This article presents the first three years of results for the irrigation monitoring trial conducted in vineyards overlying the Paso Robles Groundwater Basin. This study period was characterized by having above-average rainfall overall and thus the irrigation amounts are likely not representative of drier seasons. The average annual irrigation applications for the 2010, 2011 and 2012 calendar years were 10.4, 8.3 and 12.0 inches respectively.

Background

The vineyard acreage east of Paso Robles relies on the large Paso Robles Groundwater Basin for its irrigation water; the basin also supplies water for a variety of non-agricultural users. In recent years, the groundwater levels in some parts of the basin have declined significantly, raising concerns about the sustainability of the current or potential future rates of pumping by the various water users.

Pumping of water for irrigation use, primarily for vineyards, is the largest single use of groundwater in the basin. However, very little information exists to help quantify the amount of pumping, because there is currently no requirement for groundwater users to report the water volumes that they pump. This lack of accurate information creates difficulty for the ongoing efforts to model the groundwater basin and to predict how groundwater levels might respond to changes in land use patterns. Previous modeling efforts necessarily had to rely on rough estimates of agricultural water use because more accurate information was not available.

To help alleviate this lack of accurate information, a project was initiated in late 2009 to measure water use at a large number of cooperating vineyards. At that time, the focus of attention was on the groundwater declines occurring to the east of the City of Paso Robles, a region dubbed the “Estrella-Creston Area of Concern.” Utilizing funding support provided by a donation from the Paso Robles Wine Country Alliance, the UC Cooperative Extension installed automated irrigation monitoring devices at 84 vineyards within the study area, with the permission of the cooperating growers (Figure 1). The intent of this study was to take measurements over a three calendar year period from 2010 through 2012, and to report the results of the findings at the end of the period. The ultimate goals of this project are to improve our estimates of vineyard water use in the region, and to provide growers with a reference benchmark to help them evaluate and potentially improve their own irrigation management practices.

Measurements

The irrigation applications at each site are monitored using pressure switches connected to the irrigation lines in the vineyard blocks. The switch operation is tracked by a data logger which records the date and time...
when the irrigation system is pressurized or de-pressurized; with this information, the duration of the run time for each irrigation event is calculated. The volume of applied irrigation is then calculated based on the design application rate for each particular system studied. This calculation assumes that the actual flow rate is similar to the design rate; this is not always the case, as actual flow rates can vary due to emitter clogging, emitter wear, system pressure deviations, valve settings, etc. However, when looked at in the aggregate, the overall average flow from a large number of systems tends to be very close to the design flow. Of the 84 locations, 22 also had sprinkler systems in addition to the drip irrigation systems. These sprinkler systems were also monitored in a similar fashion with separate pressure switches and data loggers.

Results

The rainfall as measured at the City of Paso Robles for the three winter rainfall seasons prior to the vineyard growing season is shown in Figure 2. The average winter rainfall at this station from 1952 through 2012 has been 14.7 inches. The average rainfall for the three years of the study was 17.6 inches, with the first two years being significantly wetter than average and the third year being about average for the location.

Seven additional rain gauges were also operated throughout the study area during the same three years of the study. The average rainfall of these seven rain gauges was less than the rainfall at the City of Paso Robles (Figure 3). This follows the known trend of rainfall tending to diminish with increasing distance east from Paso Robles.

The average annual irrigation application for all locations in 2010 was 10.4 inches; amounts for 2011 and 2012 were 8.3 and 12.0 inches respectively. These amounts include all drip and sprinkler applications. For readers interested in comparing their own water use amounts to these figures, several useful conversion formulas are provided on page 7 of this article to make these calculations easier.

