Vineyard Water Management During a Drought

Rain or shine, we're under drought conditions—be good stewards of a precious resource.

Mark Greenspan

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I'M A LITTLE BIT ticked off. Correct that: very much ticked off. But let me reserve my venting until the end of this article. We are in a midst of a drought cycle in the west and southwest—about three years into it. As of press time, there are suggestions that this may be a mega-drought or a long period of dry weather, which may be punctuated by periods of adequate or high rainfall, yet still lower rainfall than what we typically experience. It has not been since the mid '70s (which preceded my professional viticulture career) that we've had such dry weather. I am not equipped to forecast the long-term climatic conditions going forward (or next week's weather for that matter); but as growers of a relatively water-stingy crop (winegrapes), we can show ourselves, and the general public, how we manage a scarce resource and show the world that grapes are a crop that can be sustainably grown in numerous regions.

As I write this in February, I do not even know how this season will look water-wise. The North Coast received a decent soaking recently that filled the soil profile to field capacity of 3 to 4 feet in depth, after having been extremely dry just prior to the rain events. The Central Coast was not so fortunate and still struggles at this point with only a couple of inches under its belt. Because I don't know what the moisture conditions will be going forward, I can only make suggestions about best water management practices. Actual water management will be site-specific, region-specific and weather-specific. And since this is a big part of what I do for a living, I expect to be very busy this year, as will many of my viticulturist colleagues.

I have written about vineyard water management numerous times[1] over the last eight-plus years, and I sometimes feel like I am creating monotony in my message. Yet I feel that it is important to keep stressing these points almost every year and especially during these times of scarce rainfall.

Measure to Manage

I respect farmers who have been working in their vineyards for decades. Their common refrain of "I know my vineyard" has a solid basis of truth. But vineyard-water relations are something that is not easily understood by a gut feeling and is therefore not intuitive. Few people understand everything about how water moves into and within the soil during and after rainfall or irrigation, is stored in the soil pores, gets redistributed within the profile, is taken up by the vine, transpired by the vine into the atmosphere and dissipated, and creates physiological changes within the vine and fruit. After studying this for about 25 years, I feel that I have a pretty good command on the subject, yet I learn something new all the time about all of these processes.

Quantification of water relations is key. That means we need to measure things. I've been a big fan of plant water status measurements, and you can refer to my previous articles on irrigation for deeper descriptions. The two pieces of plant moisture equipment that I rely on most are the pressure chamber and the porometer. I've described both in previous articles, but both are portable instruments that we use primarily during midday to measure plant water status. I find both tools to be indispensable. I only wish there were ways to make those measurements automatically because the short afternoon window, travel time and expense make extensive measurements with those instruments difficult and costly. I am looking at other options for these measurements; but until then, we are getting our money's worth out of them. Knowing the water stress level of the vine allows us to modify our irrigation regime to dial in specific stress levels in the vines at certain times of the growing season and avoid going overboard with stress, potentially causing crop loss or quality reduction.

I've also mentioned my turn to soil moisture monitoring. This has been nothing short of revolutionary to me; and although these instruments have been around for quite a while, the newer variants on the moisture-sensing technology have proven themselves to me where previous incarnations were either too prone to failure, too noisy in their measurements or too expensive to be practical. Soil moisture monitoring has opened up to me the portion of the vineyard ecosystem that we cannot otherwise see. I find that it gives not only me, but my clients, the assurance that moisture is in the ground and being taken up, not only between irrigations but before irrigation has even started for the season. That has allowed us to delay the first irrigation (in the North Coast) until August and even September, substantially reducing our irrigation inputs and allowing roots to exploit the full soil profile and encourage extensive root development.

Soil moisture monitoring has also allowed me to reduce the irrigation quantities applied once irrigation cycles begin. By monitoring the total amount of moisture being stored in the soil from an irrigation and then depleted by the vine, I almost always apply between 18 to 22 percent of crop evapotranspiration (ETc) as a maintenance (non-deficit) level. That is far less than is being applied by many growers, who believe that they are "deficit" irrigating at 50 to 60 percent of ETc. I believe the issue with the ETc model, in general, is that it does not account for stomatal pore closure, which occurs in the vines as the season progresses, even without water stress, but is greater (i.e., more closed) under desirable levels of water stress for fine winegrapes. Because I've discussed these measurements before and have not changed my practices, I will not go into their use further in this column but rather discuss general practices under drought conditions.

Before Irrigation: The Springtime "Wait"

Let me start by suggesting that even in most drought years, the North Coast begins the season with a full moisture profile. I do not believe that will be different this year, even if we don't get much more rainfall. That is a different situation in many areas of the state, including much of the Central Coast and the Central Valley. Practices will differ tremendously during this time. Yet, the spring and early summer are perhaps the biggest opportunities to save water in all regions.

It's easy in the North Coast. Just wait to irrigate. Some growers irrigated in late January this year because soils were extraordinarily dry—drier than I've ever seen. I think that this was justifiable, and I instructed some of my clients to irrigate because rainfall was not in the forecast. Canes were looking quite dry, and we were afraid of bud necrosis. In cold climates, dry canes and buds decrease their cold-hardiness. But after the rainfall occurred in February (with more likely to come), I suggested to everyone to hold fire and discontinue any irrigation applications until the moisture is depleted.

Growers in the North Coast can proceed pretty much normally, at least to my standards where we delay any irrigation until the vines slow down their growth in the early or mid-summer. Look at your shoot tips and let them tell you the story. Don't irrigate until those tips slow down or stop. When they stop, you will know that your vines have exploited most of the moisture that has been stored in the soil—irrigation starting time will probably be later than you think if you have not yet applied this practice.

The more arid climates are clearly more challenging. Irrigation may very well be needed during the winter and the spring, which is quite common for some regions of California. However, drip irrigation is a very poor way to "fill up the profile," as most will explain. Point sources of water move not only downward but laterally outward. The relative amount of downward and outward movement will depend upon soil texture, stoniness, heterogeneity and especially stratification. Stratified soils are quite common in all growing regions, and water from drip irrigation does not cross stratification boundaries well. So, in those soils, water tends to move more laterally than it does downward at those interfaces. This is not trivial, and I have found that water percolation patterns differ from what one might think and are very different from the furrow irrigation patterns that we were taught in school. That is because water movement in soils from drip irrigation is mostly unsaturated, moving with capillary matrix forces, while that from furrow irrigation has a saturated wetting front. Without getting too heavy into soil physics, just know that drip irrigations are not useful at all for "filling the profile." The only exceptions to this are extremely uniform, usually light-textured soils. I've seen them in the Russian River basin and in Argentina. I'm sure they exist elsewhere but believe them to be the exception and not the rule.

That said, overhead sprinklers would be the ultimate way to fill a soil profile while providing for the leaching of salts from the root zone that is needed for many regions, including eastern Paso Robles. While they look wasteful, they are much more effective than drip for that purpose and would need to be used only once at the beginning of the season or during the winter. Even microsprinklers would be more effective than drip for this purpose. That said, most growers do not have overhead sprinklers and will have to irrigate only with drip. In drought years it will be necessary to irrigate season-long, but irrigating with good technique is of extreme importance. The goal should be to develop a canopy of decent, but not excessive, size—get shoots to stop at around 3.5 to 4 feet instead of encouraging large, flopping shoots, which will transpire excessive moisture. We do not want stress during fruit set but can tolerate moderate amounts of stress at other times of the year.

Using soil moisture monitoring tools will save on water applications and will allow you to make the most out of a limited resource in any climate. Pay attention to what your farm advisors are telling you and, if you are inclined, hire a qualified consultant to get you through the challenging times.

In regions where salt leaching is necessary, do the best you can by using an occasional larger water application but with shorter, more frequent applications between. The larger application will help to move salts away from the primary wetted zone.

Drought Management Practices

There are many other practices that should be applied during periods of drought. Here is a brief list:

1. Eliminate competition by disking cover crop and controlling weeds. I normally encourage no-till or minimal tillage; but if water is scarce, save it for the vines by getting rid of the other foliage.
2. Keep canopies small (I already said that, but it's important) by discouraging excessive moisture during canopy development. Sucker and shoot-thin early and aggressively to remove wasteful water "straws."
3. Reduce irrigation during post-set to veraison. This will create smaller berries and will also improve phenolic development during ripening. You can increase the water status of the vines after all fruit has gone though veraison.
4. Reduce crop level. Fruit will be a factor after veraison so make sure that you remove your excess crop before veraison, and you may need to drop more than usual, depending upon the water conditions later this season.
5. Check vine nutrition. All nutrients that enter through the root system use water as a carrier. Nutrition will be lower when soils are dry. Check potassium status especially, as potassium helps the vines to regulate their stomatal pores.
6. The "small drink" will use less water than the "big drink." More to follow.

Small Drink vs. Big Drink vs. Big Gulp

The article I wrote on small drink versus big drink irrigation was fairly recent (June 2013), so I will not dwell on this topic. But I want to finish on it. I have found that the low-volume, frequent-irrigation approach yields better irrigation efficiency, better control of vine water status (especially in stressed conditions) and is a more sustainable approach overall. When I wrote that article, I received virtual "high fives" from many in the industry, though I did receive one criticism via a letter to the editor. I am aware that there is more than one opinion on this topic and respect that others do not always see it my way. Heck, I used to be of the big-drink camp for soils that had the moisture-holding capacity that could support it. And I do admit that the small drink is inherently less efficient because more frequent applications mean more direct evaporation. And short irrigation sets do not work well for hillside vineyards with long runs because of the potential for differential

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DRIP SYSTEM OPERATION AND MAINTENANCE

RECOMMENDED PROCEDURES FOR A DRIP IRRIGATION SYSTEM

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OVERVIEW

Subsurface Drip Irrigation (SDI) is a drip irrigation system where the dripline is permanently buried below the soil surface, supplying water directly to the roots. SDI is more than an irrigation system, it is a root zone management tool. Fertilizer can be applied to the root zone in a quantity when it will be most beneficial - resulting in greater use efficiencies and better crop performance. A number of crop protection chemicals are also available (labelled accordingly) for application through the drip system making it a powerful crop protection tool.

The longevity of the system will depend on factors such as initial water quality, proper operation, regular maintenance and the quality of the dripline. Netafim has sub-surface drip irrigation systems with more than 20 years of continuous operation. This publication details the procedures Netafim recommends to ensure the longest possible life for your SDI system.

BASIC SYSTEM LAYOUT

Figure 1 is a schematic layout of the components which make up an SDI system:

- Dripline - the heart of the system (depending upon the field conditions) can be either pressure compensating (hilly terrain) or non-pressure compensating (flat terrain).
- Filters (typically a disc or media filtration system) is the best choice to protect the dripline.
- Fertilizer Injector - injects fertilizer chemicals into the system for maximum crop performance and to maintain the dripline over the long term.
- Pipeline headers, control and air release vents complete the system.

Our intent is not to describe the process of system design in detail. Your Netafim USA Dealer is trained to design and install quality SDI systems. It is important to understand how the system is put together and why certain design elements are specified.

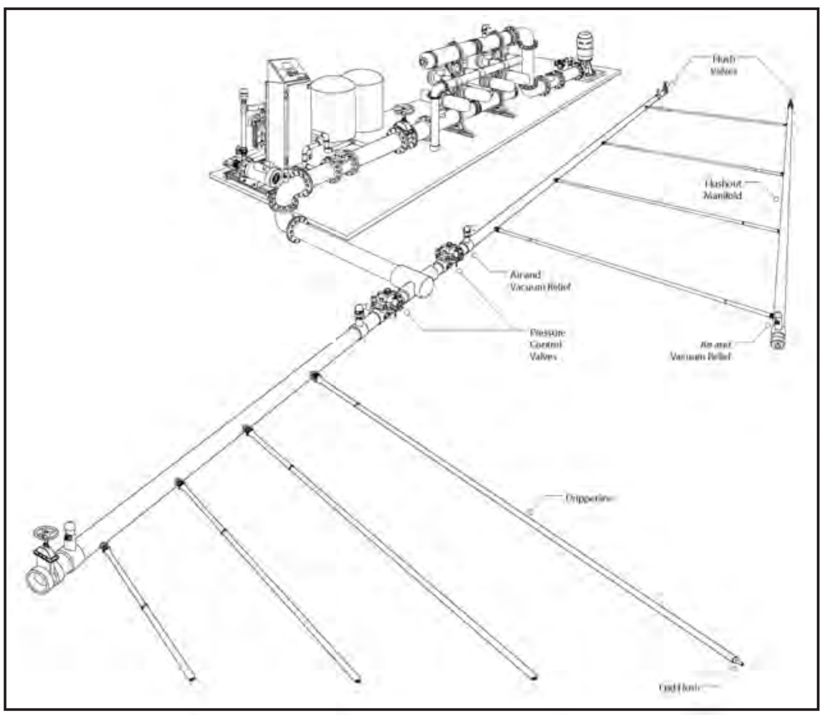


Figure 1. Schematic layout of drip system components

DRIPLINE SPECIFICATIONS

The following dripline recommendations are meant as guidelines only - soil type, topography and water quality will affect the final design. Your Netafim USA Dealer is familiar with the local conditions and will recommend a dripline that is appropriate for your area. The dripline should be installed with a GPS where possible so that its position can be determined as necessary. Depending upon local conditions the dripline can either have pressure compensating (Netafim DripNet PC or UniRam) or non-compensating drippers (Netafim Typhoon or Streamline). Factors such as length of run, topography, zone size and water quality play an important role in choosing the right dripper. Regardless of the type of dripper used there are several basic guidelines to follow:

1. The distance between driplines is determined by the crop. For corn crops with rows every 40” the typical spacing between

rows of driplines is 80”, with the dripline located in the furrow and one dripline in every other row. With this layout one dripline irrigates two rows of corn with one irrigated row followed by a dry row. This arrangement has implications for measuring the moisture content of the soil. The measurement should never be taken in the dry row. Some growers have been increasing the density of their corn plantings by moving to 20” rows and in this case the dripline is placed on 40” centers. In all cases the water application rate is set by design to meet the crop needs given the water availability.

2. Driplines are generally buried at a depth of 12” to 18”. The crop being grown, the soil texture and the presence of rodents are the main considerations for determining the burial depth of the dripline. Sandy soils generally require a more shallow burial. In areas with a large rodent population deeper burial of the dripline is less likely to cross paths with rodent’s teeth. In general rodents are not fond of sandy soil so the shallower depth is not a concern. However, deeper placement may make it difficult to germinate the crop with the drip system unless there is sufficient residual moisture in the soil. The following should be taken into consideration when designing the SDI system:
    - The distance between drippers and the dripper flow rate - selected to achieve the appropriate application rate given the water availability.
    - Dripline wall thickness - 13 to 35 mil is usually recommended, with 15 to 25 mil most commonly used.

PUMP REQUIREMENTS

The volume output of the pumping station dictates the amount of area that can be irrigated. A simple formula has been derived converting the maximum required evapotranspiration rate (ET) in inches of water per day per acre into gallons per minute per acre.

ET (inches/day/acre) *18.86 (conversion factor) = GPM/acre

Using this formula - an ET of 0.25 inches per 24 hours per acre would require 4.72 GPM/acre. This calculation is for a pump running 24 hours. More commonly as a safety factor, systems are sized for 20 hours of operation. To accomplish this use the following formula:

24 (hours in a day)/ (number of hours desired for irrigation) X (GPM/acre)
24/20 X 4.72 = 5.66 GPM/acre

On flat land the pressure output required of the pump stations is mainly dictated by the flushing requirements of the filters and pipes. On hilly terrain the pressure required to lift water to the highest point must also be considered. Most automatic filters require a minimum of 30 psi to self-clean properly. This is generally the pump’s minimum operating pressure to operate a drip system.

FILTRATION

The filter system protects the drip system from sand and other small particles which can plug the dripline’s drippers. A well designed filter system maximizes the performance and longevity of your SDI system. Two types of filters are recommended:

1. Sand media filters
2. Netafim disc filters (Figure 2)

In general, screen filters are suitable only for very clean water sources. Sand media and disc filters which utilize depth filtration are most effective at removing suspended particles from the water. The filter system should be setup to automatically clean when the pressure differential across the media is too large. A pressure differential switch in combination with a flushing controller is a common approach for automation of filter cleaning.

Figure 2. Example of a Netafim Apollo Disc-Kleen Filter

PRESSURE REGULATING VALVES

Pressure control valves (Figure 3) are recommended for non-pressure compensated dripline to achieve the correct working pressure in the drip system. Pressure regulating valves must be adjustable to accommodate higher pressures required during flushing.

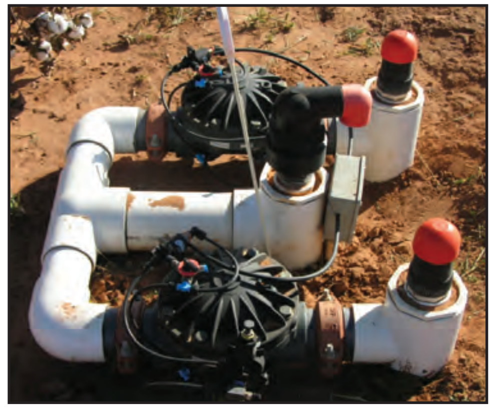


Figure 3. Example of a field installation of pressure regulating valves and air vents

AIR VENTS

Air vacuum vents (Figure 3) prevent soil suction into the drippers at system shut-down. For every 50 laterals there should be one anti-vacuum vent at the highest elevation and one mounted on the flushing manifold's highest elevation. A double-purpose automatic air vent must be installed at the pump and is usually required in the mainline.

FERTILIZER INJECTION SYSTEM

The system (Figure 4) is designed to supply fertilizer to all irrigation blocks using either an automated system or a simple injection pump. Please consult a Netafim USA Dealer to determine which fertilizers may be safely applied through the drip system.

Figure 4. Fertilizer Injection system

WATER METERS

It is essential to monitor flow in order to monitor the operation of your system and crop's water use. Your SDI system is designed to produce a specific flow rate at a given pressure. Changes in the flow rate may indicate leaks in the system, improperly set pressure regulating valves or even changes in the well and pumping plant. On the following pages, use of a water meter and a pressure gauge to determine system problems is detailed.

PRESSURE GAUGES

Use pressure gauges to ensure that the drip system, filter system and pump operate at the correct pressure. Pressure gauges are also critical to assess potential problems with the system.

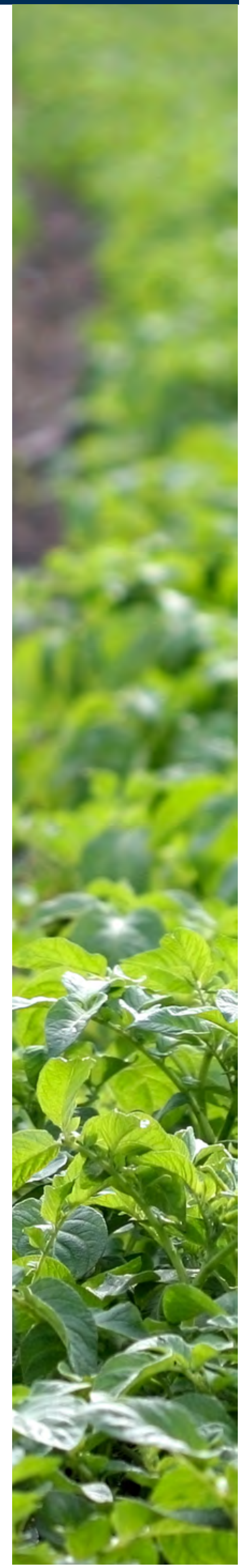
FLUSH MANIFOLDS

Most permanent SDI systems use flush manifolds to flush entire zones at a single time. A manifold at the end of the field also improves system uniformity. The use of flush manifolds is highly recommended to reduce the labor required to properly maintain the system.

SYSTEM STARTUP

Whether you have just installed a new system or are starting the system up after sitting through the off season, these simple steps, taken before irrigation will help to ensure optimum system performance.

1. Flush the well before operation through the filter. A new well or one that has been sitting during the off-season, may discharge sand at startup. This "plug" of particles can overwhelm the filtration system causing it to repeatedly trigger an unproductive backflush cycle. If the well discharges sand on a regular basis it may be necessary to install a sand separator before the regular filtration system. Consult your Netafim USA Dealer for more information on sand separators.
2. Thoroughly flush the laterals and mains before system operation. In new systems, during installation, it is possible that dirt and PVC pieces accumulated in the system - these need to be flushed out properly. During the season, systems need to be flushed on a regular basis. Filters do not filter 100% of particles, often fine silt enters. This will settle in lines and must be flushed especially from the driplines. Debris also can get into the lines after a break has occurred and should be flushed after any repairs.
3. Check for leaks in dripline laterals. Laterals are occasionally damaged during installation. System start-up is the right time to check for leaks, before the crop canopy expands making repairs difficult.



STARTUP PROCEDURE

1. Open flush manifolds on line ends.
2. If possible, run the pump station for a few minutes with the discharge to waste (not through irrigation system) to flush out any sand.
3. Open mainline flush valves, with submain valves closed, and operate your system until discharge water runs clear for 5 minutes. Check the flow rate and whether and how often the filter system backflushes during operation.
4. Open submain valves with flush manifolds still open to clear the submains of debris.
5. For each submain, open the control valve until discharge water at the end of the lateral runs clear. If the capacity of the water supply is insufficient to flush all laterals simultaneously, then flush a few laterals at a time. Close the submain valve.
6. Close the flush manifolds on lateral ends.
7. Operate the system until it is fully pressurized and all air is discharged.
8. Check system for leaks and repair.
9. Re-flush the lines after leaks are repaired.
10. Check pressure gauges and adjust all pressure regulators, or regulating valves as necessary.
11. Check for proper operation of all system components: pumps, controllers, valves, air vents, pressure regulators, gauges, water meters, filter system and fertilizer injectors.
12. Record readings from all pressure gauges and flow meters and check on the frequency of backflush cycle of your filters. If backflushing is frequent (several times an hour) consult your Netafim USA dealer.

SYSTEM PRESSURE AND FLOW TESTS

Upon initial startup it is best to evaluate the uniformity of your drip system. This is accomplished by:

1. Measuring the pressure in the system at various points and comparing this to the design pressure.
2. Reading the water meter or calculating the system flow and comparing the result to the designed flow rate.

These evaluations should be conducted as part of system startup and as an ongoing part of system maintenance. Consult the maintenance section of this guide for a complete program for system care.

SYSTEM PRESSURE EVALUATION

Drip systems are typically designed to operate between 10 and 15 psi. Measuring the pressure at several points in your drip system is the simplest way to evaluate the performance. A good evaluation will include pressure measurements at a minimum of three points along the header end of the field and three points at the far end of the field. Pressure measurements at more points in the field including along the length of the laterals will give a more complete picture of system uniformity but are usually not necessary if the end pressures are within one psi of the header pressure.

