SUITABILITY STUDY OF NAPA SANITATION DISTRICT RECYCLED WATER FOR VINEYARD IRRIGATION

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Executive Summary

The Napa Sanitation District (NSD) is looking to expand the use of recycled water in Napa County and has developed a Recycled Water Strategic Plan to explore options to maximize water recycling. Included in this plan is expanded use of recycled water for vineyard irrigation, in particular in Carneros and the Milliken-Sarco-Tulocay (MST) region east of the City of Napa.

NSD sponsored this report with a grant to the University of California in order to provide grape growers with an unbiased source of information regarding important water quality parameters relative to vineyard irrigation.

For this study, samples of NSD recycled water were collected on a weekly basis from May 1 through Oct 31, 2005. Additionally, water samples were collected three times during this time period from existing water sources at ten sites throughout Carneros and the MST regions. Analyses of these waters provide a comparison to the NSD water. Additionally, soil samples were collected from a vineyard that has been irrigated solely with NSD recycled water for eight years. These were evaluated for salinity and other factors.

Important findings from this study include:

- With long term use of NSD recycled water, soil salinities (ECe) should not exceed 1.3 mmhos/cm. Because this is lower than the threshold ECe value for grapes (1.5 mmhos/cm), the use of NSD recycled water should not create salinity problems in vineyards. This relationship assumes good irrigation management practices, and further, does not take into account leaching by winter rainfall which will reduce soil salinity annually.

- With winter rains averaging approximately 20 inches per year in Carneros and the MST regions, the reclamation-leaching functions provided by Ayers and Westcot (3) predict that about 80% of the salts that accumulate in the top three feet of soil can effectively be removed each year through natural leaching.

- Salinity values (ECe) of soil samples collected from a vineyard irrigated solely with NSD recycled water for eight years were all less than 0.8 mmhos/cm, far below the yield threshold of 1.5 mmhos/cm. These field results provide additional evidence that long-term salinity accumulation should not occur when using NSD recycled water.

- NSD recycled water averaged 4.3 meq/L of chloride (Cl). This is well below a conservative threshold value of 7.4 meq/L, indicating that this water should not pose a problem regarding Cl toxicity in grapes, assuming good irrigation management practices. If winter leaching is also taken into consideration, the case is even that much stronger that this water will not pose a problem.

- The average sodium (Na) concentration of the NSD recycled water was 5.0 meq/L and the sodium absorption ratio (SAR) was 3.9. Although this sodium level is slightly higher than the one suggested by Ayers and Westcot (3), it can readily be lowered in

soils by light gypsum applications. Sodium levels in soils irrigated with NSD recycled water should not be a problem provided adequate calcium levels and soil physical conditions are maintained.

- Analysis of soil samples collected from a vineyard irrigated solely with NSD recycled water for eight years had low levels of Na and Cl (1.6 and 1.2 meq/L, respectively). Chloride toxicity should not be a problem in soils with levels below 10 meq/L. There is no specific threshold level for Na in soils. These results indicate that sodium and chloride were not accumulating to levels of concern at this site following long-term use of NSD recycled water.

- Boron levels were low (0.4 mg/L) indicating that boron toxicity should not be a problem when using NSD recycled water. When boron levels in irrigation water exceed 1.0 mg/L, grapevine growth and productivity may be reduced.

- The ratio of calcium to magnesium in NSD recycled water does not present a concern with respect to affecting the relationship of these ions in soils. While calcium levels in the NSD water were slightly less than magnesium levels (1.6 and 2.0 meq/L, respectively), they were similar enough not to suggest the need for gypsum applications to provide additional calcium. In addition, the high rainfall of this region in relation to the amount of irrigation water applied makes changes to the soil Ca:Mg ratios unlikely to be of significance.

- Trace elements and heavy metals were all well below published thresholds for levels of concern in irrigation waters

- At typical irrigation rates of 0.4 to 0.6 acre-feet per acre, the exclusive use of NSD recycled water would deliver approximately 1-1.5 pounds of phosphorus (2.2-3.4 lbs P_2O_5) and 21-31 pounds of potassium (25-37 lbs K_2O) per acre per season. The phosphorus and potassium in the NSD water would have no detrimental effects, and the vines may benefit from application of these nutrients.

- At typical irrigation rates of 0.4 to 0.6 acre-feet per acre, the exclusive use of NSD recycled water would deliver approximately 14-21 pounds of nitrogen per acre per season. This amount of nitrogen is not exceptionally high, but it may be enough to be of concern to some growers and winemakers, especially on sites that are already fairly vigorous. Many vineyards in Carneros and the MST region are currently fertilized with nitrogen at rates approaching or exceeding these levels, but others are not, or they may not be fertilized with nitrogen every year. There are some vineyards that rarely (if ever) receive nitrogen additions. Potential mitigation measures for growers concerned about nitrogen in the NSD recycled water include selective use of cover crops and having an additional source of water available for irrigation.

- The use of NSD recycled water does not create additional risks with respect to clogging of drip irrigation systems as compared to existing water sources.

- The use of recycled water for vineyard irrigation is not restricted in the National Organic Program standards. Therefore, organic grape growers can use this water in organically certified vineyards.

Our study indicates that NSD recycled water is suitable for vineyard irrigation. Some growers may choose to adopt mitigation measures for the nitrogen delivered with this water, while others will see the nitrogen as an added benefit. Based on our results, there were no salinity or toxicity issues that would limit the use of this water for vineyard irrigation.

Introduction

The Napa Sanitation District (NSD) produces recycled water at their Soscol Water Recycling Facility south of the City of Napa. NSD's National Pollutant Discharge Elimination System Permit issued by the San Francisco Bay Regional Water Quality Control Board provides for the discharge of treated wastewater into the adjacent Napa River during the wet season (November through April), but during the dry season (May through October) river discharge is prohibited. During the non-discharge period, water is recycled for irrigation purposes or stored for wet season discharge. NSD currently delivers recycled water for irrigating vineyards, industrial landscaping, and golf courses near the Soscol Water Recycling Facility. However, one third to one half of the recycled water currently produced is applied to reclamation sites near the facility.

NSD is looking to expand the use of recycled water in Napa County and has developed a Recycled Water Strategic Plan to explore options to maximize water recycling. The use of recycled water for vineyard irrigation could be greatly expanded if a distribution system for delivery of recycled water was in place. NSD is considering building pipelines to deliver recycled water to vineyard users in the Carneros district, just across the Napa River from the Soscol Water Recycling Facility, as well as to users (vineyards and golf courses) in the Milliken-Sarco-Tulocay (MST) region east of the City of Napa. NSD will only be able to expand the use of recycled water if funding becomes available for these major projects.

The Carneros region has extensive plantings of vineyards, but water is often limited in this area. There is little surface water available from ponds or reservoirs. Groundwater is often limited in volume, and it may be high in salts, especially from wells close to San Pablo Bay. Growers in the region currently utilize a combination of wells, surface water collections, and municipal (drinking) water for vineyard irrigation. Recycled water would be a benefit to many growers in this area by providing a reliable supply of water, even during drought conditions.

The MST region includes considerable vineyard acreage along with golf courses that could benefit from the availability of recycled water. The region has been determined to be in a groundwater deficit and there are concerns about the declining aquifer among local residents and officials in the County of Napa. This region also has many wells with water that is high in boron. Recycled water could greatly benefit this region by supplying an alternative source of water for irrigating grapes and golf courses, thereby reducing the need to pump groundwater from local wells.

About Recycled Water

Water recycling involves the management and treatment of wastewater to produce water that can be used for irrigation and other beneficial uses. Recycling of wastewater has environmental benefits because it limits the discharge of treated wastewater into natural waterways, and it helps to preserve the supply of potable water for human consumption by providing an alternative source of water for irrigation and other uses (1).

Recycled water is already widely used in California agriculture on numerous food crops, as well as on pasture and feed for animals, and on nursery crops (2). Other uses include irrigation of parks, golf courses and landscaping, industrial applications and other beneficial uses.

The production of recycled water is regulated by the State of California Department of Health Services through Title 22 of the California Code of Regulations. These regulations are intended to protect public health while allowing for the safe use of recycled water. The higher the level of treatment wastewater receives, the more uses become available for the recycled water (1).

