WATER – OUR MISSION FOR 75 YEARS

Santa Clara Valley Water District

The Santa Clara Valley Water District

Handbook for Agricultural Water Use Efficiency

Funding for this project has been provided in part by the U.S. Environmental Protection Agency (USEPA) pursuant to Assistance Agreement No. C9-97968201-0 and any amendments thereto which have been awarded to the State Water Resources Control Board (SWRCB) for the implementation of California's Nonpoint Source Pollution Control Program. The contents of this document do not necessarily reflect the views and policies of the USEPA or the SWRCB, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

The Santa Clara Valley Water District

Handbook for Agricultural Water Use Efficiency

In Santa Clara County, as in the rest of California, water and water-pumping costs are important considerations for the agricultural industry. Efficient irrigation methods and scheduling are the keys to maximizing water and fertilizer use efficiency.

This handbook describes how to integrate into your operations the tools that are available to you as a Santa Clara County grower:

1. **Irrigation system fitness and distribution uniformity**
2. **Irrigation scheduling and evapotranspiration**
3. **Soil moisture monitoring**
4. **Setting irrigation run times**

1 Irrigation System Fitness and Distribution Uniformity

Evaluate and tune up your irrigation system so it is capable of performing as it was designed

DU is the foundation for irrigation efficiency. It sets the limits on the water use efficiency you can achieve through irrigation scheduling. Having a good DU is like having the proper tool for a job.

Irrigation systems decline in performance over time and need periodic tune-ups. To gauge how your system is performing, you need to test the system to determine how far its performance departs from a perfectly uniform distribution of water across all the plants in the field. This test will give you a number known as the Distribution Uniformity, or DU. Once we know the DU, corrective measures can be taken to improve water use efficiency, and we can use it to help schedule irrigations.

To obtain a DU for an irrigation system, the outputs and/or pressures from a number of sprinklers or emitters must be measured and recorded. Two averages are calculated from these records: the average of all the measurements, known as the global average, and the average of the lowest 25% of measurements, known as the low-quarter average. The DU is the ratio of these two averages and is always a number less than 1. (The DU is often multiplied by 100, and expressed as a percentage.)

$$\text{DU} = \frac{\text{Average of lowest 25\% of measurements}}{\text{global average}}$$

The DU estimates the relationship of the driest quarter of your field to the entire field. For example, if your DU is 0.75, the driest quarter of your field is getting 75% of the water that the whole field is getting on average. In other words, on the basis of the whole field average, if your irrigation was exactly replacing not only the water used by the crop, but also the water used in evaporation and drainage, the driest quarter of your field would be 25% short of water.

Consequently, the DU can be used as a guide to increase your irrigation run time to make sure the driest part of the field receives an adequate amount of water. If you calculate that four hours run time is required to replace average water used over the whole field, then dividing four hours by the DU will give you the corrected run time you need to ensure the driest quarter of the crop gets enough water:

$$\text{Corrected run time} = \frac{\text{Run Time}}{\text{DU}}$$

Using our example:

$$\text{Corrected run time} = \frac{\text{4 hours}}{0.75} = \text{5.33 hours}$$

Excellent real world DUs are:

- 75% for hand move and side roll sprinklers
- 94% for drip or microsprinklers in trees or vines
- 92% for row crop drip
- 95% for solid set under tree sprinkler systems

Your systems are performing well if their DUs are close to these numbers.

Note: Most growers irrigate to the driest parts of their fields; however, you should not apply the DU to irrigation decisions without considering other factors, such as evapotranspiration and soil moisture. These are discussed in subsequent sections.

The easiest way to figure out your system's DU is to request a free irrigation system evaluation by the Regional Ag Mobile Lab (contact information is on the inside back cover)

Low DUs indicate a waste of both water and power

The lower a DU, the more water must be pumped to adequately irrigate the driest quarter of a field.

Figure 1 illustrates the increase in the amount of water required as the DU decreases. In this example, as the DU decreases from 90% to 60%, the amount of water required to irrigate this field increases from 7.3 acre-inches* to 11 acre-inches (a 38% increase).