SYSTEM FLOW RATE

A water meter is an important component of every drip system. It gives the operator a quick indication of the operational performance of their system and is used to determine proper water application rates. Every new system should be designed with a water meter. Older systems without water meters should be retrofitted with one. The system design should include an estimated system flow rate and the measured flow rate should be within +/- 5% of the designed rate. To calculate the flow rate expected for each zone use the following formula:

Flow rate (GPM) = (0.2) X length of dripline (ft) X dripper flow rate (GPH) / dripper spacing (in)

CONVERTING SYSTEM FLOW RATE TO INCHES OF APPLIED WATER

Irrigation schedules are usually based on evapotranspiration (ET) rates which are expressed in inches of water evaporated over a given time period, usually a day or week. It is simple to convert a flow rate in GPM, either read from a meter or calculate as outlined on previous page, to inches of water applied per hour by using the following formula.

Inches of water applied per hour = (0.00221) X (flow rate, in GPM) / (# acres)

For example, a typical SDI system on alfalfa will have 40" spacing between dripline rows with 0.16 GPM drippers spaced at 24 inches. One acre of the above system has 62 rows each, 208 feet long for a total of 12,896 feet. This gives a flow rate of 17.19 GPM.

(.00221) X 17.19/ 1 = 0.038 inches per hour which equals 0.456 inches in 12 hours

MONITORING YOUR DRIP SYSTEM

To achieve the highest yields and water savings possible with a drip irrigation system, it is necessary to monitor your system and make adjustments. In addition, regular system monitoring may give advance warning of potential problems.

MONITORING SYSTEM PRESSURE AND FLOW RATES

As presented earlier, measurements of system flow and pressure give a good picture of the system's performance. Because of the large number of variables at play in an irrigation system the measured water application rate may not exactly match the predicted rate. Still large differences in calculated versus measured values may indicate a problem with your calculations or a physical system problem such as a broken or clogged line. Over the growing season changes in the flow rate or pressure in your system can be used to diagnose problems with the system. Table 2, details some of the problems that can be diagnosed by monitoring system pressure and flow rate. This is by no means a comprehensive list but is a good place to start.

DRIP SYSTEM MAINTENANCE

The maintenance of your SDI system centers on identification of the factors which can lead to reduction of the performance of your drip system and procedures to mitigate these negative impacts. Factors that can slow or stop flow through the drip system include: suspended material, chemical precipitation, biological growth, root intrusion, soil ingestion and crimping of the dripline. To ensure maximum system life reduce or eliminate the impact of the negative factors (Table 2). This may require water treatment and a systematic program for regular maintenance. In this section we outline the various potential issues that can adversely affect the drip system and offer procedures to mitigate the potential damage.

INDICATION	POSSIBLE PROBLEM
Gradual decrease in flow rate	Dripper plugging Possible pump wear (check pressure)
Sudden decrease in flow rate	Stuck control valve Water supply failure
Gradual increase in flow rate	Incremental damage to dripperline by pests
Sudden increase in flow rate	Broken lateral, submain, main line Pressure regulator failure
Large pressure drop across filters	Debris buildup in filters Inadequate flushing of filters
Gradual pressure decrease at filter inlet	Pump wear or water supply problems
Sudden pressure decrease at filter outlet	Broken lateral, submain, main line Pressure regulator or water supply failure
Gradual pressure increase at filter outlet	Dripper plugging
Sudden pressure increase at filter outlet	Stuck control valve Other flow restrictions
Sudden pressure decrease at submain	Damaged or broken lateral

Table 2. Problems diagnosed from system flow rates and pressures

WATER QUALITY

The potential for dripper plugging problems will vary with the source of the irrigation water, either surface or ground water. In general, algae and bacterial growth are usually associated with the use of surface water. Whole algae cells and organic residues of algae are often small enough to pass through the filters of an irrigation system. These algae cells can then form aggregates that plug the drippers. Residues of decomposing algae can accumulate in pipes and drippers to support the growth of slime-forming bacteria. Surface water can also contain larger organisms such as moss, fish, snail, seeds and other organic debris that must be adequately filtered to avoid plugging problems. Groundwater, on the other hand, may contain high levels of minerals that can challenge dripper function. Water from shallow wells (less than 100 feet) often will produce plugging problems associated with bacteria. Chemical precipitation is more common with deep wells.

A water quality analysis can give the grower a “heads up” on potential trouble areas for the drip system. This test should be accomplished before the final design of the system to ensure that proper components are installed to address any problem areas. Many laboratories around the United States have Water Quality Analysis services available which are able to conduct a “Drip Irrigation Suitability Test”. The analysis should include testing for pH, dissolved solids, manganese, iron, hydrogen sulfide, carbonate and bicarbonates. Table 3 lists the more common water quality issues that can affect drip irrigation systems. Having a water analysis in the moderate or even severe category does not mean drip irrigation cannot be used but only that special precautions must be applied to prevent problems. Consult your local Netafim USA Dealer for more information on water quality and drip irrigation.

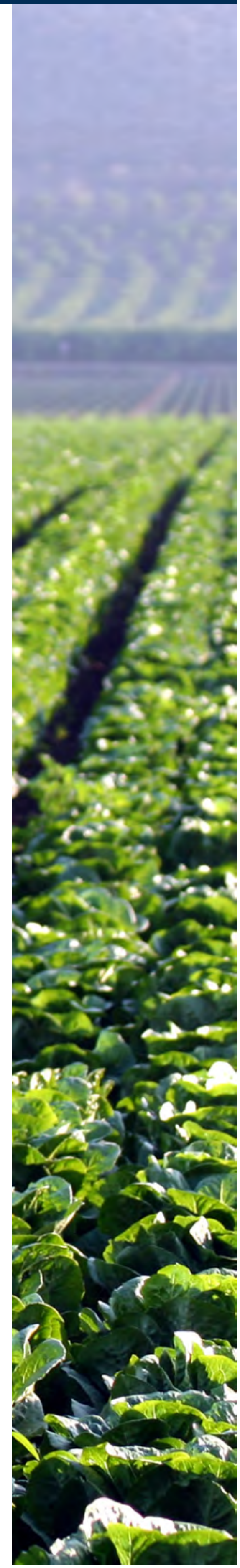
TYPE OF FACTOR	MINOR	MODERATE	SEVERE
SUSPENDED SOLIDS (ppm)			
INORGANIC	<10	10 - 100	>100
ORGANIC	<10		>10
CLOGGING			
IRON (ppm)	0.0 - 0.1	0.1 - 0.4	0.4+
MANGANESE (ppm)	0.0 - 0.2	0.2 - 0.4	0.4+
SULFIDES (ppm)	0.0 - 0.1	0.1 - 0.02	0.2+
CALCIUM CARBONATE	0.0 - 50.0	50.0 - 100.0	150.0+
BIOLOGICAL			
BACTERIA POPULATIONS	10,000	10,000 - 50,000	50,000+

Table 3. Common water quality issues with drip irrigation

SUSPENDED SOLIDS

Suspended solids in the incoming water are the most common stress impinging upon the drip system and the easiest to control. Each and every Netafim dripper has a large filter built into the unit to keep suspended particles from being trapped in the labyrinth. This filter is located at the bottom of dripper and points toward the center of the drip tubing so that it can be cleaned by flushing the dripline. This built-in filter plays an important role in the longevity of the SDI system. Thus, most water used for drip irrigation must be filtered to remove suspended solid particles that can lodge in the drippers and reduce or even stop the flow. These particles can be either organic such as algae or inorganic such as sand. Each manufacturer recommends a filtration level based on the technology of the dripper device. The Netafim drippers commonly require 120 mesh filtration. This is the lowest filtration requirement of any commercial drip irrigation product. That means that the drippers are more reliable ensuring long service even under harsh conditions.

Surface water generally contains a combination of organic and inorganic suspended particles. These include algae, moss, aquatic animals as well as suspended sand, silt and clay particles. Filtering this mix of material is a challenge that is best accomplished using three-dimensional filtration, such as disc or sand media. Well water generally has lower levels of suspended solids which can be handled using disc filtration or in cases of very low contaminant levels screen filters. If large quantities of sand are being generated by the well a sand separator may be installed before other filters. Filters for SDI should automatically clean (backflush) during operation when the contaminant levels get high enough.



CHEMICAL PRECIPITATION

Chemical plugging usually results from precipitation of one or more of the following minerals: calcium, magnesium, iron, or manganese. The minerals precipitate from solution and form encrustations (scale) that may partially or completely block the flow of water through the dripper (see Figure 5). Water containing significant amounts of these minerals and having a pH greater than seven has the potential to plug drippers. Particularly common is the precipitation of calcium carbonates, which is temperature and pH dependent. An increase in either pH or temperature reduces the solubility of calcium in water, and results in precipitation of the mineral.

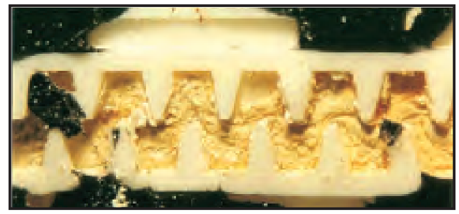


Figure 5. Dripper with calcium precipitate. The black pieces in the picture are pieces of the cut-away plastic dripline and not contaminants.

When groundwater is pumped to the surface and discharged through a micro-irrigation system, the temperature, pressure and pH of the water often changes. This can result in the precipitation of calcium carbonates or other minerals to form scale on the inside surfaces of the irrigation system components. A simple test for identifying calcium scale is to dissolve it with vinegar. Carbonate minerals dissolve and release carbon dioxide gas with a fizzing, hissing effervescence.

Iron is another potential source of mineral deposit that can plug drippers. Iron is encountered in practically all soils in the form of oxides, and it is often dissolved in groundwater as ferrous bicarbonate. When exposed to air, soluble ferrous bicarbonate oxidizes to the insoluble or colloidal ferric hydroids and precipitates. The result is commonly referred to as 'red water,' which is sometimes encountered in farm irrigation wells. Manganese will sometimes accompany iron, but usually in lower concentrations.

Hydrogen sulfide is present in many wells. Precipitation problems will generally not occur when hard water, which contains large amounts of hydrogen sulfide, is used. Hydrogen sulfide will minimize the precipitation of calcium carbonate (CaC03) because of its acidity.

Fertilizers injected into a drip system may contribute to plugging. This may be the result of a chemical reaction that occurs when different fertilizers are mixed or because the fertilizer in question is not completely soluble. This type of plugging is completely preventable. To determine the potential for plugging problems from fertilizer injection, the following test can be performed:

1. Add drops of the liquid fertilizer to a sample of the irrigation water so that the concentration is equivalent to the diluted fertilizer that would be flowing in the lateral lines.
2. Cover and place the mixture in a dark environment for 12 hours.
3. Direct a light beam at the bottom of the sample container to determine if precipitates have formed. If no apparent precipitation has occurred, the fertilizer source will normally be safe to use in that specific water source.

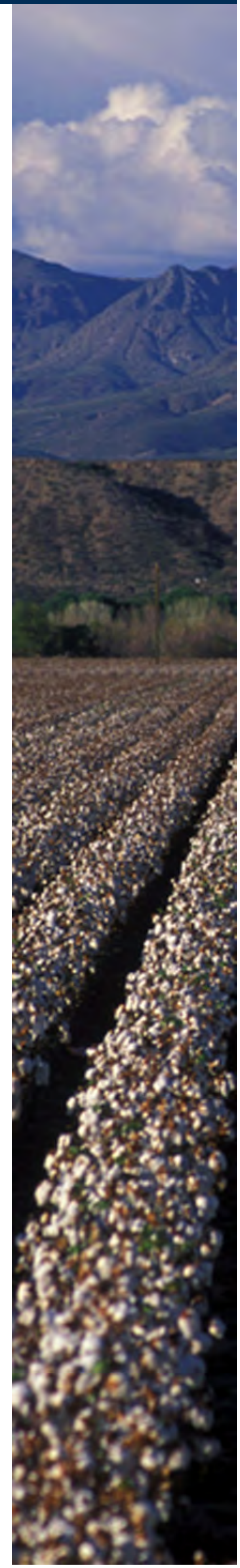
BIOLOGICAL GROWTH

A micro-irrigation system can provide a favorable environment for bacterial growth, resulting in slime buildup. This slime can combine with mineral particles in the water and form aggregates large enough to plug drippers. Certain bacteria can cause enough precipitation of manganese, sulfur and iron compounds to cause dripper plugging. In addition, algae can be transported into the irrigation system from the water source and create conditions that may promote the formation of aggregates.

Figure 6. Filamentous sulfur slime completely clogging a small water meter.

Dripper plugging problems are common when using water that has high biological activity and high levels of iron and hydrogen sulfide. Soluble ferrous iron is a primary energy source for certain iron-precipitating bacteria. These bacteria can attach to surfaces and oxidize ferrous iron to its insoluble ferric iron form. In this process, the bacteria create a slime that can form aggregates called ochre, which may combine with other materials in the micro-irrigation tubing and cause dripper plugging. Ochre deposits and associated slimes are usually red, yellow or tan.

Sulfur slime is a yellow to white stringy deposit formed by the oxidation of hydrogen sulfide. Hydrogen sulfide (H2S) accumulation in groundwater is a process typically associated with reduced conditions in anaerobic environments. Sulfide production is common in lakes and marine sediments, flooded soils, and ditches; it can be recognized by the rotten egg odor. Sulfur slime is produced by certain filamentous bacteria that can oxidize hydrogen sulfide and produce insoluble elemental sulfur.



The sulfur bacteria problem can be minimized if there is not air-water contact until water is discharged from the system. Defective valves or pipe fittings on the suction side of the irrigation pump are common causes of sulfur bacteria problems. If a pressure tank is used, the air-water contact in the pressure tank can lead to bacterial growth in the tank, clogging the dripper. The use of an air bladder or diaphragm to separate the air from the water should minimize this problem.

ROOT INTRUSION

Plan roots tend to grow toward soil areas with the highest water content. Because of this tendency, roots can clog subsurface drip systems by growing into the dripper openings. Plant roots tend to "hunt" for water when it is in short supply thus, the problem seems to be more acute when irrigation is not sufficient for the plant needs. This is a particular problem in systems that are left unused for part of the season. Several strategies can be employed to reduce the possibility of root intrusion:

1. Short frequent irrigations keep adequate water in the root zone so the roots have no need to look for water.
2. Acid injection that lowers the pH to less than four will discourage root growth and can be used to clean roots out of drippers with small amounts of root intrusion. High concentrations of chlorine (100 to 400 ppm), N-pHURIC, phosphoric or metam sodium (Vapam) will also destroy roots in the drippers.
3. In areas where it is allowed, trifluralin is an effective inhibitor of root growth and can be used to prevent root intrusion.
4. Seamed dripline encourages roots to grow along the seam and into the dripper. Netafim products are designed without a seam to discourage this intrusion.

SOIL INGESTION

Soil ingestion is not a problem in properly designed SDI systems. Soil injection occurs when soil is sucked into the dripline. When a drip system is shut off the water continues to flow to the low end of the field creating a vacuum at the higher end, sucking saturated soil into the line. A properly designed drip system will minimize this potential problem. The supply manifold must be equipped with vacuum relief vents, these vents allow air to flow into the driplines when the system is shut off. Netafim air/vacuum relief vents will allow sufficient air into the system. Insufficient air will create a vacuum (similar to not using vents). This is not a good place to skimp.

CRIMPING OF THE DRIPLINE

Pinching of the dripline can occur as the result of soil disturbance by equipment or drying out. Because it is difficult to correct crimping in an SDI system many growers are setting up their system so there is minimum traffic on the driplines. The lines are installed using GPS and the field is laid with specific traffic rows.

MAINTENANCE PROCEDURES

Filter Maintenance

Follow the standard instructions for the maintenance of your filter system. Filters are the first line of protection for your drip system and they need regular maintenance to operate at a high level. On a bi-weekly basis observe the system as it completes a backflush cycle. Make sure all pressures are within the system limits before and after backflushing. Check the operation of backflush valves, pressure differential switches and controller. Make sure you clean the command filter. At the end of the season check the media level in media tanks. Scum can build up on disc filters and the discs may need to be cleaned with acid. In areas that experience a freeze, drain all water from the filter, valves and command system.

Dripline Flushing

To minimize sediment build up, regular flushing of drip irrigation pipelines is recommended. The system design should be such that a minimum flush rate of 1.5 ft/sec can be obtained in the lines. Valves large enough to allow sufficient velocity of flow should be installed at the ends of mains, submains and manifolds. Also, allowances for flushing should be made at the ends of lateral lines. Flushing of the drip lateral lines should continue until clean water runs from the flushed line for at least two minutes. A regular maintenance program of inspection and flushing will help significantly in preventing dripper plugging.

Chemical Treatment

Chemical treatment is often required to prevent dripper plugging due to microbial growth and/or mineral precipitation. The attachment of inorganic particles to microbial slime is a significant source of dripper plugging. Chlorination is an effective measure against microbial activity. Use chlorine and all other chemicals only according to label directions. Acid injection can remove scale deposits, reduce or eliminate mineral precipitation and create an environment unsuitable for microbial growth.

CHLORINE INJECTION

Overview

Chlorination is the most common method for treating organic contaminants. Active chlorine is a strong oxidizer and as such, is useful in achieving the following:

A. Prevent clogging and sedimentation of organic substances.

B. Destroy and decompose sulfur and iron bacteria, as well as accumulated bacterial slime in the system.

C. Improve performance of filtration systems while reducing backflush water.

D. Clean systems of organic sediments. (Chlorine has no effect on scale deposits.)

If the micro-irrigation system water source is not chlorinated, it is a good practice to equip the system to inject chlorine to suppress microbial growth. Since bacteria can grow within filters, chlorine injection should occur prior to filtration.

Liquid sodium hypochlorite ($NaOCl$)--laundry bleach--is available at several chlorine concentrations. The higher concentrations are often more economical. It is the easiest form of chlorine to handle and is most often used in drip irrigation systems. Powdered calcium hypochlorite ($CaCOCl_2$), also called High Test Hypochlorite (HTH), is not recommended for injection into micro-irrigation systems since it can produce precipitates that can plug drippers, especially at high pH levels. The following are several possible chlorine injection schemes:

- Inject continuously at a low level to obtain one to two ppm of free chlorine at the ends of the laterals.
- Inject at intervals (once at the end of each irrigation cycle) at concentrations of 20 ppm and for a duration long enough to reach the last dripper in the system.
- Inject a slug treatment in high concentrations (50 ppm) weekly at the end of an irrigation cycle and for a duration sufficient to distribute the chlorine through the entire piping system.

The method used will depend on the growth potential of microbial organisms, the injection method and equipment and the scheduling of injection of other chemicals.

When chlorine is injected, a test kit should be used to check to see that the injection rate is sufficient. Color test kits (D.P.D.) that measure ‘free residual’ chlorine, which is the primary bactericidal agent, should be used. The orthotolidine-type test kit, which is often used to measure total chlorine content in swimming pools, is not satisfactory for this purpose. D.P.D. test kits can be purchased from irrigation equipment dealers. Check the water at the outlet farthest from the injection pump. There should be a residual chlorine concentration of one to two ppm at that point. Irrigation system flow rates should be closely monitored, and action taken (chlorination) if flow rates decline.

Chlorination for bacterial control is relatively ineffective above pH 7.5, so acid additions may be necessary to lower the pH to increase the biocidal action of chlorine for more alkaline waters. Since sodium hypochlorite can react with emulsifiers, fertilizers, herbicides and insecticides, bulk chemicals should be stored in a secure place according to label directions.

Recipe for Chlorine Injection

WARNING: Active chlorine solutions are dangerous to human beings and animals - **<u>the manufacturers' instructions must be followed very carefully</u>**. When using chlorine, proper protection for the eyes, hands and body parts must be worn, i.e. glasses, gloves, shoes, etc. Chlorine contact with the skin can cause serious burns, contact with the eyes can cause blindness and swallowing may be fatal. Prior to filling any tank with chlorine solution, be sure it is absolutely clean of fertilizer residue. Direct contact between chlorine and fertilizer can create a thermo reaction, which can be explosive. **<u>This is extremely dangerous.</u>** The direct contact of chlorine and fertilizer in the irrigation water after it has been injected into the system is not hazardous.

The contact of free chlorine in water and nitrogenous (ammonium and urea) fertilizer creates the combination of chlor amine which is called "combined chlorine". If possible, avoid any application of ammonium or urea fertilizers together with chlorination.

In the case that chlorination is required, it is recommended to ask your local Farm Extension Service for assistance in the computation and application methods.

Sodium hypochlorite is transported by tanks. It should be stored in a clean tank without any remnants of fertilizers. The tanks should be painted white and placed in a shaded area. In the field, storage should not exceed 20 days. In case of gas chlorine, transportation, storage and general handling should be carried out in accordance with the manufacturers' specific instructions under supervision of the relevant authorities.

CHLORINATION OBJECTIVE	APPLICATION METHOD	REQUIRED CONCENTRATION (PPM = PARTS PER MILLION)	
		SYSTEM HEAD	SYSTEM END
PREVENT SEDIMENTATION	CONTINUOUS CHLORINATION	3 - 5	0.5 - 1
	INTERMITTENT CHORINATION	10	1 - 2
SYSTEM CLEANING	CONTINUOUS CHLORINATION	5 - 10	1 - 2
	INTERMITTENT CHORINATION	15 - 50	4 - 5

CONCENTRATION AND INJECTION POINT

It is important to remember that chlorine concentration decreases as time and distance from the injection point increases. The lowest concentration will always be found furthest from the injection point. The injection point should be as close as possible to the treated system.

The required concentration of active chlorine is a result of the chlorination objective.

When the purpose of chlorination is improving filtration performance, the injection point should be close to the filtration system to assure even distribution throughout the filters. Chlorine concentration downstream of the filter battery should be no less than one to two ppm for constant chlorination and three times more for intermittent chlorination.

For continuous chlorination, the injection should start after pressurizing the system. For intermittent chlorination, the procedure should be as follows:

START	By flushing the system.
INJECTION	Inject required amount over time, preferably at the beginning of the cycle.
CONTACT TIME	Preferably one hour, but not less than thirty minutes.
FLUSH	At the end of the process, open the end of the line, flush out and run fresh water for an hour.

CALCULATIONS - Liquid Chlorine

Use the following worksheets to determine the proper injection rate of chlorine in terms of GPH for liquid and lbs./hr for gas.

1. Choose the proper chlorine solution factor:
   5% Chlorine Solution: The factor is = 2.00
   10% Chlorine Solution: The factor is = 1.00
   15% Chlorine Solution: The factor is = 0.67
2. Multiply the solution factor by the treated flow in terms of GPM.
3. Multiply by the desired chlorine concentration in terms of ppm.
4. Multiply by the factor of 0.0006.
5. The result will be the required injection rate of chlorine in terms of GPH

FOR EXAMPLE:
The chlorine solution is 10%. The flow is 100 GPM. The desired chlorine concentration is 10 ppm.

