately 48 inches in diameter and installed to a depth of approximately 10 feet. Pump operation is controlled automatically by a float-operated or electrode-operated switch. Some storage can be provided in the collecting ditch.

The size, capacity, location, and selection of equipment for these systems are functions of the main irrigation system, the topographic layout of the field or fields, and the farmer's irrigation practice and desires (see figure below).

If a sump is used, the pump should be capable of pumping 40 percent of the initial water supply. This system has the disadvantage that water is applied intermittently, making efficient application rather difficult.

When a dugout is used, it should have the capacity to store the tailwater from a complete irrigation set. The pump capacity depends on the method or schedule of reuse planned. The pump can be designed to empty the storage in approximately one-fourth to one-third the desired application time and, in this way, provide a cutback operation, or it can be designed for continuous operation after the first set is completed with additional furrows watered after the first set.

Plan for a return-flow system used in conjunction with an underground pipeline distribution



Laser Land-Leveling

Laser land-leveling is really laser-controlled land-leveling. The idea of moving dirt to level land is very old. (Although in agriculture most of the time we are talking about putting a smooth surface with a specific slope on the ground.) What is important with laser land-leveling is that the actual surface finish can be controlled to very tight tolerances.

Lasers are a device that produce a very concentrated beam of light. Where a common household light bulb produces diffuse light, a laser produces a single, very thin, high energy beam. Instruments can be made that respond to the energy of a laser beam.

A laser-controlled land-leveling system could be described as follows. A rotating laser light source (like a miniature lighthouse) is located somewhere in the field. As the laser rotates rapidly, a virtual "plane" of light is produced in the field. (You might think of a phonograph record rotating on the turntable as like that plane of light).

A “receiver” is mounted on the leveling equipment and connected hydraulically to the actual earthmoving blade. When activated, the receiver (and thus, the blade) will “lock on” to the laser source, thus, providing a smooth surface.

If the earthmover has to climb over a high spot in the field, the blade will dig in as the receiver tries to stay locked on to the laser source. If the earthmover goes over a low spot, the blade will lift up, again keeping locked onto the laser source, and dump soil into the low spot. If the rotating source is tilted according to the prescribed grade, a grade can be installed in the field. Laser setups like this are also used to quickly survey fields.

Again, the source is set up in the field. A receiver is mounted on a truck with a stationary staff gauge. As the truck drives over a preset grid, the receiver will move up or down as it stays locked on the laser source. The movement of the receiver against the stationary staff gauge is then read to record the differences in elevation throughout the field.

Laser land-leveling in itself can improve irrigation efficiency by reducing high spots in a field that back up water, or filling low spots that contribute to excess irrigation. But if you are going to spend the money for laser land-leveling, make sure you are installing the best irrigation gradients. Also, consider the placement of any tailwater return sumps and the length of your furrows.

For additional information check the NRCS Engineering Handbook, Chapter 15, (http://www.irrigationtoolbox.com/NEH/Part652_NationalIrrigationGuide/ch15.pdf).

Furrow Torpedoes

Since our publication on furrow torpedoes, inquiries regarding its use have come in from farm agencies and publications all over the United States. That prompted Westlands' engineers to analyze torpedo use under varying conditions. Here, briefly, are the findings:

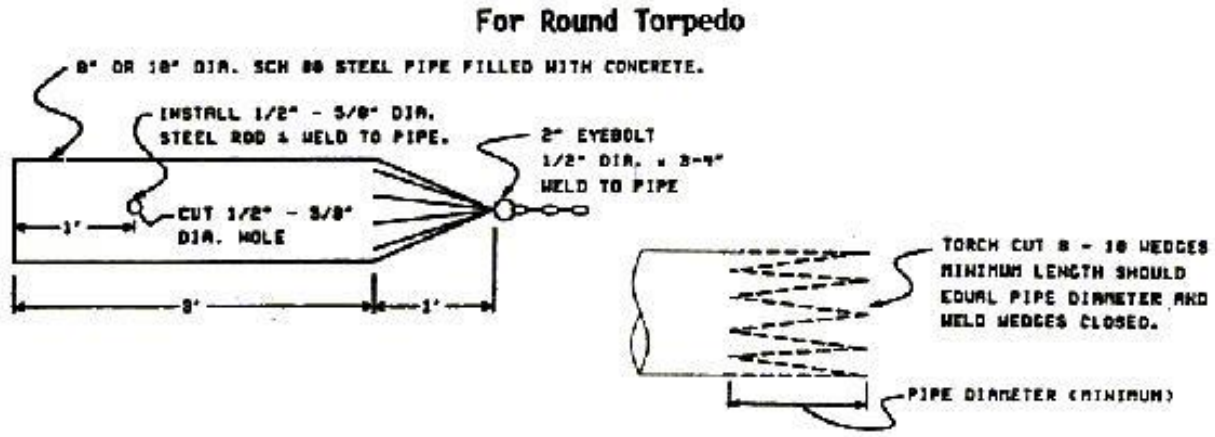
1. Ideally, differing soil textures and structures require torpedoes of different weights. This is being achieved by filling the torpedo pipe with varying amounts of concrete. If a grower is trying to reduce water intake rates as well as achieving a more uniform advance rate, the heavier the torpedo the better on most soils.

2. Soil intake characteristics can also be changed by using torpedoes of differing shapes.

The larger the torpedo diameter, the larger the wetted perimeter and the greater the intake rate on most soils. To minimize intake rate with a flow rate of 20 to 30 gpm, it appears that a 6" diameter torpedo filled with concrete is the best compromise, if it can be made heavy enough. Several farmers are planning experiments with torpedoes made of concrete shaped like the round-top car wheel stops used in parking lots but larger in size to maximize the weight of the 6" diameter torpedo. Such torpedoes could be shaped to smooth the sides of the bed and eliminate clods which fall back into the furrows when round torpedoes are used.

3. Colorado research, using a device similar to a torpedo in sandy soil, showed a reduction of 30-40% in infiltration rates over non-treated-Furrows.

Obviously the furrow torpedo can be made suitable for many different soil types and cultural practices.



Hand Probe

Five dollar gadget can help produce more profitable crops

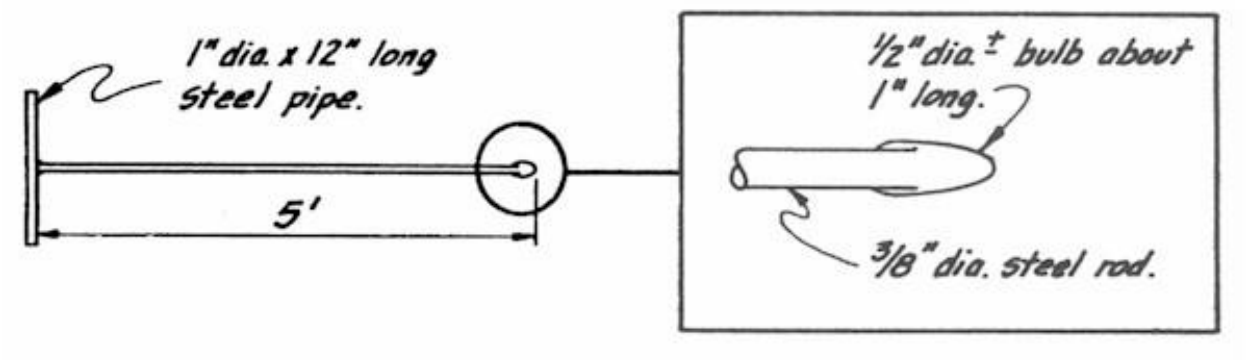
Sometimes the simplest, most obvious approaches to efficient water management escape us.

A case in point: any farm shop can make a tool for a few dollars which can produce answers to many questions facing growers seeking to improve irrigation efficiency. Such questions as: When is the crop soil profile filled? When is water being lost to the underground? Have efforts to deal with infiltration problem areas been successful?

Has changing the run length or employing surge flow irrigation improved irrigation uniformity? This sounds like data obtained through a sophisticated water management analysis. Actually, it can be obtained by using a simple hand-held probe made from five feet of 3/8" steel rod with a bulbed and pointed lower end and a short pipe crossbar handle at the top. It can easily be pushed into wet soil to measure water penetration during an irrigation. It tells the user when he hits dry soil.

When you can determine the water penetration depth at any point in the field at any given time you can learn the answers to the questions posed above, among others.

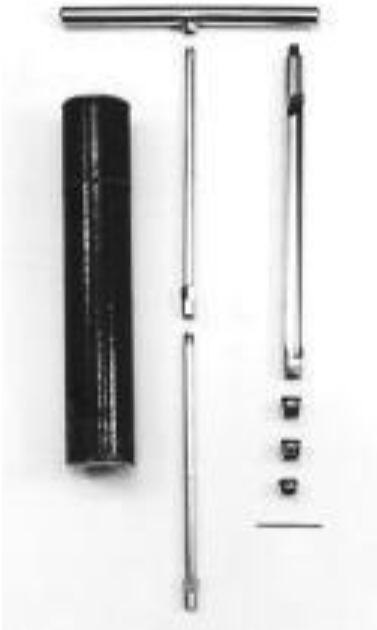
Consider the lowly hand-held probe! It's a "super gadget" in the efficient management of irrigation



Soil Samplers

Soil samplers are used to extract soil samples at particular depths in the crop root-zone. When the soil sample for the top foot has been removed from the soil tube, the second foot soil sample can be extracted from the same hole.

Typically, these samples are taken to determine the soil moisture status at the different layers in the active root-zone. The "Feel Method" is the quickest methodology to determine the soil moisture present, examine for the presents of roots or impeding layers to root expansion, or penetration of irrigation water.



Sprinkler Irrigation Systems

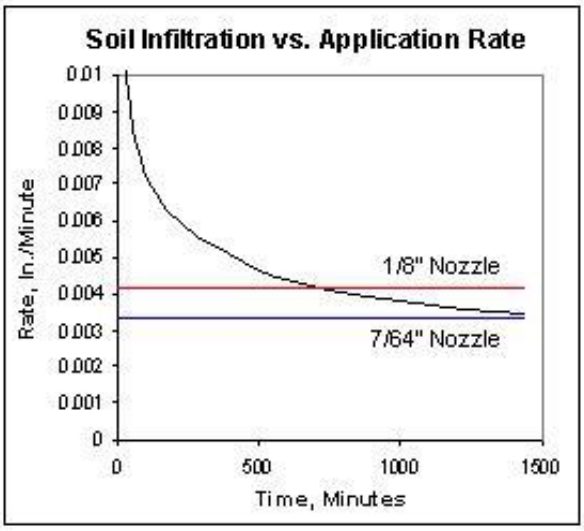
Sprinkler and drip systems have sometimes been categorized as pressurized systems, closed systems, or mechanical systems. Instead of distributing water over a field by allowing it to flow freely across graded land, the water is piped to specific locations and then sprayed or dripped onto the field. In contrast to flood irrigation system types (furrow, border, level basins), the amount of water soaking into the soil with a pressurized system (field sprinklers, drip, spitter, over/under tree sprinklers) depends on two different factors . . .

- The set time.
- The application rate of the system, assuming that the application rate of the system is less than the infiltration rate of the soil.

The system application rate is a measure of how fast water is being applied to the soil. For field sprinklers it is usually measured as a depth of water applied per hour (inches/hour).

The soil's infiltration rate, IR, is a measure of how fast water is soaking into the soil. Infiltration rates are also described in terms of inches/hour. An infiltration rate of one inch/hour means that if you ponded a one-inch depth of water on a soil with that IR, it would take one hour for it to soak in completely. Infiltration rates change constantly during an irrigation.

The figure below shows what can happen if a system is applying water at an incorrect rate, or the set time is too long. At the start of an irrigation, the application rate is less than the infiltration rate (black line) of the soil. All water soaks into the soil. Near the end of the set, the application rate, which remains constant, (red line for 1/8" nozzle) becomes larger than the infiltration rate, which decreases with time. Runoff occurs. Note that the blue line, for a 7/64" nozzle, remains below the soil infiltration throughout the entire 24-hour set. Be aware there are many other factors that affect the soil infiltration rate (http://www.fao.org/docrep/s8684e/s8684e0a.htm), and that it will vary even within the irrigation season.



With sprinklers and drip systems, the keys to distribution uniformity are pressure uniformity and device uniformity. Pressures in the system should not vary more than 20 percent. Because of energy and water economics, many engineers are shooting for 10 percent variance. Always have your systems designed and laid out by qualified engineers.

Device uniformity means using all the same size nozzles and sprinkler heads for field sprinklers. For trickle systems, each plant should have the same emitter configuration. That is, you may put more than one type of emitter in the field as long as each plant as one of each. Also, all emitters should have about the same operating pressure range.

With field sprinklers there is one more aspect, overlap uniformity. Wind is the greatest factor in dropping overlap uniformities. Use alternate-set lateral placements whenever possible. Operate in low-wind conditions and use tighter spacing's.

With pressurized systems you should know the application rate of the system. This is how fast water is being applied. Then, also knowing the soil moisture depletion, it is a simple matter to calculate required set times.

Distribution Uniformity with Field Sprinklers

The three factors to consider in achieving high sprinkler uniformities (http://cwi.csufresno.edu/wateright/900803.asp) with field sprinklers are . . .

- Pressure uniformity, water is forced out of the sprinkler nozzle due to pressure in the pipes. The amount of water flowing through the nozzle depends on the pressure at the nozzle. The more pressure, the more flow. Uniformity depends on the pressure at each nozzle being as nearly uniform as possible.

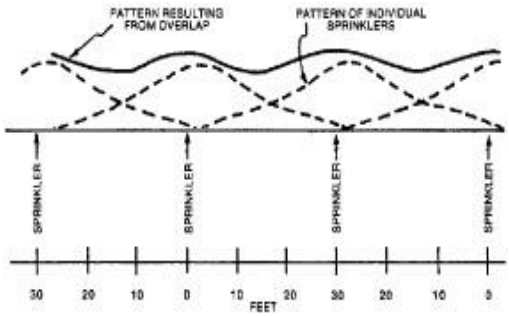
  It is virtually (and practically) impossible to design a piping system with 100 percent pressure uniformity. A starting rule of thumb is that pressures in the system should not

vary more than 20 percent. (With increasing energy costs, many Growers and Engineers are aiming for 10-15 percent). Thus, if the average pressure in a lateral was 60 PSI, the desired minimum and maximum pressure would be +/- 6 PSI.

Use a handheld pressure gauge (liquid-filled) and a pitot-tube attachment to measure pressures at sprinkler heads. Hold the gauge so that the pitot tube is just outside the nozzle and directly centered in the flow, as seen below. It is also a good idea to have pressure gauges at the pump and at the head of the mainline.

Gauge-pitot tube being held just in stream of sprinkler to measure pressure.

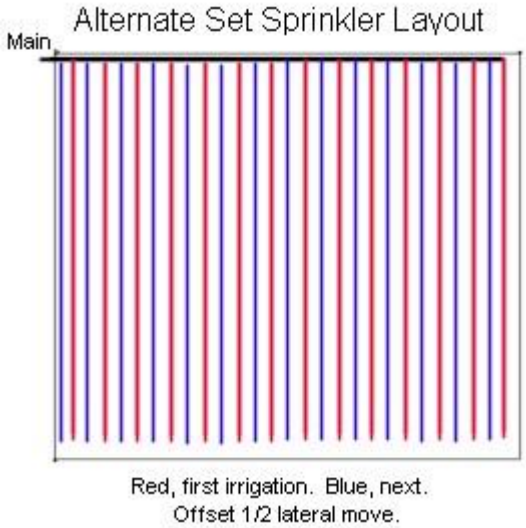
- *Device uniformity* - The amount of water flowing through a nozzle depends on the pipe pressure and the nozzle size/condition. You could have 100 percent pressure uniformity in a system and still have bad overall DU if there were two or more nozzle sizes in the field or the nozzles were worn from sand wear. Make sure that all sprinkler heads are similar and that the same size nozzles are being used. Also make sure that they are all high-pressure or low-pressure nozzles.
- *Overlap uniformity* - Each sprinkler head will cover a certain diameter of the field. However, it does not spray the same amount of water over all that part of the field. Depending on the sprinkler head, nozzle configuration, and pressure, it may spray more or less water closer to the head than farther away. Thus, sprinkler systems are set up so that the spray from one sprinkler will overlap that of another.
- The figure below shows the amount of water applied from adjacent sprinklers on a sprinkler lateral, the dashed lines. The relatively flat, solid line at the top of the figure represents the total water applied at any part of the field. Note that even though the sprays from each sprinkler fall off the farther away from the sprinkler head, the total of both sprays results in a relatively uniform application. The patterns combine differently between the sprinkler laterals, but the effect is the same.



Refer to your irrigation system dealer for the recommended spacing and operating pressure for any combination of sprinkler head and nozzle size. Also, make sure the risers are installed in an upright position and that the heads are turning freely.

Field Sprinklers and Wing

Wind effects are critical to field sprinkler distribution uniformity. It is always recommended that "Alternate-set" lateral placement be used. "Alternate-set" lateral placement is illustrated by the figure below. The lateral positions depicted in red are the positions for the first irrigation. The lateral positions for the next irrigation are colored blue. You can see that the same spacing is used for each irrigation. It's just that the laterals are offset by a half-spacing, placed in alternate locations for each irrigation.



This alternate placement of laterals can improve the distribution uniformity by up to 10 percent with no increase in labor costs. Alternate sets are a good idea anytime, but especially important in areas with consistently windy conditions.

Other things you can do to decrease wind effects are . . .

