G. Developing the Irrigation Schedule

Defining Mature Vineyard/Site Conditions

The first step in developing an irrigation schedule is to quantify both the vineyardist and winemaker's goals for the variety and style of wine. This is necessary to develop a strategy using canopy, crop, and irrigation management to achieve the set goals. From this point, vineyard conditions and the irrigation system capabilities can be used to develop an irrigation schedule that will implement the strategy. The following is a list of the necessary vineyard/irrigation/strategy information needed to develop the schedule along with a scenario to develop a deficit irrigation schedule.

Variety/rootstock	Cabernet Sauvignon/Freedom
Site	Lodi, CA
Soil	Sandy loam
Root zone	8 feet depth
Root zone total soil moisture, bud break	16.0 inches
Root zone soil moisture, threshold	12.5 inches
Root zone soil moisture, harvest (previous year)	10.0 inches
Vine spacing	7 × 11 feet
Canopy (trellis)	Bilateral cordon w/ T top
Land surface shaded	40 %
Covercrop	None
Irrigation system	Drip
Emitter flow rate	1.0 gal/hr
Emitter per vine	1
Harvest date (est.)	10/1
Deficit Threshold	-13 bars
Regulated deficit (RDI %)	50 %
Threshold date	July 16th
Post harvest irrigation	One month estimated full potential water use (Oct)

Calculated values based on above information:

Vines per acre	566
Sq ft per vine	77
Gross application rate	0.021 in/hr
Soil available water (bud break)	6.0 in.
Soil Available water (threshold)	2.5 in.

Determining How Much to Apply

Estimating Full Potential Water Use

The full potential water use varies as a result of climatic conditions and the size of the canopy. The climate factor can be estimated using the reference evapotranspiration (ETo) values, which by itself indicates vine water use will vary over the season (*Figure G-1*). Normal or average year's data (1984- 2003) is shown for Lodi, California. Water use is also influenced by vine canopy growth from bud break to full canopy expansion. Canopy growth is accounted for by a modifying factor of the ETo called the Crop Coefficient (Kc) (*Figure G-2*). The Kc, which varies from a small value after bud break and increases as the vine canopy expands to maximum size. Together, these factors (ETo × Kc) contribute to a water use pattern that begins at a low rate in spring, peaks in mid-summer, and then declines as leaf drop approaches (*Figure G-3*). Canopy management practices such as hedging or canopy disruption by machine harvesting can further modify this pattern by reducing the energy interception of the vine and therefore the Kc. When considering the water use of a single vine, a larger canopy will have a larger leaf area exposed to the atmospheric conditions that drive water use and, therefore, that individual vine will have a greater water use.