This increase also means a 38% increase in energy costs and a 38% increase in groundwater withdrawal fees.

*1 acre-inch = 27,154 gallons, the amount of water that will cover an acre with one inch of water.

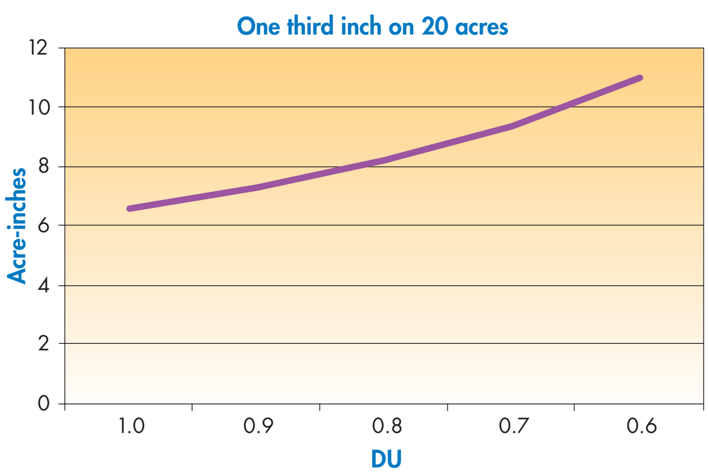


Figure 1: *Water required in acre-inches to irrigate a 20-acre field so that the driest quarter receives one third inch.*

Payback

This is an obvious example where a more efficient irrigation system will save significant water and money. Compared to a DU of .90, a DU of .75 requires 20% more water to make sure the driest part of the field is irrigated adequately. A DU of .60 requires 50% more water compared to a DU of 0.90.

Irrigation system analyses in Santa Clara County show **the major cause of low DUs in row crop drip systems** is pressure variation. This can be improved by balancing the system — roughly a half day's work for two workers on a 20-acre field.

Additional savings come through the reduced amount of fertilizer necessary on properly irrigated fields. An over-irrigated field, for example, will require more fertilizer to make up for the loss of nutrients leached below the root zone. An efficiently irrigated field needs less fertilizer to reach maximum yield.

Most improvements made to irrigation systems to increase DUs will have a single season payback if they are done at the start of the season.

The **major causes of a low DU in hand-move sprinkler systems** are:

- Irrigating in the wind
- Spacing laterals too far apart
- Running too many laterals at once
- Worn nozzles

Replacing nozzles or running an extra set is inexpensive. Replacing nozzles will definitely pay back in the same season. Whether running an extra set will pay off depends on how bad your DU was to start with. Water District staff can help you figure that out. Of course, improving your DU will also allow you to trim your run times, thus saving even more water.

Pump Efficiency

The impact of DU on energy consumption is compounded by pump inefficiencies.

Figure 2 shows the effect of DU on the amount of energy used to pump water. The irrigation volume is the same as the previous example: one-third inch irrigation on 20 acres. The energy consumption numbers are based on South Santa Clara County averages: a pumping water level of 45 feet with the pump producing 30 pounds of pressure, and using 195 kilowatt-hours (kW-h) to pump an acre-foot of water.

The three lines on the graph show the effect on kW-h consumption for three different pump efficiencies. As the DU decreases, the energy requirement increases.

- At 60% pump efficiency (purple line), as the DU decreases from 0.9 to 0.6, energy consumption increases 50% (from about 119 kW-h to 179 kW-h.)
- At 50% pump efficiency, (green line), we see another 50% increase in energy consumption. Only this time, the increase in energy consumption is from 143 kW-h to 215 kW-h.
- At 40% pump efficiency (blue line) the energy consumption is even greater.