- Irrigate in low wind situations--this seems obvious but if your operations can be modified and you are using electric motors, there might be a double bonus. In many cases, wind picks up in the afternoons. Afternoons are peak use periods for electrical utilities. Modifying your operations to avoid peak wind periods (and peak power use periods) will improve you DU's and possibly allow you to take advantage of "Time-of-Use" power rate schedules.
- Use low-angle sprinklers with closer lateral spacing's. This involves a tradeoff between the increase in distribution uniformity and the increased cost of hardware and labor (possibly more laterals in the field, certainly more moves).Another aspect to consider is that application rates increase with tighter spacing's (see table this page). If excess runoff occurs with the tighter spacing's, try a smaller nozzle size.
- A recent study on field sprinkler performance sponsored by the District also showed that it is best to maintain normal operating pressures. Although it may look like more drift, normal pressures resulted in higher overall uniformities than lower pressures.
- Many times, impact sprinklers are used in under-tree or over-vine systems. In these situations, overlap uniformity may not be as important as in field systems. Trees and vines have extensive rooting systems. Where there is no overlap at all (as in spinner-type under tree systems), it is like a drip system and distribution uniformity is a matter of supplying the same amount of water per each tree. Regardless of the overlap uniformity, always maintain good pressure and device uniformities.

Controlling Total Applications with Field Sprinkler Systems

Each sprinkler system applies water at a specific rate that is measured in inches of water applied per hour of operation, or "inches/hour". This "application rate" depends on sprinkler spacing, nozzle size, and system pressure. For example, normal application rates for sprinkler systems with standard 7/64 inch nozzles on 30 x 40 spacing's are .20 inches/-hour.

Approximate application rates in inches/hour for sprinkler systems running at 50 psi:

SPRINKLER	NOZZLE SIZES					
SPACING	3/32	7/64	1/8	9/64	5/32	11/64
30 x 30	.19	.27	.34	.44	.54	.65
30 x 40	.14	.20	.26	.33	.41	.49
30 x 45	.13	.18	.23	.29	.36	.43
35 x 40	.12	.17	.22	.28	.35	.42
35 x 45	.11	.15	.20	.25	.31	.37
40 x 40	.11	.15	.19	.25	.31	.37
40 x 45	.10	.13	.17	.22	.27	.32

Knowing the soil moisture deficit (SMD) and the application rate (AR) of the sprinkler system, you can determine the required set time. The soil moisture deficit is the amount of water that is needed to take the soil moisture in the effective root zone from its level at irrigation to field

capacity. For additional information refer to the "Soil-Water-Plant Relationships" section of this handbook.

For example, assume you want to apply 2.5 inches using a system with an application rate of .25 inches/hour . . .

$$RUNTIME_{net} = SMD / (APPLICATION\ RATE)$$

$$RUNTIME_{net} = 2.5\ inches / .25\ inches/hour$$

$$RUNTIME_{net} = 10\ hours$$

However, there are losses from evaporation and also distribution uniformity to consider. The overall irrigation efficiency (IE) may only be 80 percent. Thus, to make sure that 2.5 inches was soaked into all parts of the field you would have to increase the runtime. And . . .

$$RUNTIME_{gross} = SMD / (AR * IE)$$

$$RUNTIME_{gross} = 2.5\ inches / (.25\ in/hr * .8)$$

$$RUNTIME_{gross} = 12.5\ hr$$

Operating in windy conditions can lower DU's drastically. It could easily taking the overall irrigation efficiency to 65 percent. (Remember to use "alternate sets" in windy conditions).

Now . . .

$$RUNTIME_{gross} = 2.5\ in / (.25\ in/hr * .65)$$

$$RUNTIME_{gross} = 15.4\ hr$$

You may or may not be able to operate a set to that tight of schedule but the calculations will at least tell you what should be done. They might also indicate where a change in operations is needed. For example, the correct set time has been determined to be around 15 1/2 hours. You may not want to take a chance on a 12 hour set but a 24 hour set is too long. Possibly the irrigation scheduling can be shortened up so that irrigations occur more frequently, but with 12 hour sets.

Sprinkler System Evaluations and Recommendations

The District's Water Conservation Program is constantly looking for better ways to improve irrigation system performance. See this link for those wishing a simplified sprinkler evaluation to evaluate their own systems, developed for Westlands. Check with the District to see if a Mobile Lab program is currently available to district water users. Consultants are also available to do this for you.

Below are explanations of typical recommendations that might improve the performance of sprinkler irrigation systems. Where possible, they are related to the improvement of distribution uniformity and irrigation efficiency.

For General Recommendations . . .

- *Replace gaskets on the lateral/main pipes* - Pipe leakage in fields can be significant and easy to fix. Leakage reduces the irrigation efficiency. It can also lead to poor pressure uniformity in the field.
- *The gross application is much greater than the net required* - As previously seen, each system configuration applies water at a specific application rate. This application rate should be compared to the soil moisture depletion at irrigation to determine the set time. Refer to the previous example on preplanning an irrigation. Excessive set times result in excessive deep percolation and/or surface runoff.
- *Instruct irrigators how to probe for depth of water penetration* - This is another method of determining correct set length. Remember that the top of the root zone will nearly saturate during an irrigation, with the excess redistributing downwards after an irrigation set. Change sets before the wetting front reaches the full depth of the effective root zone.
- *The flow rate through a valve opener is too high resulting in excess head loss* -This may or may not lead to poor field pressure uniformity. It is certainly costing you money as the head loss is energy that you paid for (through pump and power costs) and did not use.
- *Need for more laterals*- This considers the "effectiveness" of an irrigation. One side of the field appears to be drying because not enough water is being pumped to the field. An equation to use in determining if the system is large enough is . . .

$$Q = 452.5 * ET_c * AREA / IE * HROP$$

where:

Q = required system flow in gallons per minute.
ET_c = daily crop water use in inches/day.
AREA = area of field in acres.
IE = overall irrigation efficiency as a decimal from 0 to 1.0 (normally in .65 to .8 range).
HROP = daily hours of operation of the system, from 1 to 24.
452.5 = conversion constant.

- *There is runoff from the field* - This is an efficiency problem, although it may not be as serious if the runoff is being picked up and utilized in a tailwater reuse system. It always represents an excess cost to you as it takes energy to run a system and if the water does not go into the ground, you did not get the full use of your energy dollar. Check the application rate of the system versus the infiltration rate of the soil. Reduce application rates by going to smaller nozzles, lower pressures, or wider spacing's. Balance the change against the effects on distribution uniformity.

Explanations for those recommendations concerning Flow Rate Uniformity (these comments address pressure and device uniformity at the same time) are . . .

- *Two or more different nozzle sizes in the field* - Different nozzle sizes at the same pressure will produce different flows. Do not put larger nozzles in areas of perceived lower pressures. The combination of the large nozzle/low pressure will decrease catch-can uniformity.
- *Sand wear in the nozzles* - This reduces flow uniformity because the nozzles may not wear at the same rate. But this also affects catch-can uniformity as the droplet size distribution may change. If sand wear is a constant problem check with a qualified agricultural engineer as to the use of a sand separator.
- *Poor pressure uniformity* - Poor pressure uniformity can be fixed in a number of ways. It may take larger pipe sizes, a different mainline position, or a different pump. In situations with very uneven terrain you may want to investigate using flow-control nozzles. It is always best to consult a qualified agricultural engineer to check your system designs. This only has to be done once.
- *Plugged nozzles* - This is an obvious problem. Use efficient trash screens where necessary.

Explanations for those recommendations concerning Catch Can Uniformity are . . .

- *Change the lateral move distance* - Closer spacing's will usually result in better catch-can uniformity. Realize that whenever you change the spacing (all other things kept equal) you will change the application rate. Recalculate set times whenever necessary.
- *Change the riser height* - It is an obvious problem if the crop is high enough to get in the way of the sprinkler spray.
- *Use alternate sets* - This has been previously discussed. It is always a good idea to use alternate sets but very important in areas with high winds.
- *Use a triangular spacing* - In some situations a triangular spacing may result in higher uniformity.
- *Try to place laterals perpendicular to the wind* - This is not as important as previously thought but still a good idea.
- *Operate in low wind conditions* - If possible, avoid each day's windy period. But remember the equation . . .

$$Q = 452.5 * ET_c * AREA / IE * HROP$$

Operating in less wind will increase IE (because of the higher distribution uniformity) but will also decrease HROP (the daily hours of operation). You may have to increase the system application rate or use more laterals and a larger pump to compensate for the decreased daily hours.

- *Incorrect operating pressures* - Check with a qualified agricultural engineer and your system supplier for the recommended operating pressure for each combination of sprinkler head and nozzle. Check for causes of excessive head losses in the system.

See the following link for information on selecting an irrigation method (http://www.irrigationtoolbox.com/NEH/Part652_NationalIrrigationGuide/ch5.pdf) from the NRCS National Engineering Handbook, Part 652.

Micro Irrigation Systems

Sprinkler and drip systems have sometimes been categorized as pressurized systems, closed systems, or mechanical systems. Instead of distributing water over a field by allowing it to flow freely across graded land, the water is piped to specific locations and then sprayed or dripped onto the field. In contrast to flood irrigation system types (furrow, border, level basins), the amount of water soaking into the soil with a pressurized system (field sprinklers, drip, spitter, over/under tree sprinklers) depends on two different factors . . .

- The set time.
- The application rate of the system, assuming that the application rate of the system is less than the infiltration rate of the soil.

The system application rate is a measure of how fast water is being applied to the soil. For micro-irrigation systems it is usually measured as a volume of water applied per hour (gallons/hour). With pressurized systems you should know the application rate of the system. This is how fast water is being applied. Then, also knowing the soil moisture depletion, it is a simple matter to calculate required set times.

The soil's infiltration rate, IR, is a measure of how fast water is soaking into the soil. Infiltration rates are described in terms of inches/hour. The application rate for the system (gallons/hour) must be divided by the wetted surface area to determine the infiltration rate for a micro system to make the comparison to the soil infiltration rate.

Runoff with micro-irrigation systems may be due to an excessive application rate. Many times it is due to surface sealing due to chemical reactions or an algae buildup. Chemical amendments are often necessary with micro systems because of the slow, frequent nature of water applications.

With sprinklers and drip systems, the keys to distribution uniformity are pressure uniformity and device uniformity. Pressures in the system should not vary more than 20 percent. Because of energy and water economics, many engineers are shooting for 10 percent variance. Always have your systems designed and laid out by qualified engineers.

For trickle systems, each plant should have the same emitter configuration. That is, you may put more than one type of emitter in the field as long as each plant as one of each. Also, all emitters should have about the same operating pressure range.

In micro-irrigation systems there is generally no overlap. The important uniformity considerations are pressure and device.

Device uniformity is especially important with micro-irrigation systems because of the small flows and small passages. Correct filtration, chemical treatment, and periodic line flushing are essential for keeping micro-irrigation systems clean.

Also, make sure all devices are the same. Many times, especially with trickle systems in orchards, emitters are added as the trees mature. Don't make the mistake of adding different types of emitters unless the recommended operating pressure ranges are similar.

Install pressure gauges or pressure taps (Schraeder valves work well if shielded) at the head of any pipe with pressure controls. Make sure all personnel know the correct operating pressure.

Preventive maintenance is a must with drip, spitter, and micro-sprinkler systems. Make sure that the level of filtration is matched to the flow, water quality, and device type. Make sure your designer/installer knows when to use sand separators, media tanks, and screen filters. Flush the filters as directed. Use chemical treatments as needed to prevent algae growth.

Once a micro system is clogged it is usually very expensive to unclog it. And, you run the risk of losing all or part of your crop as well as a significant portion of your capital investment.

See the Kansas State University link for a list of pros and cons for drip irrigation systems. (http://www.ksre.ksu.edu/sdi/News/Pros&Cons.htm).

Controlling Total Applications with Drip Systems

Since the total field is covered with field sprinkler systems the application rate can be compared to the soil moisture depletion to determine how long to run the system. With trickle, micro-sprinkler, or spitter systems all the field is not covered.

Also, these systems are operated frequently. Many times the gallons per hour per tree/vine of the system design is compared to the daily water use of the crop (evapotranspiration, ET_c) to determine required set times. The equation to convert daily ET to hours of system operation is as follows. . .

$$HR = ET_c * AREA / (GPH * AE * 1.605)$$

where:

HR = daily hours of system operation
ET_c = daily crop water use in inches/day
GPH = total flow to each plant in gallons per hour
AE = system efficiency as a decimal, 0 - 1.0

For example, there is a grape vineyard with two 1-gallon per hour emitters per vine. The vines are spaced 8 by 12. The estimated system efficiency is 80 percent (.8 as a decimal) and the current daily crop water use is estimated at .25 inches/day. Then . . .

$$HR = ET_c * AREA / (GPH * AE * 1.605)$$

$$HR = .25 * (8 * 12) / (2 * .8 * 1.605)$$

$$HR = 9 \text{ hours of operation per day}$$

With high frequency systems you should be using a soil moisture measuring device such as a tensiometer or gypsum blocks. Watch the trend in moisture measurements. If the trend is towards higher readings, increase the daily system operating time--if lower, decrease. Refer to the "Irrigation Scheduling" section of this handbook for more on planning irrigations.

You can use the same equation with "drip-tape" systems. Assume you have a drip-tape system on fresh tomatoes with a bed spacing of 60 inches (five feet). The tape is rated at 12 gallons/hour per 100 feet of tape. The crop is using water at the rate of .25 inches/day (ET_c = .25 in/day). With an 80 percent efficiency . . .

$$HR = ET_c * AREA / (GPH * AE * 1.605)$$

$$HR = .25 * (5 * 100) / (12 * .8 * 1.605)$$

$$HR = 8 \text{ hours of operation per day}$$

Micro-System Evaluations and Typical Recommendations

Many of the recommendations on the sprinkler system pertain to micro irrigation systems also.

Explaining them as they are applied to micro-irrigation . . .

- *Replace gaskets on the lateral/main pipes* - Many micro systems use underground piping. However, some portable drip tape systems will use surface transfer or "lay-flat" tubing. Pipe leakage in fields can be significant and easy to fix. Leakage reduces the irrigation efficiency. It can also lead to poor pressure uniformity in the field.
- *The gross application is much greater than the net required* - As previously seen; each system configuration applies water at a specific application rate. This application rate should be compared to the soil moisture depletion at irrigation to determine the set time. With high frequency micro irrigation systems, it is best to balance set times with daily ET_c's. Refer to the previous example on preplanning an irrigation. Excessive set times result in excessive deep percolation and/or surface runoff.
- *The flow rate through a valve opener is too high resulting in excess head loss* - This may be applicable to field drip-tape systems and may or may not lead to poor field pressure

uniformity. It is certainly costing you money as the head loss is energy that you paid for (through pump and power costs) and did not use.

- *Need for more laterals* - Micro irrigation systems should only be designed and installed by qualified engineers. Because of the piping, filtration, and pump expense, they will design a system with sufficient but not excessive capacity. A poorly designed system with insufficient capacity is usually difficult and expensive to retrofit.
- *There is runoff from the field* - If there is runoff with a micro system it usually means there is a sealing over of the surface soil due to chemical interactions. Investigate the need for chemical amendments.

For Flow Rate Uniformity (these comments address pressure and device uniformity at the same time) . . .

- *Two or more different nozzle (emitter) sizes in the field* - During routine system maintenance, or additions to a system on a growing orchard/vineyard, different types of emitters may be installed in the same field. This is not bad if the emitters are supposed to work at the same pressures and the addition is even. That is, one emitter of type A and one of type B per plant, not two type A's on one plant and two type B's on another.
- *Sand wear in the nozzles (emitters)* - This reduces flow uniformity because the emitters may not wear at the same rate. Plugging may be catastrophic to the plant. If sand wear or plugging is a constant problem check to make sure that your filtration system is sufficient.
- *Poor pressure uniformity* - Poor pressure uniformity can be fixed in a number of ways. It is very expensive to switch underground piping. It may be a matter of installing/resetting pressure regulators in the system and/or using a different pump. It is always best to consult a qualified agricultural engineer for a micro irrigation system design and installation.
- *Plugged nozzles (emitters)* - This is an obvious problem. Make sure that the filter system is matched to the water quality/emitter type combination.

Further reading, Food and Agriculture Organization of the United Nations (FAO) Irrigation Water Management: Irrigation Methods (http://www.fao.org/docrep/s8684e/s8684e00.htm), NRCS National Engineering Handbook, Chapter 9, Irrigation Water Management, (http://www.irrigationtoolbox.com/NEH/Part652_NationalIrrigationGuide/ch9.pdf). See the following link from NRCS National Engineering Handbook, Part 652, Chapter 5, for information on selecting an irrigation method - (http://www.irrigationtoolbox.com/NEH/Part652_NationalIrrigationGuide/ch5.pdf).

Border Strip Irrigation Systems

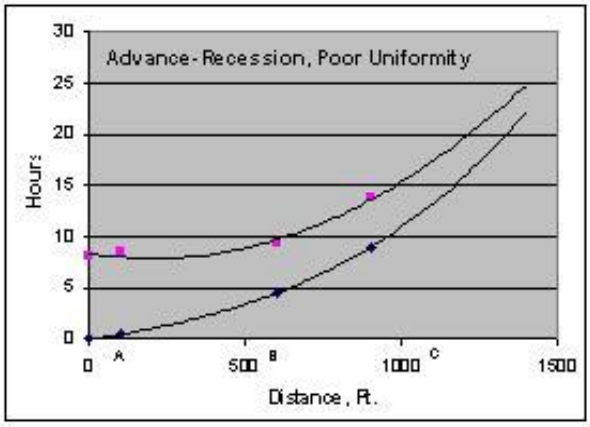
Border strips are run entirely differently than furrows. When water is turned off in a furrow it is essentially gone from the furrow immediately. In a border strip, because of the configuration and the crop friction, water takes a long time to run off. Thus, water is turned off in a border strip before it reaches the end of a strip. Border strips can be the most complex to manage as they are usually efficient only for a very narrow range of applications. If you know you will be applying small, frequent irrigations, make the strips shorter and narrower. See the following link for information of selecting an irrigation method (ftp://ftp-nhq.sc.egov.usda.gov/NHQ /pub/outgoing/jbernard/CED-Directives/neh-2of2/neh15/neh-15-03.pdf) from the NRCS National Engineering Handbook.