Figure G-1. Lodi Eto, 1984 - 2003 Average
Stations # 42 and 166

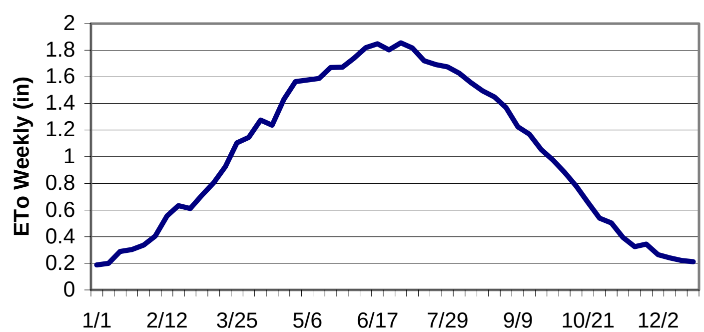


Figure G-2. Crop Coeficient (Kc) of a 50% Shaded Vineyard
at Max Canopy

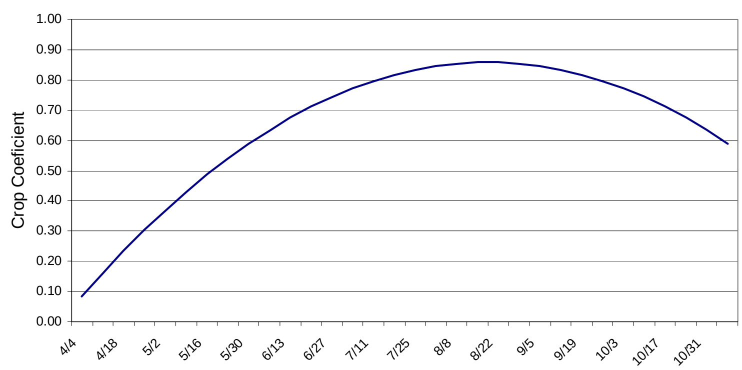
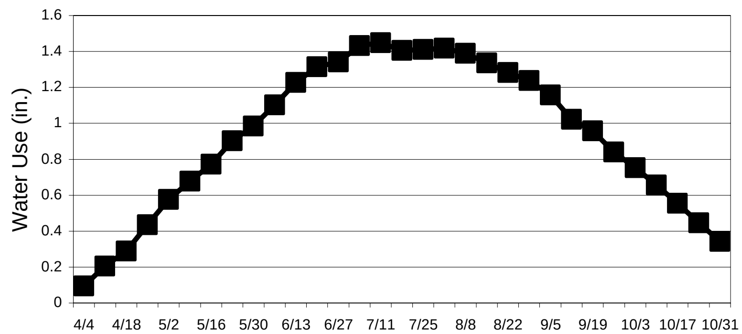


Figure G-3. Seasonal Vine Full Potential Water Use, Lodi Average ETo



When estimating the water use of an area of land planted to winegrapes (ETc), it is necessary to quantify the extent of canopy coverage by measuring the percentage of land surface shaded by the vine canopy. Row spacing can have a significant influence on percent land surface shaded since with a given trellis and canopy size a closer row spacing increases the percent land surface shading. In addition, trellis design, vine health, and vigor as a result of rootstock/scion combination, soil conditions, pests, and fertilization can affect the land surface shaded. Vine training, trellis type, and spring growth conditions can influence the rate of canopy expansion and, therefore, the land surface shaded at any point in time. These variables that contribute to land surface shading can significantly affect vine water use

The percentage of land surface shaded is measured midday (solar noon). Vine water use increases as the percent of land surface shaded increases. The practical ramifications are that wider spaced rows, young winegrapes or low vigor vines with a small canopy have a lesser percentage land surface shaded and use less water on a per- acre basis than vines with a larger coverage canopy.

The method described in the next section for estimating land surface shading seems to work well with bilateral or quadrilateral trellis systems, but less so when vertical shoot positioning (VSP) vineyards are measured. VSP canopies have the minimum land surface shaded at solar noon when row orientation is north/south and therefore may require a different method to account for the canopy/land surface relationship. Research is currently underway to develop a reliable method for use with VSP and similar trellis systems.

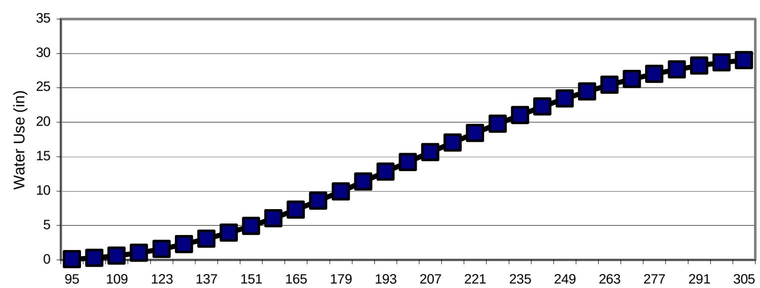
Generally, a canopy which establishes at a faster rate, i.e., cane-pruned or a quadrilateral system, increases early water use (at a faster rate) and can, at full expansion, have a larger percent land surface coverage. *Figure G-3* illustrates the weekly use over the season and *Figure G-4* the seasonal cumulative water use of a vineyard in the Lodi area with 50 percent land surface shading at maximum canopy expansion and adequate soil moisture for the entire season.

Evapotranspiration Reference × Crop Coefficient = Evapotranspiration of the Crop

ETo × Kc = ETc

If water availability is not limiting, ETc is full potential water use

Figure G- 4. Cumulative Water Use of Full Potential , Lodi Average ETo



Evapotranspiration Reference Values (Eto)

Evapotranspiration Reference Values (ETo) are calculated using measurements of climatic variables including solar radiation, humidity, temperature, and wind speed and expressed in inches or millimeters of water. A one-inch depth of water use, like rainfall or irrigation water, is equal to 27,158 gallons per acre of land. ETo values most closely approximate the water use of a short mowed full coverage grass crop. Climatic conditions are constantly collected from which ETo values are calculated and made available by the CIMIS Program. The California Irrigation Management Information System (CIMIS) is managed by the State of California Department of Water Resources, which collects, maintains and supplies Reference Evapotranspiration (ETo) values from nearly 100 weather stations throughout California. Both historical averages (normal) and real time (current year) values are available. CIMIS is on the web at: http://www.cimis.water.ca.gov

Crop Coefficient (Kc)

The Crop Coefficient (Kc) is a factor, which allows the use of Reference values (ETo) to estimate winegrape water use (ETc) of a non-water stressed vineyard. Kc values have been experimentally linked to the percent shaded area in the vineyard measured at midday. They can be measured at any time of the season, however when using the Deficit Threshold Method, it is necessary to only measure at the threshold or beginning of the irrigation. At that time, canopy expansion is complete. It should be re-measured if canopy reductions occur due to canopy management such as hedging.