Wastewater at NSD is treated through a series of primary, secondary and tertiary treatments to produce recycled water that meets the highest standard for recycled water in California ("disinfected tertiary quality"). These steps include settling, biological oxidation, clarification, coagulation, filtration and disinfection. The resulting water is clear and colorless. There may be a slight chlorine smell due to the final disinfection treatment.

Expanding the use of NSD recycled water has many economic and environmental advantages. It provides a reliable source of water to growers who might otherwise have no water available, or whose supplies diminish late in the summer and/or during periods of extended drought. The cost for NSD recycled water may be less than from other sources. Additionally, expanded use of recycled water reduces the amount of discharge to the Napa River and protects existing sources of water for other uses.

Study Overview

In order for recycled water to be a benefit to grape growers in Carneros and the MST region, they need to be confident that the water quality is suitable for vineyard irrigation and that there are no water quality parameters (such as high salinity or specific constituents in the water) that could negatively affect their vines or the soil they are grown in. Towards this end, NSD provided a grant to the University of California to produce this unbiased report on the suitability of NSD recycled water for vineyard irrigation.

For this study, samples of NSD recycled water were collected on a weekly basis during the 2005 dry season (May 1 through Oct 31). These are the months that high quality recycled water suitable for vineyard irrigation is produced at NSD. During the wet season, discharge to the Napa River is allowed, and high quality recycled water is generally not produced.

Water samples were collected from a 24-hour automatic sampler that maintains a representative sample of the recycled water produced at the plant during the previous 24 hours. The sampler collects aliquots of recycled water every 15 minutes. The quantity collected is based on the flow rate during that period. In this way, a truly representative sample is produced.

The 24-hour composite samples for analyses were collected once a week by NSD staff, marked as to their use in this study, then picked up and delivered to Caltest Analytical Laboratory in Napa. Caltest is a specialized commercial environmental analytical chemistry laboratory focusing on low-level analyses of wastewaters, groundwaters, and receiving waters for regulatory permit compliance. Caltest is accredited in the United States by the National

Environmental Laboratory Accreditation Program and approved by the United States Army Corps of Engineers and the United States Department of Energy.

In addition to the NSD recycled water quality evaluations, we collected samples from several water sources in the Carneros and MST regions that are currently being used by growers for vineyard irrigation. Similar analyses were performed at Caltest on these samples in order to have water quality data from existing sources to compare to the NSD samples.

In Carneros, we sampled three wells, one surface water storage pond and a domestic water tap from the City of Napa used for irrigating vineyards. In the MST region, we sampled three wells, one surface water storage pond, and one pond that combined surface water runoff and well water. At each of these locations, water samples were collected in May, July and October 2005, reflecting the beginning, middle and end of the dry season when NSD recycled water is available.

The collection of water samples was performed to meet guidelines from Caltest. Water was collected in three containers: one quart container with no preservatives added (for analysis of alkalinity, chloride, pH, EC, nitrate-N, nitrite-N, TDS, sulfate, fluoride and turbidity), one pint container preserved with nitric acid (for analysis of B, Fe, silica, Ca, Mg, Na, K and hardness) and one pint container preserved with sulfuric acid (for analysis of ammonia-N, organic N, total Kjeldahl N and phosphate). Samples were held in coolers and delivered to Caltest within hours of collection.

Irrigation water quality evaluations generally consider the pH of the water, the salinity hazard associated with the total soluble salt content of the water, the sodium hazard based on the relative proportion of sodium to calcium and magnesium ions, alkalinity due to carbonate and bicarbonate ions, specific ions such as boron and chloride that can have toxic effects, and other constituents such as nitrogen that can influence plant growth. All of these were evaluated in this study.

In addition to the water testing described above, we collected soil samples in September 2005 from a vineyard that has been drip-irrigated with NSD recycled water for eight seasons (1997-2005). Soil samples were collected near drip emitters and from in between the vine rows to see if there was any indication of salt accumulation or other negative affects from the application of recycled water. Soil analyses were conducted at UC Davis.

Results

Twenty-five samples of NSD recycled water were collected weekly from May 4-October 19 2005. The results of analyses performed at Caltest are summarized in the following tables:

Table 1 shows average values and standard deviations for the 25 samples of NSD recycled water, as well as maximum and minimum values.

Table 2 shows summary values from existing water supplies for vineyard irrigation in the MST region collected in May, July and October 2005.

Table 3 shows summary values from existing water supplies for vineyard irrigation in the Carneros region collected in May, July and October 2005.

Table 1. Evaluation of NSD recycled water. Values are from 25 weekly samples collected May-October 2005 from a 24-hour composite sampler.

Measurement	Units	Season Average	Max	Min	Standard Deviation
pH	pH units	7.5	7.7	7.1	0.2
Salinity & Sodicity					
EC	mmhos/cm	0.95	1.20	0.66	0.14
TDS	mg/L	582	670	430	59
SAR	units	3.9	6.4	2.6	0.7
SAR adj	units	3.8	6.6	2.6	0.8
Hardness (as $CaCO_3$)	mg/L	176	210	150	17
Alkalinity					
Alkalinity, Total (as $CaCO_3$)	meq/L	2.1	2.8	1.7	0.3
Bicarbonate (as $CaCO_3$)	meq/L	2.1	2.8	1.7	0.3
Carbonate (as $CaCO_3$)	meq/L	0	0	0	---
Hydroxide (as $CaCO_3$)	meq/L	0	0	0	---
Specific Ions					
Sodium	meq/L	5.0	6.0	3.3	0.7
Chloride	meq/L	4.3	6.4	2.7	0.9
Sulfate (as SO_4)	meq/L	1.5	1.9	0.6	0.3
Boron	mg/L	0.4	0.5	0.3	0.0
Calcium	meq/L	1.6	1.9	1.4	0.1
Magnesium	meq/L	2.0	2.4	1.6	0.2
Potassium	mg/L	18.8	24.0	12.0	2.8
Phosphate as P, Total	mg/L	0.9	2.2	0.2	0.4
Nitrogen, Nitrate (as N)	mg/L	12.1	19.0	9.3	2.0
Nitrogen, Total Kjeldahl	mg/L	1.0	1.6	0.5	0.3
Nitrogen, Ammonia (as N)	mg/L	0.2	0.4	0.1	0.1
Nitrogen, organic	mg/L	0.8	1.4	0.4	0.3
Nitrogen, Nitrite	mg/L	0	0	0	---
Iron	mg/L	0.1	0.2	0.1	0.0
Silica (as SiO_2)	mg/L	23.0	30.0	17.0	3.8
Fluoride	mg/L	0.1	0.2	0.1	0.1
Turbidity	NTU	0.7	1.4	0.2	0.3

Table 2. Evaluation of existing water sources for vineyard irrigation in the MST region. Samples were collected at each site once in May, July and October 2005.

Measurement	Units	MST Waters						
		3 Wells				2 Surface Waters		
		Season Average	Max	Min		Season Average	Max	Min
pH	pH units	7.6	7.8	7.3		8.0	9.6	5.0
Salinity and Sodicity								
EC	mmhos/cm	0.40	0.61	0.26		0.48	0.97	0.30
TDS	mg/L	316	470	210		355	690	230
SAR	units	1.3	1.8	1.0		1.4	1.6	1.1
SAR adj	units	1.2	1.8	0.7		1.3	1.5	1.0
Hardness (as $CaCO_3$)	mg/L	132	220	62		148	310	87
Alkalinity								
Alkalinity, Total (as $CaCO_3$)	meq/L	2.8	3.2	2.2		1.8	3.4	0
Bicarbonate (as $CaCO_3$)	meq/L	2.8	3.2	2.2		1.4	2.6	0
Carbonate (as $CaCO_3$)	meq/L	0	0	0		1.1	1.1	1.1
Hydroxide (as $CaCO_3$)	meq/L	0	0	0		0	0	0
Specific Ions								
Sodium	meq/L	1.4	1.7	1.1		1.6	2.6	1.2
Chloride	meq/L	0.3	0.5	0.2		0.6	0.9	0.4
Sulfate (as SO_4)	meq/L	1.2	2.9	0.3		2.8	9.0	0.4
Boron	mg/L	0.1	0.2	0		0.4	0.5	0.3
Calcium	meq/L	1.5	2.5	0.8		1.7	3.6	1.0
Magnesium	meq/L	1.2	1.9	0.5		1.3	2.8	0.8
Potassium	mg/L	6.2	8.6	4.3		7.5	9.8	4.9
Phosphate as P, Total	mg/L	0.1	0.3	0		0.1	0.3	0
Nitrogen, Nitrate (as N)	mg/L	0	0	0		0.1	0.4	0
Nitrogen, Total Kjeldahl	mg/L	0.2	0.7	0		1.1	2.0	0.7
Nitrogen, Ammonia (as N)	mg/L	0.2	0.6	0		0.1	0.2	0
Nitrogen, organic	mg/L	0.1	0.1	0		1.0	1.9	0.5
Nitrogen, Nitrite	mg/L	0	0	0		0	0	0
Iron	mg/L	0.7	4.2	0		1.5	6.2	0
Silica (as SiO_2)	mg/L	78.0	83.0	73.0		37.5	71.0	12.0
Fluoride	mg/L	0.2	0.4	0		0.2	0.5	0.1
Turbidity	NTU	4.8	30.0	0.2		16.3	60.0	1.5