Border strips share some of the same operating characteristics as furrows. That is, the amount of water infiltrating depends on the intake rate of the soil and the opportunity time at any point in the strip.

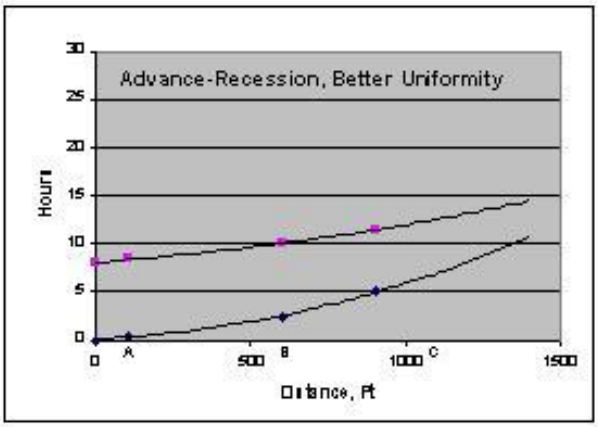
There are several important differences . . .

- When flow into a border strip is turned off, it takes time for water to run off. In other words there is a measurable recession time. (Remember that when water is turned off in a furrow, it disappears from the furrow relatively quickly).
- Also, because more surface area is wetted with border strips it doesn't take as long to soak in the same amount of water. You do not have to wait for water to sub across a bed or into a dry furrow. Thus, sets are usually shorter with border strips than with furrows.
- Finally, with a wide strip and the broadcast seeding that usually accompanies their use, there is not a problem with cross-row uniformity as with furrows.

Example 1, Poor Uniformity



Example 2, Better Uniformity



Advance-Recession Curves

The important operational characteristic of border strips is that they usually have measurable recession time. That is, when you turn water off in a border, it takes a significant, measurable amount of time for water to run off the strip.

A major reason for this is the obstruction of the crop in the strip. Water is held back by the crop, both when it is advancing down the strip and when it is running off. Another reason is that the water in a strip is not confined as it is in a furrow and thus, doesn't build up as much head (depth of flow). Because of this measurable recession we do not have to get the advance ratios as in furrows. Although set times in border strips are generally shorter than in furrows (because we are wetting more soil and thus, soaking water into the field faster), we normally turn the water off in a border strip before it reaches the end.

The impact of recession time is shown in Example 1. It depicts the advance and recession of water in a border strip during an irrigation. The bottom, solid line is the advance of water. This particular irrigation got water to the 600 foot mark in about four hours (at 'B', note the intersection of 600 feet on the horizontal line with 4 hours on the vertical). The upper, dashed line is the recession as water is turned off. Note that water was turned off eight hours after it was turned on, when it was about 1000' down the 1100' strip. This recession curve shows that water disappeared from the 600 foot mark about 9 1/2 hours after the irrigation was started.

Remember that recession is the rate at which water disappears from the soil surface. In the figure above, the distance 'A' between the advance curve and the recession curve is how long water was on the soil surface, infiltrating. It is the OPPORTUNITY TIME.

In Example 1 there was about 8 hours of opportunity time at the 100 foot mark (distance A). Water advanced to the 100 foot mark in about 1/2 hour. It finally receded from the 100 foot mark at about 8 1/2 hours into the irrigation. Thus, water was on the surface at the 100 foot mark for about 8 hours (8 1/2 recession - 1/2 advance). In contrast there was only five hours at the 900 foot mark (distance B). And only 3 hours at the end of the strip (distance C).

We've said before that good distribution uniformity with surface systems means getting the opportunity times close together. In border strips we are saying we want the rate of recession to equal the rate of advance as much as possible. The previous figure is not very good DU. Example 2 depicts a much better irrigation.

Note that there is 7 1/2 hours of opportunity time at the 100 foot mark, 6 1/2 at 900 feet, and 5 1/2 at the end of the strip. Also, note that the advance curve and recession curve are close to parallel over much of the strip.

The improvement is due to speeding the water advance. You can tell this by the difference in the Advance Curves. The curve in Example 2 is flatter than that in Example 1. Water moved faster over the strip. Where water took 4 hours to reach 600 feet in the previous irrigation, it only took about 2 1/2 hours in the irrigation in Example 2 (at 'B').

How close you should try to make the opportunity times in a border strip depends on the type of soil. As with furrows, the coarser the soil, the closer the opportunity times need to be.

Tailwater with Border Strips

There should not be much tailwater generated with border strip systems. Note the shaded portion of the two previous figures. This area represents tailwater (see how the Advance Curve "goes beyond" the end of the strip, point "C", indicating the start of runoff). If the area between the Advance Curve and Recession Curve past the end of the strip is large, then the amount of tailwater generated is large.

Improving Border Strip DU

Modifying border strip irrigation for distribution uniformity can be done in a number of ways, all related to evening the opportunity time down the strip . . .

- Increase/decrease the flow into the strip.
- Turn off the water sooner/later in the strip.
- Make the strip wider/narrower depending on side fall.
- Make the strip longer/shorter.

There is no benchmark recommendation for border strips as there is with furrows--no advance ratio that will change with soils. The most valuable tool used in border strip irrigations may be the soil probe . Use it after an irrigation to judge how far water infiltrated at the top, middle, and bottom of the strips.

One important fact is that for any given slope, strip width, soil, and crop, the recession curve will stay relatively constant, no matter what the inflow or the time of set. Thus, evening up the opportunity time may be a matter of increasing/decreasing the inflow.

Border strips can be the most complex to manage as they are usually only efficient in a narrow range of applied depths. If you know you are going to be consistently applying small depths, use shorter, narrower strips. And vice-versa for larger applications.

Efficiency with Border Strips

You should do the same sort of preplanning that was described for furrows. The same equations can be used.

$$\text{(1) GROSS APPLIED} = \text{GPM} \times \text{HOURS} \times 96.3 / \text{AREA}$$

where:
GROSS APPLIED is the inches of water applied to the AREA.
GPM is the flow in gallons per minute per strip.

HOURS is the total set time in hours.

AREA would be the width of the strip times the length of the strip.

The GROSS APPLIED is the amount of water that was turned on to the strip. If tailwater is allowed, subtract the percentage of GROSS APPLIED you think you can recover in surface runoff. That is, determine how much water that you apply will run off the field and be used. Then, subtract this from the depth applied.

Use the following equation . . .

(2) NET APPLIED = (1 - SAVED RO/100) x GROSS APPLIED

where:

NET APPLIED is the net average depth of water infiltrated in the furrow in inches

SAVED RO is the percentage (0-100) of GROSS APPLIED that you think will be saved as surface runoff

GROSS APPLIED is the gross applied as previously calculated.

Also, when determining NET APPLIED, the saved runoff percentage, SAVED RO, should be smaller than with a furrow system. And again, you will have to react to the results of the first set. Use a soil probe to judge the total amount of water infiltrating as well as the amount infiltrating at the top, middle and bottom of the strip.

Border Strip Evaluations and Recommendations

The major part of evaluating a border strip irrigation is to plot the advance and recession curves. The evaluator will mark off 100 foot increments of the strip and time the advance of water. Then, after water is turned off, the rate at which water disappears from the surface down the strip will be plotted. These plots can indicate whether inflow should be increased or decreased and also show where there are high or low spots in the field. A soil probe is used to see if enough water infiltrated.

Border strips are usually only efficient in a very narrow range of application depths. When the crop needs fall in that range, the utilization of this irrigation system can be very good. Operational flexibility is necessary to improve the performance of this type of system. The ability to efficiently deal with tailwater is key to improving flexibility. Increasing set times to increase application amounts will likely entail larger tailwater streams. Increasing onflow streams to improve advance times and distribution uniformity will also likely entail the management of larger tailwater amounts.

Further reading, Food and Agriculture Organization of the United Nations (FAO) Irrigation Water Management: Irrigation Methods (http://www.fao.org/docrep/s8684e/s8684e00.htm)

Fertigation

The application of fertilizer along with irrigation water during an irrigation event can be economic methodology to minimize application costs and tractor passes across the field.

Fertigation has been used with most types of irrigation systems. The distribution uniformity of the irrigation system is an important factor in the cost effectiveness of utilizing this method, since the amount of fertilizer applied is directly related to the amount of water infiltrated at any point in the field.

With a furrow irrigation system the head of the furrow will receive more fertilizer than the tail of the field. The destination of the tail water taken from the field will also be a factor. Do you want the fertilizer on a different field or should you return the tail water to the same field. The ability to control the depth of water applied is less with this type of system.

Sprinkler irrigation systems generally give better control of the amount of water applied, but the water is sprayed through the air and volatility may be a problem. Whether you want the material applied to go on to the foliage is another consideration.

Drip or micro irrigation systems provide the greatest uniformity and control of the depth of water applied, and so, are the best candidate for using fertigation. Care must be especially taken to consider water quality and other chemical reactions, since there is generally a large investment in the irrigation system that may be jeopardized if clogging occurs. Consideration should also be given to running the system after the application is made to clear the material out of the system.

A good source of information on fertigation basics is a paper by Dr. Charles Burt at Cal Poly's ITRC (http://www.itrc.org/papers/fertig/fertbasics.pdf). Also, there is a good reference to chemigation and fertigation laws (http://www.itrc.org/reports/chemigation/basics.pdf), on ITRC's website.

Basic Hydraulics

Basic hydraulics deal with moving water from location A to location B. Everyone knows that water flows downhill. Actually, to be more precise, it flows from a higher energy state to a lower energy state. A body of water higher on the hill has more potential energy than a body of water lower on the hill. Water in the delivery with the valve off has a higher energy state than water in the ditch that just came from the delivery. They are at the same elevation, but the water

in the delivery is under pressure. Pressure is another type of potential energy. The two types of potential energy can be converted, back and forth, by the relationship that says that 1 psi pressure equals 2.31 feet of elevation.

Water coming out of a sprinkler nozzle moves from a place of high pressure, potential energy, to just outside of the nozzle where the elevation is the same but the pressure has fallen to zero, atmospheric. Where did the energy go? There is always a conservation of energy when dealing with water, and it has changed into the velocity of the stream of water. Velocity energy is called kenetic energy.

Bernoulli Equation, named after the Swiss scientist Daniel Bernoulli, who put all of these ideas together into a formula:

$$H = V^2/2g + p/w + y$$

where:
H is the energy of the water.
V is the velocity of the water.
g is the acceleration of gravity.
w is the weight per unit volume of water.
y is the elevation.

The first factor in the equation is kinetic energy and the second two are potential energy. The units used should be consistently in the same measuring system, English or metric.

The energy of any mass of water can be described by this equation. Two masses of water, with the same energy, can have different combinations of kinetic and potential energy, but energy will be conserved and it will be in one of these two forms.

You cannot destroy energy, but the same mass of water that is transported from one place to another can lose energy to friction. The energy at point B plus the friction loss, h_f, equals the energy at point A.

$$H_a = H_b + h_f$$

If you know the energy at point A, you can calculate the energy at point B by subtracting the friction losses. Water in a pipeline that is at rest does not have friction losses, a static system. If you installed a pressure gauge at the end of the line filled with water, the pressure would read one value.

If you start to take water from the pipeline at the end of the line, the pressure will fall, depending on the flow moving through the pipeline. Eventually the friction losses plus the kinetic energy of the water would equal the energy at the head of the pipe and the pressure gauge at the end of the line would read zero and the maximum flow rate would be achieved at the end of the pipeline.

If this terminal flow was insufficient, more energy would have to be added at the head of the pipe or the friction losses would have to be reduced to get the flow at the end that you wanted. To do this you would install a pump or you would use a larger diameter of pipe. The friction losses are related to the velocity of water in the pipe and the roughness of the pipe. The higher the velocity the higher the friction losses, and the rougher the interior of the pipe the higher the losses.

Friction

You cannot destroy energy, but the same mass of water that is transported from one place to another can lose energy to friction. The energy at point B plus the friction loss, h_f , equals the energy at point A.

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Thus, when you choose the number of gates to open on a gated pipe system, when you choose the number of laterals to run on a hand move sprinkler system or when you choose the number of drip lines to run, you are changing the friction losses in the system. The system was designed to be run a particular way. If you choose to operate it outside of the design parameters you will most likely reduce the uniformity, increase the energy consumption or both.

Westlands' distribution system is a prime example. Each lateral was designed to supply 1 CFS to each 80 acre parcel, with everyone running. When few water users are irrigating on a lateral, the lateral is over-designed and the delivery flows can be greater. As more deliveries are tuned on, there are greater flows in the lateral and less water can be delivered at a particular delivery. When the design flow for the lateral is exceeded, irrigators at the end of the lateral will have degraded ability to deliver the desired flows. Since the left bank system is gravity flow, there are no options for increasing the deliveries.

For right bank laterals, which must deliver water uphill, capacity problems can trigger a control mechanism to shutdown the lateral, which creates a problem for all on the lateral.

Aluminum Irrigation Systems

Portable aluminum irrigation systems save water that could be lost to ditch seepage and give better control over the flows delivered to the furrow. The fact that they are portable allows them to be assembled in many layouts. The friction loss for each layout is unique. If the system is boosted, excessive friction loss can be counteracted by increasing the boost to increase the pressure at the head end, but with energy costs rising, this additional cost may be significant.

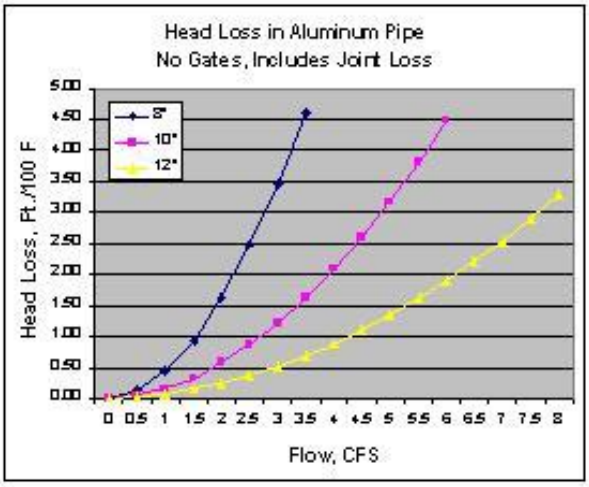
The diameter for the mainline for sprinkler and gated-pipe systems is one of the most important decisions in setting the layout. For a single line gated-pipe system all of the water delivered must pass through the first joint, nearest the delivery. Since the head loss is related to the velocity of the water, a smaller diameter pipe will have a greater velocity for the same flow.

If you were using 10" pipe for the entire mainline along the head of the field and were trying to run as many furrows as possible, you would be able to run more furrows nearer to the delivery than at the end farthest from the delivery, assuming that the flow in each furrow remained constant.

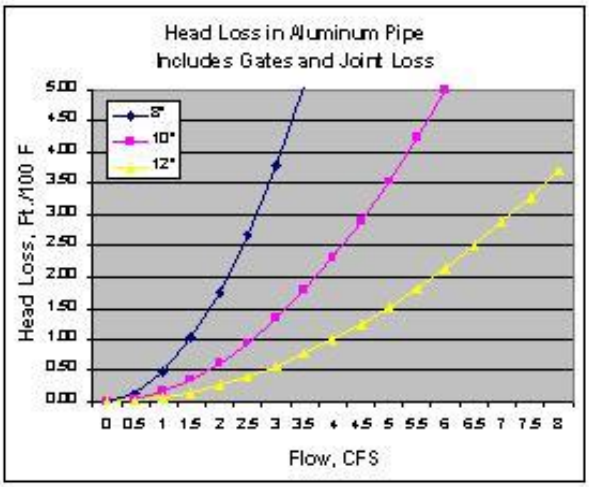
Typically, no booster is used; rather the distribution system pressure is all that is needed, 5 feet of head, minimum at the delivery, which is at the high point of the field. If more water is needed for each furrow, the number of gates open must be reduced. The specific circumstance will depend on the slope of the mainline. If the loss due to friction is canceled by the gain due to loss of elevation then there is no problem, but this depends on where the field is in the District.

One improvement that can be made to this system configuration, if 12" diameter pipe is available, is to use 12" pipe near to the delivery and reduce to 10" at some point down the field. The figures below show that the head loss using 12" pipe is less than 1/2 the loss using 10" pipe. This configuration will reduce the friction energy loss in the first section of the mainline and allow more furrows to be set, near and farther away from the delivery, which in turn will give more capability to adjust flows.

When mainline with no gates is used to transport water, the figure below shows the friction head loss (Ft./100 Ft.) for a particular pipe diameter at a flow (Source: After Hazen-Williams equation [11.10], ASCE Monograph 3, 1980)



Similarly, when a mainline has gates the following figure presents the same information:



The mainline without gates will apply to transport and sprinkler mainline. It is not uncommon to boost water in these situations. For every additional 2.31 feet of head lost an additional 1 pound per square inch of pressure must be added at the booster to maintain the same flow.

When boosting water to a sprinkler system with the mainline going down the center of the field, say1/4 mile of 10 inch mainline, 3.5 CFS will have 20.8 feet of loss from the delivery to the head of the sprinkler mainline across the field, 1.6 ft. per 100 ft. for 1,300 feet, which is equivalent to 9 psi. If 12 inch pipe was used instead the loss would be 0.7 ft. per 100 ft. or 9.1 feet, which is equivalent to almost 4 psi, less than half, or possibly a 10 percent energy savings if the booster pressure was dropped from 50 psi to 45 psi. See the pumps and pumping cost section.