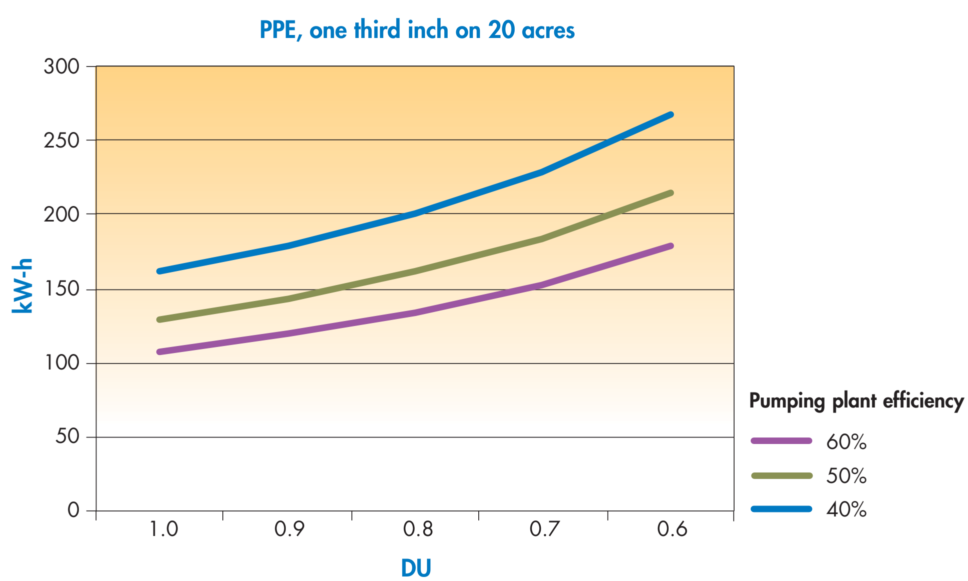


***Figure 2:** The effect of pumping plant efficiency and DU on energy consumption to irrigate one third inch on 20 acres.*

The worse shape your pump is in, the more a poor DU will cost in terms of energy consumption.

The payback calculations for a more efficient pump are not as obvious as those for replacing sprinkler nozzles or for balancing pressures on a drip system. Two or three tests over five years will give you an estimate of the rate your pump is declining, and will give you enough information to budget for a replacement.

Note: A common strategy is to schedule a replacement when the improvement in energy consumption is sufficient to pay off the pump in three years.

Performing a pump test will also help you find out if you can get by with simply trimming or adjusting the impellers in your present pump so you can run at lower flow rates and pressures if you switch to drip or microsprinklers. This may enable you to avoid the cost of changing your pump at the same time you are buying a new irrigation system.

Mobile Lab provides free irrigation and fertilization management assistance

The Regional Ag Mobile Lab provides free services in Santa Clara, San Benito, Santa Cruz, Monterey, and San Mateo counties to help improve agricultural irrigation and fertilizer management.

- Pump efficiency testing
- Irrigation system efficiency
- Assistance with fertilizer decisions and scheduling assistance

Participation in the program will provide you with data for your farm plan and agriculture waiver compliance.

For more information, contact the Ag Mobile Lab at (800) 675-6602. http://www.agmobilelab.org

2 Irrigation Scheduling and Evapotranspiration (ET_O)

Produce a crop without over- or under-irrigating

Irrigation scheduling addresses how much and when to irrigate to achieve maximum water use efficiency. Water use efficiency in this context is generally understood to mean maximizing the amount of marketable crop produced per unit of water consumed.

"Marketable crop" will mean something different to a wine grape grower than to a pepper grower, and something different again to a grower trying to harvest into a window of opportunity. A grower of fava beans or peppers may be trying to maximize yield, while a grape grower may be trying to maximize grape quality and may not use enough water to produce the greatest yield possible.

The amount of water used by any specific crop, from radishes to pecans, can be related to the amount of water used by a reference crop. The reference crop typically is grass or alfalfa that is well irrigated and covers 100% of the ground.

The reference crop's water consumption is called "reference evapotranspiration," and abbreviated ET_O.

ET_O includes the water evaporated from the soil surface and the water used (transpired) by the plant.

To relate the ET_O to a specific crop's water use, you must multiply the reference ET_O by *adjustment coefficients*.