Of significant interest is the relationship between the amount of rainfall in the winter prior to a growing season and the amount of irrigation subsequently applied in that season. These relationships are shown for the three years of data, using both the rainfall measured at the City of Paso Robles (Figure 4a) and the rainfall measured within the study area (Figure 4b) on the following page. Both rela-
tionships demonstrate the reduction in irrigation application with greater rainfall during the preceding winter. It would be expected that growers base their irrigation decisions more so on the rainfall that occurs on their actual properties rather than at any off-site rain gauge, but the relatively consistent trends of these relationships is encouraging even though they are made with a limited number of data points. These simple charts are the beginning stages of potentially useful relationships which can be used to predict annual irrigation applications based upon known or modeled winter rainfall amounts. The accuracy of these relationships will be improved by having more years of data, in particular under drier winter conditions such as are

Figures 4a and 4b. The relationship between the preceding winter’s rainfall, as measured at the City of Paso Robles (4a) or as the average rainfall amount throughout the study area (4b), and the subsequent season’s total applied irrigation amounts.

Figures 5a-5c. The individual site irrigation amounts for each season, ranked in increasing order. This presentation demonstrates the wide variability in irrigation practices within this relatively small study area.
The annual irrigation amounts for each individual measurement site for each of the three years is shown in Figures 5a-5c on the previous page. These charts demonstrate the very large variability in irrigation applications within the area vineyards. A number of very site-specific factors contribute to an individual vineyard water requirement; such factors include the actual rainfall at the site, the soil water holding capacity, vine rootstock and rooting depth, cover crop and tillage practices, fruit production goals, and the salinity conditions and leaching requirements. None of these factors were assessed in the current study, but they likely played key roles in the decision making process employed by individual growers in devising their own particular irrigation requirements.

One additional site-specific factor that was measured in this study was the irrigation crop coefficient at each location during the 2010 season; this work was funded by a grant from the American Vineyard Foundation. At each site, an estimate of that location’s crop coefficient was measured using the ‘Paso Panel’ device in late July (see the UCCE website for information on this method). This single measurement was assumed to be representative of the crop coefficient for that site for the months of July and August. The crop coefficient measured in 2010 was also assumed to be representative of the crop coefficient values for the same sites and periods in 2011 and 2012. There are weaknesses with all of the above assumptions, but for the purposes of this study these measurements, even if approximate, allow for a better comparison of irrigation use between sites.

By having even rough estimates of the crop coefficient for each location, it becomes possible to make an assessment of how irrigation is managed relative to the theoretical vineyard water requirement as determined from local climate data. We calculate the vineyard water requirement using measurements of the reference evapotranspiration (ETo) and the crop coefficient (kc). Typically we use the following relationship:

\[ \text{ETc} = \text{ETo} \times k_c \]

Where ETc is the full or 100% vineyard water requirement. Since most winegrape vineyards are generally not irrigated at 100% of ETc, we calculate the irrigation application using a deficit percentage:

\[ \text{Irrigation application} = \text{Deficit} \% \times \text{ETc} \]

Where the Deficit % may be a value such as 70%. Combining the above two equations gives us the basic formula for calculating the vineyard water requirement using climate-based irrigation scheduling:

\[ \text{Irrigation application} = \text{Deficit} \% \times (\text{ETc} - \text{ETo}) \]

Figures 6a-6c. Estimated ‘Deficit %’ (the % of full ETc applied) during the months of July and August in each of the three seasons. The relatively low values overall may reflect the contribution of stored soil moisture from the relatively abundant winter rains in helping supply vine water requirements during the season, or it may indicate that area vineyards were relatively under-irrigated.
Irrigation application = Deficit % x ETo x kc

We have estimates of all the above parameters for each site except for the Deficit %. Knowing the Deficit % value for each study site would be useful for estimating ‘how’ irrigation is being utilized at each site; this parameter allows us to estimate if vines may be under-irrigated, or if they are receiving luxury amounts of water. We can solve for the Deficit % value by rearranging the above equation:

\[
\text{Deficit } \% = \frac{\text{Irrigation application}}{(ETo \times kc)}
\]

We know the irrigation application from the monitoring results, we have an estimate of the \(kc\) from the ‘Paso Panel’ measurements, and the ETo was determined using the Spatial CIMIS values for the center of the study area each year. This calculation was only done for the months of July and August together each year; this was because the \(kc\) value corresponded more closely to this stage of canopy growth, and because this period corresponded to the main irrigation application period. The ‘Deficit %’ values calculated for each site for the three years of the study are shown in Figures 6a-6c on the preceding page.