Portable hand-move sprinkler systems can be assembled and operated in many different configurations. Typically, the initial investment for a 3 inch lateral system for a quarter section

will be less than a system using 4 inch laterals. A three inch system will have a transport mainline to the head of the sprinkler mainline running across the middle of the field, with 1/4 mile laterals coming off both sides. A four inch system will typically have a sprinkler mainline running along the head of the field and 1/2 mile laterals.

The reason for this is that a 1/2 mile sprinkler lateral using 3 inch pipe would have a larger pressure variation along its length, than the 4 inch line, which would give poorer uniformity. The 1/2 mile line would have twice the number of sprinklers and twice the flow in the first joint connected to the main. The pressure head loss would be greater. Assuming that the same number of laterals would be running with the same sprinkler heads, the same head loss could occur on the mainline, but the pressure distribution down the lateral would be significantly different.

Sprinkler laterals are laid out down slope, so that the gain in elevation head can offset the friction loss down the lateral. Friction loss is greater for a smaller lateral diameter because the velocity will be greater for the same number of sprinklers. The 3 inch laterals on the upslope side of the main in the middle of a field will have a greater pressure loss differential, since the friction loss and the elevation loss are additive and to not counteract each other as happens on the down slope side.

The head-loss of a sprinkler lateral can be calculated using the Hazen-Williams equation plus the Christiansen F factor, but it will not be discussed here.

The size of the nozzle will determine the discharge from the sprinkler head. Typically, 7/64" and 1/8" nozzles are used in Westlands. The 7/64" nozzle will discharge about 77% of the discharge of a 1/8" nozzle, assuming other conditions being equal. Thus, 7/64" nozzles will typically be used on 3 inch laterals, but this will mean that more irrigations will be needed to apply the same amount of water as with the larger nozzles, and labor requirements for hand-move sprinkler laterals would be higher.

Laterals are typically evenly spread along the mainline. There is a head-loss reason for this. The head-loss relationship to flow is not linear, so it does matter how the lateral are distributed along the mainline. The situation where all of the laterals are blocked together as far down the mainline as possible is the case where the pressure change due to head-loss will be greatest. The opposite extreme is where the block is nearest to the head of the mainline. The booster pressure, ideally, would be adjusted differently for each set. Where the laterals are evenly spread out, the pressure requirement is similar, from the first set to the last, and the difference between the maximum and the minimum is less than when using blocks.

This situation also occurs when using a solid set system. A solid set system is used on high value crops that need to have frequent, light irrigations. The investment in equipment is very high when a single lateral is not moved to the next position, but the current lateral is turned off and the next lateral is turned on, both remain in place. The hydraulics is the same. With frequent, light irrigations, small variations in sprinkler discharge due to pressure variation result in a larger variation in the distribution uniformity, on a percentage basis.

In conclusion, there are many tradeoffs between fixed and variable costs in the economic analysis of portable aluminum irrigation systems. Fixed capital costs will be higher for 4 inch sprinkler lateral systems, but variable costs such as energy and labor can be less. Similarly, fixed capital costs for 12 inch gated pipe would be higher, but variable labor costs can be less if the irrigation can be completed in a shorter period of time and water can be saved if uniformity is higher.

PVC Pipeline

Thermoplastic pipes are commonly divided into low and high pressure categories. It is typically used for buried pipelines, but it is also used for portable surface pipelines such as gated pipe.

Head loss calculations, such as with the Hazen-Williams equation, are very similar to those for aluminum pipe, and so, the head loss graphs presented for the aluminum are useable. Head loss calculations depend on the condition of the pipe. New pipe has less loss and older or corroded pipe will have greater loss. Aluminum and PVC pipe have similar hydraulic characteristics.

Buried systems are generally designed with one management scheme in mind. If it is operated differently, the uniformity can suffer, due to head-loss considerations. For example if the distribution system for a grape vineyard was designed to irrigate 6 rows of vines, evenly spaced across the field, was operated as a block of 6 adjacent rows, there probably would be uniformity problems. Typically, the cost of the distribution system for an evenly spaced configuration is less expensive than a one that was designed for more flexibility to be operated as an adjacent block. Flexibility must be designed into the system. Such a system is not necessarily the least expensive. Again, head loss considerations cause the problems with uniformity.

Any buried system must be designed with hydraulic consideration for water hammer, thrust blocking, air release, trench width and trench depth.

Ditches and Canals

Ditches and canals are used to distribute water to fields and within fields as part of irrigations systems. All water delivered by the District is delivered from a pipeline distribution system. Water moved on the surface is typically associated with tailwater reuse systems. Siphon tubes are used to deliver water from a head-ditch into a furrow in places where the soil intake rates are conducive to this practice. Typically, the lands that are suited to this type of system are on the east side of the district are near the valley trough, and as such have fine textured soils and flatter slopes.

Water that flows on the surface responds to gravity and flows downhill. Furrow and border strip systems fall into this category. Border strip irrigation systems are covered in another section.

Siphon tube, furrow irrigation systems deliver water into the furrow from a head-ditch cut into the head, or mid-field, the furrow that is lower than the level of water in the ditch. The head-ditch is generally checked with tarps to divide the head ditch into shorter segments. The irrigator begins near the head end of the head-ditch and works away. As the irrigator gets to a head-ditch

check, the check is removed and the water flows down to the next check. The irrigator will set the required number of siphon tubes to match the total flow going into the furrows to maintain the level of water in the ditch in equilibrium so it does not overflow and wash out the ditch. The ditch generally has a large cross sectional area, so that the velocity will be small and erosion minimized.

Flow of water in ditches can be categorized into two types, laminar or turbulent. In the laminar state, viscous forces predominate over internal forces and flow is smooth. Turbulent flow is the opposite. Bernoulli's equation still holds, but there is no pressure head, since the system is open to the atmosphere. When water flows there are friction losses. Water will flow in the laminar state where the level of the water surface will be parallel with the bottom of the ditch and the friction losses will equilibrate with the energy gain from the slope of the bottom. For a particular laminar flow, the depth of flow will be less with a steeper slope. As the depth gets to a critical height and the velocity is faster the state of the flow will change to turbulent. The turbulent flow state is much more complicated and will not be discussed here, since it is not desirable to occur except in a lined canal where erosion can be minimized. The shape and roughness of a canal will also influence the flow characteristics.

Erosion is minimized in head-ditches, but the slope of tailwater collection and transport ditches must be considered to minimize erosion is this case.

Economic Analysis

Investments in improved irrigation technology are necessary to manage a limited water supply with high efficiency. Irrigation systems with high distribution uniformities (DU) are necessary to achieve high irrigation efficiencies (IE) without incurring under-irrigation to parts of a field. High IE can be achieved by not refilling the root zone with an irrigation event, but eventually there will be parts of the field that will suffer water stress and yield reductions.

Generally the high DU irrigation systems include micro-irrigation and center pivot or linear move systems. In order to improve a furrow irrigation system to achieve a similar level of DU, significant capital investment is typically necessary to shorten the runs and install a tailwater reuse system. In limited situations border strip systems can achieve high DU.

Higher levels of investment can be justified by high value crops, such as trees and vines or truck crops, but there is only a limited, inelastic market for the crops produced and as such overproduction can reduce the value of these crops. Economic analysis is needed to justify the decision to invest in the equipment necessary to achieve high irrigation efficiency.

Analysis Tools

This section will attempt to present the tools necessary to make a comparative analysis in a manner that is easily understood. Investment in improved irrigation systems is just one more annual cost that goes into growing a crop on a field. Most farmers must establish an annual budget to obtain financing from their bank, so we will look at the annual cost of an irrigation system.

The annual cost of an irrigation system will be determined from the initial cost of equipment, the cost of installation, finance charges, depreciation, water costs, energy costs, labor costs, maintenance costs, replacement costs (if particular components of the system have a life less than the time period of the analysis), and salvage value. Typically, to compare the cost of different possible irrigation systems, investments are resolved to a single "net present value" to allow an "apples to apples" comparison, particularly if the system life of the systems are not the same. The "net present value" of each system is then converted to an equivalent uniform series of equal annual costs, over the time period of the analysis. These equivalent annual costs are a fixed cost for the analysis of annual irrigation costs. This equivalent cost is combined with the other fixed and variable annual costs mentioned above to establish the annual cost of irrigation for a particular system, which is used to compare the potential profitability of alternate irrigation systems. Since depreciation costs are more of a tax question, we will not address that aspect of the cost, even though it can be a significant cost.

Payment Factors

Factors will be presented to convert a single payment into a future value or a future value into the present value. Similar factors for annual series of payments will also be discussed. Single payment factors are useful for analyzing the present value of purchasing replacement equipment in the future. Series payment factors are useful to take that present value (initial cost) and convert it to a uniform annual payment. There also exist factors for uniform gradient series, but they will not be considered here. Inflation adds another layer of complexity to economic analysis, and so we will assume that we are dealing with constant dollars, no inflation. For those that need to deal with inflation, there are engineering economics books available.

The uniform annual cost over an analysis period is obtained by using the Capital Recovery Factor of uniform annual series. This factor can be thought of as indicating the equivalent present cost (P) of equal annual expenditures (A) over N years at i percent interest and is designated A/P, where:

$$(1)\ A/P = A/F \times F/P$$

and A/F is the Sinking Fund Factor, where:

$$(2)\ A/F = [A/F, i, N] = i/((1+i)^N - 1)$$

This factor is used to calculate the amount of annual investment (A) necessary to accumulate a future amount (F) when invested at i percent interest over a period of N years. And F/P is the Single Payment Compound-Amount Factor, where:

$$(3)\ F/P = [F/P, i, N] = (1+i)^{N}$$

This factor is used to calculate the future amount (F) of a single present payment (P) that must be invested at i percent interest after N years. Please note that 1/(F/P) is the Single Payment Present-Worth Factor and is designated as P/F. P/F is the present amount (P) that must be invested at i percent interest to have a future amount (F) after N years.

These are standard financial factors and will be used in the remainder of this section. An engineering economic analysis calculator (http://web.njit.edu/~wolf/calculator.html) page is available for these factors on the internet.

Interest Rate and Payment Period

These financial factors are dependent on two variables, N, the investment period, and i, the interest rate. The interest rate can be known by several names, including the capital recovery rate and the discount rate and can be defined as the cost of having money available for use. In this economic analysis we will be using it to refer to the expected rate of return from an investment. The rate selected could be expected to be limited on the maximum side by expected the expected interest rate to borrow the funds and on the minimum side by the minimum rate that the water user expects from his own capital, over the period of analysis. On the maximum side, if the investor can get cheaper money than their own capital, they would be expected to use the other funds. On the minimum side, the investor can accept less for their own capital than they could readily earn from other investments, they would not make the investment in an improved irrigation system. A range might be between the bond market and expected loan rates.

Money has time value. By this we mean that a dollar received today has greater value than a dollar received in 5 years. A dollar now can be invested at a particular rate of return and would be worth more at the end of 5 years by the compound interest rate received from the investment, see equation 3 above. Similarly, you can calculate the present value that would need to be invested to return one dollar at the end of 5 years with the inverse of the same equation.

Alternative irrigation systems are investments that will support a particular rate of return from a farming operation. The system with the lower annual cost will provide the greatest profit, but the choice to invest in an irrigation system must be weighed against alternative investments. You can use economic analysis to determine if you can receive greater return in an alternative investment. A bank would look at a loan to finance your irrigation system as an investment.

It would seem reasonable that the interest rate selected for the economic analysis will be greater than other investments outside of farming with a similar level of risk. We have used a rate of 12 percent in the examples below, but that rate will also depend upon the length of the investment period. The choice of rate will also depend on whether you are doing an economic analysis or a financial analysis. An economic analysis is usually completed first and the financial analysis is

completed to analyze the cash flow for the alternative selected. The same financial analysis factors can be used over a period that is related to the life of a loan.

The period of analysis for an economic analysis is not particularly sensitive to the length time chosen, but the most typical period is to choose it related to the useful life of the equipment involved. Equipment at the end of its useful life will generally not have a salvage value, other than say the value of the aluminum itself from a portable irrigation system. Salvage value must be considered when the period chosen is shorter than the useful life, and this adds complexity. Typically on-farm irrigation systems would be analyzed over a period of 20 to 30 years. In order to work with longer times, replacement of equipment must be considered. The example below assumes an analysis period less that the useful life for illustrative purposes. The main criteria that must be followed is that the period of analysis must be the same for all alternatives compared.

Analysis Examples

We will first consider analyzing the cost of the irrigation equipment. Assume that you are considering the purchase of portable aluminum gated pipe to serve 160 acres. There is no installation cost for this type of system. Any installation would come as labor costs for putting it into the field when it was to be used. A system would be comprised of 66, 40 foot, joints of pipe to go across the top of the field, giving 2,640 foot furrow runs. At $180 per joint, the total cost of equipment is $11,880. Assume a system life of 15 years, but that the analysis period of 10 years is used in this example. The analysis period could be the life of the equipment, the financing period or other appropriate period. The most important aspect is that any comparison is made alternatives with the same analysis period. The period length will determine if equipment replacement or salvage values should be considered. The interest rate selected should be appropriate for investment capital.

$$A = [A/P, 12\%, 10 \text{ years}] \times \$11{,}880.$$

$$A = [A/F, 12\%, 10 \text{ years}] \times [F/P, 12\%, 10 \text{ years}] \times \$11{,}880.$$

$$A = (.12/((1+.12)^{10} - 1)) \times (1 +.12)^{10} \times \$11{,}880.$$

$$A = 0.056984 \times 3.10585 \times \$11{,}880 = \$2{,}102.57 \text{ per year, or } \$13.14/\text{acre/year over 160 acres}$$

This calculation can easily be performed on a simple financial or scientific calculator.

Salvage Cost

The previous example assumes that there is no value for the pipe after 10 years. We need to calculate the uniform annual cost of the value of the equipment at the end of the planning period, the salvage value. Assume that salvage value at 10 years is 33% of original cost.

Use equation (2) to calculate

$$A/F = (.12/((1+.12)^{10} - 1)) = 0.056984$$

to calculate the uniform annual series factor for the salvage value at 10 years. This is the annual cost that needs to be invested to accumulate the salvage value at 10 years. The annual cost of this system less the annual cost for the salvage value at the end of a ten-year period is,

$$A = \$2,102.57 - 0.056984 \times 0.33 \times \$11,880 \quad A = \$2,102.57 - \$233.40$$

$$A = \$1,879.17 \text{ per year, or } \$11.74/\text{acre/year over 160 acres.}$$

It should be noted that the actual market value of the equipment at the end of 10 years will probably be different that the salvage value used in the analysis. We will assume that the system is used only on one crop per year and that there are no energy costs, since the system is connected to the District distribution system. District deliveries are situated at the highest point of the field and have a minimum of 5 feet of head.

The annual irrigation system cost would be the annual system cost, $1,879.17, plus the annual labor cost. The cost of the irrigation water will depend upon the crop grown. Therefore, in the previous example, the irrigation cost will be the cost of the system plus the cost of labor.

Improved Efficiency Alternative

Thus, the irrigation cost will depend upon the efficiency, IE, of the system. An improved system with better DU can produce better IE and reduce the amount of water applied and, therefore, the water cost. Reduced water costs can help pay for the improved system, but typically an improved system can also give improved yields, and reduce labor costs, which would help pay for the increased cost of the improved system.

Since we are in a limited water supply situation, it should also be noted that the water not applied to the field in question can be used to irrigate additional acreage. The additional profit from this additional acreage can also be used to justify the cost of the investment in improved technology.

Improved Irrigation Efficiency

Let's say that, in the interest of efficiency, you want to shorten the runs for the furrow irrigation system described above, but that the additional pipe would be purchased in increments, say 3 year periods to allow for the cash flow to improve. Assume that an additional 3/4 of a mile of pipe will be purchased to split the field into 1/4 mile runs 3 years subsequently and the remaining 7/12 of a mile (some of the gated pipe will be used for transport purposes) will be purchased 3 years later. The system will ultimately have 1/6 mile runs and could be used for a higher value crop like tomatoes. We will calculate the uniform annual cost over the same 10-year planning period and will assume the same unit cost for gated pipe.

The second investment will occur three years after the first. We will determine the present worth of the additional pipe and then use the capital-recovery factor to calculate the annual equivalent cost over the 10-year planning period. An additional 99, 40-foot, joints at $180 are needed, at a

cost of $17,820. We will assume that the salvage value of the second purchase is 50% and the third purchase will be 75% at the end of the 10-year period.

Calculating the present worth of the second purchase at 3 years we use the Single Payment Present-Worth factor, P/F, which is 1/(F/P), where F/P is equation 3 above:

$$P/F = 1/(F/P) = 1/[F/P\ ,\ 12\%\ ,\ 3] = 1/(1+i)^N = 1/(1+.12)^3 = 0.71178$$

< P > the present worth, P, of the purchase cost is $17,820 x 0.71178 = $12,683.20. Using the uniform annual cost factors used above

$$[A/P,\ 12\%\ ,\ 10] = 0.056984 \times 3.10585 = 0.17698$$

The annual cost for the second purchase is 0.17698 x $12,683.20 = $2,244.80 per year.

Assuming that the salvage value is 50% at 10 years, and the A/F value above, the annual cost for the salvage value is 0.056984 x 0.50 x $12,683.20 = $361.37 per year.

The annual cost for the second purchase is $2,240.80 - $361.37 = $1,879.43 or $11.75 per acre per year.

Similarly for the third purchase of 77 joints after 6 years, the present worth factor, P/F, is

$$P/F = 1/(F/P) = 1/[F/P\ ,\ 12\%\ ,\ 6] = 1/(1+i)^N = 1/(1+.12)^6 = 0.50663,$$

with a net present value of $7,021.89 and an annual cost of $1,242.73. If the salvage value is 75%, then the annual cost is $300.10. The annual cost for the third purchase is $1,242.73 - $300.10 = $942.63 per year or $5.89 per acre per year.