Chlorine Solution Factor		Flow GPM		Desired Chlorine concentration (ppm)				Chlorine Injection Rate GPH
10	**x**	**100**	**x**	**10**	**x**	**0.0006**	**=**	**0.6**

The injection rate of chlorine solution will be **0.6 GPH**

CALCULATIONS - Chlorine Gas

1. Determine the flow of the treated zone in terms of GPM.
2. Multiply the flow by the desired chlorine concentration in terms of ppm.
3. Multiply it by the factor of 0.0005.
4. The result will be the injection rate of the gas in terms of lbs. per hour.

FOR EXAMPLE:
The flow is 100 GPM. The desired chlorine concentration is 10 ppm.

Flow GPM		Desired Chlorine Concentration (ppm)				Chlorine Injection Rate (lbs./hr)
100	**x**	**10**	**x**	**0.0005**	**=**	**0.5**

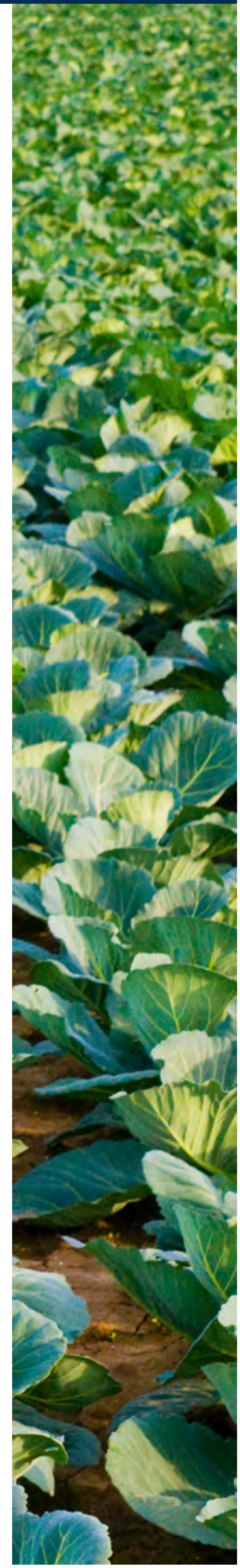
The injection rate of the gas will be **0.5 lbs./hr.**

ACID INJECTION

Overview

Acid can be used to lower the pH of irrigation water to reduce the potential for chemical precipitation and to enhance the effectiveness of the chlorine injection. Sulfuric, hydrochloric and phosphoric acid are all used for this purpose. Acid can be injected in much the same way as fertilizer; however, extreme caution is required. The amount of acid to inject depends on how chemically base (the buffering capacity) the irrigation water is and the concentration of the acid to be injected. One milliequivalent of acid completely neutralizes one milliequivalent of bases.

If acid is injected on a continuous basis to prevent calcium and magnesium precipitates from forming, the injection rate should be adjusted until the pH of the irrigation water is just below 7.0. If the intent of the acid injection is to remove existing scale buildup within the micro-irrigation system, the pH will have to be lowered more. The release of water into the soil should be minimized during this process since plant root damage is possible. An acid slug should be injected into the irrigation system and allowed to remain in the system for several hours, after which the system should be flushed with irrigation water. Acid is most effective at preventing and dissolving alkaline scale. Avoid concentrations that may be harmful to drippers and other system components.



Phosphoric acid, which is also a fertilizer source, can be used for water treatment. Some micro-irrigation system operators use phosphoric acid in their fertilizer mixes. Care should be used with the injection of phosphoric acid into hard water since it may cause the precipitation of calcium carbonate.

For safety, dilute the concentrated acid in a non-metal, acid-resistent mixing tank prior to injection into the irrigation system. When diluting acid, always add acid to water, never water to acid. The acid injection point should be beyond any metal connections or filters to avoid corrosion. Flushing the injection system with water after the acid application is a good practice to avoid deterioration of components in direct contact with the acid.

Acids and chlorine compounds should be stored separately, preferably in epoxy-coated plastic or fiberglass storage tanks. Acid can react with hypochlorite to produce chlorine gas and heat; therefore, the injection of acid should be done at some distance (two feet), prior to the injection of chlorine. This allows proper mixing of the acid with the irrigation water before the acid encounters the chlorine.

Hydrochloric, sulfuric and phosphoric acids are all highly toxic. Always wear goggles and chemical-resistant clothing whenever handling these acids. Acid must be poured into water; never pour water into acid.

Recipe for the Treatment of Drip Irrigation Systems with Acid

SAFETY PRECAUTIONS: Contact of the acid with the skin can cause burns. Contact with the eyes could be extremely dangerous. During treatment and especially when filling containers with acid, wear protective goggles, clothes and boots. Follow the instructions on the Material Safety Data Sheet (M.S.D.S.) attached to the delivered acid.

PROBLEMS OF CORROSION: Polyethylene and PVC tubes are resistant to acid. Aluminum, steel, (with or without inner concrete coating) and asbestos-cement pipes are damaged by corrosion. In every case, resume normal water flow through the system after completion of treatment for at least one hour in order to flush any remaining acid. The importance of flushing cannot be over emphasized when the pipes used are particularly sensitive to corrosion.

METHOD OF OPERATION: Acid can be applied through the drip irrigation system by a fertilizer pump resistant to acids or by conventional control head with a fertilizer tank.

APPLICATION OF ACID BY FERTILIZER PUMP: The goal of acid treatment is to lower the pH level of the water in the irrigation system to values between two to three for a short time (twelve to fifteen minutes). This is achieved by injection of a suitable quantity of acid into the system.

INSTRUCTIONS

1. Clean the filters.
2. Flush the system with clean water as follows: flush the main pipes then the distribution pipes and finally the drip laterals. Use the highest pressure possible for flushing. Deactivate the pressure regulators and flush the laterals, a few at a time. Flushing with clean water will prevent blockages during treatment.
3. Ascertain the discharge of the water from the system through which the acid will be injected, and the discharge of the fertilizer pump.
4. Calculate the required amount of acid that should be injected into the system in order to get 0.6% of acid concentration in the irrigation water.
5. Inject the acid into the system within fifteen minutes only after the system has reached maximum operation pressure.

NOTE: Acids suitable to be injected in 0.6% concentrations are:

Nitric acid	60%
Phosphoric acid	75%- 85%
Sulfuric acid	90%- 96%
Hydrochloric acid	30%- 35%

In many cases the most economical acids are sulfuric acid (battery acid) and hydrochloric acid (swimming pool acid).

CALCULATION METHOD

The injection rate of the acid to the treated zone can be calculated as follows:

Injection rate in GPH = (System flow in GPM) X (0.36/acid % in decimal form)

FOR EXAMPLE:
Sulfuric acid 90% and system flow is 100 GPM.

100 x (0.36/0.9) = 40 GPH

Because the acid is to be injected only 15 minutes the total acid required is 10 gallons

NOTE: Under certain conditions, i.e., hard water with a very high pH, there might be a need to raise the acid concentrate in the system to 1%. Please consult a Netafim USA Representative prior to such a treatment.

IRON CONTROL SYSTEM FOR DRIP IRRIGATION

Overview

Iron deposits create severe clogging problems in drip systems. Iron deposit is described as a filamentous amorphous gelatinous type of brown-reddish slime, that precipitates from water that contains iron. Iron deposits get stuck in drippers and can cause complete plugging of the system.

The problem exists in well water areas where the groundwater aquifers are formed mainly of sandy soils or organic muck soils (very common in Florida) usually with a pH of below 7.0 and in the absence of dissolved oxygen. These waters contain ferrous iron (Fe+2) which is chemically reduced, 100% water soluble and serves as the primary raw material for slime formation.
Iron bacteria, mainly from the filamentous genuses like Gallionella Sp. Leptolhris and ,Sphaerotihus and less from the rod type like Pseudomonas and Enterobacter, when present in the water, react with the ferrous iron (Fe+2) through an oxidation process. This changes the iron form to ferric iron (Fe+3) which is insoluble. The insoluble Ferric iron is surrounded by the filamentous bacteria colonies that create the sticky iron slime gel that is responsible for clogging the dripper.

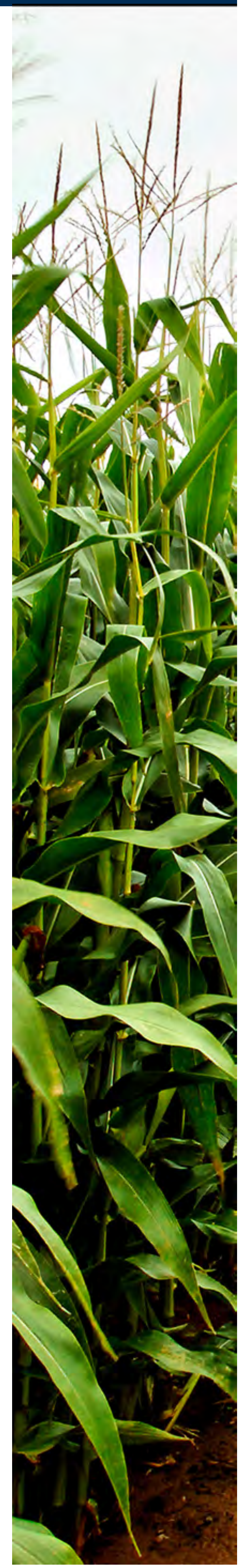
Concentrations of ferrous iron as low as 0.2 ppm are considered a potential hazard to drip systems (H.W. Ford 1982). Between 0.2-1.5 ppm dripper clogging hazard is moderate. Concentrations above 1.5 ppm are described as severe (Bucks and Nakayama -1980). Practically any water that contains concentrations higher than 0.5 ppm of iron cannot be used in drip systems unless they are treated chemically or otherwise. Experiments in Florida indicate that chlorination successfully controls iron slime when iron concentrations were less than 3.5 ppm and the pH was below 6.5 (Nakayama and Bucks -1986). It is also stated that long term use of water with a high level of iron, may not be suitable for drip irrigation. The literature mentions that water containing more than 4.0 ppm cannot be efficiently chemically treated and it should undergo a pond sedimentation process before pumping it back to a drip system.

Iron Control Methods

There are several ways to control iron slime problems. The common denominator of all treatments is prevention of the formation of slime. Basically there are two preventive treatments:

1. STABILIZATION (Precipitation Inhibitors)
   Stabilization treatments keep the ferrous iron in solution by chelating it with sequestering agents. Such agents include various poly phosphates and phosphonate.
2. OXIDATION - SEDIMENTATION - FILTRATION
   This type of treatment oxidizes the soluble "invisible" ferrous iron into the insoluble "visible" ferric iron. It then will precipitate, so it can be physically separated from the water by means of filtration.

The second procedure is generally the less expensive for the severe iron problems in supply water. The various means to oxidize iron include chlorination and aeration. There are also other oxidizers but they are generally more expensive. Chlorine injection for iron control is normally handled in the same manner as continuous chlorine injection outlined above, with residual chlorine levels of one to two ppm. Aeration is most often applied to settling ponds using sprayers or agitators to react the Iron with the air. In this case the pond becomes a pre-filtration component.



Sedimentation - Filtration

A sand media filter is the most appropriate filter for settling down the oxidized iron and filtering it from the water. When designing a filtration system for iron removal it is good practice to oversize the filter units. Larger units with slower water velocity will allow oxidized iron to settle and the resultant water will be easier to filter. This is the same principle as exhibited in settling ponds.

SCALE INHIBITORS

Scale inhibitors, such as chelating and sequestering agents, have long been used by other industries. A number of different chemicals are being marketed for use in micro-irrigation systems to prevent plugging. Many of these products contain some form of inorganic polyphosphate that can reduce or prevent precipitation of certain scale-forming minerals. These inorganic phosphates do not stop mineral precipitation, but keep it in the sub-microscopic range by inhibiting its growth. Probably the most commonly used of these materials is sodium hexametaphosphate - as little as 2 ppm can hold as much as 200 ppm calcium bicarbonate in solution.

Sodium hexametaphosphate is not only effective against alkaline scale, but also forms complexes with iron and manganese and can prevent depositions of these materials. Although the amount of phosphate required to prevent iron deposits depends on several factors, a general recommendation is two to four ppm phosphate for each ppm of iron or manganese.

These phosphates are relatively inexpensive, readily soluble in water, nontoxic and effective at low injection rates.

POND TREATMENT

Algae problems which often occur with surface water sources such as a pond can be effectively treated with copper sulfate ($CuSO_4$). Dosages of one to two ppm (1.4 to 2.7 pounds per acre foot) are sufficient and safe to treat algae growth. Copper sulfate should be applied when the pond water temperature is above 60°F. Treatments may be repeated at two to four-week intervals, depending on the nutrient load in the pond. Copper sulfate should be mixed into the pond (i.e., sprinkled into the wake of a boat). The distribution of biocides into surface water must be in compliance with EPA regulations.

Copper sulfate can be harmful to fish if alkalinity, a measure of the water's capacity to neutralize acid, is low. Alkalinity is measured volumetrically by titration with $H2SO_4$ and is reported in terms of equivalent $CaCO_3$. Repeated use of copper sulfate can result in the buildup to levels toxic for plants.

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A010 07/12

Background

Vine water status monitoring is an essential component in any vineyard irrigation management program. Two tools that can be used to measure vine water status are the pressure chamber and the porometer.

The *pressure chamber* measures leaf water potential, which is loosely defined as the sap tension (or suction) within the xylem vessels of the stem. The tension arises from evaporation from the leaf's stomatal cavities (transpiration), as well as to the matrix forces holding onto the water in the soil—a tug-of-war situation. The drier the soil, the tighter the water is held and the more energy is required to extract the water to feed the transpiration stream.

But leaf water potential only describes the energy state of the water in the vine. We don't know how the vine is responding to the condition it is in. Ideally, we would like to know about the state of all of the physiological processes in the leaves and in the fruit, but that is not at all practical. However, an instrument that measures one important physiological response to stress is the porometer, which measures the degree of stomatal opening or closing. *Stomata* (tiny leaf pores) are very important because they regulate the amount of water vapor loss from the leaves but also control the rate of CO_2 gas that enters the leaf to be assimilated as carbohydrates. So, knowledge of the *stomatal conductance*, as it is referred to, gives us very good insight into the response of the vine to current water and environmental stresses.

The Decagon Leaf Porometer

The porometer measures stomatal conductance: how open or closed are the leaf stomata. Closed leaf pores mean that the vine is experiencing some stress (among those stresses is water stress, but low humidity, deep shade and high wind can also close stomata). While not a measurement of photosynthesis, stomatal conductance may imply a relative measurement of same.

The important thing is that, no matter what you use to measure vine water status, logs must be kept of vine water status throughout the season. Sometimes patterns of water status are more revealing than absolute numbers. Keep records of visual indicators, like leaf senescence or sun-avoidance. Note the values of water potential or stomatal conductance at those times and make sure that you don't hit those stress levels again.

Measurement technique

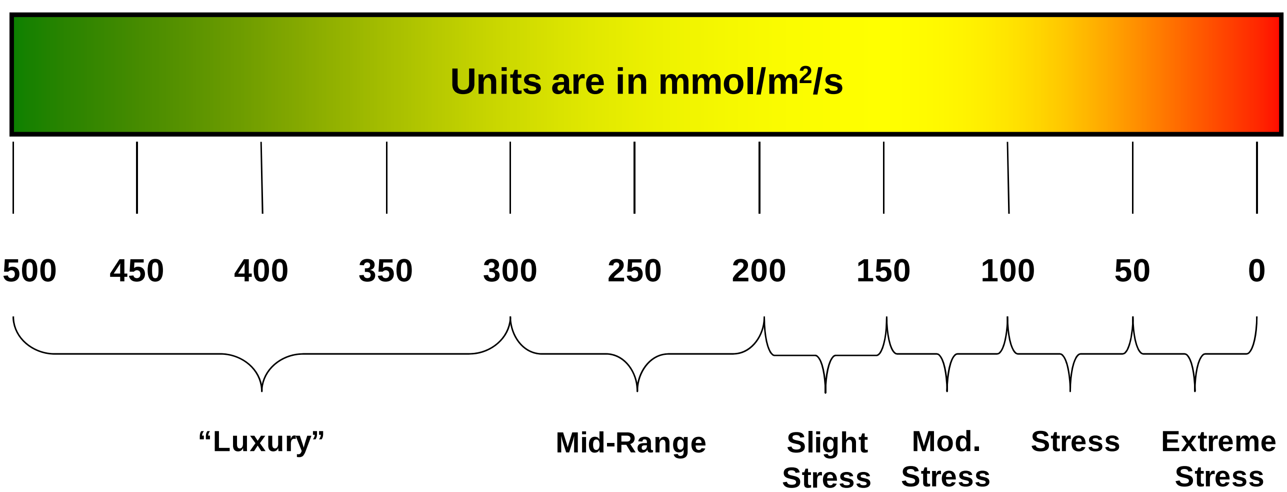
Leaf selection is essentially the same as for a pressure chamber reading. Measurements are usually made during mid-day. Typically, the time between 12:00 and 2:00 pm are optimal, but times before and after this window are allowable, but be consistent about the measurement time in each vineyard/block.

Select a typical shoot and find the most recently, fully-expanded (i.e. mature) leaf on the shoot. Make sure that it is in full sunlight. Press the "enter" button on the leaf porometer and then position the sensor on the leaf. Select a portion of the leaf that is in-between two major veins. This is to assure a proper seal against the leaf surface. The porometer will automatically begin its measurement cycle. Hold the leaf in the same position during the measurement period (default is 30 seconds).

Once the measurement is complete, it may be written down, logged (with annotations) in the Leaf Porometer, or entered into another type of field database. The units mmol/m^2/s are recommended, as that is the one most commonly used. The leaf porometer exhibits more variability than the pressure chamber. To compensate for the variability, it is suggested that a greater number of measurements be made to arrive at the average. About 5 measurements is a good idea. Fewer if the measurements are quite consistent and perhaps even additional measurements if the readings are highly variable at the location being measured. Since the measurement is quite rapid, the additional measurements will not require a substantial amount of additional time.

Additionally, it has been found through research and practice, that weather conditions (particularly humidity or vapor pressure deficit) has a strong influence on stomatal conductance. Be sure to take weather into account when interpreting the data. Fortunately, practice has indicated that as vineyards get more stressed as the season progresses (for instance around the target levels of stomatal conductance described below), the environmental effects are less pronounced.

Interpretation and usage
Like the pressure chamber, the leaf porometer does not indicate *how much* irrigation to apply. That decision depends upon too many factors to discuss here. Nevertheless, the porometer does tell you how stressed the vines are. This stress level can be used to modulate the irrigation applications (either by increasing/decreasing the amount applied or the number of days per week, which is preferred). Are the vines at "luxury" levels? Decrease the irrigation applications. Are the vines getting too stressed? Increase the irrigation applications. It his highly suggested that the leaf porometer be used in conjunction with continuous-measured soil moisture devices to determine irrigation volumes and intervals. Here is a general guideline about its interpretation:



For premium wine grapes, it is a good idea to arrive at the ideal stress level about 2 weeks prior to veraison. For most red varieties, aim for the "Moderate Stress" range of between 100 and 150 mmol/m^2/s. For most white varieties, that level of stress is not needed and the "Slight Stress" range of between 150 and 200 mmol/m^2/s is appropriate. Levels below 100 are indicative of excessive stress and below 50 is a warning sign that severe consequences may result if that level is sustained. Some rootstocks have difficulty in recovering from severe water deficits, so it is important that those levels be avoided. On the other hand, quality wine grapes are produced when some stress is applied to the vines, so avoid the luxury levels of stomatal conductance, especially during and after veraison.

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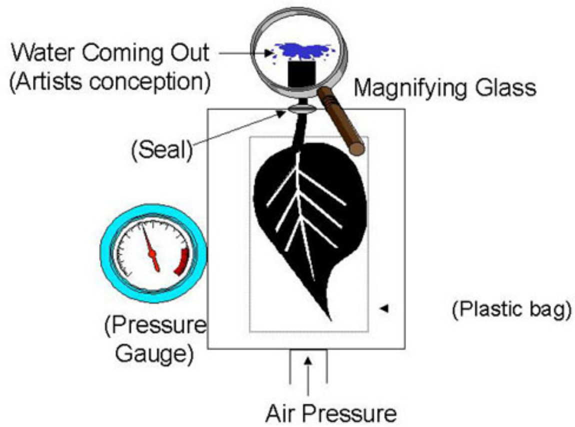
Revised July 2003, R. Smith

Using a Pressure Chamber in Winegrapes

The amount of pressure required to force water out of the cut end of the petiole equals the leaf's "water potential." This is equivalent to the amount of tension the leaf is holding on to the water it contains. Leaf water potential (LWP) is measured in units of negative bars. The more negative the number, the greater the water tension inside the leaf, thus the more stressed the vine is.



Important: when someone says that their pressure bomb readings were "higher" this week, ask if they mean more or less stress.

Factors that Influence Leaf Water Potential

The most important factors are:

- weather conditions at the time of sampling, and
- soil moisture content

For fully irrigated vines with a healthy root system, weather conditions can have a large impact on leaf water potential. Higher air temperature and lower relative humidity is reflected by more negative values. In all cases, hotter and dryer conditions cause more negative (more stress) water potential. For midsummer conditions in California, the values of water potential measured on a fully irrigated grapevine will typically be between -7.0 bars and -10.0 bars. To minimize the effect of temperature, measurements should be taken only when average conditions exist. For example, if average midday temperatures are 92ºF, measurements can be made on days with midday temperatures of 90 to 95º with no need to make an adjustment for climate. Cloudy or foggy days or days with high winds should be avoided. LWP of water stressed vines is less affected by climatic conditions and more sensitive to soil moisture content.

Levels of winegrape water deficits measured by mid-day leaf water potential	
less than -10 Bars	no stress
-10 to -12 Bars	mild stress
-12 to -14 Bars	moderate stress
-14 to -16 Bars	high stress
above -16 Bars	severe stress

When to Sample

The loss of water from the leaf is not constant throughout the day and varies with a number of factors including the environmental demand. This factor can be minimized however by measuring when the leaf water potential is relative static. Before the sun reaches the leaf in the morning, the vine has had a chance to uptake water and translocates it to all parts of the plant. The leaf water potential is the least negative at this time. As the sun contacts the leaf and heats the surface, the rate of transpiration increases, causing a more negative leaf water status. During the midday (solar noon), the water potential is again static at the daily maximum deficit. An appropriate sample period is between 11:30 am and 1:30 pm. Mid-day measurements of leaf water potential are better related to the soil moisture content than predawn measurements.

Vine selection

• avoid vines with obvious nutritional, disease problems • want vines in area that is in a soil type or depth that is typical for that block. If there is a lot of variability within the block, then optimally monitor more than one site. • Flag the row and/or vines so that you can return to same area

Sample Number

The number of vines, which are measured depends somewhat on the variability of the vineyard; however it is necessary to measure enough leaves to closely approximate the average condition. For a 20-acre vineyard, selection of six vines located in all parts of the vineyard should be adequate. Select two leaves per vine for measurement.

Leaf selection

Select an undamaged fully expanded leaf from the "sun side" of the vine that has been in full sun for a few hours. This will be the south side of east-west rows and the west side of north-south rows. Leaves in the interior of the canopy, which are shaded, will not accurately represent the maximum leaf water potential and should not be sampled. Young leaves, which have not achieved full size, should also be avoided.