Table 3. Evaluation of existing water sources for vineyard irrigation in the Carneros region. Samples were collected at each site once in May, July and October 2005.

		Carneros Waters				
		3 Wells			Surface source	Domestic source
Measurement	**Units**	**Season Average**	**Max**	**Min**	**Season Average**	
pH	pH units	7.7	8.3	7.0	7.6	7.2
Salinity and Sodicity						
EC	mmhos/cm	0.94	1.40	0.45	0.45	0.35
TDS	mg/L	541	750	300	267	217
SAR	units	7.7	16.0	2.9	1.5	1.3
SAR adj	units	7.8	17.0	3.2	1.5	1.2
Hardness (as $CaCO_3$)	mg/L	106	180	42	123	101
Alkalinity						
Alkalinity, Total (as $CaCO_3$)	meq/L	4.8	6.2	2.8	3.3	1.6
Bicarbonate (as $CaCO_3$)	meq/L	4.8	6.2	2.8	3.3	1.6
Carbonate (as $CaCO_3$)	meq/L	0	0	0	0	0
Hydroxide (as $CaCO_3$)	meq/L	0	0	0	0	0
Specific Ions						
Sodium	meq/L	6.4	10.4	3.0	1.7	1.3
Chloride	meq/L	3.5	5.6	1.1	1.0	0.4
Sulfate (as SO_4)	meq/L	0.8	1.3	0.5	0.4	1.5
Boron	mg/L	0.4	1.0	0	0	0.1
Calcium	meq/L	1.1	2.0	0.4	1.4	0.8
Magnesium	meq/L	1.1	1.8	0.4	1.1	1.2
Potassium	mg/L	8.5	19.0	2.1	7.2	2.7
Phosphate as P, Total	mg/L	0.6	4.6	0	0.4	0.2
Nitrogen, Nitrate (as N)	mg/L	2.3	7.5	0	0.1	0.2
Nitrogen, Total Kjeldahl	mg/L	0.2	0.4	0.1	2.2	0.2
Nitrogen, Ammonia (as N)	mg/L	0	0.3	0	1.4	0
Nitrogen, organic	mg/L	0.1	0.3	0	0.8	0.1
Nitrogen, Nitrite	mg/L	0	0	0	0	0
Iron	mg/L	0	0.3	0	1.0	0
Silica (as SiO_2)	mg/L	44.0	58.0	36.0	22.3	17.7
Fluoride	mg/L	0.2	0.5	0	0.1	0
Turbidity	NTU	0.4	1.2	0.2	3.8	0.2

Terminology and Units

The acidity of water is indicated by pH, which is a measurement of the hydrogen ion concentration (pH < 7.0 is acidic; pH > 7.0 is basic). Chemical reactions are affected by pH as is the availability of some nutrients.

The electrical conductivity of water, ECw, is a measurement of total salinity (saltiness) resulting from all ions dissolved in the water, both positive and negative. It does not give any indication of the salt composition. Electrical conductivity is measured by placing two electrodes into the sample and passing an electric current between them. As the salinity level in the sample increases, more current will pass between the electrodes and the ECw reading will increase. Reporting units for EC include deciseimen per meter (dS/m) and millimhos per centimeter (mmhos/cm) which are equal measures. Caltest reports EC values in micromhos per centimeter (µmhos/cm). These were converted to mmhos/cm by dividing by 1,000.

Another measure of salinity is total dissolved solids, TDS. For this measurement, a specific volume of water is evaporated and the weight of the remaining solids (mostly salts) is determined. TDS is expressed in milligrams per liter (mg/L).

Salts, such as sodium chloride (NaCl) and calcium sulfate ($CaSO_4$), consist of positively charged cations and negatively charged anions bonded together by opposing charges. In water, these bonds are broken and water contains individual cations and anions. Calcium (Ca^{2+}), magnesium (Mg^{2+}), and sodium (Na^+) are the predominant cations in irrigation water that contribute to total salinity, while bicarbonate (HCO_3^-), carbonate (CO_3^{2-}), sulfate (SO_4^{2-}) and chloride (Cl^-) are the main anions.

The preferred unit for reporting most individual ions is milliequivalents per liter (meq/L). This unit is used specifically in salinity evaluation because it indicates not only the concentration of the specific ion, but also considers its electrical charge. This is important because soils contain negatively charged clay particles that attract charged ions in relation to both their concentration and charge. Most agriculturists are familiar with the reporting units parts per million (ppm) or milligrams per liter (mg/L) which are equal measures in irrigation water, but may be unfamiliar with meq/L. Both are included in this report. A table of conversion factors is shown below.

Table 4. Factors to convert milligrams per liter (mg/L) or parts per million (ppm) to milliequivalents per liter (meq/L).*

Cation or Anion	Symbol	Conversion factor
Calcium	Ca^{2+}	20.0
Magnesium	Mg^{2+}	12.0
Sodium	Na^+	23.0
Bicarbonate	HCO_3^-	61.0
Carbonate	CO_3^{2-}	30.0
Chloride	Cl^-	35.5
Sulfate	SO_4^{2-}	48.0

* mg/L ÷ factor = meq/L.

The sodium absorption ratio (SAR) and adjusted sodium absorption ratio (SAR_{adj}) are indices of Na levels in comparison to Ca and Mg. Rising levels of Na reduce soil stability, decrease water infiltration, and increase the likelihood of salt accumulating in the soil. Rather than simply measuring Na cation levels alone, SAR and SAR_{adj} are used to evaluate sodicity problems because more Na can be tolerated when Ca increases proportionally to Na. SAR_{adj} additionally takes into account carbonate and bicarbonate reactions in soil which will affect Ca availability.

Hardness is the sum of Ca and Mg concentrations, both expressed as calcium carbonate in milligrams per liter (mg/L). The higher the hardness, the greater the potential for calcium carbonate precipitation in drip systems.

Alkalinity is a measure of the water's capacity to neutralize acid. Alkalinity is affected primarily by dissolved bicarbonate and carbonate ions. Alkalinity establishes the buffering capacity of water and affects how much acid is necessary to change the pH.

Nitrogen occurs in recycled water primarily in the form of nitrate (NO_3-N). Other forms include ammonium (NO_3-N), nitrite (NO_2-N) and organic nitrogen. Total Kjeldahl nitrogen is a measurement of nitrogen in reduced forms (primarily ammonium and organic nitrogen). The total amount of nitrogen in the water samples can best be estimated by adding the values for nitrate nitrogen and Kjeldahl nitrogen.

Salinity

Salinity of irrigation water is of concern because high levels can reduce growth and production of grapevines and other plants. As the salt concentration of the water in the root zone increases above a threshold level, both the growth rate and ultimate size of the crop progressively decrease. However, the threshold and the rate of growth reduction vary widely among different crop species.