The uniform annual cost for the new improved system is now the sum of the individual annual costs,

$$\$1{,}879.17 + \$1{,}879.43 + \$942.63 = \$4{,}701.23$$

per year or $29.38 per acre per year over the planning period of 10 years plus labor costs. This example assumes that the equipment would be sold at the end of the planning period, but demonstrates how to establish the annual cost of an irrigation system investment.

Typically, to achieve the highest DU a tailwater reuse system would be necessary. We will not develop the annual cost for this improvement because the configuration will be quite variable. A system that would integrate the tailwater management for several fields would amortize the cost over the largest acreage would probably have the minimum cost. A tailwater system will also be necessary to minimize the labor costs necessary to achieve the highest DU.

To justify the additional investment to improve the system efficiency, there must be at least an economic benefit of $17.71 per acre. If you assume a water cost of $65 per acre-foot, a

reduction in the applied water of 3.3 inches, would be necessary to justify the improvement on water savings alone. If the original system was operating at 70% efficiency with a seasonal applied water of 30 inches, the improved system would need to be managed to achieve about 80% efficiency, with the same labor input, to justify the added investment by water cost reduction alone. The actual value of the water saved may not be the water cost, but it may be the value of the additional acreage that could be planted.

An investment in an improved irrigation system will typically be justified by one or more of the following factors that will increase profits by reducing costs or increasing revenues:

1. Improved yield.
2. Improved irrigation efficiency.
3. Reduced labor costs.

Crop Characteristics

Information concerning crop, soil, and irrigation system characteristics are used to determine when to apply water to a field--and how much to apply. Crop characteristics that affect the scheduling of irrigations to maintain optimum yields are rooting depth, critical growth stage, rate of development, and the amount of water that can be withdrawn from the soil profile without affecting production. Additional information is available from NRCS on this topic in (http://www.wcc.nrcs.usda.gov/nrcsirrig/irrig-handbooks-part652-chapter3.html) the National Engineering Handbook, part 652.

- Root Zone Development
- Allowable Depletion

Root Zone Development

The depth of the crop root zone determines the volume of soil from which the crop can draw water. Perennial crops, such as almonds or grapes have root zones which increase in depth over a number of years and they become more or less fixed in depth when the trees or vines mature. Cotton and safflower are crops that have deep roots which expand downward throughout much of the growing season. Lettuce and onions have roots which grow densely in the top 1 to 1.5 feet of the soil profile.

The moisture in the upper portions of the root-zone will be depleted at a faster rate than the moisture in the lower portion of the root zone because the roots are more dense in the upper portion.

The soil type and structure play a large role in determining the maximum depth of the root-zone. Course and medium textured soils usually allow deeper root zone development than fine textured

soils. The depth of a crop root zone can be estimated for a type of soil, but compacted layers or shallow water tables will limit the expansion of the root zone. The location of these restricted zones must be known to establish the depth of soil from which the crops can withdraw water.

The depth of the root-zone can be established by using a soil probe. The soil samples removed from various depths of the soil profile can be examined for roots and compared. It is difficult to see roots in a sample of course textured soil. However, the depth of the root zone can be determined by locating the change in soil moisture because the soil is drier where the roots are removing water.

Allowable Depletion

The portion of available moisture which the crop can use without reducing yields is the major factor to be considered when the allowable depletion is determined. The allowable depletion is a management decision which should consider the crop root zone, root density, growth stage, weather conditions, soil texture , irrigation system capacities, and cultural practices.

Root density and depth changes as the crop develops. Crops such as lettuce and onions have shallow dense root systems and low allowable depletion percentages which require frequent irrigations with small amounts of water. Cotton, alfalfa, and tree crops require less frequent irrigations because that have a deeper root-zone and higher allowable depletions percentages.

An irrigation may be required when the allowable depletion reaches 30 percent for shallow rooted, cool season crops. The allowable depletion can be as high as 90 percent for deep rooted crops near harvest, but 50 percent is generally a practical figure for most crops. The allowable depletion varies for different crops at different times during the growing season. The table below shows suggested allowable depletion percentages for selected crops grown in Westlands.

Suggested Range of Allowable Depletions for Selected Crops		
Crop	Seasonal Allowable Depletion (%)	Harvest Allowable Depletion (%)
Alfalfa Hay	*	*
Alfalfa Seed	50	90
Almonds	*	*
Barley	*	*
Beans (Dry)	50-60	80
Cantaloupes	*	*
Corn (Field)	50-60	75
Cotton	*	*
Garlic	30-40	70
Grapes	50	80
Lettuce	30-40	--
Onions	20-30	70
Safflower	*	*
Milo	50-60	80
Sugar Beets	*	*
Tomato	*	*
Wheat	*	*
* See Individual Crop Data Sheets		

Crop Data

Specific water management information for various crops grown in the District has been assembled for the crops listed below.

- Alfalfa Hay
- Almonds
- Barley
- Cotton
- Melon
- Safflower
- Sugarbeet
- Tomato

- Wheat

Other crop specific water management information for crops not listed above is also available.

The growth stage of a crop must also be considered when determining the allowable depletion. The soil moisture must be closely monitored during the stress sensitive growth stages of a crop, which usually correspond to the flowering and/or fruiting periods. Serious yield reductions may occur if the recommended allowable depletion during these critical periods is exceeded. Also, the allowable depletion at the end of the growing season may be greater than the early portion of the season for most crops.

Weather conditions must be considered when determining allowable depletion. The allowable depletion can be greater during periods of low evaporative demand (cool temperatures and/or fog) than during periods of high evaporative demand (hot temperatures and/or winds).

Soil texture is another consideration when determining allowable depletion. Generally the available moisture in coarse textured soils can be depleted to a greater percentage than the available moisture in fine textured soils. However, since there is more available moisture in fine textured soils, the allowable depletion measured in inches of water can be greater than in coarse textured soils. Crops grown on soil with a high salt content require a lower allowable depletion percentage because the salts restrict the water uptake by the roots.

Allowable depletion is expressed as a percentage of available moisture allowed to be removed from the root zone by the crop. The amount of water required to refill the current crop root zone or soil profile is expressed in inches of water and can be calculated as shown in the following example:

Known: Allowable Depletion = 40%
Current Root-Zone = 4 ft. Allowable
Moisture = 1.0 in./ft.
Solution:

$$\frac{40\%}{100} x\ 4\ ft. x \frac{1.0\ in.}{ft.} = 1.6 \text{ ins. per foot}$$

The allowable depletion in inches of water is the amount of water that must be replaced to return the active root-zone to field capacity.

Alfalfa Hay Crop Data Sheet

Alfalfa Hay Water Management (Established) SOIL: Coarse and Fine Textured

EFFECTIVE PRECIPITATION: The portion of the rain that satisfies a part of the crop water use will depend primarily on the amount of plant cover. Only about 30-50 percent of the rainfall is effective when the soil surface is exposed after cutting and almost 90 percent of the rainfall is effective when the crop canopy is complete and the soil is covered.

ROOT ZONE: The root zone of established alfalfa hay normally exceeds 6 feet when there are no restrictive conditions. However, restrictions can frequently limit the root zone to 4 feet.

ALLOWABLE DEPLETION: Alfalfa can endure quite dry soil conditions, but production will suffer because vegetative growth is directly related to water use by the plant. A practical allowable depletion for fine textured soils is 50 percent and for coarse textured soils should be limited to 60-70 percent.

IRRIGATIONS:
First: A mid-February irrigation that refills an unrestricted root zone will satisfy the water requirement until after the first cutting in mid-April during years of average rainfall.
Season: On fine textured soils a single irrigation seven days after cutting will carry the crop with maximum production if the root zone is refilled. This irrigation will have to place approximately six inches in the root zone. When the soil will not take seven inches in a single irrigation then two irrigations placing 3" each should be scheduled between cuttings or the irrigation should be restarted immediately after the hay is removed and stopped only to allow the soil to dry for the next cutting. The next irrigation should begin at the point where the last one started. When it is not possible to complete two light irrigations between cuttings an option is to split the field and stagger the harvest. The option to stagger harvest should be considered under restricted root zone conditions.

On coarser textured soils a single irrigation between cuttings will not maximize production because the root zone cannot hold the 8 inches of water the crop will require during these periods. A practical strategy is to apply two irrigations that will add 4 inches each to the root zone. The first irrigation should occur about 7 days after cutting and the second irrigation should be discontinued 5 days before the next cutting and restarted at that point 7 days after cutting. When it is not possible to complete two irrigations, an option is to split the field and stagger the harvest.

WATER BUDGETING:

Average Seasonal ET (N/C/S)	3.6/3.8/3.4'
Average Effective Precipitation	0.5'
Average Salinity Control	0.5'

Water Use, in*	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Northern	0.3	0.7	2.7	3.2	5.6	6.1	6.4	6.5	6.0	2.9	2.2	1.1	43.6
Central	0.3	0.9	3.3	3.2	5.6	6.4	6.9	6.5	5.4	4.5	1.8	0.4	45.2
Southern	0.3	0.8	2.9	3.1	5.1	5.8	6.3	6.2	4.5	4.3	1.1	0.5	40.6
Deliveries-%		15			15	15	15	15	15	10			100
* Note: Coarse soils can have 10% greater ET.													

Last updated April 2002

Almond Crop Data Sheet

Almond Water Management (Mature, Drip)
BUD BREAK: February 15

SOIL: Coarse and Fine Textured
DORMANCY: November

EFFECTIVE PRECIPITATION: The average effective precipitation during the growing season is about 1" (0.1'). A portion of the winter rainfall may be stored in the root zone. However, only 35-50 percent of the winter rainfall can be considered effective because the ground is not covered.

ROOT ZONE: The effective root zone for mature trees can extend to a depth of six feet in fine soils and to more than 9 feet in coarse unrestricted soils.

ALLOWABLE DEPLETION: Allowable depletions should range from 50 percent for fine textured soils to 70 percent for coarse textured soils.

STRESS SENSITIVE PERIODS: Severe water stress during bloom and kernel filling can cause sizeable yield reductions.

IRRIGATIONS: It is important to fill the entire root zone with water during the winter or at the beginning of the growing season. Insufficient irrigations early in the season can cause severe water stress by the end of harvest. This is particularly critical because the trees may have to go without an irrigation for up to 6 weeks during harvest. The amount of water required to fill the root zone will depend on the residual soil moisture and the moisture contributed by winter rains. Irrigations should be managed to avoid standing water around the trees.

Post Harvest - If leaves are remaining on the trees, an irrigation immediately after harvest replaces moisture which goes into bud differentiation during the period between September and November.

WATER BUDGETING:

Average Seasonal ET (N/C/S)	2.9/2.9/2.6'
Average Effective Precipitation	0.2'
Average Salinity Control	0.3'

Water Use-in.*	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Northern		0.1	1.0	3.2	5.4	6.9	7.8	5.7	3.1	1.4			34.6
Central		0.1	1.2	3.5	5.7	7.3	7.9	5.5	2.9	1.2			35.3
Southern		0.1	1.1	5.1	5.1	6.5	7.0	4.8	2.4	0.9			31.1
Deliveries-%				10	20	25	25	20					100
Trees irrigated with micro-irrigation system.													

Last updated April 2002

Barley Crop Data Sheet

BarleyWater Management
PLANT: November 15 - January 15

SOIL: Coarse and Fine Textured
HARVEST: June

EFFECTIVE PRECIPITATION: The portion of the rain that satisfies a part of the crop water use will depend primarily on the amount of plant cover. The rain during December and January is only 35-50 percent effective because it can evaporate freely from the exposed soil surface. However, after mid-February, more than 75 percent of the rainfall may be effective. Historical data indicates approximately 1.4" (0.1') of the rainfall is effective before mid-February and approximately 2.2" (0.2') during the remainder of the season.

ROOT ZONE: During the first two months of plant growth, the effective root zone is limited to the top one foot of the soil profile. The maximum effective root zone on fine textured soil is about 4 feet and on coarse textured soil is about 4.5 feet.

ALLOWABLE DEPLETION: For fine textured soils the maximum allowed depletion should be limited to 50- 60 percent during the growing season and can be extended to 80-90 percent at harvest.
For coarse textured soils the maximum allowed depletion should be limited to 60- 70 percent during the growing season and can be extended to 90 percent at harvest.
STRESS SENSITIVE PERIODS: The primary stress sensitive periods are during boot and heading, but stress during tillering (shoots growing from the base of the stem) can reduce the number of heads.

IRRIGATION: First: Rainfall can normally carry a crop into March without an irrigation if the crop has been irrigated up or pre-irrigated, but if the lower portion of the soil profile is too dry to permit root extension, the maximum root zone can be restricted. The first irrigation should normally begin during mid-March to prevent stress during the last irrigation set if March happens to be dry. The March irrigation could be skipped if the effective rainfall in early March is greater than 2" but the next irrigation must be started early to allow time to get across the field.
Final: The date of the final irrigation depends on the amount of available moisture in the root zone, the amount of water that can be placed in the root zone by the irrigation, and the remaining water use between the date of the last irrigation and crop maturity.
As an example, during average years, an irrigation that refills the crop root zone on April 18, April 15 and April 11, in the northern, central and southern zones, respectively, could be expected to provide the 5.8" of water the crop normally consumes between the final irrigation and crop maturity. This final irrigation date would depend upon additional root-zone extension to provide part of the required soil moisture, for a mid-December plant date.

WATER BUDGETING:

Average Seasonal ET (N/C/S)	1.0/1.0/0.9'
Average Effective Precipitation	0.4'
Average Salinity Control	0.2'

Water Use-in.*	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Northern	0.1	0.7	3.2	5.2	2.0							0.1	11.3
Central	0.3	1.0	3.6	5.4	1.1							0.2	11.4
Southern	0.1	0.9	3.4	5.2	1.1							0.1	10.9
Deliveries-%			20	30								50	100
Note: Assumes mid-December plant.													

Last updated April 2002

Cotton Crop Data Sheet

Cotton Water Management
PLANT DATE: March 10 - May 15

SOIL: Fine and Mid Textured
DEFOLIATION: September 20

EFFECTIVE PRECIPITATION: Rain normally does not satisfy a portion of the water requirement during the growing season, but rainfall during the winter can contribute to pre-irrigation. However only 35-50 percent of the winter rainfall can be considered effective because the ground is not covered.

ROOT ZONE: Cotton grown on fine textured soils generally develops a maximum effective root zone of 4 to 5 feet. Cotton grown on coarser textured soils develops a maximum effective root zone of 5-6 feet. However, root zones may be limited by high water tables, compacted layers or high salinity.

ALLOWABLE DEPLETION: Fine textured soils do no release moisture to plants as readily as coarse textured soils. The moisture in coarse textured soils can be easily taken up by the cotton plant so that during the growing season the average depletion in the root zone may safely range from 60-70 percent before an irrigation without stressing the plant where fine textured soils have a recommended allowable depletion of 50-60 percent. With the increased use of growth regulators, less emphasis has been placed on regulating excessive vegetative growth with water stress.

Care should be taken when approaching the upper limits of depletion because a couple of hot or windy days just prior to a scheduled irrigation can seriously stress the plant. It is important to schedule each irrigation so that the allowable depletion for the last portion of the field to be irrigated is not exceeded. Coarse textured soil may be depleted to 80-90 percent at the time cotton is defoliated where the recommendation for fine textured soils is 80 percent.

STRESS SENSITIVE PERIODS: Severe water stress during bloom may lead to sizeable yield reductions.

IRRIGATIONS:

First: The first irrigation generally replaces water depleted from the top two feet of the soil profile. Delaying the first irrigation during a period of normal temperatures will limit fruiting and early growth. When temperatures are below normal, an early first irrigation may limit growth and fruiting because the additional water decreases soil temperatures.

Final: The date of the final irrigation depends on the amount of available moisture in the root zone, the amount of water than can be placed in the root zone by the irrigation and the remaining water use between the date of the last irrigation and crop maturity. The last irrigation must provide adequate soil moisture to fully develop those bolls expected to mature. As an example, during average years, an irrigation that refills the crop root zone on August 7 for fine textured soils and August 22 for coarser textured soils will provide the 9.5"/6.6" of water the crop normally consumes, respectively, between the final irrigation and defoliation.

WATER BUDGETING:

Average Seasonal ET (N/C/S)	2.0/2.1/1.9'
Average Effective Precipitation	0.1'
Average Salinity Control	0.3'

Water Use-in.*	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Northern				0.2	0.4	3.9	8.5	8.4	3.3				24.7
Central				0.2	0.5	4.4	9.0	8.5	2.8				25.3
Southern				0.2	0.5	4.1	8.3	7.3	1.9				22.2
Deliveries-%					10	15	30	25				20	100%
* Note: Assumes mid-April plant date.													

Last updated April 2002

Melon Crop Data Sheet

Melon Water Management
PLANT DATE: April - July

SOIL: Coarse and Fine Textured
HARVEST: June-September

EFFECTIVE PRECIPITATION: The portion of rain that satisfies a part of water use is normally insignificant.

ROOT ZONE: The effective root zone can extend to a depth of five feet in fine textured soils and to a depth of six feet in coarser textured soils.

ALLOWABLE DEPLETION: A practical allowable depletion is 50 percent in fine soils and 50-60 percent in coarser textured soils. The root zone of melons planted on the 80" beds that are normally used cannot be completely refilled by a furrow irrigation. This condition must be considered when probing the soil to determine the moisture status after the first irrigation.

IRRIGATION:
Pre-irrigation: Pre-irrigating 80" beds with sprinklers or 40" furrows and then reforming the furrows into 80" beds will insure that the entire bed has been uniformly wetted.