Sample collection

• place a plastic bag around the leaf and use a razor blade to cut the petiole off close to the shoot
• insert the petiole through the seal in the lid • put bagged blade into the leaf chamber ASAP and lock lid
• typical time from the initial cut to when you begin to pressurize the chamber is 10 to 15 seconds

Measurement

• start the air flow into the chamber at a rate of about 0.3 bars per second • watch the petiole's cut end with a magnifying glass and stop pressurizing as soon water STARTS to appear • QUICKLY read the pressure gauge. A leaf water potential reading of –10 bars should take 33 seconds. A higher rate of pressure increase followed by 0.3 bar rate near the endpoint causes a more stressed reading. .

Problems

• OPERATOR ERROR • crushing the petiole • holes or torn leaf blade

Reproducibility

• If 2 leaves sampled per vine, they should be within 0.5 bars • if 2 or more adjacent vines sampled, they should have values within 1.0 bar • keep track of readings from each vine • resample if necessary

Drip and Micro Irrigation Design and Management

for

Trees, Vines, and Field Crops

Practice plus Theory

4th Edition - 2011

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SECTION 1

DRIP AND MICRO IRRIGATION GENERAL PRINCIPLES

CHAPTER 1

BACKGROUND TO DRIP/MICRO IRRIGATION

Drip/micro irrigation delivers water directly to relatively small areas adjacent to individual plants through emitters placed along a water delivery line (called a "lateral"). In a vineyard, there will typically be one or two emitters per plant. In an orchard, the number of emitters per plant may vary from one (such as with some microspray systems) to sixteen (for a double-hose buried drip system on wide tree spacings). **Figures 1 through 4** show typical lateral installations on trees and vines.

Figure 1. Lateral hose with emitters on a vineyard. Hose is suspended above the ground.

Figure 2. Microsprayer. Non-rotating head. Photo courtesy of Bowsmith Irrigation.

Figure 3. Microsprayers on young trees. Very high percentage wetted area.

Figure 4. Double line drip. Photo shows (i) typical non-uniform wetted pattern in soils, and (ii) typical close spacing of double hoses.

Typical ingredients for drip/micro systems include a pump, filters, chemical injectors, main and submain lines, laterals, and emitters. A schematic of a simplistic drip system is shown in **Figure 5**.

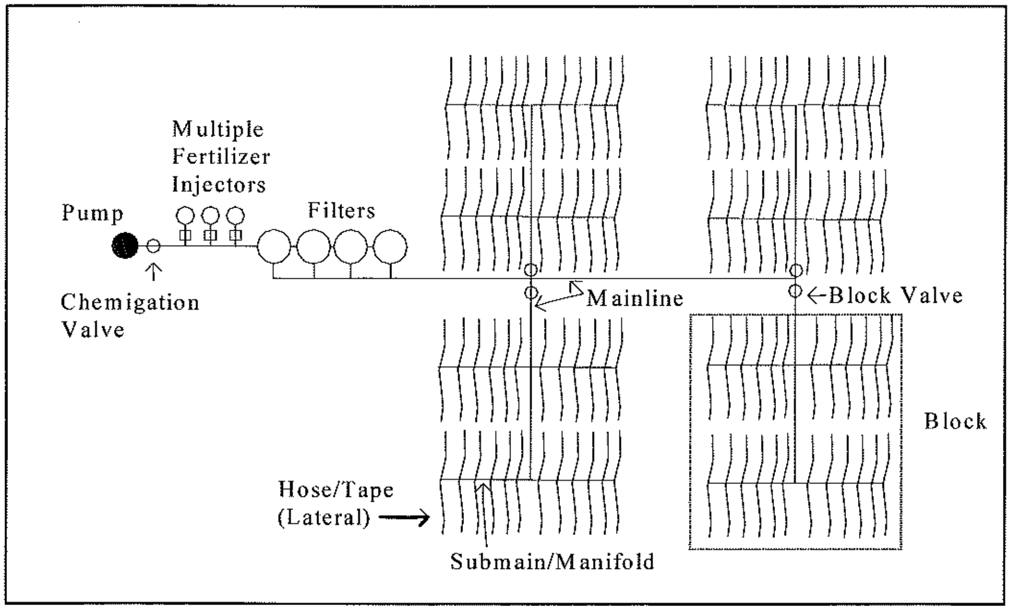

Figure 5. Simplistic drip system layout.

For smaller plants planted in rows, such as broccoli, lettuce, peppers, melons, and cotton, and for field crops (alfalfa and grains) the emission devices are spaced closely enough so that the capillary action of the soil provides water to each plant root zone. It is unusual to use drip on field crops because of the difficulties in wetting all of the plants, and the low prices of such crops.

In the irrigation industry the preferred terminology to describe these systems varies by individual and geography. However, "drip" irrigation generally refers to systems that use low flow rate emitters of less than 2 GPH (7.6 LPH) from which water drips onto or into the soil. "Micro" irrigation often refers to systems with emission devices that throw water horizontally and vertically with a spray or sprinkler pattern. Some persons distinguish between "microsprayers" that have no moving parts, and "microsprinklers" that have rotating parts. "Trickle" irrigation was a widely used term in the early days of drip/micro irrigation, as was "low volume" irrigation. **This book generally uses the term "drip/micro" when discussing topics that pertain to both "drip" and "micro" irrigation systems.**

Equipment such as hoses and emission devices typically remain in one place during the growing season. Systems are typically permanently installed for trees and vines and for some row/field crops, but for other row/field crops (lettuce, cotton, etc.) they may be portable and moved to a different field after an irrigation season is complete. Other systems are hybrid, with a buried mainline distribution system and removable or disposable laterals and/or manifolds/submains.

Drip/micro irrigation systems require very clean water to avoid plugging of the emission devices. Filtration components represent a large portion of the cost and maintenance of drip/micro irrigation. In addition, chemigation is typically required to avoid plugging due to bacterial growth and/or chemical precipitation in the laterals and emission devices. Filtration and chemigation for plugging prevention can only be minimized if the water is very clean and/or if the laterals with emitters will be discarded after a short life.

Flow rates for individual drip emitter devices are typically very small. However, some microsprayer irrigation systems have such large nozzle diameters that it is questionable if they should be considered sprinkler systems or drip/micro irrigation systems. The determining factor for calling them drip/micro systems is that filtration is extremely important. Typical ranges of emission device flow rates for drip emitters are in the range of 0.4 - 2.0 GPH *(1.5 - 8 LPH)*, and flow rates for microsprayers are in the 5 - 15 GPH *(20 - 60 LPH)* range.

Irrigation water is generally applied through emission devices daily or several times per week. Some managers pulse the systems on hourly intervals, although that practice is not standard except on buried drip systems for trees and vines, where the 30 - 45 minute pulse durations help to prevent water from flowing to the soil surface. Some drip/micro systems are designed to irrigate a whole field at once (in one "set"). However, the almost universal trend toward higher emitter flow rates (such as microsprayers) or more closely spaced emitters (such as on row crops) usually requires that the full pump flow rate be rotated between two to eight blocks within a single field.

Drip/micro irrigation systems are easily automated if the water supply is readily available and flexible. Most irrigation projects do not supply water with sufficient flexibility to automate the drip/micro irrigation systems unless the farmers install a reservoir on the farm. The authors have spent many years working with irrigation projects to automate water delivery systems so that they can provide the degree of flexible water delivery service necessary to support drip/micro irrigation. Persons interested in the topic of improving the flexibility of water delivery to farms should contact the authors at the Irrigation Training and Research Center (ITRC) to learn about the large number of short courses, publications, and projects that ITRC has on that topic.

Drip/micro irrigation systems are ideal for irrigation managers who are interested in fine-tuning the applications of water and fertilizer (fertigation) through the irrigation system. Persons interested in more information on this extremely important topic can obtain the book *Fertigation* (Burt et al., 1995) from ITRC. It is an essential companion to this book.

Historical Drip/Micro Irrigation

Drip/micro irrigation became widespread in some areas of the U.S. by the mid-1970s. At that time, there were two primary forms of drip/micro irrigation:

1. Row crop drip, using thin-walled "tape" products. Those products generally used a double chamber, closely-spaced orifice design. Large acreages of strawberries and sugarcane were converted from sprinkler or furrow irrigation to drip irrigation because of clear advantages in water, fertilizer, and power savings. Yields also increased with the new irrigation method.
2. Orchard and vineyard drip, using flexible polyethylene hose and molded emitters. Those emitters were generally sized for 0.5 - 2.0 GPH *(1.9 - 7.6 LPH)* each.

For some crops the dominant irrigation method now utilizes microsprayers, which have flow rates of 10 - 20 GPH *(37.8 - 75.6 LPH)* each. In some areas of the U.S., this form of irrigation is called "microspray" or "microsprinkler" irrigation to distinguish it from drip emitters. As stated earlier, this book uses the term "*drip/micro irrigation*" for all forms of irrigation that have discharge points or sections of hose with low flow rates and sufficiently small hole sizes so that filtration is of primary concern.

Drip/micro irrigation has steadily increased in popularity since the first large commercial installations of the early 1970s. The days of frequent and rapid introductions of completely new products slowed in the 1980s, but since the late 1980s there have been steady improvements in product quality. In the very late 1990s there were many new innovations such as pulsating emitters, completely new designs of pressure compensating emitters, new large pressure regulators that operate with a low pressure loss yet can maintain low pressures needed for drip tape, and some new filter designs. In the period from 2002-2007, there was a rapid expansion of "tape" drip (both above-ground and SDI) on row crops such as cotton, corn, and tomatoes. These applications expanded into non-traditional drip areas such as Texas and Kansas.

Drip/micro irrigation now has many different forms that are sometimes defined by the crop it irrigates and other times by the specific hardware used. These are summarized below.

Variations of Drip/Micro Irrigation

There are many variations of drip/micro irrigation systems. Some of the differences are due to agronomic or horticulture requirements. For example, frost protection is very important for citrus and avocados in some regions, and microsprinklersprayer designs offer better climate control than do emitters (but much less protection than standard sprinklers). Drip emitters may be preferred in almond orchards because they enable one to irrigate alternate tree rows without wetting the soil around adjacent rows, as would happen with microsprinkler/sprayer designs. This alternate row irrigation is important with almonds because alternate rows may be planted with different varieties that require stress at different dates prior to harvest.

An orchard crop with an extensive, shallow root system such as avocado, or a widely spaced tree such as walnuts, will typically perform better under microsprinkler/ sprayer than under drip because a larger soil area can be wetted than with drip. Conversely, closely spaced (hedgerow spacing) trees are better suited to drip emitters. There are many emitters per acre in a hedgerow spacing. The wetted soil volume is high, and microsprayer/sprinkler designs suffer from problems of tree and trunk interference of the sprayer patterns. Citrus growers in some regions prune the trees so that the leaves never touch the ground; microsprayers in these situations can wet a large area. If the citrus is pruned so that the leaves touch the ground, microsprayers may, in actuality, become high flow rate drip emitters because the water hits the leaves and cannot spread out.

Drip emitters typically wet less soil area per emitter on sandy soils than on loam or clay soils, given the same water quality (although it is quite risky to use generalized soil characteristics to estimate the extent of lateral water movement from emitters). Therefore, it is generally more expensive to use drip on orchards with sandy soils than on heavier texture soils because more emitters (and sometimes an extra hose per tree row) are needed on sandy soils to obtain sufficient soil wetted area (often desired to be in the 60% range). Microsprayer/sprinkler systems would cost the same on either soil type, because the wetted area is so large that the capillary spread of water beyond the spray pattern is not very important.

Above-Ground Orchard and Vineyard Drip

These systems typically have one hose per plant row on closely spaced rows (row spacing less than 4 meters), and may have two or more hoses per row on wider spaced rows. Emitters are often spaced in arid regions so that at least 60% of the potential root zone volume is wet, which provides an adequate moisture reservoir for periods of high evapotranspiration, and as insurance against several days of breakdowns. Less wetted area is common in areas with supplemental rainfall. When this book was written, growers of Clementine mandarin oranges in arid areas were promoting a very small percentage wetted area as a means of being able to quickly control root zone conditions. However, this is an exception to general applications.

The emitters used in orchards and vineyards are often manufactured separately from the hose, and those "on line" emitters may be installed on the hose either at the factory or in the field, depending upon the emitter configuration and design. The general trend, however, is to purchase "in line" emitters that come pre-installed in hose; this reduces the labor required for field installations. Most hose is manufactured from polyethylene, with common diameters of 0.58" – 1.05" (16 – 30 mm). Hose lengths (in one direction from the hose inlet) vary from about 300 – 1300 ft (100 – 400 meters).

In the case of orchards or vineyards with a single hose per row, the hose is generally installed down the plant row. It is placed on the soil surface next to the tree trunks with only a small percentage of extra length (1.5 – 2.5%) to accommodate hose expansion and contraction due to temperature changes. Recent designs rarely use spaghetti tubes to move water from the emitters to distant locations, although this was common in earlier designs. The use of spaghetti tubes has been discontinued because it was found that after time, the spaghetti tubes were typically wind-blown or kicked together. If a single line of emitters will not provide sufficient soil wetted area, it is common to install two hoses, one on each side of the tree row, but out of the way of tractor traffic.

Figure 6. Double line drip system on almonds.

On vineyards a single hose per row is almost universal because the rows are tightly spaced. Usually one or two emitters are used per vine. Depending upon the region and harvesting/tillage equipment, the hose may be placed on the soil surface next to the vine trunks, or be suspended in the air at a height of approximately 1 ft (0.3 meters) (refer to **Figure 1**). Suspension requires the existence of a trellis system with wires onto which both the vine branches and the hose are attached. Suspension provides the ability to till under the vines without damaging the hose and emitters. Because the hose often sags between the vines, it is quite common that the flow from one emitter (on a high point) will move laterally along the hose to the low point – combining with the flow from the emitter at the low point. This creates only one wetted point rather than two; clamps must be placed on the hose near the emitters to ensure that the water drips down at the emitter location.

Orchard and vineyard drip systems were well established on large acreages in many areas of the world by the early 1980s. The equipment has continued to improve, with excellent choices of well-designed emitters and hoses now available. Most emitters are now of one of two designs: tortuous path or pressure compensating. Tortuous path designs are popular because they provide relatively large passageways and reduced plugging problems compared to vortex or laminar flow emitter designs. Tortuous path designs also provide a reasonable degree of pressure compensation (flow rate changes are approximately proportional to the square root of pressure changes). Because they have no moving parts, emitters with tortuous designs tend to be relatively inexpensive, well-made, and durable.

The second most popular emitter design incorporates some type of pressure compensation provided by a moving part that progressively restricts the passageway size as the pressure increases. This is described in more detail in Chapter 6.

Subsurface Orchard/Vineyard Drip (SDI)

Buried drip systems (also known as subsurface drip irrigation, or SDI) on orchards and vineyards have a limited acreage, but they are the subject of a considerable number of discussions. They are handled in more detail in Section 3 of this book.

Figure 7. SDI on walnuts. Root growth above and below the hose can be seen, indicating potential root pinching problems in the future.

Microspray and Microsprinklers in Orchards

Microspray and microsprinkler systems became very popular in the western U.S. in the early 1980s, and many drip systems were converted to "micro" at that time.

Micro systems typically have larger hose diameters than drip because the flow rates of the emission devices are much higher than for drip. They tend to have smaller lateral hose lengths than drip for the same reason. Because of the high application rates, a micro field is often divided into 3 or more sets with only one set being irrigated at a time, whereas many drip systems are only divided into two sets. The net result is that micro systems are often more expensive than drip systems because micro requires more valves and manifolds, and shorter/larger hoses than drip. An exception would be on widely-spaced plants such as walnuts, in which case several drip hoses would be required per tree row compared to only one hose for micro. Another exception would be a comparison of a single hose micro system against a double hose drip system on almonds, where the double hose is needed to provide adequate wetted soil volume. In California, about half of the almond acreage with drip/micro is double line drip with six to eight emitters per tree; the other half is microspray with one or two sprayers per tree.

Microsprayers and microsprinklers are typically attached to a stake (poked into the ground) that is connected to the lateral hose with a spaghetti hose of 1 - 3 ft *(0.3 - 1.0 m)* in length. This allows the lateral hose to move due to temperature changes or equipment contact, yet the emission devices remain standing undisturbed. There are many designs of stakes to support the microsprayers and microsprinklers above the ground (typically 1 - 3 ft *(0.1 - 0.3 m)* high). Some growers prefer to slightly bury the lateral hose and connect the emission device risers directly to the hose, from which they protrude above the soil surface. Such an installation minimizes some picker damage, coyote damage, and also keeps the hose cooler and eliminates the shrink/expansion of the hose length. However, there have been problems with roots crimping the hoses with even relatively shallow burial depths.

Microspray/sprinklers can also provide some frost protection, plus give a larger soil wetted volume than a single hose drip system. Frost protection is achieved in some areas by actually placing the microsprayer in the citrus canopies during periods of frost. The microsprayer is re-positioned on the ground for the irrigation season. Note that the use of microsprayers for frost protection should be done with extreme caution, as a severe frost (especially with dry air and some wind) can quickly convert the microsprayer discharge from a protective mechanism to an evaporative cooling mechanism.

The disadvantages of microspray/sprinkler, as compared to drip, include the higher cost in some designs, somewhat higher relative humidity in the air, and an inability to easily restrict the wetted area during certain times of the year.

Figure 8. Microsprayer.

Figure 9. Inverted microsprayers used for both irrigation and freeze protection on peaches.
This is an unusual application because of its high costs and because of disease problems associated with wetting the leaves and fruits during the summer.

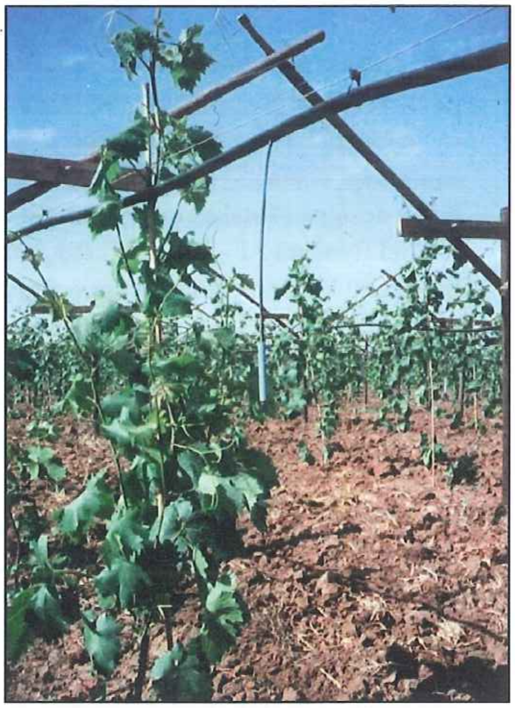

Figure 10. Microsprayer with weight suspended upside down on vineyard. Microspray is used by some table grape growers to increase the soil wetted area. Once the grapes are older, the spray pattern will only be below the leaves.

Above-Ground Row Crop Drip (crops other than orchards and vines)

Above-ground row crop drip irrigation was one of the earliest forms of drip irrigation. Presently there are three major categories of above-ground drip for row crops such as lettuce, celery, cotton, and cauliflower. All of these crops are characterized by their ability to withstand a wet soil surface.

1. Drip with "plastic culture", as found in Florida's coral sands.
2. Disposable drip tape, for which the tape is used only one season and discarded.
3. Retrievable tape or hose with in-line emitters that is used for multiple seasons.

There is a fourth variation now used with processing tomatoes in California. Drip tape is installed in the furrows themselves after "lay-by". That is, the tomatoes are germinated, or the transplants are irrigated, with sprinklers during the first of the season. Then just before the plants begin to cover the furrows and tractors will no longer enter the fields (lay-by), the sprinklers are removed and drip tape is installed in the furrows.

Figure 11. Drip tape retrieval unit – widely used for surface tape.

The details of these variations are discussed in Section 2 (Row Crop Drip).

Subsurface (SDI) Row Crop Drip

There are two main categories of subsurface (SDI) row crop drip: "one crop" and "permanent". The "one crop" systems have typically been either strawberries or sugar cane. The "permanent" SDI systems were in vogue in the western U.S. in the early-mid 1990s, have been abandoned by some farmers, and are rapidly expanding in other areas/crops. In some cases, they are used because the crops in question cannot be grown with a wet soil surface (e.g., melons and tomatoes). The two categories are described in more detail in Section 2 of this book (Row Crop Drip).

Figure 12. Evaluation of row crop SDI system requires uncovering the emitters for flow tests. Typical burial depth = 8-12" (20 – 30 cm).

Advantages and Disadvantages

Drip/micro irrigation systems have the following typical advantages over some other irrigation methods:

1. They can be used effectively on extremely steep ground. No other irrigation method can be used on extreme terrain.
2. They require minimal land grading. Land grading is necessary to prevent surface drainage problems that might occur with rain, and to accommodate any special tillage equipment used.
3. It is more difficult to have gross over-irrigation during months of peak ET. This is generally because many drip/micro systems are not designed with a large system pump capacity, rather than just because drip/micro irrigation system managers are inherently better than other irrigation managers.
4. The Distribution Uniformity (DU) of systems can be very high (0.93 or greater) in reasonable terrain and with an excellent design and maintenance
5. The new system DU depends only upon hydraulics and equipment design, rather than upon management, soil differences, and/or overlap patterns of sprinklers. As the industry provides even better pressure compensating emitters, the new system DU values will probably consistently fall in these high (> 0.93) ranges.
5. Systems can be installed on virtually any size or shape of parcel.
6. Generally, there are no runoff problems to contend with. However, runoff can be a problem with very pure water or with high Mg/Ca ratios or high Na/Ca ratios.
7. The systems are sometimes capable of high frequency irrigation without degradation of DU such as occurs with surface irrigation methods, and without excessive non-beneficial evaporation losses such as can occur with sprinkler methods. High frequency irrigation allows the maintenance of optimum soil moisture content in the root zone, which is especially important for salty water,

or for shallow rooted crops. It should be noted that very high frequencies are not necessarily desirable for some crops such as lettuce.

8. Fertilizer can be directly applied uniformly to the root zone at any stage of growth on any day and with any dosage, without wetting plant foliage.
9. The upper portion of the root zone can be maintained moist, which enhances the uptake of nutrients such as phosphorus and ammonium that are typically concentrated near the soil surface. This single advantage is probably exceptionally important in improving yields with some crops.