Larry Williams demonstrated in a weighing lysimeter at the Kearney Ag Station that vineyard water use increases linearly with the percentage of land surface shaded by the crop (*Figure G-5*). He suggests measuring the percent shaded at midday and using the relationship to determine the Kc. The equation to describe the relationship between the crop coefficient Kc and percent shaded area is:

$$Kc = 0.002 + 0.017 \times \text{the percent shaded area}$$

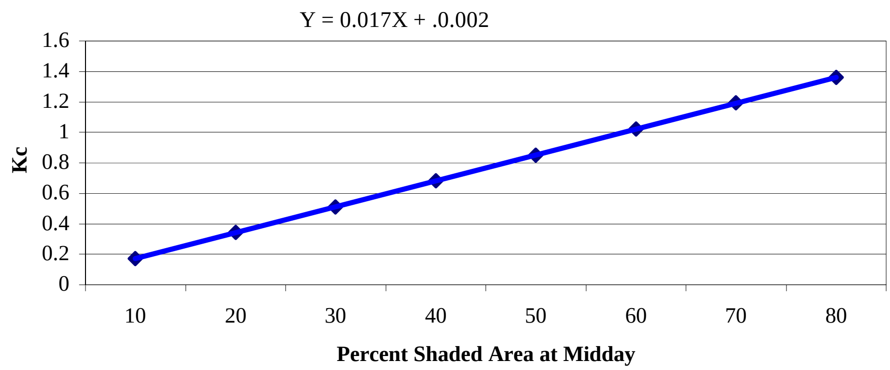
Simplified Equation:

$$Kc = 1.7 \times \text{percent shaded area (ie., 0.40 or 40\%)}$$

The procedure would entail measuring the average shade on the floor at mid-day of (as an example above), a 11-foot row spacing with a 7 foot vine spacing. The average amount of shade between two vines is measured at 31 sq ft compared to the vine spacing of 77 or 40% of the square foot area of one vine. The Kc is calculated as follows:

$$Kc = (0.40 \times 1.7) = 0.68$$

Figure G-5. Relationship between land surface shaded and crop coefficient (Kc) after Williams 2002



Calculating Full Potential Water Use with Historical Average Eto

After the -13 bar threshold was achieved (July 8 in this example), the net irrigation requirement can be calculated from the threshold date to the end of the season using average historical ETo values The product of ETo and Kc yields the full potential water use.

$$ETo \times Kc = \text{Full Potential Water Use (ETc).}$$

Figure G-1 shows an example calculation of weekly full potential water use for Lodi, CA using the 1984 to 2003 historical average ETo for CIMIS stations #42 and #166. The Kc used is 0.68 which developed above for a 40% midday shaded area. Calculations are made only after the threshold MDLWP (-13 bars) was measured in the vineyard on July 8.

Figure G-6. Irrigation Scheduling Worksheet - Lodi, CA

ETo are the averages of daily data from 1984 to 2003.
from the Lodi (CIMIS #42) and West Lodi (#166) weather stations

Assumptions
1. Leaf Water Potential trigger was reached July 8th.
2. Harvest Date was October 1.

Date	**A = Historical Eto[a]**	**B = Crop Coefficient[b]**	**C = A x B: Potential Water Use**
Period	Inches/Period	Kc	(in)
Jly 8-14	1.82	0.68	1.24
Jly 15-21	1.720	0.68	1.17
Jly 22-28	1.692	0.68	1.15
Jly 29 to Aug 4	1.676	0.68	1.14
Aug 5-11	1.626	0.68	1.11
Aug 12-18	1.556	0.68	1.06
Aug 19-25	1.494	0.68	1.02
Aug 26 to Sept 1	1.448	0.68	0.98
Sept 2-8	1.368	0.68	0.93
Sept 9-15	1.225	0.68	0.83
Sept 16-22	1.171	0.68	0.80
Sept 23-29	1.054	0.68	0.72
Sept 30 to Oct 6	0.974	0.68	0.66
Oct 7-13	0.883	0.68	0.60
Oct 14-20	0.779	0.68	0.53
Oct 21-27	0.660	0.68	0.45
Oct 28 to Nov 3	0.540	0.68	0.37
Total			14.75