Salinity affects plants in two ways: by osmotic effects and by specific ion effects (9). Osmotic effects occur because increases in the salt concentration in the root zone reduce the osmotic potential of the soil water solution. Plants must then expend more energy to absorb water, and their growth rate declines. The most common whole-vine response to salt stress is a general stunting of growth. This is generally referred to as the osmotic effect. The osmotic effect is directly related to the salt content in the soil water, which in turn is related to the salinity of the irrigation water and the extent of leaching that takes place, either from excess irrigation water or winter rains. Specific-ion effects will be discussed below.

Salinity of irrigation water may be characterized by two common water quality parameters. Salinity is sometimes reported as total dissolved solids (TDS), a measurement of the total salt concentration. The units of TDS are usually in milligrams of dissolved solids per liter (mg/L). This term is still used by commercial analytical laboratories and represents the total amount of salt (in mg) that would remain after a liter of water is evaporated to dryness. TDS may also be reported as parts per million or ppm. For dilute solutions, parts per million is numerically the same as mg/L. The higher the TDS, the higher the salinity of the water.

The other measurement of salinity is electrical conductivity (or specific conductance) of the irrigation water (ECw). Salts that are dissolved in water conduct electricity and therefore the salt content in the water is directly related to the ECw. ECw is a much more useful term than TDS because the measurement can be made instantaneous and easily by farm managers in the field. Moreover, EC is the measure by which crop salt tolerance is defined (12).

Often, conversions between ECw and TDS are made, but caution is advised because conversion factors depend both on the salinity level and the composition of salts in the water. Based on the evaluation of water quality reports of NSD recycled water (Table 1), the relationship is best described as TDS (mg/L) = 613 x ECw (mmhos/cm).

Salinity Affecting the Yield Potential of Grapes

Historically, yield potential has been determined based on the Maas-Hoffman salinity coefficients. Maas and Hoffman (12), as described by Ayers and Westcot (3) proposed that salt tolerance can best be described by plotting relative yield as a continuous function of average root zone soil salinity (ECe). They proposed that this response curve could be represented by two line segments: one, a tolerance plateau with a zero slope and the second, a concentration-dependent line whose slope indicates the yield reduction per unit increase in soil salinity.

For soil salinities exceeding the threshold of any given crop, relative yield (Yr) or "yield potential" can be estimated using the following expression:

$$Yr\ (\%) = 100 - b(ECe - a)$$

where a = the salinity threshold soil salinity value expressed in dS/m; b = the slope expressed in % per dS/m; and ECe = average root zone salinity in the saturated soil extract. It is important to note that this ECe value for the soil is different than the ECw for the irrigation water (see below). The most current up-to-date listing of specific values for "a" and "b", called “salinity coefficients” are found in a publication by Maas and Grattan (11). For grapes, the “a” and “b” salinity coefficients are 1.5 and 9.6. Therefore, for grapes,

$$Yr\ (\%) = 100 - 9.6(ECe – 1.5).$$

This indicates that grape yields are not adversely affected until the seasonal average root zone salinity (ECe) exceeds 1.5 mmhos/cm.

Leaching and the Relationship between ECw and ECe

In order to assess the impact of irrigation water with a known ECw on crop yield, the relation between irrigation water salinity (ECw) and average root zone salinity (ECe) needs to be known or predicted. This relationship depends on the salinity of the irrigation water (ECw), the leaching fraction, and on whether the irrigation method is conventional (such as surface irrigation), or high frequency (such as drip irrigation). The leaching fraction (LF) is defined as the fraction (or percentage) of infiltrated water that drains below the root zone. For example if 5 acre-inches of water were applied to one acre and 1 acre-inch of water drained below the root zone, the leaching fraction would be 0.20, or 20%. Soil salinity is controlled by applying sufficient water to leach excessive levels of salts from the root zone. The desired leaching fraction, called the leaching requirement, depends on the salinity of the irrigation water and the threshold soil salinity level for a particular crop.

Relationships between ECw and ECe at various leaching fractions under both conventional and high-frequency irrigation systems have been presented (e.g., 13). These relationships assume that water extraction by roots is proportionately higher in the upper part of the root zone, and even more so with drip irrigation. The relationships also assume steady-state conditions.

In the case of NSD water, the average ECw is 0.95 mmhos/cm. Based on this parameter, using the high-frequency relationship proposed by Pratt and Suarez (13) and a long-term leaching fraction of 10%, the formula becomes (ECe = 1.35 x ECw). This indicates that soil salinity (ECe) over the long term will not exceed 1.3 mmhos/cm. Because this is lower than the threshold ECe value for grapes of 1.5 mmhos/cm, use of NSD recycled water should not create salinity problems in vineyards. This relationship assumes good irrigation management practices, and further, does not take into account leaching by winter rainfall which will reduce soil salinity annually.

Soil Salinity and Drip Irrigation

Historically, the leaching requirement has been determined using several approaches. One approach is to measure soil and irrigation water salinities then use appropriate equations or graphs to estimate the leaching fraction. A second approach is the water balance method which involves determining seasonal crop evapotranspiration (ET) and the seasonal amount of applied water. The difference between applied water and ET is the field-wide leaching fraction.

Recent research in the San Joaquin Valley indicates that these historical approaches are not easily applied to drip irrigation. Although the ECe-ECw-LF relationships could be used as a first approximation or guide, steady-state conditions are never achieved under field conditions. Under drip irrigation, soil moisture content, root density, and soil salinity vary spatially around drip lines. Soil moisture content is highest near the drip line and decreases with distance and depth. Root density is generally highest near the drip line and decreases with distance and depth.

In drip irrigated fields, salt distribution is different than what occurs under sprinkler or surface irrigation. Salts in the profile tend to accumulate in an onion-like pattern below the soil surface where salinity is lowest under the emitter and becomes greater toward the outer edges of the "onion." If irrigation water is applied in excess of the soil water holding capacity, leaching will occur but primarily under the emitter and salts will still build up laterally.

Additionally, grapevines in premium wine producing areas such as Carneros and the MST region are intentionally under-irrigated to induce stress. A moderate level of water stress helps to control vine growth and ultimately can improve wine grape quality. By applying less water, salts from the irrigation water will tend to increase in the root zone as the season progresses.

Leaching must eventually be satisfied to prevent salt accumulation. Winter rains will play a vital role in leaching these accumulated salts.

Rainfall

Rainfall appears to be the main factor controlling soil salinity in Napa Valley soils, although it is not possible to correlate rainfall amounts with specific soil salinity levels.

Analysis of rainfall for the past twelve rainfall years (July-June, 1994-2005) at the California Irrigation Management Information System's (CIMIS) Carneros weather station (number 109) showed total annual rainfall to vary from 11.4 inches to 36.8 inches (Fig.1). The average rainfall during this 12-year period was 22.7 inches.

Leaching is ideally accomplished in the winter during the dormant period. With winter rains averaging approximately 20 inches per year in Carneros and the MST regions, the reclamation-leaching functions provided by Ayers and Westcot (3) predict that about 80% of the salts that accumulate in the top three feet of soil can effectively be removed each year through leaching.

This assumes that the soil profile is replenished with irrigation water before the winter rains occur. It is therefore advisable for growers to apply a post-season irrigation in the late fall allowing the soil in the crop root zone to return to field capacity, making winter leaching more effective. Post-harvest irrigation is already a standard practice in many Napa Valley vineyards if water for irrigation is still available.

Soil Salinity in a Napa Vineyard Irrigated With NSD Recycled Water

Recycled water from NSD has been applied to a few vineyards near the facility for many years. To see if there was any evidence of a long-term buildup of soil salinity from the use of NSD recycled water, we tested soil samples from one of these vineyards in order to measure ECe near the drip zone and compare the results to the threshold ECe for grapevines.

Soil samples were collected on 15 September 2005 at various depths and locations in a field that has been drip-irrigated solely with NSD water for the last eight seasons (1997-2005). The grower typically applied 75-100 gallons of water per vine per season. Because the soil samples were collected late in the growing season (but before winter rains occurred), they represent the maximum soil salinity in the field over the season.