The above advantages are "typical", meaning that they are not universal. As with any other irrigation method, good results depend upon good design, good equipment, and good maintenance. Similarly, drip/micro irrigation systems can have the following disadvantages:

1. The DU can degrade quickly with time due to standard causes such as insufficient water filtration, lateral flushing, and/or chemical injection. The DU may also degrade quickly due to some unforeseen and unusual circumstance such as fresh water clams growing inside the hoses, or an unusual insect that prefers to nest inside a certain type of emitter. Rodent damage can be devastating in some areas. Insect damage to thin drip tape has been extensive.
2. Drip/micro systems are susceptible to damage by vandalism, and vandalism repairs may be complicated, time consuming, and costly. For example, brass valves may be stolen.
3. Evaporation losses can be high with some micro designs that frequently wet large areas of bare soil.
4. Although the potential for excellent results (water savings fertilizer efficiency, optimization of yield) often exists, they can only be achieved with excellent design and excellent management. Often it takes several years for irrigators and farmers to develop even average management skills, and catastrophic failure can result before those skills are gained. Drip/micro methods are sometimes perceived by growers and planners as being able to provide a magical cure for problems associated with other irrigation methods that are actually caused by the poor management with those other methods. Unless the management style changes when drip/micro systems are installed, the problems may change from being moderate to being severe. Fortunately, many growers are willing to completely re-learn irrigation operation techniques when introduced to a new irrigation method.
5. Water must be available to the system on a very frequent and dependable basis. Drip/micro cannot be used in irrigation projects that deliver water on a rotation schedule (which includes most of the world's acreage) unless the fields are supplied with groundwater.
6. Energy costs for irrigation system installation and operation are usually higher than for surface irrigation methods (assuming similar efficiencies) on flat ground. However, the total energy use efficiency may actually be higher under drip/micro if fertilizer usage is reduced and if yields are improved; similarly, energy requirements may be less under drip/micro if less land grading is required.

7. There are dozens of different types of essential parts (fittings, valves, etc.) in any single system. The systems must be supported by an excellent resupply infrastructure.
8. In very arid areas, a sprinkler system may be needed once every few years (and in some cased more often, such as with some buried row crop drip) to leach salts that have built up near the soil surface.
9. Drip/micro systems can have a very high initial cost in some situations.
10. Although excellent irrigation dealers abound, inept irrigation dealers also abound. The Irrigation Consumer Bill of Rights (Chapter 12) is meant to provide some help with this.

The hardware, prices, and management of each form of drip/micro irrigation will vary. There are also large differences in equipment selection from country to country, state to state, and even from county to county. Perhaps this can best be illustrated by the tremendous variability in stakes, risers, trajectory heights, trajectory shapes, and nozzle sizes found in microsprayer designs. Growers in a certain area of Florida, for example, will prefer completely different models of microsprayers and materials for spaghetti hoses than growers in California, even though citrus may be the crop in both cases.

Nevertheless, design **principles** are transferable between areas. The distribution uniformity (DU) of a system should be discussed the same way in New York as in Hawaii, even though the crops may be completely different and the emission devices have different shapes and flow rates. The principles of friction and filtration are universal, although certain water quality problems may be localized.

This book is divided into four different sections:

1. General principles of drip/micro irrigation
2. Row crop drip, including variations of subsurface drip
3. Permanent buried drip (SDI) on trees/vines
4. Example drip designs

Time and millions of acres of experience have shown that if a system is designed appropriately, installed correctly, **and** managed well, it can be a success. Excellent designers and managers with many years of drip/micro experience will sometimes encounter problems that are very difficult to resolve; it may take several years of experimentation to learn the best solution, and the solution is sometimes expensive. Furthermore, history has repeatedly proven that poorly designed, installed, **or** managed drip/micro irrigation systems can fail catastrophically, or at a minimum provide substandard performance. It is essential to recognize the difference between the words "**and**" and "**or**" in the statements above.

Wine Grape Irrigation Management

by

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May 2012

Due to the many varieties, soils, canopy sizes, trellis designs, growth stages, etc. of wine grape crops, there is no "one" optimum ETc value for wine grapes in any area with a specific ETo value. In more technical terminology, there is no one crop coefficient "Kc" that is valid.

The Classic "ET" Approach

One concept that is commonly mentioned by wine grape growers is that of "full ETc". This approach is technically very sound, and is used extensively around the world on most crops. The general concept is:

$$\text{Full ETc} = \text{Kc} \times \text{ETo}$$

where ETc = crop and soil ET
Kc = a published crop coefficient, that is primarily dependent upon the canopy size
ETo = a reference ET value, computed directly from weather information such as CIMIS

A rational approach to irrigation scheduling takes into account good records of weather and proper crop coefficients. However, for a large operation with numerous small fields, there just isn't enough time to take detailed real-time soil and plant measurements, process those data, and continuously modify the irrigation schedule. So having a relatively simple process at the start of the year that will utilize weather data has a lot of merit, assuming that plant indicators, yields, and yield qualities are assessed throughout the season and scheduling adjustments are made for the next year's irrigation program.

That said, there are very few crops that are as complicated to irrigate with the ET approach as wine grapes. Four categories of complications that seem particularly apparent for Central Coast wine grape growers who want to use the classic "full ETc" approach are:

1. There is some uncertainty as to how the Kc should be adjusted based on canopy size and canopy shape (height, vertical density of leaves).

2. In the early part of the season, there can be challenges with accounting for how much stored soil moisture (from rainfall) contributes to the ETc, versus how much needs to be supplied by the irrigation system.

3. Most wine grape growers apply some type of "% of full ET" factor to achieve specific vine performance via stress. The "% of full ET" factor will vary during the season, by crop variety, and by the target wine quality.

4. The ETo data may be incorrect. One of the challenges with wine grapes in the coastal regions of California is that the ETo varies tremendously within a few miles. Additionally, there are only few CIMIS stations to measure the weather variations. Therefore, growers often rely on inexpensive, private weather stations. The quality of the information can be highly variable, so the different weather stations, on the same day with the same identical weather, will provide different values of "ETo". As a result, the understanding of what is an appropriate "Kc" to use in other areas can be challenging.

These challenges are discussed below, one at a time.

<u>Crop Coefficient, Kc.</u> With the "full ETc" equation (Full ETc = Kc × ETo) rearranged, the crop coefficient, Kc, can be defined as:

$$Kc = \frac{\text{Full ETc}}{\text{ETo}}$$

One Kc formula found in California wine grape literature is:

$$Kc = .002 + .017x$$

where x = % shading at noon (Williams, 2001)

However, at a high percentage shade (also referred to as "percentage cover", or "percentage canopy") such as 100%, this formula gives a Kc of about 1.7, which is far beyond what is commonly accepted as a possible maximum value of about 1.25 to 1.30 for any crop.

Figure 1 shows two curves: one with the formula by Williams (2001), and another showing what ITRC considers to be a more likely Kc value for "full ET". It is obvious that this difference introduces confusion when talking about what reduction factor should be applied to "full ETc" if the computation of "full ETc" is different among growers.

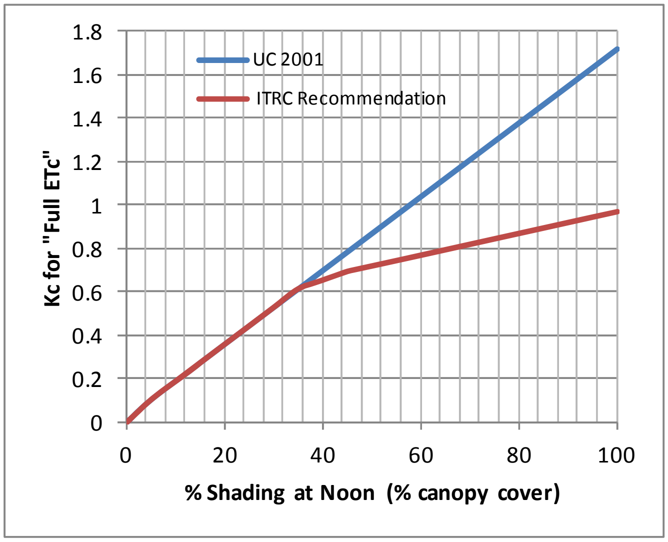

Figure 1. Recommended Kc values for initial estimates of "full ETc" before the "Percentage of ETc" factor is applied

ITRC recognizes that there is still something to be learned in this area. For example, how does one determine "canopy size" or canopy percentage? That is, what percentage of the ground surface is shaded by the canopy at mid-day? It is well understood that the Kc value depends on the shape of the trellis in addition to the percent shade at noon. One technique utilizes a solar panel that is placed on the ground surface at various points under and between plants. This technique provides a different amperage output depending upon the amount of shading, thus giving a simple reading of percentage cover.

The example below shows one possible method for adjusting the Kc value based on the Height/Width ratio.

Rule: If you have an established Kc and a Height/Width ratio
modify the Kc as follows:
for a new Height/Width ratio, FOR THE SAME % CANOPY SHADING

New Kc = Old Kc * (1 + .55*(New HWR)/Old HWR - 1)

Where	HWR = the Height/Width ratio of the trellis and the Width = (% Canopy Shading/100)* Row spacing				
For example:	Old % shade =	30	gives>	0.51	old Kc
	Old Height =	6	feet		
	Old spacing =	10	feet		
Computed:	Canopy width =	3	ft		
	Old HWR =	2			
	Assume new height =	7	feet		
	new HWR =	2.3		(same width)	
New Kc		0.56			

Soil Moisture Contribution to ETc. This is an important consideration at the beginning of the irrigation season. Certainly, irrigation stress cannot be induced if there is a deep, moist soil with a high available water holding capacity. Computations are complex because during the early season, while the canopy is developing, the ET of the cover crop may be much greater than the ET of the grape vines. Additional complications arise because different wine grape rootstocks have different rooting patterns; some tend to spread out and others may go as deep as 20 feet (rare with Central Coast vineyards because the soil is often much shallower than this).

Although there is a section later in this technical note regarding computations of a soil moisture balance, the reality is that such a computation is problematic because of the large variations in soils and soil depths, and the uncertainties in cover crop ET values. Therefore, the "when to first irrigate" rules for grape growers tend to rely on plant vigor indicators rather than on soil moisture balance computations.

Percentage of Full ET. It is common practice among most wine grape growers to start with the "full ETc" value and then apply a factor such as "70%" to that ETc, thereby irrigating to some "percentage of full ETc". One of the most difficult things to translate from "ART" to "SCIENCE" is how growers will treat grapes that produce $40/bottle wine, as opposed to $6/bottle wine. In general, grapes that are destined for more expensive wine are grown with smaller berry sizes. In other words, the "% of full ETc" will vary, depending upon the variety, time of season, and market destination.

In short, premium grape growers may use as low as 50% of "full ETc" prior to verasion, but other growers who are focused more on volume may apply closer to 90% during this time.

Incorrect ETo data. There is no easy answer to the problem of inconsistent ETo data. Even with high-quality CIMIS weather stations, a good analysis of weather data begins with checks of the solar radiation and relative humidity data. The sensors for those data are subject to errors, which are even more prevalent with inexpensive weather stations. If a grower wants to use excellent ETo data, a good option is likely to have a few very high-quality weather stations using standard CIMIS equipment, and then to have a more intense grid of stations that only monitor temperature and precipitation. There are techniques that ITRC uses to extrapolate the CIMIS ETo values to other areas, based on temperature differences. This requires some work.

Recommendations for Wine Grape Irrigation on the Central Coast

The following are guidelines to procedures and techniques for wine grape irrigation.

1. Never rely on just one tool. Use all three of these:
    - *Weather-based ET estimates*. Utilize real-time weather data from a well-situated, neighboring weather station to develop estimates of ETo.
    - *Plant observations*, including leaf bomb measurements for either leaf water potential, or stem water potential, and simple observations of berry size and vegetative vigor.
    - *Soil measurements*. Different people prefer different devices, but the most important thing is to actively measure different depths, and occasionally dig backhoe pits. With sandy and sandy loam soils, or shallow soils, it is particularly important to monitor soil moisture at various depths in addition to using leaf water potential readings. This is shown in the three hypothetical soil moisture characteristic curves in **Figure 2**. The key point is that the vast majority of the AVAILABLE water held in a sandy loam soil is held at a matrix potential between (0) and (-2) bars. Once that soil moisture is used up, the matrix potential plummets rapidly.

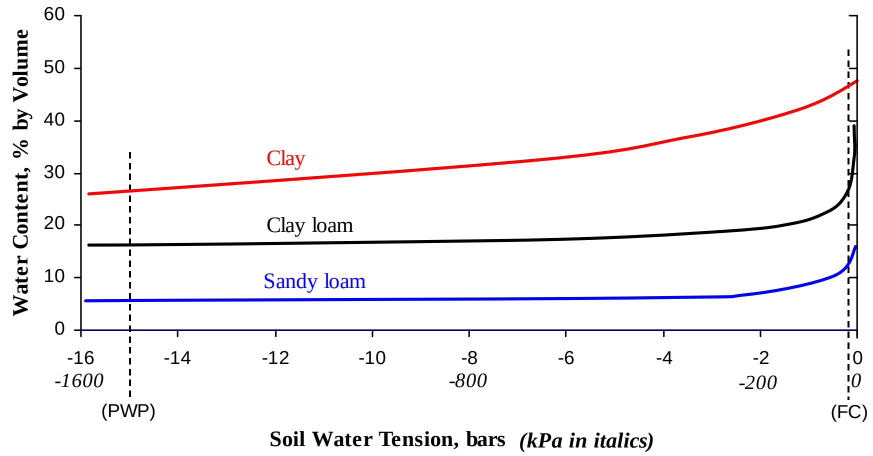

Figure 2. Example of soil moisture content curves

What this means in a practical sense is that if a manager waits until the leaf water potential equals (-12) bars, with a sandy or sandy loam soil, there is a reasonable chance that the leaf water potential can quickly drop because suddenly there isn't much soil moisture remaining.

Therefore, one must always weigh the possibilities:

- Irrigate no sooner than the target leaf water potential, which is "just on the edge", or
- Wait until the plant is "just on the edge" and risk having a hot day, an irrigation scheduling problem, or understand that there is a DU of less than 1.0 in the field, and risk losing the crop.

2. A requirement for good water management it that it is essential that the system be blocked out by soil types and depths as well as by variety and plant spacings because of the impact of rain storage, differences in plant stress due to various moisture contents, and numerous other factors.

3. It is always essential to have an excellent (better than 0.85) irrigation system Distribution Uniformity (DU). Measure it on existing systems, and specify it (better than 0.92) on new systems.

4. Keep excellent records, by date. This means that flow rates are measured and frequency/durations of irrigations are known.

5. Sampling locations for soil moisture and for plant water status must be near "average" emitters to give an "average" result.

6. Although most people schedule irrigations with long intervals between irrigations, an examination of plant physiology and photosynthesis seems to indicate that it would be best to maintain a "consistent desired" stress for Regulated Deficit Irrigation (RDI).

7. Start the plant growth period (prior to bud break) with a full soil profile of water.

8. Do not stress the grape vines until the desired canopy size is achieved.

9. Once the desired canopy size is achieved (or just before then), and after fruit set, reduce irrigation to stop tendril and shoot growth. Moderate stress (or somewhat higher) should be maintained until veraison. For high value red grapes (for which small berries are desirable) it may be desirable to have some of the basal leaves fall down just before veraison. This may equate to irrigating at "50% of full ETc". Other less valuable grape varieties will have less ETc reduction.

10. "Full ETc" for grapes can be estimated using **Table 1** on the next page.

11. After veraison, <u>increase</u> the irrigation frequency to maintain turgid berries and maintain the canopy.
    - Do not allow vegetative growth to restart. This means it is good to have some Regulated Deficit Irrigation (RDI).
    - Protect the fruit (do not lose leaves). This means that excess RDI is harmful.
    - Continue photosynthesis, and thereby continue sugar accumulation. This means excess RDI is harmful.

12. Talk to your good neighbors, verify results, keep good records, and use information such as this as a starting point as opposed to the final word.

Table 1. Full ETc estimates for wine grapes.

		Ballpark (Gallons per acre per day) for central coast wine grapes at various **% Ground Shading** - Cal Poly ITRC 2012										
Typical Days in May-Aug	ETo, in/day	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%
	0.11	1,075	1,329	1,582	1,836	1,955	2,075	2,150	2,224	2,299	2,373	2,448
	0.12	1,172	1,449	1,726	2,003	2,133	2,263	2,345	2,426	2,508	2,589	2,671
	0.13	1,270	1,570	1,870	2,170	2,311	2,452	2,540	2,629	2,717	2,805	2,893
	0.14	1,368	1,691	2,014	2,337	2,489	2,641	2,736	2,831	2,926	3,021	3,116
Cool	0.15	1,466	1,812	2,158	2,504	2,667	2,829	2,931	3,033	3,135	3,236	3,338
	0.16	1,563	1,932	2,301	2,671	2,844	3,018	3,127	3,235	3,344	3,452	3,561
	0.17	1,661	2,053	2,445	2,838	3,022	3,207	3,322	3,437	3,553	3,668	3,783
	0.18	1,759	2,174	2,589	3,004	3,200	3,395	3,517	3,639	3,762	3,884	4,006
	0.19	1,856	2,295	2,733	3,171	3,378	3,584	3,713	3,842	3,971	4,100	4,228
Moderate	0.2	1,954	2,415	2,877	3,338	3,555	3,772	3,908	4,044	4,180	4,315	4,451
	0.21	2,052	2,536	3,021	3,505	3,733	3,961	4,104	4,246	4,389	4,531	4,674
	0.22	2,150	2,657	3,165	3,672	3,911	4,150	4,299	4,448	4,598	4,747	4,896
	0.23	2,247	2,778	3,308	3,839	4,089	4,338	4,494	4,650	4,807	4,963	5,119
	0.24	2,345	2,899	3,452	4,006	4,266	4,527	4,690	4,853	5,016	5,178	5,341
	0.25	2,443	3,019	3,596	4,173	**4,444**	4,716	4,885	5,055	5,224	5,394	5,564
	0.26	2,540	3,140	3,740	4,340	4,622	4,904	5,081	5,257	5,433	5,610	5,786
	0.27	2,638	3,261	3,884	4,507	4,800	5,093	5,276	5,459	5,642	5,826	6,009
	0.28	2,736	3,382	4,028	4,674	4,978	5,281	5,471	5,661	5,851	6,041	6,231
	0.29	2,833	3,502	4,171	4,840	5,155	5,470	5,667	5,864	6,060	6,257	6,454
Real hot	0.3	2,931	3,623	4,315	5,007	5,333	5,659	5,862	6,066	6,269	6,473	6,676
		Example:	ETo of .25"/day (pretty warm, but not real hot)									
			40% ground shading at mid-day									
			Gallons/day/acre =		4,444							
		Assume a 6' x 10' vine spacing ==>				726	vines/acre					
		Gallons/vine/day =			4750/726 =	**6.1**	Gallons/day					
						**Before applying "% of ETc" factor						

<u>Other Background Information</u>

There has been an abundance of research on wine grape irrigation. As noted earlier, the challenge is always how to apply it to a specific field. Publications and the notes below may help shed some light on the theory and thinking behind some research results. Some recommended reading includes:

1. Winegrape Irrigation Scheduling Using Deficit Irrigation Techniques, by Terry Prichard. http://ucanr.org/sites/CE_San_Joaquin/files/35706.pdf
2. Deficit Irrigation of Quality Winegrapes Using Micro-Irrigation Techniques, by Prichard, Hanson, Schwankl, Verdegaal, and Smith. http://www.lodiwine.com/Final_Handbook.pdf
3. Irrigation of Wine Grapes in California, by Larry Williams. http://www.practicalwinery.com/novdec01p42.htm

Recommendations for First Irrigation Date

A "pre-irrigation" is different from the "first irrigation". In general, wine grape growers try to have a "full soil profile" of water prior to bud break. If there has been sufficient rain, then there may be no "pre-irrigation" required. However, if there has been insufficient rain, growers will typically operate their drip systems long enough to bring the wetted volume of soil to field capacity.

Williams (2011) noted the following for the first irrigation of the season:

- - White wine cultivars: -10 bars or more negative <u>Leaf</u> Water Potential (LWP) has been reached.
- - Red wine: -12 bars or more
- Date of 1st irrigation
    - This may be at the beginning of May near Fresno
    - It may be early June or later near Napa
    - The date depends on the rooting depth, rainfall, AWHC, etc.

The bottom line is that at the beginning of the season most wine grape growers want to rapidly achieve their desired canopy size and aren't interested in stressing the vines until that happens. Once the canopy size is obtained, or relatively soon before then, there is a movement to "RDI" as explained below.

Regulated Deficit Irrigation (RDI)

Regulated Deficit Irrigation, known as “RDI”, simply means that during one or more stages of plant growth, the irrigation management is regulated to deliberately achieve an ETc that is less than the potential (100%) ETc. In the past, this has been referred to as “irrigating to some percentage of ETc”.

There are numerous reasons to use RDI. Typical reasons include:

- Reducing vegetative matter, especially prior to veraison. Excess vegetative matter can:
    - Require extra pruning
    - Provide excessive fruit shading
    - Stimulate fungal diseases
- Controlling berry size, primarily after veraison. RDI will typically reduce berry size. Potential benefits include:
    - A greater skin/pulp ratio, which can improve quality of wine
    - Better aeration between berries, thereby reducing diseases
    - Smaller chance of large berries that, with some varieties, will split when they push against adjacent berries – causing disease problems.

In most cases, the total yield will be reduced with RDI as compared to irrigating for 100% ETc. The difficulty is in quantifying these effects. Three basic questions still face grape growers:

1. What specific level of stress is best?
2. What should the timing and duration of that stress be?
3. Should there be multiple optimal levels of stress for different growth stages?

We know that the actual impacts of RDI depend upon the variety, rootstock, general vigor of the plant, trellising technique, severity of RDI, and its timing.

Achieving RDI

1. Reduced vegetative growth and vigor can be achieved using several techniques, including using chemical growth regulators, selecting less vigorous grape varieties and rootstocks, and selecting special pruning techniques. Girdling with table grapes has been used for decades as a physical means to regulate growth. However, one of the most effective techniques to manage vegetative growth is via the irrigation system. As one moves from a rainy area (such as Napa or the Central Coast of California) to the desert (e.g., the southern San Joaquin Valley), careful water management is less of an option and more of a necessity in managing vigor.

2. "Traditional" furrow or border strip irrigation wets large percentages of the soil volume. Therefore, it is difficult to achieve RDI because one cannot manage the water for a "constant" deficit or plant stress. The nature of furrow and border strip irrigation is that it is possible to completely avoid stress by irrigating frequently, but it is impossible to hold a desired level of stress – simply because a large root zone, when irrigated, goes completely to field capacity. After irrigation with furrows or border strip on well-aerated soils, stress disappears.

   Some furrow and border strip irrigators have, for many decades, practiced "<u>Partial Rootzone Drying</u>" (PRD) [this is discussed later]. When they irrigate, they only irrigate half of the furrows or border strips at once, thereby wetting only one side of a vine row. This enables the farmers to irrigate the whole field in half the time it would normally take if every furrow was irrigated. They then irrigate the field again, but this time they irrigate the alternate side of each row.

   With furrow and border strip irrigation, this PRD practice has the following characteristics:
   a. One side of the plant is under no stress at any time.
   b. One side of the plant is under stress at any time.

   The result is that the plant as a whole does not experience a wide cycling of soil matrix potential (water content). Research on PRD in Australia in the 1990's indicated that this practice is physiologically better for the vines than irrigating both sides of the plant simultaneously. However, we now know that PRD with drip does not work.