The first adjustment is called the "crop coefficient," abbreviated K_C. The K_C adjusts the ET_O to account for the difference between the inherent water-using characteristics of the specific crop compared to the reference crop. This adjustment may be upward or downward, because the crop may use more or less water than the reference crop. For example, the K_C for stone fruits without ground cover is 0.95, and the K_C for bell peppers is 1.05.

Daily reference ET_O results for the previous seven days are available on the Santa Clara Valley Water District website (http://www.valleywater.org/Water/Water_in_agriculture), and on the California Irrigation Management Information System (CIMIS) website from the California Department of Water Resources (DWR) (http://wwwcimis.water.ca.gov/cimis/data.jsp) The DWR site contains historical data, and is also useful for checking the weather in other growing districts around the state.

A second adjustment is called “Kground cover”, and is abbreviated K_G. The K_G accounts for the difference between the portion of ground covered by the crop compared to the reference crop, which covers 100% of the ground. Since the amount of ground covered by the crop will increase as the crop grows, this number will change quite a bit in the early part of the season.

Two ways to figure out your crop’s adjusted ET_C follow. The first involves working the calculations yourself. The second takes advantage of the Santa Clara Valley Water District’s online irrigation calculator.

To do it yourself

We’ll use an example of bell peppers that are planted in two rows on 40-inch beds in late June in the Coyote Valley. At their peak in early September, the pepper plants cover 67% of the field. For this example, we will apply K_C and K_G to the reference ET_O. To find the ET_O, we check the CIMIS website, and get the cumulative ET_O from Sept. 1 through Sept. 7: 1.39 inches. The K_C for peppers is 1.05, and the ground cover at that point in the season is 67%.

Multiplying this ET_O by the two adjustment coefficients, K_C and K_G, we get:

$$ET_C = (K_C)(K_G)(ET_O) = (K_C)(K_G)(1.39 \text{ inches}) = (1.05)(0.67)(1.39 \text{ inches}) = 0.98 \text{ inches}$$

This grower should apply 0.98 inches of irrigation per acre, assuming a perfect drip system. Since the perfect drip system hasn’t been built yet, let’s assume the grower had a system DU of 0.90:

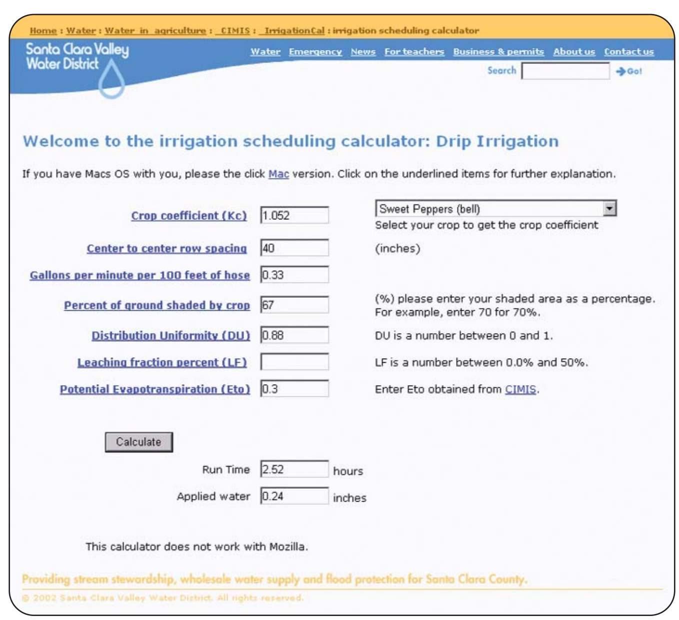
$$\text{Irrigation requirement} = \frac{0.98 \text{ inches}}{0.90} = 1.09 \text{ inches}$$

Using the online irrigation calculator

The online calculator is found at:
http://www.valleywater.org/Water/Water_in_agriculture/

The online irrigation calculator will guide you through the process of finding the correct ET_C for your crop and growing conditions. The calculator has a pull down menu of K_C’s for most of the crops grown in Santa Clara County. It will take you all the way through to a calculation of your required run time, and it works for sprinkler and drip systems.