These figures show a wide range of ‘Deficit %’ values amongst the sites in summer. Sites with smaller ‘Deficit %’ values may be utilizing soil moisture from the preceding wet winters during the summer and thus have less need for supplemental irrigation, or the vines may be substantially under-irrigated. Sites with very large ‘Deficit %’ values may be on droughty soils with very low water storage capacity and hence need more supplemental irrigation, or they may be over-irrigated. Individual sites will vary significantly in their need for irrigation based on the many factors listed previously, but this type of calculation is a good first step to compare how water is managed on an ‘apples to apples’ basis.

The few very high readings in Figures 6a-6c indicate situations where the particular vineyards are receiving far more irrigation than they can theoretically utilize during that period. This does not necessarily mean that these vineyards are receiving more than the average irrigation amounts; this situation can arise for example if a vineyard with a well below-average leaf canopy is given an average amount of irrigation. This occurs in vineyards suffering from canker diseases with the associated dead spurs and cordon, which leads to a large reduction in the leaf canopy; the smaller leaf canopy results in a lower crop coefficient and hence a reduction in the irrigation water requirement (Figure 7). Matching irrigation applications to the optimum vine water requirements of a particular vineyard is not a simple task, but the process can be improved if growers have site-specific crop coefficient information (Figure 8).

Figure 7. Eutypa and Bot Canker diseases as well as lingering cold damage can lead to vines with significantly reduced leaf canopies; such vines will have reduced irrigation water requirements as compared to healthy vines with full canopies. Measurements of the midday canopy shaded area is a simple way to quantify the overall size of the canopy.

Figure 8. The size of the vine leaf canopy has a strong influence on its irrigation water requirement. All else being equal, the block on the left will require more irrigation as compared to the block on the right. This is a good example of why generic crop coefficient values may have limited usefulness in vineyards, due to the huge variability in canopy size amongst different locations or different blocks in the same vineyard.
Lastly, the annual irrigation applications were also calculated as cumulative daily values over the entire calendar year (Figure 9). Each of the three yearly lines represents the average water use for all sites throughout that year.

**Future work**

The monitoring equipment continues to operate in 2013; with permission of the cooperating growers, collection of the 2013 calendar year data will continue as for the previous three years. Given the current dry winter, having this additional fourth year of data will be very important to this project, as it will help fill in the information lacking from the previous higher rainfall years.

The UCCE recently received a CDFA Specialty Crops Block Grant to in part continue the current irrigation study, and to expand the measurements to vineyards throughout the Paso Robles Groundwater Basin. With the continued cooperation of the existing growers, measurements will continue at their locations in a similar fashion through 2016. Additionally, new study sites will be sought at vineyards throughout the entire Paso Robles Groundwater Basin. Monitoring devices will be installed at these new locations in the fall of 2013. Data collection and management will follow the same protocol as for the original study, with all measurements remaining anonymous. If you have interest in being a cooperator in the expanded study, please contact Mark Battany.

![Figure 9](image.png)

**Figure 9.** The average cumulative irrigation application for the 2010, 2011, and 2012 calendar years. The steeper the slope of the line, the higher the irrigation application rate during that time period. The highest application rates occur from June through September in all years. Small spikes occur in early April, likely due to the application of sprinkler frost protection water at that minority of the sites that had sprinkler frost protection systems.

**Additional resources:**

Detailed reports from the various studies of the Paso Robles Groundwater Basin are available at:


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**About the UC Cooperative Extension**

The University of California’s Cooperative Extension offices are local problem-solving centers. Campus-based specialists and county-based farm, home, and youth advisors work as teams to bring the University's research-based information to Californians. UCCE is a full partnership of federal, state, county, and private resources linked in applied research and educational outreach. UCCE develops and extends timely and pertinent information in a manner which is independent, unbiased, non-commercial, and research-based. These fundamental criteria set it apart from all other information resources.