3. With drip irrigation in a vineyard <u>with only a small portion of the total soil wetted</u> (e.g., less than 30% of the total soil volume receives water), an interesting phenomenon often occurs. With grapes, the first irrigation (as noted earlier) is sometimes withheld to help discourage excess vegetative growth. As a result of both grape vine ET and the ET of cover crops, the complete soil is often fairly dry when the first irrigation occurs. Therefore, the source of the majority of the ET water for the rest of the season will come from the wetted area supplied by emitters.

   What has often (but not always) been observed in almonds and grapes is this: <u>With a restricted root system, even though part of that wetted area is maintained moist (soil matrix potentials are fairly close to zero), the plant ET is reduced</u>. Once stress begins to occur, it can be difficult to remove the stress even though one applies what should be adequate for 100% ET.

   Two important notes are related to this observation:
   a. Growers often see no correlation between matrix potential (measured about 1' away from the emitter) and leaf water potential.
   b. It is extremely important to watch deep moisture because if the active root zone is too restricted, a few hot days can quickly cause excessive vine stress, resulting in large drops in yield. Furthermore, it can be difficult for the grapes to "recover" to a larger ET rate once they have been stressed excessively if there is a restricted root zone.

4. In areas of hot climates (e.g., the Fresno, Bakersfield, and Coachella areas), some grapes can have water stress without the growers really trying to achieve it. Furthermore, with very hot climates some growers believe that having a large soil wetted area is quite important – hence the trend towards using microsprayers on grapes in the Delano-Bakersfield area. Some growers believe that the combination of a larger water <u>and nutrient</u> reservoir is better for the vines in those climates, especially for table grapes.

5. Emphasizing point (4) above, when temperatures start to reach about 98 degrees in the Lodi area, it has been found that RDI needs to be abandoned and the full ET needs to be met. During the summer of 2005 near Lodi, growers who anticipated the heat spikes did well in keeping the foliage through the season. Growers who did not had detrimental early leaf loss, and had difficulty obtaining the desired sugar levels.

6. Nutrient deficiencies can cause adversely severe effects on vines that are treated with RDI.

7. In general, RDI is associated with drip irrigation. However, in order to realistically manage a vineyard for RDI, one must be capable of supplying the same amount of water to different plants throughout a field. This means the Distribution Uniformity of the drip system (accounting for all factors) must be better than 0.85. Furthermore, because rainfall water storage is so important in determining the optimum date of the first irrigation, the irrigation system must be blocked out so that:
   a. There is only one soil type and depth in a block (i.e., the total available water holding capacity in the root zone is the same throughout the block), and
   b. The actual control of the blocks must be such that it is easy to control the timing of irrigation in different blocks with ease.

   These requirements of an excellent DU <u>and</u> proper blocking of the field will add about $100-$1000/acre to the cost of a drip system on vines.

Partial Rootzone Drying (PRD)

The PRD concept is to alternately irrigate two sides of a vine so that the wet/dry sides alternate. The proposed benefit has been to reduce vegetative vigor while suffering no decrease in yield or quality. Furthermore, this was reported to be accompanied by a reduced ET, which resulted in water savings.

There is an abundance of literature from Australia and some researches in California on the topic of PRD. Benefits were by no means consistent and appeared to be heavily influenced by the soil type, irrigation method, percent of soil wet by the irrigation method, and whether the adoption of PRD is simultaneously associated with other changes in irrigation management. In summary, the purported benefits of PRD were:
1. Reduced ET
2. Reduced canopy vigor
3. No reduction in yields
4. No reduction in wine quality

The reported physiological mechanism of PRD in vines is this: Abscisic acid (ABA) is synthesized in drying roots and leaves. The chief function of ABA is to control the closing of the stomata (the cell void through which water vapor passes during transpiration). High levels of ABA enhance the closing of stomata, restricting the exit of water vapor but also restricting the entrance of CO_2 (and with less CO_2, there is less photosynthesis).

If part of the root system is slowly dried (and produces ABA) while the rest of the root system is kept moist, grape berry growth is not adversely affected.

However, since 2003 it has been generally accepted by researchers and growers in California that ***there is no obvious benefit to PRD***. Evidently, much of the early PRD research results were related more to applying less water (i.e., RDI), rather than the PRD effect itself. The general conclusion since 2003 is that good management of RDI is more effective and cheaper than attempting PRD. Two papers from Australia and one paper from Israel, presented at the IVth International Symposium on Irrigation of Horticultural Crops (Sept 2000, Davis CA, published in *Acta Horticulturae* 664, Dec. 2004) regarding PRD on wine grapes all concluded there was no unique response to PRD when compared against the same amount of RDI.

Timing of Stress for Wine Grapes as Reported by Three Researchers

The three examples given below are typical of what can be found through a literature search.

1. Williams, 2001
   - Variety, location: Cabernet Sauvignon, Chardonnay; Napa to Edna Valley; various rootstocks.
   - The research applied continuous ET reduction to accomplish 75% of full ET (when compared to 1.25 ET). Results were:
     - 2-5% reduction in berry weight
     - 0-19 % reduction of total yield
     - 0-21% reduction in pruning weight

2. Prichard et al., 1997
   - Variety, location: Cabernet Sauvignon, Dogridge rootstock, bilateral-cordon trained on 7.5 x 11' spacing – Lodi, Calif.
   - The research examined severe pre-veraison and moderate post-veraison stress. This treatment had more impact than severe post-veraison stress. The results, when compared to 100% ET, were:
     - *Reduced wine pH*
     - Reduced wine potassium (K)
     - *A significant increase in wine color density*
     - *A 19% yield reduction as compared to 100% ET*

3. Mayne, 1999
   - Variety, location: Results near Mendoza, Argentina (varieties not specified)
   - Evidently, these were similar trials as in Prichard, above. They found slightly different results than Pritchard. Both report an increase in wine color density and a yield reduction, but there are differences in wine pH results. However, Pritchard induced some level of stress throughout the season, not only before and after veraison.
   - Mayne reports that RDI before veraison will:
     - Reduce growth of buds
     - *Increase pH*
     - *Reduce total titratable acidity*

     RDI after veraison will:
     - Reduce yield
     - Reduce soluble solids
     - *Increase pH*
     - *Reduce titratable acidity*
     - Increase "quality of wine" because of the larger skin/pulp ratio of smaller berry sizes, resulting in more anthocyancs and phenols and color

     Berry growth is most sensitive to RDI applied 4-5 weeks after veraison

<u>Other Points to Consider for Wine Grape Irrigation</u>

1. Stress at different times of the season will impact different aspects of vine/berry growth, as seen in **Figure 3**.

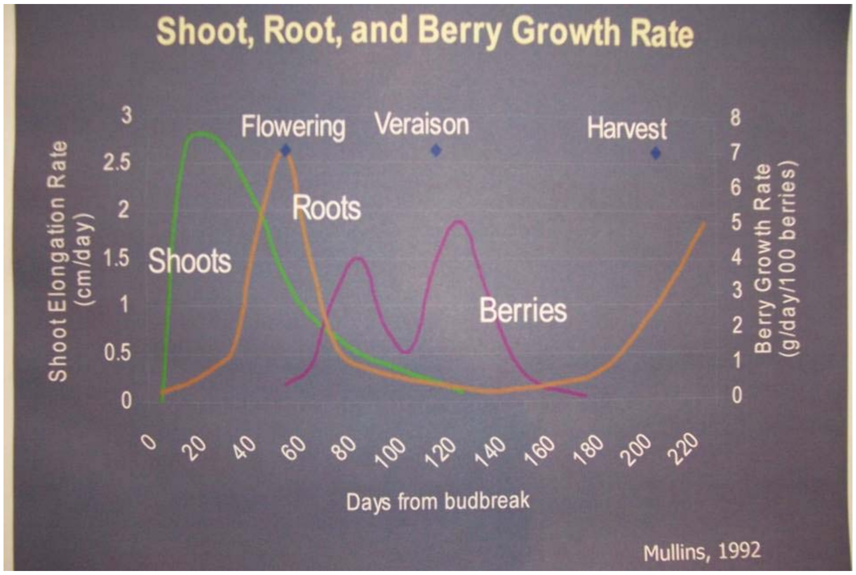

Figure 3. Growth by plant part and date (Prichard et al, 2004)

2. **Figure 3** shows that vegetative control should ideally be accomplished prior to veraison by inducing water stress. It can be difficult to accomplish this stress on heavy, deep soils because there is so much rainwater stored in the soil. As a result, in many areas with low ET rates and a small percent canopy cover, irrigation does not begin until veraison.

3. Expansive vegetative growth can be restricted by water stress without impacting net photosynthesis.

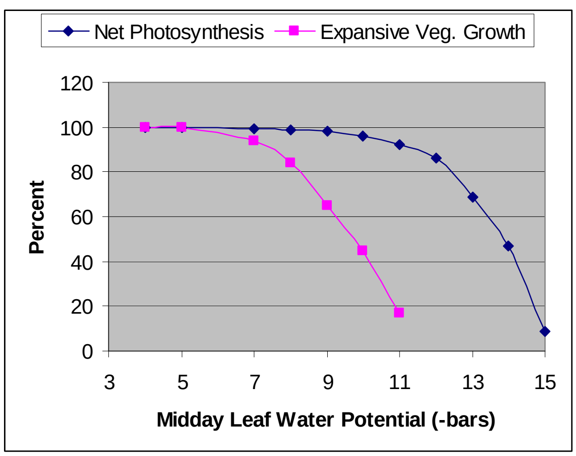

Figure 4. Relationship between leaf water potential, vegetative growth, and photosynthesis for a "typical" wine grape

<u>Approximate dates for Paso Robles Cabernet Sauvignon (Central Coast)</u>

Bloom – May 20 Veraison – July 24 Harvest – Sept. 27

Plant and Soil Sensors

"Tension" is a synonym for "Pressure". There are many units used to describe pressure, including:

1 bar	= 100 centibars
	= 1.01 atmosphere, atm.
	= 100 kilopascals, kPa
	= 0.1 Megapascals, MPa
	= 33.4 feet
	= 100 joules/kg
1 kPa	= 0.01 bars
1 MPa	= 10 bars

Some reference points are listed in **Table 2**.

Table 2. Units of Plant and Soil Water Tension

Item	Bars	kPa
Soil matrix potential, at:		
Saturation	0.0	0
Field Capacity (in the field)	-0.02 to -0.06	-2 to –6
Field Capacity (in a lab analysis)	-0.33	-33
Permanent wilting point	-15	-1,500
Leaf water potential at the beginning of stress for a healthy, vigorous vine	-10	-1,000
Range of leaf water potential that irrigation managers may attempt to maintain during the summer	- 10 to -16	

Leaf Bomb (Pressure Chamber)

The following tips are from UC irrigation specialists Larry Williams and Terry Prichard for leaf water potential measurement. Stem water potential is somewhat different because it involves putting an aluminum bag over a leaf while still attached, and leaving it there for a half hour or so before cutting it off.

- Select young, fully extended leaves on the outside of the canopy, exposed to direct sunlight (no shading).
- Leaf must not be yellow, diseased, or have insect damage.
- Take at least two samples per vine.
- Sample at solar noon (plus or minus 1.5 hour).
    - First, put a plastic sandwich bag around the leaf.
    - ***During the whole process, do not break any leaf veins.***
    - Then cut the petiole with a SHARP razor blade.
    - Within 10 seconds of enclosing the leaf in the plastic bag, place it inside the pressure chamber.
- Pressurize the leaf at a rate of less than 1 bar per second, slowing to 0.2 bar/sec as you near the leaf water potential.
- Use a magnifying glass to see when sap begins to exude. ***It should not form a drop or even a hemisphere or lens.***

Soil Moisture Sensors

With drip irrigation, the soil moisture content (and therefore the soil moisture tension) is different at every point. On one extreme, directly below an emitter one will find the highest soil moisture levels, and outside the wetted soil area, one will find the lowest moisture levels. Between these two locations, in a 3D image, one finds a gradation of soil moisture contents. Therefore, if one places a sensor 1' away from another one (either higher or lower or to one side), one will obtain a different reading.

With drip irrigation, then, one is looking for TRENDS when one examines soil moisture tension readings. Is the soil getting dryer, wetter, or staying the same? Is the upper part of the root zone staying moist, but the lower part of the root zone drying out with time? (This indicates consistent under-irrigation.) When one irrigates, is there a change in the reading for the lower sensors? (This indicates that water has reached that depth.) How long does it take for the irrigation water to show up at the lower sensor? (If it shows up in 1 hour, and the irrigation lasts 2 hours, this indicates over-irrigation for about 1 hour.)

Proper positioning of soil moisture sensors is important. **Figures 5 and 6** illustrate the proper siting for two or three sensors at one location.

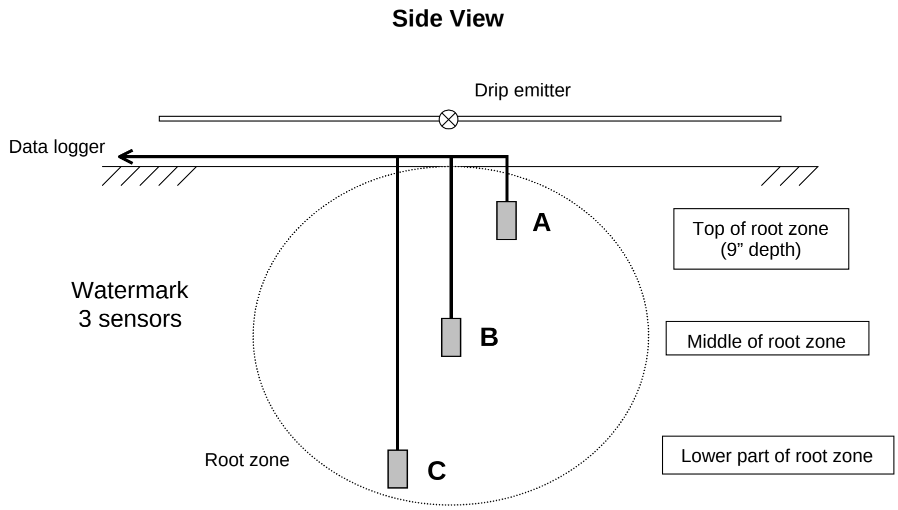

Figure 5. Side view of Watermark or Capacitance probe installation

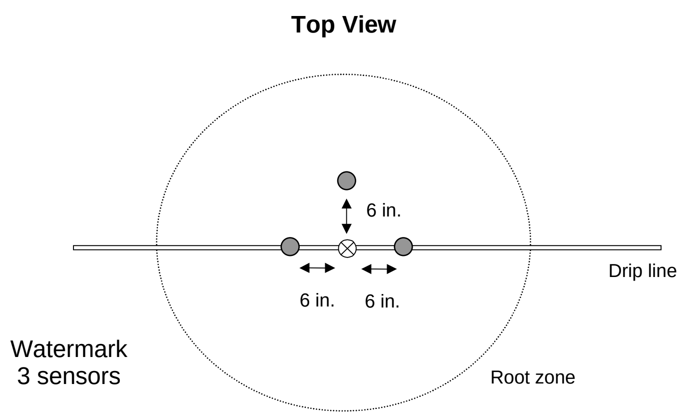

Figure 6. Plan view of soil moisture sensor installation

Example Results of Soil Moisture Monitoring in Solano County

The following field example used the soil water balance computations, together with observations of the soil water volume (within the drip wetted pattern) from a capacitance probe.

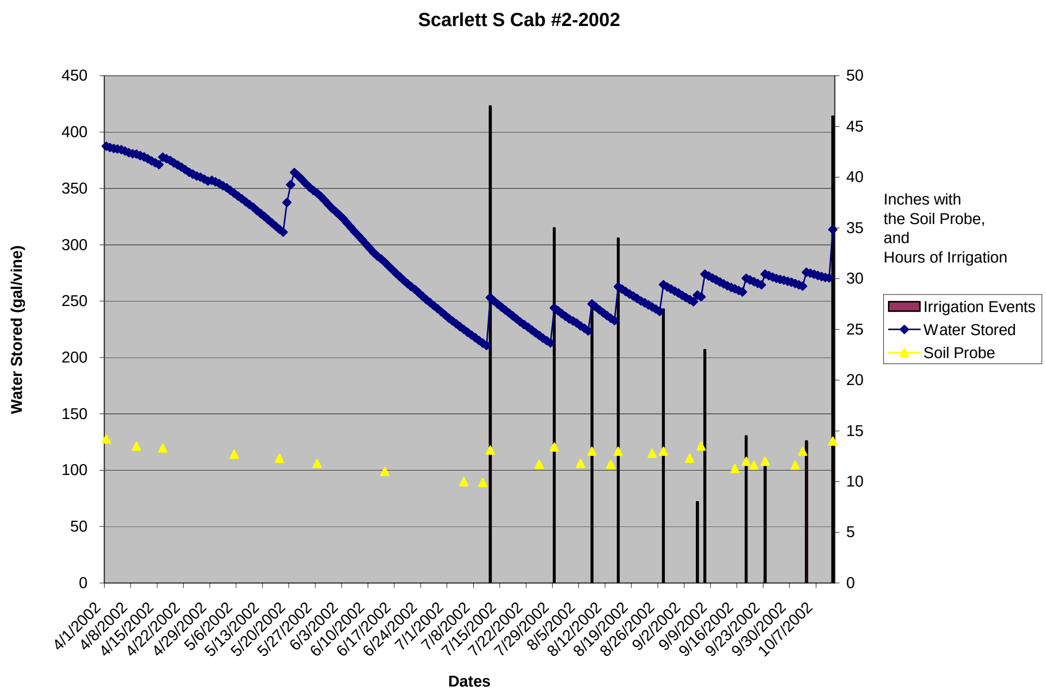

Figure 7. Example of successful irrigation scheduling in Solano County by Lisa Tenbrink of ITRC. Veraison was about July 22.

Figure 7 shows the following:

- In BLUE (thick zig-zag line segments on the upper part), the gallons of water (per vine) stored in the whole root zone, as estimated by the classic water balance worksheet (see example on next page).
- YELLOW triangles, showing actual inches of water measured by a vertical capacitance probe located 6" away from the emitter, with measurements every 4" in depth to a total depth of 40".
- Dark vertical lines, showing hours of irrigation events by date.

There are several observations that can be made from the figure above:

1. The ESTIMATED moisture content in the soil slowly climbed in the last half of the season, as the MONITORED (granted, in a very restricted area near the emitter) moisture content stayed relatively constant during that time. This shows the difficulty of trying to reconcile a theoretical balance (with numerous assumptions) with soil moisture measurements (that have a very small sample area).
2. In this particular case, the first irrigation was before veraison.
3. After getting down to 40", the moisture content, measured near the emitter, was not allowed to significantly decrease after veraison.

**The two practices that made this successful (in terms of both quality and quantity) as compared to "typical" irrigation were:

1. The soil was not allowed to dry down as much before veraison as is typical.
2. The moisture content in the wetted area remained fairly constant once veraison was reached – as opposed to letting it decline.

Example of a Soil Moisture Accounting Spreadsheet

Shown below is an example of a soil moisture accounting procedure. It has all of the classical components of ETo, Kc, AWHC, precipitation, etc.

												Kc - Parameters
Title:		Irrigation Scheduler				Date:	03-30-95					-
Filename:		SCHEDULE.WK1	WK3	Version:		2.1 Spec Wine Grape Exp						B1
Author:		Don Pitts, Irrigation Engineer, IFAS, University of Florida										B2
Address:		PO Drawer 5127, Immokalee, FL 33934										KC1
Description:		Irrigation Scheduler Worksheet										KC2
Inputs:	//////////////	////////////////	////////////////	////////////////		////////////////	////////////////		////////////////			KC3
Farm :		Scarlett South		Number of Plants in Block:					8465			Pd
Block :		2		Plant Spacing............:					8			DA
Crop :		Cab		Row Spacing (ft).........:					10			DB
Owner :		Lanza Vineyards		Wetted Area (sq ft)......:					12			DC
Irrigator:		Ken & Larry		Soil WHC (in/ft).........:					1.3			DD
Area (ac):		15.5		Rooting Depth (ft).......:					6			DE
Year :		2002		Emitters Per Plant.......:					2			PER
Emitter :		Netafim		Application Efficiency...:					95			SHADED %
k-value :		1.13		Average Pressure (psi)...:					20			
x-value :		-0.03		Soil-water on Day 1 (%)..:					100			
Soil :		Sandy Loam										
				Canopy (%)...............:					20			
-----------	-------------	---------	---------	---------		---------	---------		---------			
Emitter Flow Rate (gph).:			0.50									
-----------	-------------	---------	---------	---------		---------	---------		---------			
	Sprinkler	Irrigation			ETc	*Total Soil-H2O*		Cum Water				Water
Day	or Rain	Run-time	ETo	ETc	Cum	Soil-H2O	Soil-H2O	Use	Probe			Stored
	(inches)	(hours)	(inches)	(inches)	(inches)	(percent)	(inches)	(inches)	(inches)	Kc		(gal/vine)
-----------	-------------	---------	---------	---------	---------	---------	---------	---------	----------			-----------
01-Apr			0.17	0.03	0.03	100	7.77	0.03	14.2	0.38		387
02-Apr			0.13	0.02	0.05	99	7.75	0.05		0.38		386
03-Apr			0.10	0.02	0.07	99	7.73	0.07		0.39		385
04-Apr			0.05	0.01	0.08	99	7.72	0.08		0.40		385
05-Apr			0.07	0.01	0.09	99	7.71	0.09		0.40		384
06-Apr			0.14	0.02	0.12	99	7.68	0.12		0.41		383
07-Apr			0.14	0.03	0.14	98	7.66	0.14		0.42		382
08-Apr			0.11	0.02	0.16	98	7.64	0.16		0.42		381
09-Apr			0.04	0.01	0.17	98	7.63	0.17	13.5	0.43		380
10-Apr			0.15	0.03	0.20	97	7.60	0.20		0.44		379
11-Apr			0.11	0.02	0.22	97	7.58	0.22		0.44		378
12-Apr			0.18	0.03	0.25	97	7.55	0.25		0.45		376
13-Apr			0.20	0.04	0.29	96	7.51	0.29		0.46		374
14-Apr			0.17	0.03	0.32	96	7.48	0.32		0.46		373
15-Apr			0.16	0.03	0.36	95	7.44	0.36		0.47		371
16-Apr	0.15		0.08	0.02	0.37	97	7.58	0.22	13.3	0.48		378
17-Apr			0.14	0.03	0.40	97	7.55	0.25		0.48		376
18-Apr			0.15	0.03	0.43	96	7.52	0.28		0.49		375
19-Apr			0.22	0.04	0.48	96	7.47	0.33		0.50		373
20-Apr			0.17	0.04	0.51	95	7.44	0.36		0.50		371
21-Apr			0.19	0.04	0.55	95	7.40	0.40		0.51		369
22-Apr			0.21	0.04	0.60	94	7.35	0.45		0.52		367
23-Apr			0.22	0.05	0.64	94	7.31	0.49		0.52		364
24-Apr			0.16	0.04	0.68	93	7.27	0.53		0.53		363
25-Apr			0.14	0.03	0.71	93	7.24	0.56		0.54		361
26-Apr			0.08	0.02	0.73	93	7.22	0.58		0.54		360
27-Apr			0.15	0.03	0.77	92	7.19	0.61		0.55		358
28-Apr			0.15	0.04	0.80	92	7.15	0.65		0.56		357
29-Apr	0.04		0.11	0.03	0.83	92	7.16	0.64		0.56		357
30-Apr			0.11	0.03	0.85	91	7.14	0.66		0.57		356
01-May			0.13	0.03	0.89	91	7.10	0.70		0.58		354
02-May			0.16	0.04	0.92	91	7.07	0.73		0.58		352
03-May			0.14	0.03	0.96	90	7.03	0.77		0.59		351
04-May			0.20	0.05	1.01	90	6.98	0.82		0.60		348
05-May			0.22	0.05	1.06	89	6.93	0.87	12.7	0.60		346
06-May			0.20	0.05	1.11	88	6.88	0.92		0.61		343

Figure 8. Example soil moisture accounting spreadsheet

How Much Water Should Be Applied Per Irrigation?