- The calculator works for field crops, vineyards and orchards
- Percent ground cover is estimated by measuring shaded ground at high noon
- If you are growing a crop that is not included in the list, you can call the Water District and request its K_C



Viticulturists may need to add a management coefficient, K_M, to account for restricting irrigation to less than the plant's water requirements. For example, a management coefficient of 0.5 can be worked into the above ET_C equation as follows:

$$ET_C = (K_M)(K_C)(K_G)(1.39 \text{ inches}) = (0.5)(1.05)(0.67)(1.39 \text{ inches}) = 0.49 \text{ inches}$$

The calculator is also available on diskette to load into a computer using the Windows operating system. Water District staff can visit your office and help you get started.

The ET_C calculations are not applicable to row crops until the crop covers 30 to 40 percent of the field. Prior to then, water loss from the field is mainly caused by evaporation from the soil surface.

Note: Using CIMIS ET_O along with coefficients does not work for greenhouses since their climate is different from the climate measured by the CIMIS stations. Direct soil moisture measurement is a better method for greenhouses. See the soil moisture monitoring section.

Irrigation scheduling frequency:

Now that we know how much to irrigate and how to work our system DU into our calculations, we need to think about how often to irrigate. There are, of course, practical considerations that must be taken into account. Labor availability may dictate the number of days per week a drip irrigated field is irrigated. Similarly, irrigation schedules need to be shifted back and forth to accommodate cultural operations.

Available Water Capacity

The amount of soil moisture available to a plant is called the Available Water Capacity (AWC). The AWC is the difference in the amount of water retained by the soil after quick drainage (conventionally 2-3 days after irrigation, termed "field capacity"), and the amount of water retained by the soil at the point it is so dry that plants begin to wilt permanently (the "permanent wilting point").

The soil water content at field capacity is roughly half the water content at saturation, and the soil water content at the permanent wilting point is about half that of the field capacity. For example, a loam soil may contain 5.5 inches of water per foot at saturation, 3 inches of water per foot at field capacity and 1.36 inches per foot at the permanent wilting point. The AWC (field capacity minus permanent wilting point) would be 1.64 inches of water per foot of soil.

Row crop irrigation should follow two basic rules:

1. Soil moisture depletion should be limited to no more than 20% of AWC in the active root zone for sensitive crops such as celery and peppers. (The active root zone is not the same as the total root zone. The active root zone for drip irrigated crops cannot be larger than the wetted volume of soil around each plant.)

2. Applications should not exceed a half inch in any single irrigation. This will help maintain aeration in the root zone.

The AWCs of your soils can be obtained from the Water District or from the Natural Resources Conservation Service (NRCS) in Hollister. Once you know the names of your soils, you can get their composition in terms of the percentages of sand, silt and clay. Knowing these, you can use the "Soil Water Characteristics" program available from the NRCS on this page: http://www.wcc.nrcs.usda.gov/nrcsirrig/irrig-mgt-models.html. This program is a useful tool for soil moisture monitoring, which is discussed in the next section.

3 Soil Moisture Monitoring

Soil moisture monitoring is a necessary check on the accuracy of ET_O-based irrigation scheduling.*

Soil moisture-monitoring equipment measures either the volume of water contained in the soil or the force with which the soil holds the water, called moisture tension. Experience has shown that plant response is better correlated with soil moisture tension than it is with soil moisture volume.