[a] http://wwwcimis.water.ca.gov/cimis **or** http://ucipm.ucdavis.edu
[b] Crop Coeficient calculated based on 40% midday land surface shaded (0.68)

Calculating the Water Use Using the Regulated Deficit % (RDI%)

Once the full potential water requirement is calculated for the vineyard as in *Figure G-6* the Regulated Deficit percent (RDI %) can be used to calculate the amount of water the vineyard will use under the RDI % you have selected. In our example, 0.50 or 50 % of full potential water use was selected. *Figure G-7* shows the full potential water use (calculated in *Figure G-6*) x RDI% equals the amount of water use for the selected RDI%. Notice the RDI % increased to 1 or 100% after harvest as full water is required to encourage root growth and further carbohydrate accumulation.

Figure G-7. Irrigation Scheduling Worksheet - Lodi, CA

ETo are the averages of daily data from 1984 to 2003.
from the Lodi (CIMIS #42) and West Lodi (#166) weather stations

Assumptions
1. Leaf Water Potential trigger was reached July 8th.
2. Harvest Date was October 1.

Date	**C = A x B: Potential Water Use**	**D = RDI coefficient[c]**	**G = [(C x D) - E - F]: Net Irrigation Requirement**
Period	(in)	RDI %	(in)
Jly 8-14	1.24	0.5	0.62
Jly 15-21	1.17	0.5	0.58
Jly 22-28	1.15	0.5	0.58
Jly 29 to Aug 4	1.14	0.5	0.57
Aug 5-11	1.11	0.5	0.55
Aug 12-18	1.06	0.5	0.53
Aug 19-25	1.02	0.5	0.51
Aug 26 to Sept 1	0.98	0.5	0.49
Sept 2-8	0.93	0.5	0.47
Sept 9-15	0.83	0.5	0.42
Sept 16-22	0.80	0.5	0.40
Sept 23-29	0.72	0.5	0.36
Sept 30 to Oct 6	0.66	1	0.66
Oct 7-13	0.60	1	0.60
Oct 14-20	0.53	1	0.53
Oct 21-27	0.45	1	0.45
Oct 28 to Nov 3	0.37	1	0.37
Total	14.75		8.68

[a] http://wwwcimis.water.ca.gov/cimis **or** http://ucipm.ucdavis.edu
[b] Crop Coeficient calculated based on 40% midday land surface shaded (0.68)
[c] Regulated Deficit is 50% (0.5)

Accounting for the Soil Contribution and Effective Rainfall.

The soil moisture content declines as the vine extracts moisture from the beginning of shoot growth until the leaf water potential threshold is reached. The vine can still remove additional moisture from the root zone; however since the available moisture is at deeper depths, the rate of extraction is slow. In order to account for this water input to meet the water volume, we calculated in *Figure G-3* that it is necessary to measure or estimate its volume. In deep (7 ft) medium texture soils, an average amount of water which will be removed by harvest is typically 2½ inches. On shallower soils, this amount can be as low as 1 inch. Using a calibrated instrument which reads in inches of water per foot of soil, the water content of the root zone can be measured (see Section C). Measure at bud break, the threshold and at harvest. These times represent the full point, the threshold and the dry point respectively. Subtracting the threshold content form the bud break content will represent the amount of soil moisture used up until the threshold. Additionally, subtracting the dry point from the threshold count represents the volume of water the vines will use from the threshold through harvest. *Table G-1* shows the readings typical of a 7 ft depth sandy loam soil in Lodi, California. If soil measurements are not available, use the estimations mention above.

Table G-1. Total Root Zone Soil Moisture Content		
Total Moisture	Inches	
A – Bud Break	16.0	
B – Threshold	12.5	
C – Harvest	10.0	
Available Water		Inches
Bud Break	A – C	6.0
Threshold	B – C	2.5

The water that will be used from the threshold to harvest is called the soil contribution. Divide the amount (in this example, 2.5 inches) by the weekly periods from the threshold to the estimated harvest date, July 8 through Sept 30.

2.5 inches / 12 weekly periods = 0.2 inches per period

Figure G-8 illustrates the addition of the estimated soil contribution of each weekly period from the threshold to harvest.