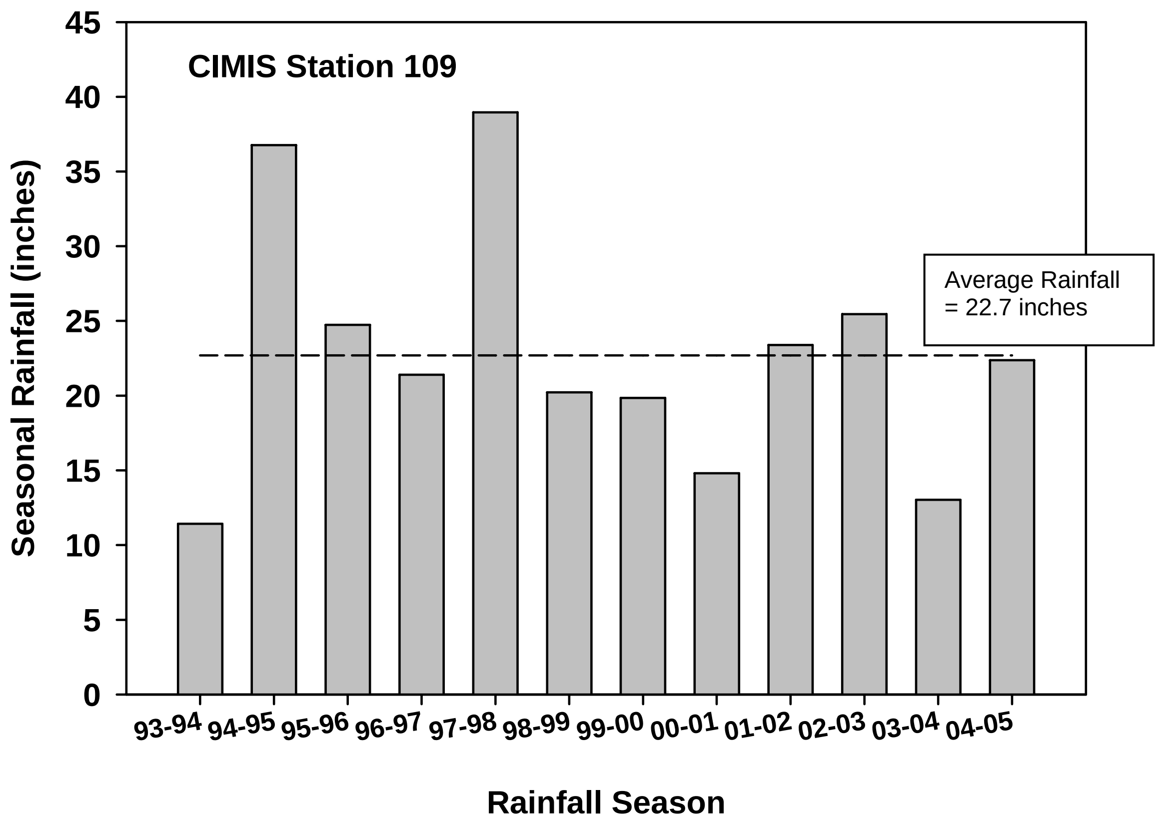
We attempted to take sufficient samples with distance and depth from drip lines to show the pattern of soil salinity around drip lines. However, a hard pan at about 18 to 24 inches deep prevented sampling at deeper depths. It is unlikely that many roots had penetrated this layer. Soil samples were analyzed for ECe, saturation percentage (SP), pH, calcium, magnesium, sodium, chloride, bicarbonate, and carbonate.

Table 5 shows ECe and SP values for the soil samples taken at different distances from drip emitters and at different depth intervals. The SP values, typical for a sandy loam soil, were all similar indicating no major changes in soil texture between sampling locations. The maximum

ECe value among the samples was 0.79 mmhos/cm; most were between 0.25 and 0.5 mmhos/cm. No trends with depth or distance from the emitter were evident.

The ECe values were all less than 0.8 mmhos/cm, far below the yield threshold of 1.5 mmhos/cm. These field study results provide additional evidence that long-term salinity accumulation should not occur when using NSD recycled water.

Figure 1. Seasonal rainfall (July-June) recorded at the CIMIS station in Carneros. Average rainfall for the 12 seasons (22.7 inches) is indicated by the dotted line.



Crop Toxicity (chloride, sodium and boron)

In addition to the osmotic effect of salinity, grape production can be directly affected by toxicity due to specific ions. Grapes are sensitive to chloride (Cl) and to some extent sodium (Na) in the irrigation water and can develop injury to leaves if concentrations exceed certain levels. Specific ion injury, if severe enough, will reduce yields beyond that predicted by salinity (i.e., EC or TDS) alone.

Although boron (B) is an essential element required for plant growth, it is nonetheless a potentially toxic constituent in the soil water should the concentration become too high. Threshold levels for plant injury from Cl and B in irrigation water are reported in FAO 29 (3).

Table 5. ECe and SP of soil samples from a vineyard irrigated with NSD recycled water for eight seasons (1997-2005). Samples were collected at various distances from drip emitters and depth intervals.

Site	Distance from emitter (inches)	Sample depth (feet)	SP (%)	ECe (mmhos/cm)
1	8	0-1	34	0.79
	8	1-2	37	0.59
	20	0-1	36	0.67
	20	1-2	37	0.38
	40	0-1	37	0.78
	40	1-2	37	0.47
2	6	0-1	29	0.34
	6	1-2	33	0.31
	18	0-1	34	0.36
	18	1-2	35	0.29
	30	0-1	37	0.67
	30	1-2	38	0.25
3	6	0-1	31	0.50
4	6	0-1	30	0.37
5	6	0-1	29	0.38
6	6	0-1	28	0.40

-- Chloride Toxicity

Many woody species are susceptible to chloride (Cl) toxicity, with variation among varieties and rootstocks within species. The degree of tolerance is often reflected in the plant's ability to restrict or retard Cl translocation (11). For example salt tolerance in grapes is closely related to the Cl accumulation properties of the rootstock. By selecting rootstocks that exclude Cl from the scions, some degree of Cl toxicity problems can be avoided (4).

The maximum Cl concentration in irrigation water that can be used by a particular crop without leaf injury can be found in FAO 29 (3). The guidelines for grapes are reproduced in Table 6. This list is by no means complete since data for many cultivars and rootstocks are not available, particularly those that are currently in use in the Carneros and MST regions. Original data listed by Maas and Hoffman (12) are in relation to maximal Cl concentrations in the soil water, but data were converted to maximal tolerance in the irrigation water by assuming that the EC of the soil water is twice the ECe and that a long-term leaching fraction of 10% is achieved using high frequency drip irrigation. These are reasonable yet conservative assumptions.

Table 6. Maximum chloride (Cl) concentrations in irrigation water that various rootstocks and cultivars can tolerate without developing leaf injury. Values are for drip irrigation and a 10% leaching fraction (adapted from 11 and13).

Grape Variety		Max. Cl concentration (meq/L)
Rootstocks	Salt Creek; 1613 C	29.6
	Dog Ridge	22.2
Table grapes	Thompson seedless; Perlette	14.8
	Cardinal; Black rose	7.4

Data in Table 6 indicate that the maximum Cl concentration of irrigation water to avoid crop injury is about 7.4 meq/L for sensitive grape cultivars (i.e., ‘Black rose’ and ‘Cardinal’). The predominant grape rootstocks in the Carneros and MST regions are 101-14, 5C, 3309 and 110R. Unfortunately, no tolerance data have been compiled for these rootstocks. Therefore as a conservative approach, we have selected the most sensitive cultivar as a means of setting an upper limit. As more research is conducted on these rootstocks, the limits can be adjusted accordingly.

Based on this assumption, the maximum Cl concentration in the irrigation water that grapes can tolerate without showing adverse symptoms is 7.4 meq/L (262 mg/L). Since the NSD water averages 4.3 meq/L, this water will not likely pose a problem regarding Cl toxicity in grapes, assuming good irrigation water management. If winter leaching is also taken into consideration, the case is even that much stronger that this water will not pose a problem.