Seasonal: Three seasonal irrigations on fine textured soils that replace 2" of water in the crop root zone each will usually supply the crop with the 6" of water that is not placed in the root zone during pre-irrigation.
In coarser textured soils, frequent irrigations will be required because coarser textured soils have a low moisture-holding capacity. five seasonal irrigations, each replacing an average of 1.5" of water used by the crop, may be required because furrow irrigations cannot refill the entire root zone of melons grown on 80" beds.

WATER BUDGETING:

Average Seasonal ET (N/C/S)	0.9/0.9/0.8'
Average Effective Precipitation	0.0'
Average Salinity Control	0.1'

Water Use-in.*	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Northern					1.2	3.2	5.6	0.4					10.4
Central					1.3	3.6	5.5	0.2					10.6
Southern					1.2	3.3	4.2						9.2
Deliveries-%		30			20	40	10						100
* Note: Assumes May 1 plant date.													

Last updated April 2002

Safflower Crop Data Sheet

Safflower Water Management
PLANT DATE: February 15

SOIL: Coarse and Fine Textured
HARVEST DATE: August

EFFECTIVE PRECIPITATION: The average effective precipitation during the growing season is about 2" (0.2'). Rainfall during the winter may contribute to pre-irrigation.

ROOT ZONE: The effective root zone on coarser textured soils can exceed a depth of 15 feet under nonrestrictive soil conditions. Roots in fine soils can extend as deep as 10 feet in unrestrictive soil profiles

ALLOWABLE DEPLETION: A practical allowable depletion is 70 percent for coarser textured soils and 60 percent for fine textured soils.

STRESS SENSITIVE PERIODS: Severe water stress during bud and flowering stages will cause significant yield reductions.

IRRIGATION:
Pre-irrigation: A pre-irrigation is recommended to provide deep soil moisture during periods of high water use when water cannot be replaced in the soil as quickly as the crop extracts it. Safflower is commonly planted on shallow water table affected soils and in this case no pre-irrigation is needed.

Seasonal Irrigation: Prolonged irrigations should be avoided to minimize the possibility of rot. Safflower can use water from a perched water table if the quality is good. A water table may provide up to 50 percent of the seasonal crop water requirement.

WATER BUDGETING:

Average Seasonal ET (N/C/S)	1.9/1.9/1.8'
Average Effective Precipitation	0.2'
Average Salinity Control	0.3'

Water Use-in.*	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Northern		0.3	0.7	3.6	8.7	9.0	1.1						23.2
Central		0.3	0.9	4.1	9.2	8.5	0.4						23.4
Southern		0.3	0.9	3.8	8.3	7.8	0.3						21.3
Deliveries-%	15			20	35	30							100

Last updated April 2002

Sugarbeet Crop Data Sheet

Sugarbeet Water Management
PLANT DATE: November

SOIL: Coarse and Fine Textured
HARVEST DATE: August

EFFECTIVE PRECIPITATION: The portion of rain that satisfies a part of crop water use is insignificant.

ROOT ZONE: The effective root zone can extend ot 6 feet under non-restrictive conditions.

ALLOWABLE DEPLETION: A practical allowable depletion is 50 percent or less. Depleting the soil moisture at the end of the season just prior to harvest will not increase the sugar yield.

STRESS SENSITIVE PERIODS: Beets are very moisture sensitive during their early establishment period.

IRRIGATION: Beets can show wilt even when soil moisture is adequate during high climatic demand. The long growing season usually requires a large number of irrigations to satisfy the seasonal water requirement. Frequent irrigations are required on soil types with limited intake rates. Limited intake conditions can be characteristic of the soil or due to reuse of the furrows.

WATER BUDGETING:

Average Seasonal ET (N/C/S)	2.7/2.8/2.4'
Average Effective Precipitation	0.3'
Average Salinity Control	0.3'

Water Use-in.*	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Northern	0.1	0.3	1.0	3.6	7.7	8.5	8.2	2.4			0.4	0.2	32.1
Central	0.2	0.3	1.3	4.4	8.0	8.6	8.3	0.7			0.4	0.3	33.4
Southern	0.1	0.3	1.3	4.2	7.2	8.0	7.3	0.2			0.3	0.3	28.4
Deliveries-%				10	25	25	20				20		100
* Note: Assumed November 1 plant date.													

Last updated April 2002

Tomato Crop Data Sheet

Tomato Water Management
PLANT DATE: March - May

SOIL: Coarse and Fine Textured
HARVEST DATE: August - September

EFFECTIVE PRECIPITATION: Seed beds are usually prepared before the first of the year and planted as early in the year as possible. Germination is dependent upon soil temperature. A germination irrigation is not required if there is sufficient rain but this is exceptional.

ROOT ZONE: The effective root zone will extend to 5-6 feet in fine textured soils and to 6 feet in coarser textured soils, under non-restricting conditions.

ALLOWABLE DEPLETION: A practical allowable depletion is 50 percent, but since refilling irrigations are difficult to achieve while attempting to avoid mold during the latter part of the season, a workable strategy is to adjust the frequency to reflect the ability of an irrigation to replace water. This will maintain the water stored in the profile for use later in the season.

IRRIGATION: Deep moisture in the soil profile is important during the late season to meet the usual climatic demand and maintain yields. This deep water can come from a pre-irrigation or from the germination and/or crust softening irrigations required to insure proper emergence. These irrigations are usually inefficient.

Seasonal irrigations are typically small and frequent (5-8 days) due to the possibility of mold caused by wet beds and a lower soil intake rate as the furrows are reused. The most efficient water users will sprinkle until layby and then furrow irrigate with a tailwater recovery system.
Final-: The final irrigation must be scheduled to provide sufficient moisture until harvest and still allow the soil to be dry enough to support a mechanical harvester. The actual timing will depend upon the fruit holding characteristic of the variety and the amount of soil moisture remaining in the lower portion of the root zone.

WATER BUDGETING:

Average Seasonal ET (N/C/S)	1.6/1.7/1.4'
Average Effective Precipitation	0.1'
Average Salinity Control	0.3'

Water Use-in.*	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Northern				0.9	4.1	8.9	5.1						19.0
Central				1.0	4.6	9.5	4.3						20.0
Southern				0.9	4.1	8.4	3.6						17.1
Deliveries-%		10	10		25	45	10						100
* Note: Assumed April 1 emergence date for mid-season length variety.													

Last updated April 2002

Wheat Crop Data Sheet

Wheat Water Management
PLANT: November 15 - January 15

SOIL: Coarse and Fine Textured
HARVEST: June

EFFECTIVE PRECIPITATION: The portion of the rain that satisfies a part of the crop water use will depend primarily on the amount of plant cover. The rain during December and January is only 35-50 percent effective because it can evaporate freely from the exposed soil surface. However, after mid- February, more than 75 percent of the rainfall may be effective. Historical data indicates approximately 1.4" (0.11) of the rainfall is effective before mid-February and approximately 2.2" (0.2') during the remainder of the season.

ROOT ZONE: During the first two months of plant growth, the effective root zone is limited to the top one foot of soil profile. The maximum effective root zone on coarser textured soil is about 4-5 feet and about 4 feet on fine textured soils.

ALLOWABLE DEPLETION: Tor coarser textured soils the maximum allowed depletion should be limited to 60-70 percent during the growing season and can be extended to 90 percent at harvest. For fine textured soils the maximum allowed depletion should be limited to 50-60 percent during the growing season and can be extended to 80-90 percent at harvest.

STRESS SENSITIVE PERIODS: The primary stress sensitive periods are during boot and heading, but stress during tillering (shoots growing from the base of the stem) can reduce the number of heads.

IRRIGATION:
First: Rainfall can normally carry a crop into March without an irrigation if the crop has been irrigated up or pre-irrigated, but if the lower portion of the soil profile is too dry to permit root extension, the maximum root zone can be restricted.
The first irrigation should normally begin in early March for coarser textured soils or in mid-March for fine textured soils to prevent stress during the last irrigation set if March happens to be dry. The March irrigation could be skipped if the effective rainfall in early March is greater than 2" but the next irrigation must be started early to allow time to get across the field.

Final: The date of the final irrigation depends on the amount of available soil moisture in the root zone, the amount of water that can be placed in the root zone by the irrigation, and the remaining water use between the date of the last irrigation and crop maturity. As an example, during average years, an irrigation that refills the crop root zone on May 3 will provide the 6.0" of water the crop normally consumes between the final irrigation and crop maturity.

WATER BUDGETING:

Average Seasonal ET (N/C/S)	1.3/1.4/1.2'
Average Effective Precipitation	0.4'
Average Salinity Control	0.2'

Water Use-in.*	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Northern	0.1	0.8	3.2	5.2	5.8							0.1	15.3
Central	0.3	1.1	3.6	5.5	4.8							0.2	16.3
Southern	0.2	1.0	3.4	5.2	4.5								14.5
Deliveries-%			20	25	20							35	100
* Note: Assumed a mid-December plant date.													

Last updated April 2002

Irrigation System Evaluation

Efficient use of available water is essential because of a limited water supply and a serious drainage problem in a portion of the District. As early as 1986 Westlands Water District responded by increasing the resources devoted to its long-standing Water Conservation and Management Program.

These cost-sharing Programs, the Irrigation Improvement Program (IIP), 1986-1991, were sponsored by Westlands and DWR, through the Westside Resource Conservation District, and were designed to encourage farmers to utilize the services of approved, private-sector irrigation advisory teams to evaluate their irrigation systems and practices and to make water-conserving recommendations.

The goal of these Programs was to assist farmers in using less water without sacrificing optimum crop yields, thereby reducing the over-irrigation that percolates into the shallow groundwater table.

Irrigation system evaluations were performed by consultants early in an irrigation event and the information was reported as soon as possible. The intent was that the information gained from the evaluations would be available to the irrigation manager so that it might influence the irrigation in progress so that over application of irrigation water might be avoided and the efficiency would be improved.

The program was similar to the DWR Mobile Lab program, but the pre-irrigation and two seasonal irrigations were evaluated for each field enrolled. Mobile Lab services may be available to District water users for evaluations of irrigation system events and well pumps, on a cost-share basis. Check the website.

The District took the results of the many evaluations performed in the IIP and developed abbreviated procedures that were intended to provide a quick estimate of the irrigation system performance, but with less effort and detail.

These procedures have been implemented in web pages and are available on this site. These pages are intended to minimize the calculations involved and facilitate the evaluation of furrow and sprinkler irrigation systems. It is not known if these procedures apply outside of the local conditions of the District.

Irrigation Efficiency and Distribution Uniformity

Irrigation efficiencies are directly related to the uniformity of water application (distribution uniformity) on the individual fields. Furrow irrigated field distribution uniformity is directly related to the advance ratio and the average depth of water infiltrated per hour. Improvements in distribution uniformity of furrow irrigations will result from improvements in the advance ratio.

Distribution uniformity can be visualized as a potential efficiency when the amount applied in the low quarter just equals the soil moisture depletion. Even so, approximately one-eighth of the field still will be under-irrigated.

A value for a high distribution uniformity is 80 percent in production agriculture, and it is considered to be excellent for all irrigation methods. Only a few specialized cases may have higher potential distribution uniformities for actual field conditions throughout an entire year. Most of the very high irrigation performance values reported by the media have been from small acreage research plots using new equipment and input from many technical personnel.

On-farm conditions are large scale with competing management interests (equipment scheduling, spraying, etc.), and farmers must use economical equipment, all of which cannot be brand new.

With only a small amount (less than 12.5 percent of a field) of under-irrigation, the highest potential on-farm Irrigation Efficiency is equivalent to:

$$IE = DU \times [1-ML/100)]$$

Where:
DU = Distribution Uniformity
ML = Minor Losses (primarily on-farm conveyance losses) and Evaporation Losses

Evaporation losses vary with the method and frequency of irrigation, but conservatively equal 3 percent. Hand-move sprinklers typically have six to ten percent losses (from the plant surface and wind drift). Surface irrigation will have low soil surface evaporation losses (two percent) once the plant canopy is high. Micro-spray (a form of drip) on trees may have four to six percent losses.

Conveyance losses from ditch seepage equal about three percent based primarily upon ditch and pond seepage (conveyance) losses determined in studies by the District with furrow irrigation (Boyle Engineering Corporation, 1988). Even hand-move sprinklers have some losses due to worn gaskets and leaky pipe. Drip systems have losses due to line filling and emptying and due to lost filter back flush water.

Using these values, an estimated District-wide average Irrigation Efficiency, using excellent management and the proper equipment, would be:

$$IE = 80\% \times (1 - .06) = 75\%$$

The Annual Irrigation Efficiency is defined as:

$$AIE = (SMR + LR)/AW$$

where:

SMR is the soil moisture replacement,

LR is the leaching requirement,
AW is the applied water.

Rearranging,

$$AIE = SMR/AW + LR/AW$$

SMR/AW is the irrigation efficiency, not considering a leaching requirement, or this is the ability to replace water within the maximum root zone.

LR/AW is the portion of the applied water that must pass below the maximum root zone to maintain the salt balance.

We have calculated a District leaching requirement of four percent. So the maximum attainable would be:

$$AIE = 75\% + 4\% = 79\%$$

As deep percolation increases, irrigation efficiency decreases. Therefore, when deep percolation amounts are the least, the calculated irrigation efficiencies are the highest. Subsequently, when all the factors influencing distribution uniformity and irrigation efficiency are balanced, a 79 percent District-wide on-farm average Annual Irrigation Efficiency seems to be the maximum reasonably attainable. This level of performance is achieved on sprinkler/furrow irrigation systems with short furrows, but this is for a high value crop where the farmer has justified an intensive level of management and capital investment.

Furrow Irrigation Systems

The advance ratio is an important factor for managing a furrow irrigation system. Generally, water should get to the end of a furrow in less than 1/2 of the set time to achieve good distribution uniformity. Whether that should be as quickly as 1/4 of the set time would depend on the soil texture and conditions.

An irrigation system evaluation will help to more precisely determine the performance of an irrigation event. This section presents a simplified procedures to estimate the distribution uniformity, DU, and irrigation efficiency, IE. These procedures were developed from data collected on district fields for the Irrigation Improvement Program, 1985-1991. Their applicability outside of Westlands is unknown.

Soil characteristics and field conditions are major factors controlling the efficiency of furrow irrigation systems . Factors the farmer can readily vary or manage are: irrigation set time; furrow shape, roughness, and length; and furrow stream size:

- Irrigation set time is determined by furrow inflow rate, furrow shape, roughness, and length.

- Furrow conditions can be altered with torpedoes (heavy weights that are dragged in furrows to smooth, shape, and/or compact the soil). Torpedoes can reduce the differences in water infiltration rates between furrows in which tractor wheels have or have not traveled.
- Advance rates are influenced by both soil conditions and furrow inflow rates.

In most cases, tailwater reuse systems are essential to properly manage furrow irrigation systems so that the best distribution uniformity and irrigation efficiency may be achieved.

However, the economics of other cultural operations and irrigation system costs weigh heavily on any farmer's decision to use a little less water without decreasing net profit.

Simplified Procedures

The simplified furrow evaluation procedures basically involve collecting information on the inflow to the furrows and the times that it takes the water to reach mid-field, the end of the furrow and the set time. With this information you calculate the advance ratios and the applied water and estimate the DU and the IE for the field. A list of recommendations is provided to suggest a course of action to help you decide what can be done to improve the situation.

The evaluation begins by logging the water meter reading and time. A section is provided to calculate the rate of flow because the cubic feet per second (cfs) reading is the least accurate information on the meter. After, say an hour, take a second reading and calculate cfs by multiplying AF by 43,560 and dividing by the number of seconds. Multiply cfs by 450 to get gallons per minute (gpm).

Use the feel-method to determine the soil moisture depletion to the maximum root zone depth. This information should be recorded on the bottom of the evaluation worksheet. This information is important because this is the amount of water that needs to be replaced to refill the soil to field capacity. Be aware of situations where the whole root zone is not rewetted, such as mid-season tomato irrigations.

Enter the length and spacing of the furrows and the number of furrows being irrigated. Not all furrows will advance at the same rate. Typically wheel rows, where the tractor tires ran, will advance faster than non-wheel rows. Because of this the inflow to the wheel rows is typically smaller. Enter an estimate of the inflow to the typical wheel furrow and non-wheel furrow. An estimate can be made by filling a known volume container and measuring the time or using a plastic bag to catch the water in a period of time and pour the water into a measuring container.

Since the rows are advancing differently, the time at the mid-field point will be more of an average time for the set, as will be the time to the end of the field. If a cutback is made when the water gets out, note the time and new flow being used in the furrows. Note the time and water meter readings when the set is changed.

Other factors could affect the field DU, such as, set time differences and soil type differences, but these are not considered here.

Sprinkler Systems

Under low-to-moderate wind conditions, irrigations with well-maintained sprinkler systems can produce good pre-irrigation efficiencies, since the water application rate is controlled by the irrigation system and not by soil characteristics. Well-designed sprinkler systems must apply water at a rate that is less than the soil infiltration rate to minimize or eliminate runoff.

The amount of water applied by sprinkler irrigation systems is directly related to the set time. The set time is the period of time that water is applied with a specific irrigation system configuration.

Therefore, irrigation set time is a significant management factor. The set time can be varied so the water applied matches the soil moisture deficit. The interval between irrigations also can be varied to match the soil moisture deficit. Properly adjusting these two factors can result in optimum irrigation efficiency.

The management for set times that are not a multiple of 12 hours are not desirable since the lateral move times will constantly vary. It is possible to have an "effective" set time that is the desired set time but the laterals are actually changed on convenient 24 hour sets.

The method involves changing the move distance to produce the application rate that will apply the amount of water desired while moving on a 24 hour set. The table below presents a move distance that will give the equivalent hourly set, based on a standard 40 foot move, 24-hour set.