Effective rainfall is usually minimal in the period of time from the threshold through harvest. However, significant rainfall is possible and must be accounted for as a water source to meet the calculated vine requirement. The most practical method to estimate effective in-season rainfall for vineyards is using the formula:

$$\text{Effective Rainfall} = [\text{rainfall (in)} - 0.25 \text{ in}] \times 0.8$$

This method discounts the first 0.25-inch as lost to evaporation after the event and estimates 80% of the remainder is stored in the soil for vine use (see Section C for a detailed discussion).

In the example spreadsheet the effective rainfall is entered the week beginning October 28. The measured rainfall was 0.65 inches. Calculations are as follows:

$$\text{Effective Rainfall} = [0.65 - 0.25] \times 0.8 = 0.32\text{in.}$$

Effective rainfall is entered in the spreadsheet in column F on the week beginning October 28 (*Figure G-8*).

Notice that the 0.32 inches is nearly equal to that weeks calculated vine use and the irrigation volume is reduced to near zero for that period.

Figure G-8. Irrigation Scheduling Worksheet - Lodi, CA

ETo are the averages of daily data from 1984 to 2003.
from the Lodi (CIMIS #42) and West Lodi (#166) weather stations

Assumptions
1. Leaf Water Potential trigger was reached July 8th.
2. Harvest Date was October 1.

Date	**C = A x B: Potential Water Use**	**D = RDI Coefficient[c]**	**E = Soil Contribution**	**F = Effective Rainfall[d]**	**G = [(C x D) - E - F]: Net Irrigation Requirement**
Period	(in)	RDI %	(in)	(in)	(in)
Jly 8-14	1.24	0.5	0.2	0	0.42
Jly 15-21	1.17	0.5	0.2	0	0.38
Jly 22-28	1.15	0.5	0.2	0	0.38
Jly 29 to Aug 4	1.14	0.5	0.2	0	0.37
Aug 5-11	1.11	0.5	0.2	0	0.35
Aug 12-18	1.06	0.5	0.2	0	0.33
Aug 19-25	1.02	0.5	0.2	0	0.31
Aug 26 to Sept 1	0.98	0.5	0.2	0	0.29
Sept 2-8	0.93	0.5	0.2	0	0.27
Sept 9-15	0.83	0.5	0.2	0	0.22
Sept 16-22	0.80	0.5	0.2	0	0.20
Sept 23-29	0.72	0.5	0.2	0	0.16
Sept 30 to Oct 6	0.66	1		0	0.66
Oct 7-13	0.60	1		0	0.60
Oct 14-20	0.53	1		0	0.53
Oct 21-27	0.45	1		0	0.45
Oct 28 to Nov 3	0.37	1		0.32	0.05
Total	14.75		2.40		5.96

[a] http://www.cimis.water.ca.gov/cimis **or** http://ucipm.ucdavis.edu
[b] Crop Coeficient calculated based on 40% midday land surface shaded (0.68)
[c] Regulated Deficit is 50% (0.5)
[d] Effective rainfall is calculated from actual rainfall.
Calculations are not shown on this sheet.

Determining the Weekly Vine Irrigation Volume

Irrigation systems, including brand new systems, do not apply water evenly to the entire vineyard. This is known as uniformity. When practicing deficit irrigation, generally no runoff or deep percolation losses occur; however, variation in the flow of the emitters (called manufacture's coefficient of variation) can account for 5% of the variation. Other causes of non-uniformity include pressure variations in the system and emitter clogging. A method to determine the emission uniformity and the average emitter discharge in your vineyard at the same time is presented in (Section H).

To continue our example spreadsheet, *Figure G-9* begins in the first column (G) Net Irrigation Requirement which was calculated in *Figure G-8*. Emitter uniformity has been measured to be an excellent 92 %. The average application rate is 0.96 gallons per emitter with one emitter per vine. The last variable to enter is the vine spacing in square feet. The spacing is 11 × 7 ft or 77 sq ft per vine. By using the calculation indicated at the top of each column of the spreadsheet, the gallons per week and the hours of operation can be determined.

Figure G-9. Irrigation Scheduling Worksheet - Lodi, CA

ETo are the averages of daily data from 1984 to 2003.
from the Lodi (CIMIS #42) and West Lodi (#166) weather stations

Assumptions
1. Leaf Water Potential trigger was reached July 8th.
2. Harvest Date was October 1.