-- Sodium Toxicity

The ability of vines to tolerate sodium (Na) varies considerably among rootstocks, but tolerance is also dependent upon calcium nutrition as well. Much of the earlier research on sodium toxicity was done before understanding the importance of adequate calcium nutrition for maintaining ion selectivity at the root membrane level. Since this early work, there is a considerable amount of literature that indicates sodium can cause indirect effects on crops either through nutritional imbalances (e.g., sodium-induced calcium or potassium deficiency) (8), or by disrupting soil physical conditions (3). These indirect effects by sodium make diagnoses of sodium toxicity per se very difficult. Moreover, sodium toxicity is often reduced or completely overcome if sufficient calcium is made available to the roots (3) through the addition of gypsum or by acidifying soils high in residual lime. Calcium addition reduces the Na:Ca ratio in the soil water, thereby reducing the sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP), resulting in both improved soil conditions and reduced Na toxicity. Ayers and Westcot (3) indicate that there are no “restrictions on use” provided that the SAR is less than 3. They provide no concentration limits above which toxicity will result. This is presumably because of the indirect Na-Ca interactions mentioned above.

The average sodium concentration of the NSD recycled water was 5.0 meq/L and the SAR was 3.9 (Table 1). Although this sodium level is slightly higher than the one suggested by Ayers and Westcot, it can readily be lowered by light gypsum applications. Therefore, these values indicate that sodium will not be a problem over the long term provided adequate calcium nutrition is maintained and the soil physical conditions are maintained.

Soil samples collected from a vineyard irrigated with NSD recycled water for eight seasons (described previously) provide further evidence that toxicities from Na or Cl are unlikely to occur. Table 7 shows the soluble salts extracted from the soil samples. The average sodium and chloride concentrations were 1.6 meq/L and 1.2 meq/L, respectively. Chloride toxicity should not be a problem unless the concentration in the saturated soil extract exceeds 10 meq/L (355 mg/L) (7). There is no specific threshold level for Na in soils, as discussed above.

The results of these soil tests indicate that toxicities from sodium or chloride are not occurring at this site following long-term use of NSD recycled water.

Table 7. Chemical constituents of soil samples from a vineyard irrigated with NSD recycled water for eight seasons (1997-2005). Samples were collected at various distances from drip emitters and depth intervals.

Site	Distance from emitter (inches)	Sample depth (feet)	pH	Ca (meq/l)	Mg (meq/l)	Na (meq/l)	Cl (meq/l)	HCO_3 (meq/l)
1	8	0-1	5.1	2.3	1.1	3.2	2.0	0.4
	8	1-2	5.4	2.2	1.0	2.3	1.5	0.3
	20	0-1	5.3	3.4	1.2	1.5	2.2	0.5
	20	1-2	5.7	1.6	0.7	1.3	0.8	0.4
	40	0-1	5.3	4.4	1.5	1.1	1.1	0.3
	40	1-2	5.5	2.2	0.8	1.2	0.7	0.4
2	6	0-1	6.0	1.0	0.4	1.7	0.6	0.6
	6	1-2	5.8	1.2	0.6	1.1	0.9	0.6
	18	0-1	5.6	1.6	0.6	0.8	1.1	0.5
	18	1-2	5.7	1.2	0.6	0.8	0.8	0.7
	30	0-1	5.6	3.9	1.2	0.7	1.4	0.4
	30	1-2	5.6	1.3	0.5	0.6	0.6	0.4
3	6	0-1	6.4	1.6	1.1	2.6	1.2	1.0
4	6	0-1	6.4	1.3	0.8	1.9	1.3	1.2
5	6	0-1	6.6	1.1	0.8	1.9	1.2	1.3
6	6	0-1	5.9	1.2	0.5	2.2	1.3	0.5
Ave.			5.7	2.0	0.8	1.6	1.2	0.6

-- Boron Toxicity

Boron (B) is an essential element for plants but has a small concentration range between levels considered deficient and those considered toxic. Grapes are particularly sensitive to B in the irrigation water and can develop injury to leaves and shoots if concentrations exceed certain limits.

The characteristics of boron injury are crop specific and are related to the plant's ability to mobilize this element (5). In certain tree species (e.g., walnut and pistachio) boron is immobile within the plant and consequently it does not move out of the leaves once it has accumulated there. As such, B injury is characterized by necrosis (burn) along the margins and tips of older leaves. In other tree species (e.g., almond, apricot, apple, nectarine, peach, and plum) as well as grape, boron is relatively mobile within the tree/vine and injury may not appear first on leaves, but rather in young shoots as tip dieback.

Threshold levels in irrigation water that produce such injury are reported in FAO 29 (3). Many of these data were taken from Maas (10) who extracted most of the information from work conducted by Eaton (6), including grape. When the limited data set from Eaton is examined in detail, growth of grape does not decline until B concentrations in the irrigation water exceed 1 mg/L.

The guidelines for boron tolerance are limited. With the exception of a few sand tank studies that actually provide B coefficients (i.e., threshold and slope) for some crops (see 10), most of the B classification has come from work conducted over a half a century ago by Eaton (6). Research on common rootstocks is lacking. More importantly, these older studies defined the B-tolerance limit largely based on the development of incipient injury on the crop (i.e., foliar burn) or growth reduction, not yield response under a range of B concentrations.

The average boron concentration of the NSD recycled water was 0.4 mg/L (Table 1). This value is well below the 1 mg/L level where grapevines have shown sensitivity. Therefore it is highly unlikely that boron will be problematic over the long term from the use of NSD recycled water. Winter rains will help in leaching soil boron below the root zone.

Leaching of Soils

Once the salinity of irrigation water is known and a leaching requirement has been established, a key question is whether or not the soil profile has sufficient permeability to pass the required amount of water through and out of the root zone.

Soils in Carneros and the MST region vary widely in physical characteristics. Soil textures range from loam to clay. Some soils have limiting bedrock within close proximity of the surface, while others are low-lying and prone to wetness and flooding. These characteristics can affect the soil's ability to leach. Fortunately, the Napa County Soil Survey is available to help assess these conditions.

The Napa County Soil Survey was conducted by the United States Department of Agriculture, Soil Conservation Service, in cooperation with the University of California Agricultural Experiment Station. It was completed in 1978. Today, the report can be found online at http://www.ca.nrcs.usda.gov/mlra02/napa/.

The survey includes 63 different soil series within Carneros and the MST region. A soil series consists of soils that formed from a particular kind of material and have horizons that, except for texture of the surface soil or of the underlying substratum, are similar in differentiating characteristics and in arrangement in the soil profile. Among these characteristics are color, texture, structure, reaction, consistence, and mineral and chemical composition. These soil series are listed by name and number along with important physical characteristics in Table 8.

Table 8. Carneros and MST region soil types and important characteristics regarding permeability and leaching.

Soil Name & Map Symbols*	Hydrologic Soil Group	Capability Subclass Units	Depth (in)	Depth to restrictive layer (in)	Permeability (in/hr)
Bale: 103,104,105,106	C	2	0-60	>60	0.6-2.0
Boomer: 107,108,109	B	1	0-4 4-44	40-60	0.6-2.0 0.2-0.6
110,111 Boomer part	B	1	0-4 4-44	40-60	0.6-2.0 0.2-0.6
Forward part	B	1	0-35	20-40	2.0-6.0
Felta part	B	1	0-7 7-26	>60	2.0-6.0 0.6-2.0
Bressa: 112,113,114,115 Bressa part	C	1	0-10 10-33	30-40 30-40	0.6-2.0 0.2-0.6
Dibble part	C	1	0-9 9-34	20-40	0.6-2.0 0.06-0.2
Clear Lake: 116	D	5	0-69	>60	0.06-0.2
117	D	5	0-18 18-69	>60	2.0-6.0 0.06-0.2
Cole: 118,119	C	2	0-8 8-64	>60	0.6-2.0 0.2-0.6
Coombs: 122,123	B	3	0-14 4-54 54-60	>60	0.6-2.0 0.2-0.6 >6.0
Cortina: 124	A	4	0-11 11-60	>60	2.0-6.0 6.0-20
Diablo: 126,127,128,129	D	5	0-60	>60	0.06-0.2
Egbert: 130	C	3	0-60	>60	0.06-0.2