Hour Set	18	20	22	24	26	28
Move, Feet	53.3	48.0	43.6	40.0	36.9	34.2
Factor	0.75	0.83	0.92	1.00	1.08	1.17
Hour Set	30	32	34	36	38	40
Move, Feet	32.0	30.0	28.2	26.7	25.3	24.0
Factor	1.25	1.33	1.42	1.50	1.58	1.67

Note that the distribution uniformity will vary with the move distance. In general, as the move distance increases the uniformity tends to decrease, but this varies with the wind speed. Moves over 40 feet must take this into consideration. Realize also that the number of moves increases as the move distance decreases. The reduction in water cost will offset this increase in labor costs.

The factor presented is used to determine the amount of water applied. Multiply the depth applied by the system with 40 foot moves by this factor to determine the new depth applied. As the amount of water applied in a 24 hour set goes increases, the rate of application increases, which can exceed the ability of the soil to infiltrate water, causing runoff. The width of the beds will determine the number of beds for each set move. With 40 inch beds an equivalent 36 hour

set will move 8 beds where a 24 hour set would move 12 beds. The new number of beds to be moved can be determined by dividing the old number of beds by the factor.

Simplified System Evaluation

This worksheet is based on a previous Water Conservation Program work-sheet.

Six Easy Steps to Optimum Sprinkler System Operation

A one percent increase in sprinkler system field distribution uniformity (DU) can result in nearly a one percent savings in water. By using this worksheet, you will be able to determine with reasonable accuracy the field DU and necessary set time of your sprinkler system as currently operated. You also can estimate the effects of any changes you choose to evaluate. The worksheet will guide you in combining the factors that have the greatest effects on sprinkler system DU (http://cwi.csufresno.edu/wateright/duie.asp) to arrive at your system's DU. The field DU can then be applied to the system's flow rate to determine optimum set time.

Getting Started

Most of the necessary information to complete an evaluation can be gathered in less than one hour by inspecting you system in operation. With the water off, use a feeler gauge or drill bit to measure nozzle orifices for sand wear and check for mixed sizes. You will also need a gauge with a pitot tube to take water pressure measurements at the beginning and the end of your pipeline and laterals. The remaining information, lateral spacing, leakage, non-rotating sprinklers, and plugged nozzles should be readily apparent. The only other requirements are a clipboard and a sharp pencil.

Fill in the Blanks

Once you've gotten your boots muddy and your overalls wet, it is time to sit down and enter the data. This evaluation page can be completed in less than 15 minutes. This page will do the work that previously required referring to several easy-to-use charts and graphs to determine DU reduction factors, including pressure uniformity and miscellaneous losses. After these factors are multiplied together, you will arrive at an estimated field DU.

The Results: Set Time, Trouble Spots, Dollars

Once you know the field DU, you can easily calculate the required set time for a given irrigation, thus, maximizing irrigation efficiency. Trouble spots will also be apparent so that system repairs and improvements can be considered based on their relative value compared to other available options. You can now convert water savings to dollar savings.

Note: The equipment required to measure pressures at the sprinkler head is a Pitot Tube attached to a Liquid Field Pressure Gauge. One possible source is the Rainbird part number A90917 and D22810, respectively. This reference is given because it is readily available and no recommendation is intended.

You can link to the worksheet page and use it in place or save this page from your internet browser for later use offline, without being connected to the web site. The results of this worksheet can be printed right from the browser.

Drip/Trickle Systems

Drip/trickle systems often are perceived to be the most efficient irrigation systems available. However, the few systems analyzed in this program were used on trees and had lower distribution uniformities than the average of the other types of systems.

While the efficiencies were significantly better than the other systems in this study, it appears to have been achieved by under-irrigation since the distribution uniformities were considerably less than the efficiencies.

Drip systems do not reduce the crop water requirement, but usually increase evapotranspiration because water is applied frequently in small quantities. Drip/trickle systems usually require more careful management than other irrigation systems.

The following equations are after the Hardie Irrigation Micro-Irrigation Design Manual (1984). Drip emitters are classified as either a laminar flow or turbulent flow. Flow through an emitter is described in the following equation:

$$Q = Kd\ (H)^X$$

where:

Q = Flow Rate (gph)
H = Operating Pressure (psi)
Kd = Flow Coefficient
X = Flow Coefficient

The flow exponent will range from 0 to 1.0. The lower the exponent, the more pressure compensating is the emitter, with zero as fully compensating.

Uniformity

Since the pressure is the variable in the equation, the Emission Uniformity (EU) is the measure of the performance of the system. The EU is related to the manufacturer's coefficient of variation for the emitters (variation in the manufacturing process) and the variation in the flow rates in the various parts of the system.

$$EU = (1-1.27Cv/\ (n)^{0.5})\ (Q_m/Q_a)$$

where:

n = For a point-source emitter on a permanent crop, the number of emitters per plant. For a line-source emitter on a annual crop, either the spacing between plants divided by the same unit length of lateral line used to calculate C_v, or 1, whichever is greater.

C_v = The manufacturer's coefficient of variation for point or line-source emitters, expressed as a decimal. C_v is typically less than .10, but can vary up to .40.

Q_m = The minimum emitter flow rate for the minimum pressure Hm in the system in gph

Q_a = The average, or design, emitter flow rate for the average or design pressure Ha in gph.

This equation is used by the designer to design to a specific level of performance. A system cannot be more uniform that it was designed to be. An evaluation will attempt to establish the current EU, given aging of the system and other factors that degrade the system performance.

The EU equation can be written in terms of pressures as follows:

$$EU = (1-1.27Cv/ (n)^{0.5}) (H_m/H_a)^X$$

Where the variables are as defined above. Note that with a perfect pressure compensating emitter the EM is dependent only on the coefficient of variation for the manufacturing process.

These two equations suggest two methods that a system EU could be evaluated:

1. Measure flow rates.
2. Measure pressures.

With a buried system it might be more practical to measure pressures. With point emitters on the surface it might give better information to measure flows from individual emitters.

It is not that easy since distribution pressures would help explain differences in flow rates, and additional information, X, is needed to use measured pressures and the original X may not still be the value. Pressure test points, Schrader valves, on the distribution are important to setting up the pressure regulators for the individual irrigation blocks.

The EU can be thought of as a distribution uniformity (DU), which is the amount applied at the point receiving the least water to the average amount applied. In other systems distribution uniformity is usually defined in relation to the average amount applied to the quarter of the field receiving the least amount of water. Thus the standard DU for the system will be higher than the EU. The EU is more stringent, since no part of the field would be under-irrigated, where 1/8 of the field would be under-irrigated if the standard DU definition was utilized to describe the uniformity. Even though more water is applied to refill the same depletion using the EU, the EU values possible with a micro-irrigation system are higher than the DU for most other systems, so the net result can be better with a well maintained micro-irrigation system. EU = 0.9 are typically used for a new system design and could be designed for values up to 95 percent, but

field topography can cause design values to be as low as 75 percent. Cost for systems in varied topography is usually higher to achieve the pressure regulation necessary for high EU.

Drip/Trickle Systems, Evaluation

System evaluations are necessary because system components do not maintain a constant performance with age. This performance is not just related to age of the materials used to manufacture the components, but can be greatly affected by contaminants introduced during the operation of the system. Proper maintenance is very important and can significantly increase the life and efficiency of the system.

A proper evaluation does not just look at the emitter performance, but it must consider all components from the filtration system, to the pressure regulation in the distribution system, to the lateral lines and the emitters. An evaluation must look at the pressure distribution throughout the entire system. The District may have a Mobil Lab program that can perform these services and consultants are also available.

Appendicies

Definitions of Irrigation Terms

Acre-Foot (AF): The volume of water required to cover one acre to a depth of one foot (43,560 cubic feet). An acre-foot equals 325,851 U.S. gallons.

Advance Ratio (AR): For furrow irrigation, the ratio of the total time irrigation water is applied to the furrow (set time) to the time needed for irrigation water to reach the lower end of a sloping furrow (advance time).

$$AR = \frac{SetTime}{AdvanceTime}$$

Annual Distribution Uniformity (ADU): *See "Distribution Uniformity."*

Annual Irrigation Efficiency (AIE): *See "Irrigation Efficiencies."*

Applied Water (AW): Water applied to a field by irrigation, excluding the tailwater which runs off the field and is collected for reuse in the irrigation of another field on that farm, expressed as a depth of water in inches or feet.

Available Soil Moisture: The difference in soil moisture content between Field Capacity and Permanent Wilting Point. This represents the moisture which can be stored in the root zone for use by crops, expressed as a depth of water in inches or feet (*Israelson & Hanson, 1979*).

Beneficially Used Water (BU): Irrigation water used to satisfy a portion or all of the following: evapotranspiration, leaching requirement, special cultural practices, and/or water stored in the soil for use by crops, expressed as a depth of water in inches or feet (*ASAE, 1988; Burt, et al., 1988*).

Conservation: ". . . planned management of a natural resource . . . ." (*Webster's New World Dictionary, 1989*).

Crop Root Zone: The soil depth from which a mature crop extracts most of the water needed for evapotranspiration. The crop root zone is equal to effective rooting depth and is expressed as a depth in inches or feet. This soil depth may be considered as the rooting depth of a subsequent crop, when accounting for soil moisture storage in efficiency calculations (*Burt, et al., 1988*).

Crop Water Requirement (CWR): The infiltrated water required to grow a crop, expressed as a depth of water in inches or feet (*Burman, et al., 1981*).

$$CWR = ET - EP + LRD + CP$$

Cultural Practices (CP): Irrigation water which is used for necessary farming practices such as soil reclamation, climate control, crop quality, and weed germination, expressed as a depth of water in inches or feet (*Burt, et al., 1988*).

Deep Percolation (DP): The amount of irrigation water that flows below the crop root zone and is unavailable for evapotranspiration, expressed as a depth of water in inches or feet (*Merriam*

& Keller, 1978).

Depth of Water: The depth of a volume of water spread over a given area, expressed as a depth of water in inches or feet.

Distribution Uniformity (DU): The ratio of the average low-quarter depth of irrigation water infiltrated to the average depth of irrigation water infiltrated, expressed as a percent (*ASAE, 1988*).

Effective Precipitation (EP): That portion of rainfall that contributes to satisfying the evapotranspiration and/or leaching requirement of a crop, expressed as a depth of water in inches or feet (*Burman, et al., 1981*).

Electrical Conductivity (EC): The property of a substance to transfer an electrical charge and a measure of the salt content of water. EC_w is the term used as a measure of the salt content of irrigation water, ECe is the term used as a measure of the salt content of an extract from a soil when saturated with water, expressed as decisiemens per meter (dS/m) (*Doorenbos & Pruitt, 1984*).

Evapotranspiration (ET): The amount of water loss over a period of time through transpiration from vegetation and evaporation from the soil, expressed as a depth of water in inches or feet (*Doorenbos & Pruitt, 1984*).

Evapotranspiration of Applied Water (ETAW): The portion of the total crop evapotranspiration that is satisfied by applied water, expressed as a depth of water in inches or feet (*Central Valley Water Use Study Committee, 1987*).

Evapotranspiration Potential (ETP): Evapotranspiration potential is a value calculated with a modified Penman equation and is equal to daily alfalfa evapotranspiration when the crop occupies an extensive surface; is actively growing, standing erect, and at least eight inches tall; and is well watered so that soil water availability does not limit evapotranspiration, expressed as a depth of water in inches or feet (*Burman, et al., 1980*).

Field Capacity: Depth of water retained in the soil after ample irrigation or heavy rain when the rate of downward movement has substantially decreased, usually one to three days after irrigation or rain, expressed as a depth of water in inches or feet (*Doorenbos & Pruitt, 1984*).

Groundwater Table: The upper boundary of groundwater where water pressure is equal to atmospheric pressure, i.e., water level in a bore hole after equilibrium when groundwater can freely enter the hole from the sides and bottom (*Doorenbos & Pruitt, 1984*).

Infiltration Rate: The rate of water entry into the soil expressed as a depth of water per unit of time in inches per hour or feet per day. The infiltration rate changes with time during irrigation (*Burt, et al., 1988*).

Irrigation Efficiencies: Irrigation efficiencies are used to determine the efficiency of replacing moisture in the soil profile and may be calculated for single or multiple irrigations and are the ratio of the depth of water stored to the depth of applied water. The equations for single and multiple irrigations are as follows:

<u>Pre-irrigation Efficiency (PIE)</u>: This definition is used to calculate the efficiency of an on-farm pre-irrigation and is the ratio of the sum of the depth of water used for soil

moisture replacement and cultural practices to the depth of applied water, expressed as a percentage (*Burt, et al., 1988*). No leaching requirement is included.

$$PIE = \frac{SMR_1 + CP_1}{AW_1} x100$$

Regular Season Irrigation Efficiency (RIE): This definition is used to calculate the efficiency of one or more regular season on-farm irrigations and is the ratio of the sum of the depth of soil moisture replacement water and water used for cultural practices for each irrigation after the pre-irrigation to the sum of the depths of water applied during these irrigations, expressed as a percentage. No leaching requirement is included (*Burt, et al., 1988*).

$$RIE = \frac{SMR_2 + CP_2 + SMR_3 + CP_3 + \cdots + SMR_n + CP_n}{AW_2 + AW_3 + \cdots + AW_n} x100$$

Annual Irrigation Efficiency (AIE): This definition is used to calculate the efficiency of all on-farm irrigations and is the ratio of the sum of the depth of soil moisture replacement water and water used for cultural practices for all irrigations plus the water to satisfy the seasonal leaching requirement to the sum of the depths of water applied during all irrigations, including the pre-irrigation, expressed as a percentage (*Burt, et al., 1988*).

$$AIE = \frac{SMR_1 + CP_1 + SMR_2 + CP_2 + \cdots + SMR_n + CP_n}{AW_1 + AW_2 + \cdots + AW_n} x100$$

Where n = total number of irrigations, n = 1 is the pre-irrigation.

Leaching Fraction (LF): The ratio of deep percolation V_{dp} to infiltrated irrigation water V_{iw}. It is the fraction of water that enters the root zone by irrigation that is not used in ET and which passes below the root zone as deep percolation (*Rhoades, 1991*).

$$LF = V_{dp}/V_{iw}$$

Leaching Requirement (LR): The theoretical amount of infiltrated irrigation water that must pass (leach) beyond the root zone in order to keep soil salinity within acceptable levels for sustained crop growth. Different models may be used to estimate LR. For uniform and no rainfall conditions, a simple estimate is:

$$LR = \frac{EC_w}{5EC_e - EC_w}$$

Where EC_w is the electrical conductivity of the infiltrated irrigation water and EC_e is the maximum EC of the saturated extract of the soil tolerable (not causing significant yield loss) by the crop in question. Actual leaching needed for salinity control may be more or less than this estimate dependent upon uniformity of irrigation/infiltration and amount and distribution of rainfall, respectively.

Leaching Requirement Depth (LRD): The depth of water corresponding to the leaching requirement including extra water for non-uniformity in distribution.

$$LRD = \frac{ETAW}{(DU \div 100)} x \frac{LR}{(1 - LR)}$$

Low Quarter Depth: The average depth of water infiltrated into the quarter of the field infiltrating the least amount, expressed in inches or feet.

Minor Losses (ML): Water losses due to evaporation during irrigation, uncollected surface runoff from the field, and on-farm conveyance and storage systems expressed as a depth of water in inches or feet.

Permanent Wilting Point (PWP): The moisture remaining in a soil at a uniform soil moisture tension of about -15 bars of atmospheric pressure, which is the approximate tension at which plants irreversibly wilt due to moisture stress, expressed as a depth of water in inches or feet.

Pre-irrigation: An irrigation that occurs prior to the planting of a crop.

Pre-irrigation Efficiency (PIE): See "Irrigation Efficiencies."

Regular Season Irrigation Efficiency (RIE): See "Irrigation Efficiencies."

Salt Balance: The condition when the amount of salts added to a soil profile through irrigation and the amount removed by leaching are equal (i.e., no net gain nor loss of salt in the crop root zone). This balance will be established if adequate leaching occurs each year; the average root zone salinity at equilibrium will depend upon the amount of leaching and the quality of the applied water (*Hoffman, et al., 1980*).

Seasonal Application Efficiency (SAE): This term measures the efficiency of applied irrigation water based on crop water requirements, where evapotranspiration is estimated using a modified Penman equation and crop coefficients and is expressed as a percentage.

$$SAE = \frac{BU}{AW} x100 = \frac{CWR}{AW} x100$$

$$CWR = ET - EP + LRD + CP$$

Soil Moisture Deficit (SMD): The amount of water needed to refill the crop root zone to field capacity at the time of irrigation, expressed as a depth of water in inches or feet (*Westlands Water District, 1985*).