Date	G = [(C x D) - E - F]: Net Irrigation Requirement	H = Emission Uniformity[e]	I = G/H:Gross Irrigation Amount	J = Vine Spacing[f]	K = (I x J x .623): Gallons per Vine/ Period	L = Average Application Rate	M = (K/L): Hours of PREDICTED Irrigation Time
Period	(in)	(%)	(in)	(sq feet)	(gal/week)	(gph/vine)	(hours)
Jly 8-14	0.42	92	0.45	77	21.8	0.96	22.7
Jly 15-21	0.38	92	0.42	77	20.1	0.96	20.9
Jly 22-28	0.38	92	0.41	77	19.6	0.96	20.4
Jly 29 to Aug 4	0.37	92	0.40	77	19.3	0.96	20.1
Aug 5-11	0.35	92	0.38	77	18.4	0.96	19.2
Aug 12-18	0.33	92	0.36	77	17.2	0.96	17.9
Aug 19-25	0.31	92	0.33	77	16.1	0.96	16.7
Aug 26 to Sept 1	0.29	92	0.32	77	15.2	0.96	15.9
Sept 2-8	0.27	92	0.29	77	13.8	0.96	14.4
Sept 9-15	0.22	92	0.24	77	11.3	0.96	11.8
Sept 16-22	0.20	92	0.22	77	10.3	0.96	10.8
Sept 23-29	0.16	92	0.17	77	8.3	0.96	8.6
Sept 30 to Oct 6	0.66	92	0.72	77	34.5	0.96	36.0
Oct 7-13	0.60	92	0.65	77	31.3	0.96	32.6
Oct 14-20	0.53	92	0.58	77	27.6	0.96	28.8
Oct 21-27	0.45	92	0.49	77	23.4	0.96	24.4
Oct 28 to Nov 3	0.05	92	0.05	77	2.4	0.96	2.5
Total	5.96		6.47				

Gallons per vine applied though harvest =	191.3
Hours of irrigation time through harvest =	199.3

[e] Under deficit irrigation, Irrigation Efficiency is assumed equal to Emission Uniformity.
[e] spacing 7 x 11 ft = 77 ft sq.

In our example, the 6.5 inches of water is required through the end of the season, based on an emission uniformity of 92% and an average application rate of 0.96 gallons per vine. The hours of operation would be 191 hours through harvest and a 98-hour post harvest irrigation. It should be noted that if effective rainfall occurs during the post harvest periods or if leaf drop is earlier than November 3, this amount should be reduced.

Adjusting the Schedule for the Current Season's Climate

When real time (the current season) ETo and effective rainfall values become available, they can be substituted into the table to account for the variance from normal ETo values and the actual effective rainfall. Real time ETo and rainfall are available on a one day lag time from the CIMIS network.

The Deficit Threshold Method relies on a calculation of the historical for a one-week period, then applying the indicated amount of water to the vineyard. After the end of that week, the real time data is downloaded and input into the spreadsheet to replace the historical ETo used to develop the last weeks schedule. Any differences between the previous week's application volume/time should be adjusted as a addition or subtraction on the new current week's schedule. For example if 12 hours were applied using the historical ETo values then upon re-calculating using real-time data the amount should have been 11 simply subtract 1 hour from the current week schedule.

In order to react to rapidly changing climate, if an extraordinary high hot and dry period begins and is expected to last a few days—increase the irrigation volume to try to meet the increase in water use. When recalculating with real time ETo values the next week's result will indicate your success in estimation.

Figure G-10 depicts the water consumed by the vineyard in our example and the sources of the water. For comparison full water is compared to the water use and sources of the deficit treatment in *Figure G-11*.

Figure G-10. Water Consumption and Sources for Deficit Irrigation, Lodi, -13/60%

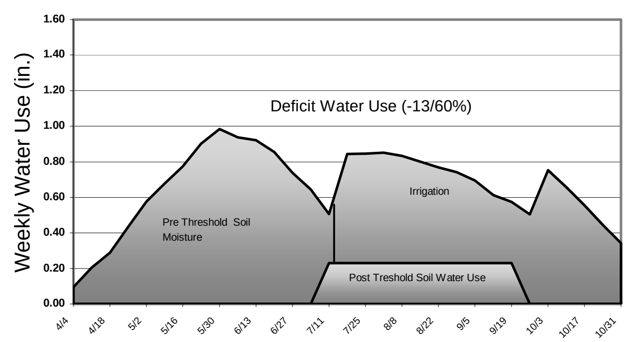


Figure G-11. Full Potential and Deficit Water Use and Sources