Soil Name & Map Symbols*	Hydrologic Soil Group	Capability Subclass Units	Depth (in)	Depth to restrictive layer (in)	Permeability (in/hr)
Fagan: 131,132,133,134	C	3	0-16 16-28 28-46	40-60	0.2-0.6 0.06-0.2 0.2-0.6
Felton: 135,136,137	C	5	0-10 10-33	30-40	0.6-2.0 0.2-0.6
Forward: 138,139,140 141	C	5	0-4 4-35	20-40	2.0-6.0 2.0-6.0
Guenoc: 142, 143,144	C	1	0-12 12-30	25-40	0.6-2.0 0.2-0.6
Haire: 145,146,147,148, 149,150	C	3	0-27 27-60	>60	0.2-0.6 <0.06
Hambright: 151,152	D	1	0-12	10-20	0.6-2.0
Henneke: 153,154	D	1	0-7 7-15	10-20	0.6-2.0 0.2-0.6
Kidd: 155,156	D	1	0-14	12-15	2.0-6.0
Millsholm: 164,165	D	1	0-12	12-20	0.6-2.0
Perkins: 168,169	C	3	0-29 29-60	>60	0.6-2.0 0.06-0.2
Pleasanton: 170,171	B	1	0-11 11-66	>60	0.6-2.0 0.2-0.6
Reyes: 172,173	C/D	9	0-60	>60	0.06-0.2
Sobrante: 178,179	C	1	0-30	25-40	0.6-2.0
Yolo: 181,182	B	1	0-60	>60	0.6-2.0

***** Information in this table comes from the Soil Survey of Napa County, Tables 11 and 12, and the Guide to Mapping Units (pages 105-107).

Soils are assigned to one of four hydrologic soil groups based on estimates of water infiltration rates:
Group A - Soils having a high infiltration rate (low runoff potential) when thoroughly wet. These consist mainly of deep, well drained to excessively drained sands or gravelly sands. These soils have a high rate of water transmission.
Group B - Soils having a moderate infiltration rate when thoroughly wet. These consist chiefly of moderately deep or deep, moderately well drained or well-drained soils that have moderately fine texture to moderately coarse texture. These soils have a moderate rate of water transmission.
Group C - Soils having a slow infiltration rate when thoroughly wet. These consist chiefly of soils having a layer that impedes the downward movement of water or soils of moderately fine texture or fine texture. These soils have a slow rate of water transmission.
Group D - Soils having a very slow infiltration rate (high runoff potential) when thoroughly wet. These consist chiefly of clays that have a high shrink-swell potential, soils that have a high water table, soils that have a clay pan or clay layer at or near the surface, and soils that are shallow over nearly impervious material. These soils have a very slow rate of water transmission.

Soils in Group C may not have the permeability to provide for adequate salt leaching due to the fine texture of a soil layer. Those in group D are similarly affected but also may require tile drains or open ditches to keep the water table below the root zone and to maintain a leaching gradient.

An important soil property in determining if a particular leaching fraction can be achieved is soil hydraulic conductivity, a measure of its ability to transmit water. In the absence of precise measurements, soils may be placed into relative hydraulic conductivity or permeability classes through studies of structure, texture, porosity, cracking, and other characteristics of the horizons in the soil profile in relation to local experience. The Soil Conservation Service grouped soil series into five permeability classes based on the percolation rate of the least permeable horizon in the profile. They are as follows:

Permeability Class	Permeability (in/hr)
Slow	< 0.2
Moderately Slow	0.2 to 0.6
Moderate	0.6 to 2.0
Moderately Rapid	2.0 to 6.0
Rapid	> 6.0

Growers can use the Napa County Soil Survey to identify the soil types present in their vineyards. Sites with soils in hydrologic groups C and D, and/or soils with slow to moderately slow permeability may need to be monitored periodically with soil tests to ensure that adequate leaching is taking place. Given the high rainfall in this region, and our use of a conservative 10% leaching fraction in the calculations above, we do not anticipate limited leaching to be a significant factor when using NSD recycled water.

Calcium:Magnesium ratios

Some soils in Napa County and other parts of the north coast of California are derived from serpentine parent materials, leading to high magnesium concentrations (in relationship to calcium) that can reduce plant growth. A review of research studies indicates that plant growth reductions may occur when there is twice as much magnesium (Mg) in the soil as compared to calcium (Ca). Levels of Ca and Mg in soil are usually expressed as a percentage of the cation exchange capacity, or on a concentration basis from a saturated paste extract. When comparing concentrations, the levels should be expressed in milliequivalents per liter (meq/L).

The relationship between calcium and magnesium is often expressed as a Ca:Mg ratio. When magnesium is present at 3-4 times the concentration of calcium (i.e., Ca:Mg ratios of 0.33:1 to 0.25:1), plants, including grapes, often exhibit reduced growth and yield, and have low potassium concentrations in the leaves and petioles. High rates of fertilizer potassium are necessary to increase the potassium concentration in the plants. Calcium concentrations may also be lower than desired for normal growth and development. These effects on plant growth often begin to occur when the level of magnesium in soil is twice that of calcium (Ca:Mg ratio 0.5:1).

Adding calcium to serpentine soils (normally in the form of gypsum) can increase the calcium concentration and alter the Ca:Mg ratio. If the Ca:Mg ratio of the soil immediately around the grape roots is altered to a 1:1 or even higher calcium concentration, plant growth will improve and potassium concentrations in the grapes will increase without the addition of potassium fertilizers. Likewise, calcium concentrations in the plant and water infiltration into the soil may increase following applications of gypsum. Table 9 indicates what action may be necessary depending on the Ca:Mg ratio in soils being used for grape or other crop production.

Table 9. Potential impacts of various soil Ca:Mg ratios on plant growth.

Ca:Mg ratio	Plant growth condition	Action necessary
8:1 or higher Ca	Magnesium deficiency may occur	Apply magnesium
8:1 – 0.5:1	Normal range	No action necessary
0.5:1 or higher Mg	Excess magnesium may retard plant growth and restrict potassium and calcium uptake	Apply gypsum in localized area near plant roots

The Ca:Mg ratio of irrigation water is similarly important because over time, soil characteristics may be changed to reflect the characteristics of the water. If large amounts of irrigation water are applied to soils relative to the amount of rainfall, the soil characteristics will eventually take on the irrigation water characteristics.

Table 10 shows the average calcium and magnesium levels from Tables 1, 2 and 3 for the NSD recycled water and the existing water sources in Carneros and the MST region, and shows the Ca:Mg ratios derived from these values.

Table 10. Ca:Mg ratios of NSD recycled water and existing water sources in Carneros and the MST region.

		NSD	MST		Carneros		
Nutrient	Units	Season ave.	3 wells	2 Surface	3 wells	Surface	Domestic
Calcium	meq/L	1.6	1.5	1.7	1.1	1.4	0.8
Magnesium	meq/L	2.0	1.2	1.3	1.1	1.1	1.2
Ca:Mg ratio		0.8:1	1.25:1	1.31:1	1:1	1.27:1	0.67:1

The MST and Carneros well and surface waters all had calcium concentrations equal to or higher than magnesium concentrations. The NSD recycled water and the Carneros domestic water had calcium concentrations slightly less than that of magnesium, but were not at levels to raise concerns about long term effects on soils.

When irrigation waters have twice as much (or more) magnesium as compared to calcium, then gypsum additions should be made to increase calcium levels in order to keep the soil ratios in balance. The calcium and magnesium levels in the NSD recycled water do not indicate the need for gypsum additions in conjunction with the use of this water. In addition, the high rainfall of this region in relation to the amount of irrigation water applied, make changes to the soil Ca:Mg ratios unlikely to be of significance.

Trace Elements

Tests for trace elements, including heavy metals, were conducted on NSD recycled water samples per their permit requirements. Depending on the element, tests were conducted once a month from May-October, or once in May and once in October. The results of these tests are shown in Table 11, along with recommended maximum levels for irrigation water (3).

Table 11. 2005 trace elements analyses of NSD recycled water.