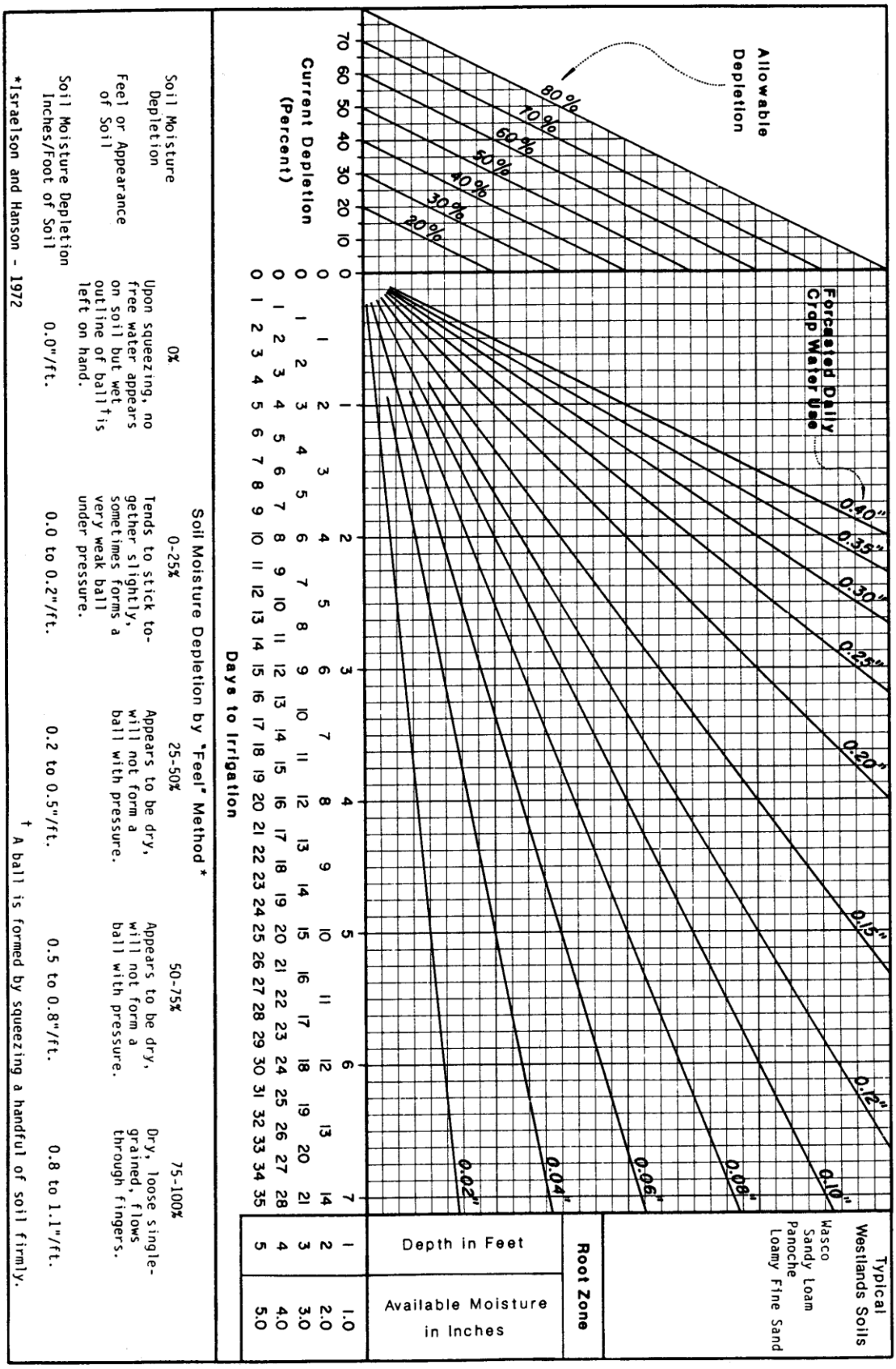
Soil Moisture Replacement (SMR): The amount of water that is used to replace a portion or

the entire soil moisture deficit, expressed as a depth of water in inches or feet.

Tailwater: Applied irrigation water that runs off the lower end of a field. Tailwater is the average depth of runoff water, expressed in inches or feet.

Under-irrigation (UI): The difference between the water actually stored in the crop root zone during irrigation (soil moisture replacement) and the water needed to refill the root zone to field capacity (soil moisture deficit) in all or part of the field, expressed as a depth of water in inches or feet.

Graphic Scheduling Sheets



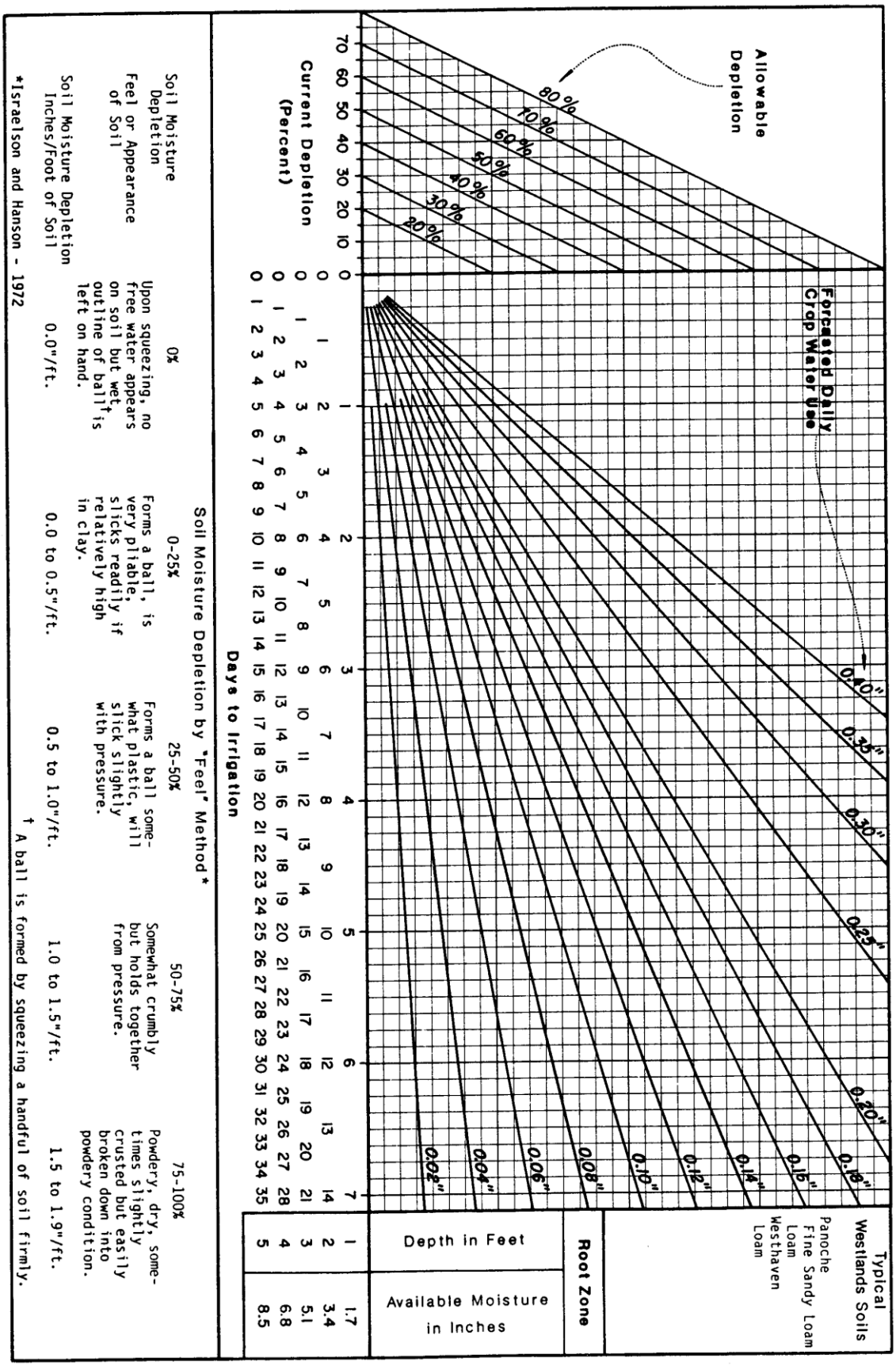
Soil Moisture Depletion by "Feel" Method *

Soil Moisture Depletion	0%	0-25%	25-50%	50-75%	75-100%
Feel or Appearance of Soil	Upon squeezing, no free water appears on soil but wet, outline of ball† is left on hand.	Tends to stick together slightly, sometimes forms a very weak ball under pressure.	Appears to be dry, will not form a ball with pressure.	Appears to be dry, will not form a ball with pressure.	Dry, loose single-grained, flows through fingers.
Soil Moisture Depletion Inches/Foot of Soil	0.0"/ft.	0.0 to 0.2"/ft.	0.2 to 0.5"/ft.	0.5 to 0.8"/ft.	0.8 to 1.1"/ft.

*Israelson and Hanson - 1972

† A ball is formed by squeezing a handful of soil firmly.

Soil Type: Coarse



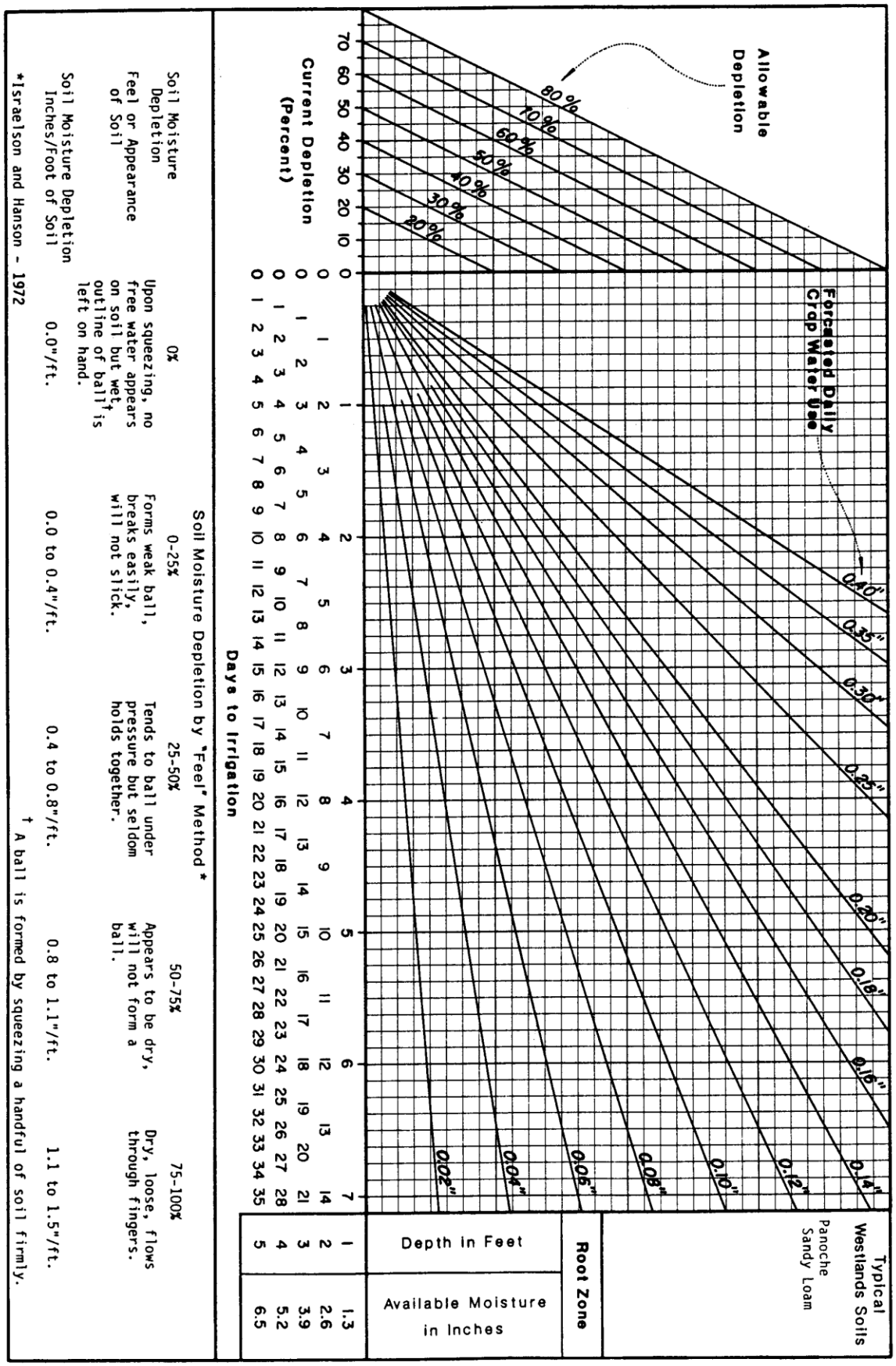
Soil Moisture Depletion by "Feel" Method*

Soil Moisture Depletion	0%	0-25%	25-50%	50-75%	75-100%
Feel or Appearance of Soil	Upon squeezing, no free water appears on soil but wet outline of ball† is left on hand.	Forms a ball, is very pliable, slicks readily if relatively high in clay.	Forms a ball somewhat plastic, will slick slightly with pressure.	Somewhat crumbly but holds together from pressure.	Powdery, dry, sometimes slightly crusted but easily broken down into powdery condition.
Soil Moisture Depletion Inches/Foot of Soil	0.0"/ft.	0.0 to 0.5"/ft.	0.5 to 1.0"/ft.	1.0 to 1.5"/ft.	1.5 to 1.9"/ft.

*Israelson and Hanson - 1972

† A ball is formed by squeezing a handful of soil firmly.

Soil Type: Fine



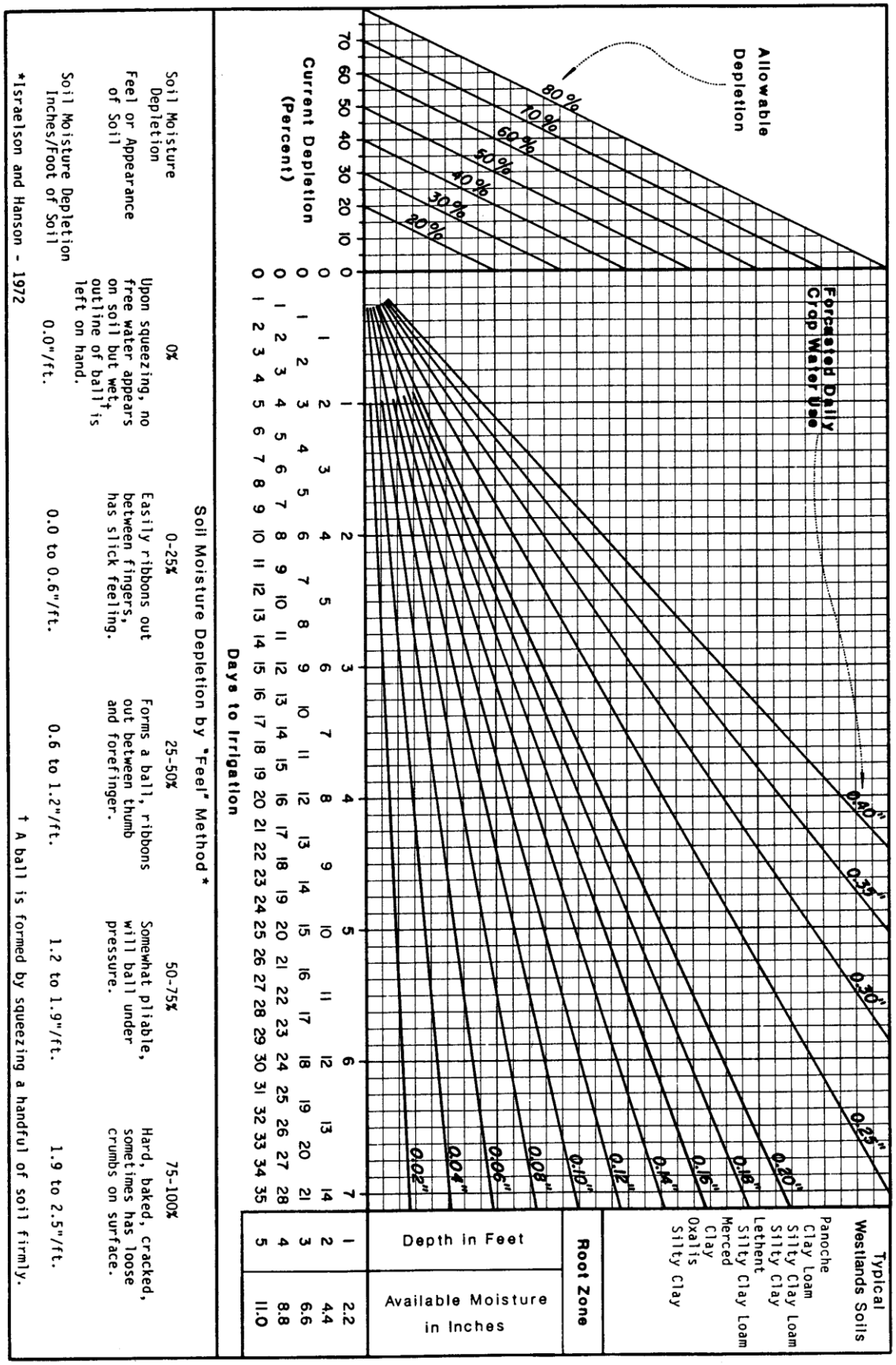
Soil Moisture Depletion by "Feel" Method *

Soil Moisture Depletion	0%	0-25%	25-50%	50-75%	75-100%
Feel or Appearance of Soil	Upon squeezing, no free water appears on soil but wet outline of ball† is left on hand.	Forms weak ball, breaks easily, will not slick.	Tends to ball under pressure but seldom holds together.	Appears to be dry, will not form a ball.	Dry, loose, flows through fingers.
Soil Moisture Depletion Inches/Foot of Soil	0.0"/ft.	0.0 to 0.4"/ft.	0.4 to 0.8"/ft.	0.8 to 1.1"/ft.	1.1 to 1.5"/ft.

*Israelson and Hanson - 1972

† A ball is formed by squeezing a handful of soil firmly.

Soil Type: Medium



Soil Moisture Depletion by "Feel" Method *

Soil Moisture Depletion	0%	0-25%	25-50%	50-75%	75-100%
Feel or Appearance of Soil	Upon squeezing, no free water appears on soil but wet, outline of ball† is left on hand.	Easily ribbons out between fingers, has slick feeling.	Forms a ball, ribbons out between thumb and forefinger.	Somewhat pliable, will ball under pressure.	Hard, baked, cracked, sometimes has loose crumbs on surface.
Soil Moisture Depletion Inches/Foot of Soil	0.0"/ft.	0.0 to 0.6"/ft.	0.6 to 1.2"/ft.	1.2 to 1.9"/ft.	1.9 to 2.5"/ft.

*Israelson and Hanson - 1972

† A ball is formed by squeezing a handful of soil firmly.

Soil Type: Very Fine