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[http://ucanr.org/grapenotes](http://ucanr.org/grapenotes)
Comparing your own irrigation amounts to the values in this study

The common unit of measure for irrigation application is a depth of water over the entire irrigated field; in this project this value is expressed as inches over the entire season. Most vineyard growers do not calculate this same value unless they are using climate-based irrigation scheduling. Instead, most growers will keep track of how many hours they have run their irrigation system, or how many gallons of water they have applied per acre or per vine. Because the math to convert these values to their equivalents in inches of water depth can be confusing, some shortcut formulas are presented below. These can be used for any length of time period; for direct comparison to the numbers in this study, the annual calendar year totals should be used. An Excel spreadsheet is also available for these calculations: http://cesanluisobispo.ucanr.edu/Viticulture/

**Hours of runtime to inches (using emitter flow rates in gallons per hour):**

\[
\text{Inches} = 1.60 \times \frac{\text{Runtime (hrs)} \times \text{Total emitter flow rate per vine (gph)}}{\text{Row spacing (ft.)} \times \text{Vine spacing (ft.)}}
\]

**Example:**

Runtime: 400 hours  
Total emitter flow rate per vine: 1 gph (Two 0.5 gph emitters per vine)  
Row spacing: 10 feet, Vine spacing: 6 feet  
\[
\text{Inches} = \frac{1.60 \times 400 \text{ hrs.} \times 1 \text{ gph}}{10 \text{ ft.} \times 6 \text{ ft.}} = \frac{640}{60} = 10.7 \text{ inches}
\]

**Hours of runtime to inches (using emitter flow rates in liters per hour):**

\[
\text{Inches} = 0.424 \times \frac{\text{Runtime (hrs)} \times \text{Total emitter flow rate per vine (lph)}}{\text{Row spacing (ft.)} \times \text{Vine spacing (ft.)}}
\]

**Example:**

Runtime: 400 hours  
Total emitter flow rate per vine: 4 lph (two 2 lph emitters per vine)  
Row spacing: 10 feet, Vine spacing: 6 feet  
\[
\text{Inches} = \frac{0.424 \times 400 \text{ hrs.} \times 4 \text{ lph}}{10 \text{ ft.} \times 6 \text{ ft.}} = \frac{678.4}{60} = 11.3 \text{ inches}
\]

**Gallons per vine to inches**

\[
\text{Inches} = 1.60 \times \frac{\text{Total gallons applied per vine}}{\text{Row spacing (ft.)} \times \text{Vine spacing (ft.)}}
\]

**Example:**

Total gallons per vine: 400  
Row spacing: 10 feet, Vine spacing: 6 feet  
\[
\text{Inches} = \frac{1.60 \times 400 \text{ gallons}}{10 \text{ ft.} \times 6 \text{ ft.}} = \frac{640}{60} = 10.7 \text{ inches}
\]

**Gallons per acre to inches**

\[
\text{Inches} = \frac{\text{Gallons per acre}}{27,154}
\]

**Example:**

Total gallons applied per acre: 300,000  
\[
\text{Inches} = \frac{300,000}{27,154} = 11.0 \text{ inches}
\]

**Note on emitter flow rates per vine:**

The above calculations use the total emitter flow rate per vine. For systems where the emitters are spaced at an interval that doesn’t match the vine spacing (for example, emitters spaced every 2.5 feet on a vine row with 6 feet between the vines), then one must calculate the number of emitters per vine:

\[
\text{Emitters per vine} = \frac{\text{vine spacing}}{\text{emitter spacing}}
\]

Using the above numbers as an example:

Emitters per vine = 6 feet / 2.5 feet = 2.4 emitters per vine  
If each emitter has a 0.5 gph flow rate, then the total emitter flow rate per vine is:

Flow rate per vine = 2.4 emitters per vine x 0.5 gph = 1.2 gallons per hour