For a given ETo demand, it stands to reason that a certain soil moisture content *and a certain active root wetted area in the soil* will create a specific root stress, which will in turn create a specific leaf water potential at midday.

If you accept this thesis, then once the ideal leaf water potential (stress level, such as –12 bars) is reached, ideally you would begin to replenish the soil water at the same rate as it is being removed. This is, after all, the concept of the classic soil/water balance. However, why not just observe the soil moisture content (down to about 6’ of depth for vines) and try to maintain the same AVERAGE soil moisture content at that location, from that date onwards?

This gives two indicators to attempt to manage simultaneously:

1. A fairly consistent leaf water potential and visual plant status.
2. A fairly constant average soil moisture content (down to 6’) near the emitter. Depending upon the soil and root characteristics, the average soil moisture content may need to slightly rise or decline with time after the initial irrigation to maintain a consistent plant status.

The leaf water potential measurement has already been described. The physical layout of Watermark sensors around the emitter has also previously been described. The same layout can be used with a wide variety of capacitance probes (that give a measure of water volume, rather than matrix potential).

In general, what one will see with proper scheduling is virtually no change is matrix potential or moisture content at the deep sensor. If one does see an increase in soil moisture content there, there is one big question: Did the water “just reach” that sensor, or did it continue to drain down below it for some time? The measurement will show the same result in both cases.

The easiest way to answer this, while also keeping a record of actual irrigation dates, is to hook a drip hose pressure sensor into the datalogger. It will indicate when irrigation events start and stop. If, for example, the deep sensor sees a change in moisture three hours after an irrigation begins and the irrigation continues for another three hours, then basically, the irrigation was twice as long as it should have been.

Table Grape Quality and Dormancy in the Coachella Valley (from Neja, 1990)

Note
Stress of 12.5% more than the "standard" irrigation treatment results in droopy vines with Perlettes Note – table grapes are harvested in June in Coachella Valley.
"Standard" treatment definition: - When shoot tips begin to trail the ground and the leaf canopy is uniform down the vine row (trellis is filled), reduced the daily water application amount to discourage vigorous shoot-tip growth. Instead, encourage only moderate tip growth during the pre-harvest and harvest period for early harvest and good berry size. - Stop shoot-tip growth within 2-5 weeks after 15-20% defoliation of the old basal leaves, during the transition period from moderate harvest time tip growth to the no shoot tip growth post-harvest period. Continue a daily, but limited water schedule. - Mid-late September, hold the leaf canopy in a no growth or no re-growth state. Allow the shoot tip (tiny terminal leaf) to wither, but maintain about 75% of the harvest time canopy through mid to late September. Use these post-harvest Kc values: July 0.45 – 0.50 August 0.50 – 0.55 September: 0.45 – 0.50 (Note that a Kc of 0.75 is needed with a 120 deg. heat wave; the Kc is lower with 115 deg. head. This indicates a weakness of the vine root system in acquiring water, which may be related to a reduced rooting system.) - Apply an "adequate amount" of water during post-harvest rains of more than 0.5" to dilute salts in the root zone. This may delay the date of drought-induced defoliation, but it's essential. - Terminate irrigation in mid to late September to initiate a drought-induced defoliation and dormancy. This gives much better results than terminating in November. - In Nov-December, after defoliation, rewet the root zone. But wait long enough to be sure that you do not stimulate re-growth right away.
To stimulate dormancy (**accumulate degree-days of dormancy**), in Nov-Dec., sprinklers (typically hand move) are placed every 4th row and are operated during the daytime on the dormant vines. This can drop daytime temperatures by as much as 12 deg. F.

References

Prichard, T., B. Hanson, L. Schwankl, P. Verdegaal, and R. Smith. 2004. Deficit irrigation of quality winegrapes using micro-irrigation techniques. UC Coop Extension, Dept. of LAWR. UC Davis. Draft.

Neja, R. 1990. CV Grape Water Coefficients Still Being Tested. Farm Water Watch. Coachella Valley Water District. Vol 1(5):2-3.

Mayne, R. 1999. Drip Irrigation in Vineyards. International Water and Irrigation 19(4): 30-31.

Prichard, T.L., P.s. Verdegaal, and C. Rous. 1997. Improving Winegrape Quality Using Deficit Irrigation Techniques. Proceedings of the Irrigation Management Nutrient Conference in Salinas, CA. February. 7 p.

Williams, L.E. 2001. Practical Vineyard and Winery. Nov/Dec issue. pp 42-55.

National Marine Fisheries Service
Southwest Region

Fish Screening Criteria for Anadromous Salmonids

January 1997

Fish Screening Criteria for Anadromous Salmonids [1]
National Marine Fisheries Service
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January 1997

Table of Contents

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[1] Adapted from NMFS, Northwest Region

I. General Considerations

This document provides guidelines and criteria for functional designs of downstream migrant fish passage facilities at hydroelectric, irrigation, and other water withdrawal projects. It is promulgated by the National Marine Fisheries Service (NMFS), Southwest Region as a result of its authority and responsibility for prescribing fishways under the Endangered Species Act (ESA), the Federal Power Act, administered by the Federal Energy Regulatory Commission (FERC), and the Fish and Wildlife Coordination Act (FWCA), administered by the U.S. Fish & Wildlife Service.

The guidelines and criteria are general in nature. There may be cases where site constraints or extenuating circumstances dictate a waiver or modification of one or more of these criteria. Conversely, where there is an opportunity to protect fish, site-specific criteria may be added. Variances from established criteria will be considered on a project-by-project basis.

The swimming ability of fish is a primary consideration in designing a fish screen facility. Research shows that swimming ability varies depending on multiple factors relating to fish physiology, biology, and the aquatic environment. These factors include: species, physiological development, duration of swimming time required, behavioral aspects, physical condition, water quality, temperature, lighting conditions, and many others. Since conditions affecting swimming ability are variable and complex, screen criteria must be expressed in general terms and the specifics of any screen design must address on-site conditions.

NMFS may require project sponsors to investigate site-specific variables critical to the fish screen system design. This investigation may include fish behavioral response to hydraulic conditions, weather conditions (ice, wind, flooding, etc.), river stage-discharge relationships, seasonal operations, sediment and debris problems, resident fish populations, potential for creating predation opportunity, and other pertinent information. The size of salmonids present at a potential screen site usually is not known, and can change from year-to-year based on flow and temperature conditions. Thus, adequate data to describe the size-time relationship requires substantial sampling over a number of years. NMFS will normally assume that fry-sized salmonids are present at all sites unless adequate biological investigation proves otherwise. The burden of proof is the responsibility of the owner of the screen facility.

New facilities which propose to utilize unproven fish protection technology frequently require:

1) development of a biological basis for the concept;
2) demonstration of favorable behavioral responses in a laboratory setting;
3) an acceptable plan for evaluating the prototype installation;
4) an acceptable alternate plan should the prototype not adequately protect fish.

Additional information can be found in *Experimental Fish Guidance Devices*, position statement of the National Marine Fisheries Service, Southwest Region, January 1994.

Striped Bass, Herring, Shad, Cyprinids, and other anadromous fish species may have eggs and/or very small fry which are moved with any water current (tides, streamflows, etc.). Installations where these species are present may require individual evaluation of the proposed project using more conservative screening requirements. In instances where state or local regulatory agencies require more stringent screen criteria to protect species other than salmonids, NMFS will generally defer to the more conservative criteria.

General screen criteria and procedural guidelines are provided below. Specific exceptions to these criteria occur in the design of small screen systems (less than 40 cubic feet per second) and certain small pump intakes. These exceptions are listed in Section K, Modified Criteria for Small Screens, and in the separate addendum entitled: Juvenile Fish Screen Criteria For Pump Intakes, National Marine Fisheries Service, Portland, Oregon, May 9, 1996.

II. General Procedural Guidelines

For projects where NMFS has jurisdiction, such as FERC license applications and ESA consultations, a functional design must be developed as part of the application or consultation. These designs must reflect NMFS design criteria and be acceptable to NMFS. Acceptable designs typically define type, location, method of operation, and other important characteristics of the fish screen facility. Design drawings should show structural dimensions in plan, elevation, and cross-sectional views, along with important component details. Hydraulic information should include: hydraulic capacity, expected water surface elevations, and flows through various areas of the structures. Documentation of relevant hydrologic information is required. Types of materials must be identified where they will directly affect fish. A plan for operations and maintenance procedures should be included- i.e., preventive and corrective maintenance procedures, inspections and reporting requirements, maintenance logs, etc.- particularly with respect to debris, screen cleaning, and sedimentation issues. The final detailed design shall be based on the functional design, unless changes are agreed to by NMFS.

All juvenile passage facilities shall be designed to function properly through the full range of hydraulic conditions expected at a particular project site during fish migration periods, and shall account for debris and sedimentation conditions which may occur.

III. Screen Criteria for Juvenile Salmonids

A. Structure Placement

1. General:

The screened intake shall be designed to withdraw water from the most appropriate elevation, considering juvenile fish attraction, appropriate water temperature control downstream or a combination thereof. The design must accommodate the expected range of water surface elevations.

For on-river screens, it is preferable to keep the fish in the main channel rather than put them through intermediate screen bypasses. NMFS decides whether to require intermediate bypasses for on-river, straight profile screens by considering the biological and hydraulic conditions existing at each individual project site.

2. Streams and Rivers:

Where physically practical, the screen shall be constructed at the diversion entrance. The screen face should be generally parallel to river flow and aligned with the adjacent bankline. A smooth transition between the bankline and the screen structure is important to minimize eddies and undesirable flow patterns in the vicinity of the screen. If trash racks are used, sufficient hydraulic gradient is required to route juvenile fish from between the trashrack and screens to safety. Physical factors that may preclude screen construction at the diversion entrance include excess river gradient, potential for damage by large debris, and potential for heavy sedimentation. Large stream-side installations may require intermediate bypasses along the screen face to prevent excessive exposure time. The need for intermediate bypasses shall be decided on a case-by-case basis.

2. Canals:

Where installation of fish screens at the diversion entrance is undesirable or impractical, the screens may be installed at a suitable location downstream of the canal entrance. All screens downstream of the diversion entrance shall provide an effective juvenile bypass system- designed to collect juvenile fish and safely transport them back to the river with minimum delay. The angle of the screen to flow should be adequate to effectively guide fish to the bypass. Juvenile bypass systems are part of the overall screen system and must be accepted by NMFS.

3. Lakes, Reservoirs, and Tidal Areas:

a. Where possible, intakes should be located off shore to minimize fish contact with the facility. Water velocity from any direction toward the screen shall not exceed the allowable approach velocity. Where possible, locate intakes where sufficient sweeping velocity exists. This minimizes sediment accumulation in and around the screen, facilitates debris removal, and encourages fish movement away from the screen face.

b. If a screened intake is used to route fish past a dam, the intake shall be designed to withdraw water from the most appropriate elevation in order to provide the best juvenile fish attraction to the bypass channel as well as to achieve appropriate water temperature control downstream. The entire range of forebay fluctuations shall be accommodated by the design, unless otherwise approved by NMFS.

B. Approach Velocity

Definition: *Approach Velocity* is the water velocity vector component perpendicular to the screen face.

Approach velocity shall be measured approximately three inches in front of the screen surface.

1. Fry Criteria - less than 2.36 inches {60 millimeters (mm)} in length.

If a biological justification cannot demonstrate the absence of fry-sized salmonids in the vicinity of the screen, fry will be assumed present and the following criteria apply:

Design approach velocity shall not exceed-

Streams and Rivers:	0.33 feet per second
Canals:	0.40 feet per second
Lakes, Reservoirs, Tidal:	0.33 feet per second (salmonids) [2]

2. Fingerling Criteria - 2.36 inches {60 mm} and longer

If biological justification can demonstrate the absence of fry-sized salmonids in the vicinity of the screen, the following criteria apply:

Design approach velocity shall not exceed -
All locations: 0.8 feet per second

[2] Other species may require different approach velocity standards, e.g.- in California, the U.S. Fish & Wildlife Service requires 0.2 fps approach velocity where delta smelt are present in the tidal areas of the San Francisco Bay estuary.

3. The *total submerged screen area required* (excluding area of structural components) is calculated by dividing the maximum diverted flow by the allowable approach velocity. (Also see Section K, Modified Criteria for Small Screens, part 1).

4. The screen design must provide for uniform flow distribution over the surface of the screen, thereby minimizing approach velocity. This may be accomplished by providing adjustable porosity control on the downstream side of the screens, unless it can be shown unequivocally (such as with a physical hydraulic model study) that localized areas of high velocity can be avoided at all flows.

C. Sweeping Velocity

Definition: *Sweeping Velocity* is the water velocity vector component parallel and adjacent to the screen face.

1. Sweeping Velocity shall be greater than approach velocity. For canal installations, this is accomplished by angling screen face less than 45° relative to flow (see Section K, Modified Criteria for Small Screens). This angle may be dictated by specific canal geometry, or hydraulic and sediment conditions.

D. Screen Face Material

1. Fry criteria

If a biological justification cannot demonstrate the absence of fry-sized salmonids in the vicinity of the screen, fry will be assumed present and the following criteria apply for screen material:

a. Perforated plate: screen openings shall not exceed 3/32 inches (2.38 mm), measured in diameter.

b. Profile bar: screen openings shall not exceed 0.0689 inches (1.75 mm) in width.

c. Woven wire: screen openings shall not exceed 3/32 inches (2.38 mm), measured diagonally. (e.g.: 6-14 mesh)

d. Screen material shall provide a minimum of 27% open area.

2. Fingerling Criteria

If biological justification can demonstrate the absence of fry-sized salmonids in the vicinity of the screen, the following criteria apply for screen material:

a. Perforated plate: Screen openings shall not exceed 1/4 inch (6.35 mm) in diameter.

b. Profile bar: screen openings shall not exceed 1/4 inch (6.35 mm) in width

c. Woven wire: Screen openings shall not exceed 1/4 inch (6.35 mm) in the narrow direction

d. Screen material shall provide a minimum of 40% open area.

3. The screen material shall be corrosion resistant and sufficiently durable to maintain a smooth and uniform surface with long term use.

E. Civil Works and Structural Features

1. The face of all screen surfaces shall be placed flush with any adjacent screen bay, pier noses, and walls, allowing fish unimpeded movement parallel to the screen face and ready access to bypass routes.

2. Structural features shall be provided to protect the integrity of the fish screens from large debris. Trash racks, log booms, sediment sluices, or other measures may be needed. A reliable on-going preventive maintenance and repair program is necessary to ensure facilities are kept free of debris and the screen mesh, seals, drive units, and other components are functioning correctly.

3. Screens located in canals - surfaces shall be constructed at an angle to the approaching flow, with the downstream end terminating at the bypass system entrance.

4. The civil works design shall attempt to eliminate undesirable hydraulic effects (e.g.- eddies, stagnant flow zones) that may delay or injure fish, or provide predator opportunities. Upstream training wall(s), or some acceptable variation thereof, shall be utilized to control hydraulic conditions and define the angle of flow to the screen face. Large facilities may require hydraulic monitoring to identify and correct areas of concern.

F. Juvenile Bypass System Layout

Juvenile bypass systems are water channels which transport juvenile fish from the face of a screen to a relatively safe location in the main migratory route of the river or stream. Juvenile bypass systems are necessary for screens located in canals because anadromous fish must be routed back to their main migratory route. For other screen locations and configurations, NMFS accepts the option which, in its judgement, provides the highest degree of fish protection given existing site and project constraints.

1. The screen and bypass shall work in tandem to move out-migrating salmonids (including adults) to the bypass outfall with minimum injury or delay. Bypass entrance(s) shall be designed such that out-migrants can easily locate and enter them. Screens installed in canal diversions shall be constructed with the downstream end of the screen terminating at a bypass entrance. Multiple bypass entrances (intermediate bypasses) shall be employed if the sweeping velocity will not move fish to the bypass within 60 seconds [3] assuming the fish are transported at this velocity. Exceptions will be made for sites without satisfactory hydraulic conditions, or for screens built on river banks with satisfactory river conditions.

2. All components of the bypass system, from entrance to outfall, shall be of sufficient hydraulic capacity to minimize the potential for debris blockage.

3. To improve bypass collection efficiency for a single bank of vertically oriented screens, a bypass training wall may be located at an angle to the screens.

4. In cases where insufficient flow is available to satisfy hydraulic requirements at the main bypass entrance(s), a *secondary screen* may be required. Located in the main screen's bypass channel, a secondary screen allows the prescribed bypass flow to be used to effectively attract fish into the bypass entrance(s) while allowing all but a reduced residual bypass flow to be routed back (by pump or gravity) for the primary diversion use. The residual bypass flow (not passing through the secondary screen) then conveys fish to the bypass outfall location or other destination.

5. Access is required at locations in the bypass system where debris accumulation may occur.

6. The screen civil works floor shall allow fish to be routed to the river safely in the event the canal is dewatered. This may entail a sumped drain with a small gate and drain pipe, or similar provisions.

G. Bypass Entrance

1. Each bypass entrance shall be provided with independent flow control, acceptable to NMFS.

2. Bypass entrance velocity must equal or exceed the maximum velocity vector resultant along the screen, upstream of the entrance. A gradual and efficient acceleration into the bypass is required to minimize delay of out-migrants.

[3] In California, 60 second exposure time applies to screens in canals, using a 0.4 fps approach velocity. Where more conservative approach velocities are used, longer exposure times may be approved on a case-by-case basis, and exceptions to established criteria shall be treated as variances.

3. Ambient lighting conditions are required from the bypass entrance to the bypass flow control.

4. The bypass entrance must extend from floor to water surface.

H. Bypass Conduit Design

1. Smooth interior pipe surfaces and conduit joints shall be required to minimize turbulence, debris accumulation, and the risk of injury to juvenile fish. Surface smoothness must be acceptable to the NMFS.

2. Fish shall not free-fall within a confined shaft in a bypass system.

3. Fish shall not be pumped within the bypass system.

4. Pressure in the bypass pipe pipe shall be equal to or above atmospheric pressure.

5. Extreme bends shall be avoided in the pipe layout to avoid excessive physical contact between small fish and hard surfaces and to minimize debris clogging . Bypass pipe centerline radius of curvature (R/D) shall be 5 or greater. Greater R/D may be required for supercritical velocities.

6. Bypass pipes or open channels shall be designed to minimize debris clogging and sediment deposition and to facilitate cleaning. Pipe diameter shall be 24 inches (0.610 m) or greater and pipe velocity shall be 2.0 fps (0.610 mps) or greater, unless otherwise approved by NMFS. (See *Modified Criteria for Small Screens*) for the entire operational range.

7. No closure valves are allowed within bypass pipes.

8. Depth of flow in a bypass conduit shall be 0.75 ft. (0.23 m) or greater, unless otherwise authorized by NMFS (See Modified Criteria for Small Screens).

9. Bypass system sampling stations shall not impair normal operation of the screen facility.

10. No hydraulic jumps should exist within the bypass system.

I. Bypass Outfall

1. Ambient river velocities at bypass outfalls should be greater than 4.0 fps (1.2 mps), or as close as obtainable.

2. Bypass outfalls shall be located and designed to minimize avian and aquatic predation in areas free of eddies, reverse flow, or known predator habitat.

3. Bypass outfalls shall be located where there is sufficient depth (depending on the impact velocity and quantity of bypass flow) to avoid fish injuries at all river and bypass flows.

4. Impact velocity (including vertical and horizontal components) shall not exceed 25.0 fps (7.6 mps).

5. Bypass outfall discharges shall be designed to avoid adult attraction or jumping injuries.

J. Operations and Maintenance

1. Fish Screens shall be automatically cleaned as frequently as necessary to prevent accumulation of debris. The cleaning system and protocol must be effective, reliable, and satisfactory to NMFS. Proven cleaning technologies are preferred.

2. Open channel intakes shall include a trash rack in the screen facility design which shall be kept free of debris. In certain cases, a satisfactory profile bar screen design can substitute for a trash rack.

3. The head differential to trigger screen cleaning for intermittent type systems shall be a maximum of 0.1 feet (.03 m), unless otherwise agreed to by NMFS.

4. The completed screen and bypass facility shall be made available for inspection by NMFS, to verify compliance with design and operational criteria.

5. Screen and bypass facilities shall be evaluated for biological effectiveness and to verify that hydraulic design objectives are achieved.

K. Modified Criteria for Small Screens (Diversion Flow less than 40 cfs)

The following criteria vary from the standard screen criteria listed above. These criteria specifically apply to lower flow, surface-oriented screens (e.g.- small rotating drum screens). Forty cfs is the approximate cut off; however, some smaller diversions may be required to apply the general criteria listed above, while some larger diversions may be allowed to use the “small screen” criteria below. NMFS will decide on a case-by-case basis depending on site constraints.

1. The required screen area is a function of the approach velocity listed in Section B, Approach Velocity, Parts 1, 2, and 3 above. Note that “maximum” refers to the greatest flow diverted, not necessarily the water right.

2. Screen Orientation:

   a. For screen lengths six feet or less, screen orientation may be angled perpendicular to the flow.

b. For screen lengths greater than six feet, screen-to-flow angle must be less than 45 degrees. (See Section C Sweeping Velocity, part 1).

c. For drum screens, design submergence shall be 75% of drum diameter. Submergence shall not exceed 85%, nor be less than 65% of drum diameter.

d. Minimum bypass pipe diameter shall be 10 in (25.4 cm), unless otherwise approved by NMFS.

e. Minimum pipe depth is 1.8 in (4.6 cm) and is controlled by designing the pipe gradient for minimum bypass flow.

Questions concerning this document can be directed to NMFS Hydraulic Engineering Staff at:

National Marine Fisheries Service
Southwest Region
777 Sonoma Ave. Room 325
Santa Rosa, CA 95402
Phone: 707-575-6050

Adopted,

Date: 24 Feb 97

Authorizing Signature: Hilda Diaz-Soltero

NAPA VALLEY GRAPEGROWERS
FARMING FOR A DROUGHT

January 23, 2014

In our continuing efforts to promote sustainable best practices and stay at the forefront of grower issues, the Napa Valley Grapegrowers hosted a "Farming for a Drought" town hall meeting on January 23, 2014 at the Yountville Community Hall.