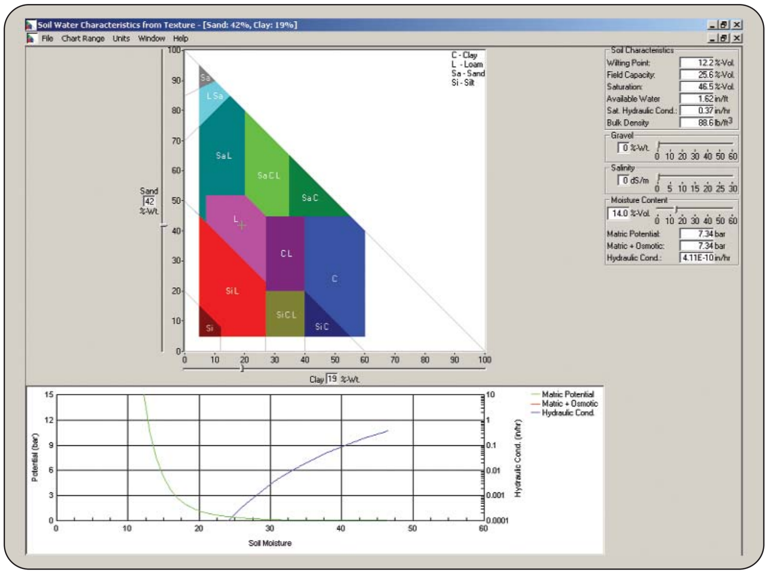
Soil moisture tension is reliably measured with either resistance blocks or tensiometers. Both tools are available on loan from the Santa Clara Valley Water District for a period of two years to help growers become familiar with these technologies.

*ET_O based scheduling does not account for drainage differences across the field, so actual soil moisture levels may diverge from expected levels after a while due to the accumulated effects of drainage.

Calculate soil moisture

First we will use the NRCS computer program "Soil Water Characteristics" to discover the correct soil moisture tension to begin irrigating. Using the 1.63 AWC example from the previous section, let's assume a crop with a root zone depth of 18 inches and sensitivity to water deficits.

The "Soil Water Characteristics" program is available for download at: http://www.wsi.nrcs.usda.gov/products/W2Q/water_mgt/Water_Budgets/SPAW_Model.html. The program is also available on compact disc. Water District staff can help you get started.



If we can only deplete 20% of the AWC of 1.63 in/ft, that will be approximately 0.33 inches per foot. Multiply that by 1.5 for a foot and a half of root zone and we get about 0.49 inches of water we can deplete before we need to irrigate.

Texture Class	=	Loam
Wilting Point	=	12.8 % of water in soil by volume
Field Capacity	=	25.6 %
Saturation	=	46.5 %
Available Water (AWC)	=	1.62 in/ft

We know from the program output above that the amount of water in one foot of soil at field capacity is 25.4% of 12 inches, or 3.05 inches per foot. Twenty percent depletion of the AWC is about 0.33 inches per foot. Subtracting the 0.33 inches from the field capacity reduces the soil's water content to 2.72 inches per foot, the level below which we should not deplete the soil further. That is 22.67% of water in the soil by volume (2.72 inches/12 inches/ft).

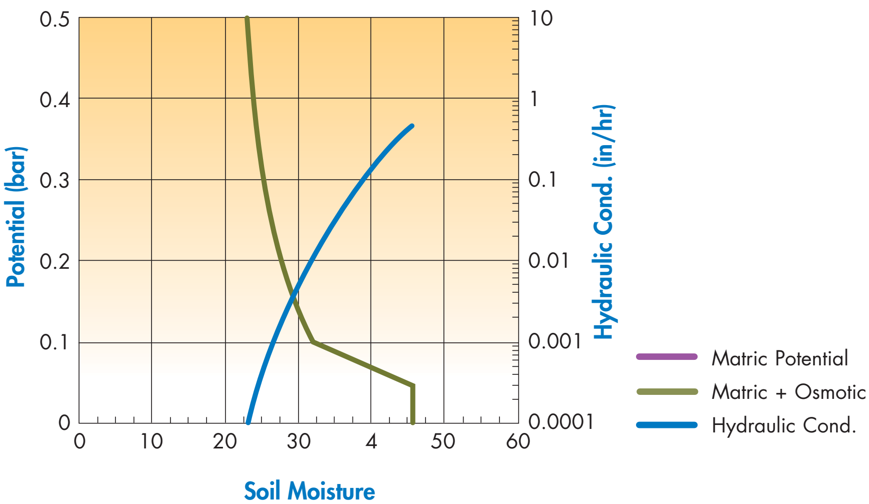


Figure 3: *Curve of soil moisture tension (potential) changes as soil water content changes.*

If we plug this percentage into the program, it will show us a soil moisture tension of 0.5 bars, or 50 centibars. This is the point on the graph in Figure 3 where the green line intersects the top of the graph.

So, you will be looking for your soil moisture sensors to indicate about 50 centibars about the time you start to irrigate.

Guidelines for placing the sensors

- The most obvious locations for sensors are areas that dry out quickly, and areas where your irrigation DU tests show the least water being applied. Remember to re-calculate your DU after tuning up your system.
- One sensor should be placed close to the top of the active root zone and one towards the bottom. In our example, that would be one at six inches deep and one at 18 inches. The top sensor will guide your irrigation startups, and the bottom sensor will indicate whether you are applying enough water or too much water.
- Sensors should also be a consistent distance from drip emitters. Half way between emitters in the plant row is a good starting point in vegetable crops. District staff will help you find good locations by putting in extra sensors and eventually leaving you with the two best locations.

Remember, sensors are available on loan from the Water District.

4 Run Time

The Water District's Mobile Lab can measure the field application rate of your sprinkler or drip systems.

Finally, you have to take the results of the calculations to the field and figure out how long you need to run your system. If you have a flow meter, you can obtain the measure of gallons pumped in one hour, and use this information to calculate the run time.

To calculate the run time, you first need to convert inches of irrigation required to gallons, at the rate of 27,154 gallons per acre-inch. So, for example, 0.45 acre-inches requires (0.45 acre-inches per acre)(27,154 gallons per acre-inch) = 12,219 gallons per acre.

You can use the formulas below to calculate your application rates in inches per hour for sprinkler and drip systems if you know the output from your sprinkler nozzles or drip tape:

a. Sprinklers

$$\text{Field application rate (inch/hour)} = \frac{(95.9)\ (\text{nozzle discharge rate gpm})}{(\text{lateral spacing, in feet})\ (\text{sprinkler head spacing, in feet})}$$

b. Drip

$$\text{Field application rate (inch/hour)} = \frac{(11.55)\ (\text{tape discharge rate in gpm/100 ft.})}{\text{drip line spacing in inches}}$$

Contacts and further information

Taking advantage of the Santa Clara Valley Water District's Mobile Lab, the online irrigation calculator, the CIMIS climate measurement system and checking the results of your calculations with soil moisture sensors will give you information for rational irrigation scheduling decisions.

Using these free tools will require a little more calculator time in the beginning, but you will soon have gained the experience to know what an ET_O of 0.24 inches means for your operation in terms of run time. The use of these tools will also, in many cases, increase your fertilizer use efficiency by increasing the uniformity of fertilizer distribution, and by decreasing fertilizer leaching.

There is a wealth of information available to help, and the following list is not exhaustive. You can always get additional instruction in the topics mentioned throughout this handbook by calling the Santa Clara Valley Water District, and by attending grower seminars and U. C. Cooperative Extension classes.

Regional Ag Mobile Lab
(800) 675-6602
www.agmobilelab.org

Bob Siegfried
Santa Clara Valley Water District
Water Use Efficiency Unit
(408) 265-2607, ext. 2969
www.valleywater.org
rsiegfried@valleywater.org

Aziz Baameur
UC Cooperative Extension,
Santa Clara County
700 Empey Way, Suite 110
San Jose, CA 95128
(408) 282-3127
fax: (408) 298-5160
azbaameur@ucdavis.edu

Bob Rohde
District Conservationist
Natural Resources Conservation Service
2337-C Technology Parkway
Hollister, CA 95023
(831) 637-4360 ext. 105
bob.rohde@ca.usda.gov

Agriculture and Land-Based Training Association
A.L.B.A.
P. O. Box 6264
Salinas, CA 93912
(831) 758-1469
gary@albafarmers.org

Santa Clara Valley
Water District

5750 Almaden Expressway
San Jose, CA 95118-3686
(408) 265-2600
Fax: (408) 266-0271

www.valleywater.org

Printed on recycled paper using soy-based inks. 8/05, 2500, YD