Overview of the Current Water Situation

The last serious drought to affect the Napa Valley was in the growing seasons of 1976 and 1977, with about a third of the normal rainfall. The NVG is optimistic that with continued communication and awareness we can collaborate and provide feasible solutions and strategies to dealing with the drought.

The Napa Valley's water supply is unique to our region and differs from the rest of California due to our groundwater resources. The current water supply in the Napa Valley is comprised of two main water sources: surface water and groundwater.

- Surface water – Surface water supplies vary significantly from year-to-year and are affected by drought years. The 2013 calendar year was the driest in record, however, since growers do not operate on the calendar year, we still have a few months of "rainy season" to contribute to our growing season totals.
- Groundwater – The underground reservoir in the Napa Valley is both unique and important to this region. It is important to note that even in drought years, the groundwater supply, with some exceptions, has been relatively stable. This underground reservoir provides an important buffer to the surface water levels each year and particularly in drought years.

How do other dry regions handle drought?

Decisions surrounding water use and strategies for dealing with drought can be derived from other regions that typically experience dry weather conditions. However, most other regions rely on water transfers from other areas or surrounding snow melt. A few applicable tips from other regions include:

- Adequate water and adequate nutrients at bud break
- Adding compost to increase the water holding capacity of your soil
- Be aware of drip irrigation systems and the location of your roots – often not under the emitter

The Current Weather Pattern and ENSO

We are currently in an El Nino Southern Oscillation (ENSO) neutral pattern. The 10 month position of the jet stream is unprecedented and is causing a blocking high pressure system that is keeping storms from our area. It is unclear whether this pattern will continue through winter of 2014 or into future years as well. To learn more about weather patterns and their effects on growing conditions in the Napa Valley, please sign-up for the 2014 Growing Conditions Report on February 6.

Tools and Resources for Napa Valley Grapegrowers:

- Growing Conditions Report – February 6, 2014
- FREE NVG Weather Alert for all Grower and Vineyard Manager members
- NVG Discounted Services for Members:
    - ET modeling for irrigation scheduling
    - Pressure chamber measurements
    - Neutron probes
    - Soil moisture probes
    - Sap flow sensors
    - Dendrometers
    - Porometers
    - NVDI imagery
    - Well level sensors
    - Weather stations

Irrigation Practices

Decisions surrounding when to irrigate and how much can be critical for the cultivation of fine wine grapes. As with many other aspects of viticulture, the answer should always be site specific. Irrigation protocols and run times should also be tailored to the water holding capacities of different soil types.

Irrigation Timing

The timing of irrigation will be critical in a dry year and it is important to approach the season with a plan and water budget. It is critical to address water availability throughout the growing season while also carefully monitoring canopy size and timing of bud break. Growers should plan to time operations early and begin a water deficit program to acclimate the vines for the continuation of a dry season.

Key irrigation times:

1. Bud break
2. Flowering and fruit set
3. Begin your water deficit program between bloom and veraison

Irrigation Methods

Decisions surrounding irrigation methods in a drought year should be made with careful consideration and planning. When deciding between drip irrigation and overhead irrigation system growers should consider (there are pros and cons to both methods):

1. Evaporation rates – Drip irrigation has a much lower evaporation rate than overhead systems.

2. Root zone – With standard drip irrigation we are not reaching more than 15% of the total soil volume. In most areas, not more than 30% of the root volume is in this drip irrigated area. Consider determining your root zone.
3. When possible, irrigate at night. There is less evapotranspiration at night, so you'll conserve water.

Other irrigation tips:

- Be sure every emitter is functioning and take the time to plug emitters where you may not need them
- Be aware that most issues with individual wells are not because of decreasing groundwater levels, but in the plumbing of the well. Be sure your well is functioning efficiently.
- Install meters on your irrigation systems—it is easy to see your gallons per minute and measure efficiency
- Water in larger, but less frequent volumes, try to water more of the soil area when watering

How do to we manage our vineyards to require less water?
To the greatest extent we can, we need to accept the fact that we are looking at a smaller crop in a drought year. In terms of water use and conservation, growers should be aware and proactive in performing practices that will promote smaller vines. In some cases, on rocky, hillside sites, it will simply not be possible to time irrigation as outlined above. The critical aspects of conserving water in your vineyard are:

1. Do not encourage excess root growth and thus, excess canopy growth
2. Address soil nutrition issues with excessive growth in-mind
3. When limiting the size of the vines, plan ahead and get your work done early
4. Be wary of tipping shoots during active growth because it will encourage lateral growth and evapotranspiration. It is much safer to tip once the shoots stop growing (# of inches less relevant)

Is dry farming the answer?
Dry farming is much more complex than the conversion of irrigated vineyards to dry farming. Dry farming is both a concept and philosophy that involves intensive soil care and specific cultivation patterns. In addition, it relies on 30" of rain in the winter and is therefore not the solution to a drought year. There are some techniques that may be applicable, but we have built a generation of "thirsty" vineyards.

Cover Crops, Soils & Nutrition

Cover Cropping:
Cover crops are planted for erosion control and any grower considering disking or removing a permanent cover crop should first consult the county. In normal years cover crops offer several benefits, however, in drought years they can cause competition for water. The majority of cover crops adapt to the drought—for example, we do not see many lush cover crops currently due to lack of water. The cause for concern occurs when late rainfall in the spring allows the potential for big growth and therefore, water consumption and competition. With that in mind, a drought year may be a good year to disk a permanent cover crop and replant in 2015.

Soil Nutrition: Compost and Mulch

There are several pros and cons to adding compost or mulch to your vineyard.

Pros:

- Improves soil water holding capacity and (CEC) Cation Exchange Capacity
- Allows vines to take advantage of native soil nutrients
- Encourages vine health, without excessive vine growth

Cons:

- Mulch can cause an increase in rodent population – gophers & voles
- Can be Expensive
- When mulch breaks down it will need water and nitrogen—be aware that it is potentially taking nitrogen from your vines

Fertilizers

Typically, we deal with excessively wet soils in the springtime; in a dry year, nutrient uptake will be difficult if we lack the roots to absorb them. If we do not have any soil moisture by the time we begin bud break, we can see problems with nutrient uptake. In order to promote vine health and nutrient uptake growers should consider:

1. Fertilizer injections
2. Foliar fertilizers

If you are adding nitrogen in a drought year, it is recommended to consider using slow-release nitrogen such as: compost, fish emulsion or time-release nitrogen products that will not encourage a large growth spurt.

Newly Planted Vineyards & Young Vines

In a drought year, young vines are more susceptible to damage that could affect their future productivity. Increases in "Young Vine Decline, Petri Disease, Esca" complexes can all be seen without adequate irrigation. In order to effectively manage young vines in a drought year, you will want to implement an irrigation program that will train the young vines to seek water. One effective strategy is to prune back to two buds and calculate how much water you have for that particular block—work backwards.

Skipping a Vintage—is it possible?

If you have an under-performing vineyard (in absence of disease) it is a great opportunity to t-bud. However, this is only applicable if you were going to exercise this practice in the near future despite drought conditions. If you wanted to "skip a vintage", in theory, you would implement the small vine theory to an extreme: shorten cordons, prune to one bud, remove the crop as early as practical, and continue to exercise the same weed control to minimize water use competition. However, the farming practices of 2014 will affect the crop of 2015 and all growers should keep this in mind when assessing the future productivity of your vineyard.

Frost Protection & Heat Management

Frost Protection

Frost protection and heat management are key components to retaining a high-quality crop. Recommendations for frost protection during a drought include:

- Pre-pruning and pruning later to suppress your growth. When the season is set-up for an early bud break it makes us particularly susceptible to frost damage.
- Know your site and possibly start your sprinklers at 32 degrees versus 34 degrees
- Install sensors to get real-time, accurate information
- Adjust your frost protection practices in certain areas or blocks and understand the physics and thermodynamics

Heat Protection

Canopy management is critical in heat protection—leaf removal and size management needs to be done strategically. When leafing, be sure the leaves you are removing are not playing a key role in sunburn protection. Other methods for heat protection include:

- Shade cloth – effective, but cost prohibitive. Shade cloth should be evaluated in the context of the value your crop. Costs roughly $1800/acre in the first year to purchase and install.
- Once the canopy is sized, dropping wires in July or August can be effective in protecting against sunburn

Regulations

Groundwater Resources Advisory Council (GRAC)

In 2011, the GRAC did a study of 660 wells in Napa County and found that the groundwater levels are generally stable with the exception of the Milliken Sarco Tulocay district. It is key for all growers in the Napa Valley to note the importance of our groundwater resources and continued monitoring.

In addition, a drought year attracts increased public pressure on overall water use in the state of California and the county. It is important to be proactive about monitoring our own usage and communicate to regulators that we have the ability to do so effectively.

Best Practices for Consecutive Dry Seasons

There is an opportunity in a drought year to learn and implement new strategies. With that in mind, the quickest way to reduce water use is to reduce our canopy size—one of those variables must shift. It is also important to build in some buffers for future vineyard developments and consider row orientation, vine density, vine size, well sensors, and the overall sustainability of our practices.

As we enter our second consecutive dry season, the importance of quality and preserving our land and reputation for future generations is at the forefront of our local industry. The biggest challenge we face is strategizing and adapting with quality as our priority. There are opportunities in replant situations to think about a redesign – and which varieties might be truly best suited to our diverse sites. One of the biggest assets we have is grower collaboration through the Napa Valley Grapegrowers.

NAPA VALLEY GRAPEGROWERS BEST PRACTICES
- IRRIGATION -

Prepared by the Napa Valley Grapegrowers Industry Issues Committee

In our continuing efforts to promote sustainable best practices, the NVG offers the following suggestions for irrigation. This is not an all-inclusive list, but includes some of the important aspects to consider in your planning.

Decisions surrounding when to irrigate and how much can be critical for the cultivation of fine wine grapes. As with many other aspects of viticulture, the answer should always be site specific. While there are some areas of Napa that can be dry-farmed quite effectively, there are other sites that certainly require water. Similarly; different rootstocks, different scion varieties and different rootstock/scion combinations have different demands as well. Irrigation protocols and run times should also be tailored to the water holding capacities of different soil types.

Pre-season Preparations:

- Ensure all pumps are well maintained
- If using a well, check static water depth and record this number
- Flush all hoses to remove fine particulates that could clog emitters
- Inspect all lines for leaks
- Check all emitters to ensure vines are receiving water, replace as necessary
- Measure individual emitter output with a graduated cylinder to quantify uniformity, compare calculated water use with meter readings
- Remove or add spaghetti hose based on vine age and vine strength
- Test all valves, solenoids and timers to ensure proper operation
- If financial means exist, consider adding a second irrigation line to irrigate weaker areas to increase uniformity
- Given the risk of toxicity and other issues, water sources should be analyzed periodically to confirm suitability for vineyard irrigation

During Irrigation (throughout the season):

- Double check all emitters are functioning as designed
- Check and clean filters as necessary
- Ensure that pumps and pipes can maintain adequate pressure to irrigate desired blocks

Post-season:

- Flush hoses thoroughly
- If necessary, flush with a material that will clean mineral deposits on the emitters and inhibit microbiological growth
- If utilizing a well, check static water depth and record this number
- Open valves if located in areas prone to freezing

Determining Water Status (Stress Levels) Of Your Vineyard

Here's a short list of some of the tools available to today's grower:

- Sap Flow Technology
  - This is a form of non-destructive vine water status monitoring
  - Pros – real time vine monitoring, 24 hours a day, 7 days a week
  - Cons – still expensive, as it is new technology, this limits the number of vines that can be monitored.

- Pressure Bomb (Leaf Water Potential)
  - Pros – relatively accurate, can move freely throughout the vineyard block to test low and high vigor areas with one unit
  - Cons – destructive sampling, requires a skilled technician and knowledge of climactic variables (temp, vapor pressure deficit) at time of sampling
  - Climactic variation makes threshold interpretation difficult
  - Different options for measurement of Leaf Water Potential
    - Pre-dawn measurements can decrease the variability in the results *Measurements should be taken before sunrise when root tissue is in equilibrium with soil moisture*
    - Stem Water Potential – samples taken at mid-day from leaves bagged 40 minutes before measurement. More accurate than mid-day measurements
    - Mid-day measurements will have more fluctuations, but easier timing for technician. Mid-day measurements reflect the effects of weather more than the effects of soil moisture

- Visual and Tactile observation
  - Pros – no tools necessary. Typically looking at leaf orientation, leaf temperature, and visual cues such as general vine condition. Extremely useful during grand growth or spring growth
  - Cons – often leads to unnecessary irrigations

- Soil Probes
  - Pros – gives an idea of soil moisture content, often used with other tools
  - Cons – does not tell the stress level of vine, only whether water is in the ground and not necessarily whether it's available to the plant

- Irrigation Consultants
  - Consultants utilize a vast array of these tools and can often help as a separate set of eyes and ears in your vineyard

2014 SUSTAINABLE VINEYARD PRACTICES - "STRATEGIES FOR USING LESS WATER"

RESOURCES

Neutron Probe

- Accurately measure water use in the soil
- Readings taken weekly and compared to previous week, past seasons, and target levels
- Field observations recorded (tips, growth stage, shoot growth, general condition) and then related to soil measurements
- Irrigation plan created from data collected (soil, visual, weather, etc)
- Probe data can show effect of irrigation, root activity, compacted layers, subsurface drainage, and general soil texture

Pressure Chamber

- Directly measure current vine water status (Leaf Water Potential - LWP)
- Can be Midday LWP or Pre-Dawn LWP
- Very portable (use on ATV, tailgate, or carry to sample location)
- Usually compared to a target LWP
- Results used with visual observations, other vineyard data, and weather to schedule irrigations

Sap Flow Sensor

- Measure vine water use directly on the plant
- Accurately assess the level of vine water needs satisfaction through sensors installed on the vine
- Direct, plant-based, continuous measurement (24 hours a day, 7 days a week)
- Non-invasive and non-destructive
- Track in real time the vine response to climate, soil, irrigations and other practices
- Relate to fruit maturation, leaf area development and nutritional uptake

General Costs

- Neutron Probe readings for a season ~$600 per site
- LWP readings for a season ~$450 per site
- New Pressure Chamber (PMS Instrument Co.) ~$2800
- New Neutron Probe (InstroTek-CPN) ~$6000 also requires state license for ownership and use (~$1500 annually)
- Aquacheck Soil Moisture Probe - 6 depths with internal data logger
    - ~ $1070 each, with discounts for multiple units
    - Rental for 1 year ~ $420
- Decagon Leaf Porometer (to measure stomatal conductance) ~ $2,575
- Sap Flow Sensors ~ $5,000 per season
- Consultant Services:
    - Weekly moisture probe downloads, with charts ~ $360 per site depending on # of sites per property (pricing shown is for 4 sites)
    - Weekly moisture probe downloads PLUS leaf water potential (pressure chamber) and stomatal conductance (porometer) measurements ~ $585 +/- depending on # of sites per property (pricing shown is for 4 sites)

Before embarking on any new project please remember:

1. It is important to recognize that rainwater catchment systems require ongoing maintenance to remain effective, and to factor this maintenance into your plans. If you have already installed a catchment system, please review the maintenance sections of this brochure for tips on getting the most out of your existing features.

2. ALWAYS check with applicable regulatory agencies to determine if a permit is necessary for any project. Building a retaining wall, installing a large cistern, sending runoff to a creek or stream, and directing water to a neighboring property may all require a permit.

3. CALL BEFORE YOU DIG! Call 811 or 1-800-227-2600 for assistance from Underground Service Alert (USA).

4. Important Considerations for Properties with Septic Systems: In Sonoma County there are many homes served by onsite sewage disposal systems (aka septic systems). Not only do these systems have subsurface leach fields where the household sewage is treated and disposed of, but many also have subsurface drains (interceptor drains) associated with their design. It is imperative that any planned stormwater project be designed to not intercept subsurface sewage or interfere with the functioning of a septic system or interceptor drain. When you are in the stormwater project design phase, always check with your local jurisdiction first for the location of your septic system and leach field replacement area. If there are no records available, consult with a qualified individual to locate your system and its replacement area prior to design and installation of the project. Septic systems also have statutory setback requirements that you will need to consider in the planning process. The Sonoma County Permit and Resource Management Department, see Local Resources, is a good place to obtain information about your septic system and local regulations.

Rain barrels come in a variety of shapes, sizes, and colors.

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Productive lands. Thriving streams.

Local Resources

Local Resources - refer to the Resource Guide in the Slow It. Spread It. Sink It. Store It! guide.

Developing a Rainwater Catchment Project

If you are interested in developing a rainwater catchment project, call the Sonoma Resource Conservation District for more info at 707.569.1448

This fact sheet was prepared by the Napa County Resource Conservation District with funding from the California Department of Fish and Wildlife, and revised by the Sonoma Resource Conservation District.

Slow It. Spread It. Sink It. Store It!

Rainwater Catchment

Rainwater Collection Systems

Water from a rain barrel can be used for irrigation in place of potable water.

Rain tanks and cisterns can be placed outside buildings to store water collected from roof downspouts. The stored water can then be used for irrigation. Collecting and storing water from roofs is an excellent way to SLOW water down by temporarily storing it. Captured water can be reused for irrigation or other non-potable options or metered off slowly after storm events to allow for infiltration and reduced flooding.

RAIN BARRELS are small to medium-sized containers placed outside buildings and connected to roof downspouts to collect runoff for later use in non-potable applications. Rain barrels have many advantages in urban settings. They take up very little space, are inexpensive, and easy to install. Rain barrels conserve water and reduce the volume of runoff moving off-site.

MAINTENANCE: Rain barrels require regular draining after rainstorms and removal of leaves and debris collected on screens. Always check that the overflow is clear and directed to an appropriate location. Fine mesh screens should be used to seal lids and vents. A hole larger than 1/16 of an inch can allow mosquito access and result in significant larvae production.

A local rainwater catchment system that utilizes old wine barrels.

DID YOU KNOW?

It takes only one inch of rain falling on a typical 1500-square-foot roof to generate approximately 1,000 gallons of runoff. Annual rainfall in Sonoma County ranges from 20 to more than 70 inches depending on where you live (residents at higher elevations generally receive higher amounts of rainfall). This means that in one winter, your roof alone could shed between 20,000 and 65,000 gallons of water as runoff!

Mosquito-Proofing For Rainbarrels

- Place a mosquito-proof screen (fine mesh - 1/16th of an inch) under the lid of each rain barrel making sure to cover the overflow hole.
- Keep your rain barrel lid and all connectors in the system sealed.
- If possible, place your barrel on a surface that will soak up or promptly drain water that has overflowed.
- Keep your barrel free of organic materials such as leaves and debris.
- Remove water that may have pooled on the top of the barrel at least 1 to 2 times a week during the spring or whenever mosquitos are active, or use a barrel with a self-draining lid.
- Use a downspout diverter to direct water into the barrel.
- Inspect the system on a regular basis to be sure there are no cracks or leaks and that all seals and fittings remain intact.
- Keep gutters and downspouts clean and free of debris.

DO

- Use water regularly. (e.g., water indoor plants)
- Use gravity to your advantage.
- Use multiple barrels where possible.
- Keep barrels sealed and maintained to eliminate debris accumulation and mosquito breeding.

DON'T

- Allow access for mosquitos, rodents, children, pets, or debris.
- Use for drinking.
- Capture water from roofs with excessive debris (e.g., leaves, pine needles, or bird droppings.)

Large Water Tanks/Cisterns

Large water tanks or cisterns are manufactured water storage containers for non-potable use in residential, commercial, agricultural, or industrial applications. Water tanks can be installed both above and below ground. Some tanks come as sectional pieces that can be put together to fit different space constraints. Tanks can be used with most guttered roofs to collect runoff and reduce runoff volume. Both water tanks and rain barrels can be used without pumping devices, instead relying on gravity flow. However, depending on the desired use for the water, a pump may be necessary for best performance.

A 20,000-gallon cistern at New Technology High School in Napa.

Larger tanks can be designed to also function as privacy screens, fences, or small retaining walls. Tanks can also be hidden under decks or serve as the foundation for play structures or other landscape features. Get creative!

Underground tanks are excellent options for areas with limited space. However, do not install underground systems beneath the path of vehicles or heavy machinery traffic unless they have been engineered for that purpose. Extra precautions may be needed when placing tanks in locations with high water tables or saturated clay soils. Contact an experienced licensed professional for tank installations under these conditions.

Mosquito-Proofing For Tanks or Cisterns

- Cisterns (above and below ground) should be completely enclosed with no openings to the outside environment.
- Tightly seal cistern lids and connections.
- Cover all inlets, outlets, and vents with mosquito-proof screening (fine mesh -1/16 of an inch).
- Inspect the system on a regular basis to be sure there are no cracks or leaks and that all seals and fittings remain intact.
- The area surrounding cisterns should be designed to either divert or absorb excess water from overflow.
- The inside of the cistern must be accessible for periodic maintenance as well as inspection by mosquito control personnel.

DID YOU KNOW?

Sediment and debris that collect in the corners and edges of gutters support the growth of bacteria, mosquitos and other organisms that could contaminate rainwater and spread disease. Because rounded gutter systems have fewer edges than their square-cornered counterparts, they provide cleaner water for rainwater catchment systems.

Basic components of a rainwater collection system:

- Catchment surface
  ~This is normally a roof, but there are other options.
- Gutters and downspouts
  ~Round gutters are recommended because they are less likely to collect sediment in corners and edges. Accumulated sediment can support bacteria growth.
- Screening of tanks or barrels and downspout openings
- First-flush device/Downspout Diverter
- Water tanks
  ~There are various options including manufacturing on-site.
- Water tank vent
- Overflow device
  ~This should be equal to or larger in diameter than the inflow pipe to avoid backup.
- Faucet and valve
- Filters and pumps (optional)

A rainwater catchment system can include multiple large tanks.

Maintenance:

- Remove accumulated sediment and debris annually and inspect all components such as gutters and downspouts regularly. The inside of the tank must also be inspected.
- Look for system leaks and cracks. Check all connections and hoses for wear and all screens or mesh for debris accumulation and holes.
- Make sure overflow is clear and directed to an appropriate location. Inspect all seams for leaks.
- Follow all manufacturers' recommended maintenance for any storage device.

DO

- Obtain necessary permits.
- Secure tanks with straps for protection from earth movement.
- Use gravity to your advantage wherever possible.
- Keep underground tanks a minimum of ¼ full at all times to prevent collapsing of certain tank types.
- Place tank in an accessible location

DON'T

- Place tanks on steep hillsides.
- Place water tanks below ground unless they are approved for this use.
- Collect water from cedar or highly degraded roofs.
- Collect roof water from areas prone to large amounts of debris (leaf litter, etc.)
- Use or install older type cisterns with open tops or sides