Trace Elements	Concentration (ug/L)							Rec'd Max. Level (ug/L)*
	May	Jun	Jul	Aug	Sep	Oct	Average	
Al - aluminum	170					190	180	5000
Ag - silver	<0.1	<0.1	<0.1	<3.0	<0.1	<0.1	<0.58	NL**
As - arsenic	<0.5	<0.5	0.6	<10.0	0.79	<0.5	<2.15	100
Ba - barium	9.6					7.6	8.6	NL
Be - beryllium	<0.1					<0.1	<0.1	100
Cd - cadmium	<0.1	<0.1	<0.1	<1.0	<0.1	<0.1	<0.25	10
CN - cyanide	<3.0	<3.0	<3.0		<3.0	<3.0	<3.0	NL
Co - cobalt	<0.5					0.5	<0.5	50
Cr - chromium	0.7	0.6	<0.5	<5.0	0.8	0.5	<1.35	100
Cu - copper	4.4	4.7	4.7	<10.0	5.8	2.5	<5.35	200
F - fluoride	<110	<110	<110	<110	<180	<130	<130	1000
Hg - mercury	0.05	<0.01	<0.01	<0.2	<0.05	<0.01	<0.13	NL
Li - lithium	12.0					10.0	11.0	2500
Mn - manganese	0.1					93.0	46.6	200
Mo - molybdenum	1.4	1.6	1.9	<5.0	1.1	0.98	<2.0	10
Ni - nickel	4.4	4.6	3.9	<5.0	4.0	4.4	4.38	200
Pb - lead	<0.25	<0.25	<0.25	<5.0	<0.25	<0.25	<1.04	5000
Se - selenium	<1.0	<1.0	<1.0	<10.0	<1.0	<1.0	<2.5	20
Sn - tin	<1.0					<1.0	<1.0	NL
Sr - strontium	210					240	225	NL
Ti - titanium	6.9					3.1	5.0	NL
V - vanadium	<2.0					<2.0	<2.0	100
W - tungsten	<0.5					<0.5	<0.5	NL
Zn - zinc	24.0		11.0	<20.0	12.0	11.0	<15.6	2000

* Recommended maximum concentrations of trace elements in irrigation water, Table 21 in (3).
** NL = not listed

Levels of trace elements in NSD recycled water were all well below established thresholds of concern for irrigation water.

Irrigating Wine Grapes

Irrigation amounts and frequency vary considerably from vineyard to vineyard. Important factors include soil type and depth, climate, vineyard spacing, variety, rootstock and farming philosophies of growers and winemakers. Water is essential for grapevine growth, but too much water can stimulate excessive growth which is detrimental to ultimate wine quality.

Vines are usually irrigated beginning in May or June (the start date depends upon spring rainfall patterns) and continues though harvest in September or October. Many vineyards receive a final irrigation after harvest if the leaves are still functioning.

As a rule of thumb, many vineyards in Napa County receive about 100 gallons per vine of applied water during the entire season, consisting of several irrigation runs of 6-10 gallons per vine. With typical vineyard spacings used in Carneros and the MST region, this translates to 0.3-0.5 acre-feet per season of applied water per acre of vineyard (Table 12). Table 13 compares two vine spacings at a normal irrigation rate of 100 gallons per vine and a high irrigation rate of 125 gallons per vine. The annual application volumes are still in the range of 0.3-0.5 acre-feet per season.

Irrigation scheduling is an important consideration in vineyard management. Applying too much water can be deleterious to wine quality and adds to the expense of running the vineyard. Not applying enough water will stress vines more than what is considered optimal. Viticulturists use many tools to ensure that vines receive adequate irrigation without applying excess water. Soil moisture sensors and leaf water sensors can be used to help decide when to irrigate a vineyard. Careful visual observations of vine growth and soil moisture assessment with a shovel are also important.

Table 12. Annual irrigation volumes per acre at various vine spacings, assuming applications of 100 gallons per vine per season.

Spacing (feet)	Vines/acre	Gallons/vine/year	Gallons/acre/year	Acre-feet*/acre/year
8 x 10	545	100	54,500	0.17
6 x 10	726	100	72,600	0.22
6 x 8	908	100	90,800	0.28
5 x 7	1245	100	124,500	0.38
4 x 6	1815	100	181,500	0.56

* One acre-foot of water is 325,850 gallons.

Table 13. Annual irrigation volumes per acre at various vine spacings and application rates.

Spacing (feet)	Vines/acre	Gallons/vine/year	Gallons/acre/year	Acre-feet*/acre/year
6 x 8	908	100	90,800	0.28
6 x 8	908	125	113,500	0.35
5 x 7	1245	100	124,500	0.38
5 x 7	1245	125	155,625	0.48

* One acre-foot of water is 325,850 gallons.

Fertilizer Value of NSD Recycled Water

NSD recycled water contains the plant nutrients nitrogen, phosphorus and potassium in concentrations that make it a dilute fertilizer solution. The amount of plant nutrients delivered to grapevines will depend upon their concentrations in the recycled water and the amount of water applied.

Seasonal averages of NSD recycled water (Table 1) indicate a nitrogen content of approximately 13.1 mg/L of nitrogen (mostly as nitrate-nitrogen), 0.9 mg/L of phosphorus, and 18.8 mg/L of potassium. The averages of the well and surface waters from all sites (Tables 2 and 3) were 1.4 mg/L of nitrogen, 0.3 mg/L phosphorus, and 7.4 mg/L potassium.

Table 14 indicates the amount of nutrients in pounds per acre that would be applied to vineyards using average NSD recycled water, MST well or surface water and Carneros well, surface or domestic water at various application rates. At typical irrigation rates of 0.4 to 0.6 acre-feet per acre, the exclusive use of NSD recycled water would deliver approximately 14-21 pounds of nitrogen, 1-1.5 pounds of phosphorus (2.2-3.4 lbs P_2O_5) and 21-31 pounds of potassium (25-37 lbs K_2O) per acre per season. Fertilizer rates for phosphorus and potassium are normally expressed as P_2O_5 and K_2O, respectively.

The phosphorus and potassium in the NSD water would have no detrimental effects on the vines. In fact, the vines may benefit from application of these nutrients. Nitrogen is required for proper growth and development of grapevines, but high levels of nitrogen can create problems due to excess growth and vigor. High vigor vineyards which produce large amounts of leaf growth result in shaded fruit. This can lead to reduced yields and lowered wine quality. Fruit produced under shaded conditions is likely to be higher in pH, lower in sugar and color, and may have herbaceous characteristics that are undesirable. In addition, high vigor vineyards often have a greater incidence of Botrytis bunch rot and powdery mildew diseases.

Table 14. Amount of nutrients in pounds per acre that would be applied to vineyards by using average NSD recycled water, MST well or surface water and Carneros well, surface or domestic water at various application rates. Values shown are based on data in Tables 1, 2 and 3.*

Nutrient	Applied Water (acre feet)	Pounds per Acre of Nutrients in Applied Water					
		NSD	MST		Carneros		
		Recycled	Wells	Surface	Wells	Surface	Domestic
Nitrogen (as N)	1.0	35.6	1.6	4.1	6.8	6.3	1.1
	0.8	28.5	1.3	3.3	5.4	5.0	0.9
	0.6	21.4	1.0	2.4	4.1	3.8	0.7
	0.4	14.3	0.7	1.6	2.7	2.5	0.4
Phosphorus (as P)	1.0	2.4	0.5	0.8	1.6	1.1	0.5
	0.8	2.0	0.4	0.7	1.3	0.9	0.4
	0.6	1.5	0.3	0.5	1.0	0.7	0.3
	0.4	1.0	0.2	0.3	0.7	0.4	0.2
Phosphorus (as P_2O_5)	1.0	5.6	1.2	1.9	3.7	2.5	1.2
	0.8	4.5	1.0	1.5	3.0	2.0	1.0
	0.6	3.4	0.7	1.1	2.2	1.5	0.7
	0.4	2.2	0.5	0.7	1.5	1.0	0.5
Potassium (as K)	1.0	51.1	16.9	20.4	23.1	19.6	7.3
	0.8	40.9	13.5	16.3	18.5	15.7	5.9
	0.6	30.7	10.1	12.2	13.9	11.8	4.4
	0.4	20.5	6.7	8.2	9.2	7.8	2.9
Potassium (as K_2O)	1.0	61.4	20.2	24.5	27.7	23.5	8.8
	0.8	49.1	16.2	19.6	22.2	18.8	7.1
	0.6	36.8	12.1	14.7	16.6	14.1	5.3
	0.4	24.5	8.1	9.8	11.1	9.4	3.5

*Average NSD recycled water contains 13.1 mg/L N, 0.9 mg/L P, and 18.8 mg/L K.

Table 15 shows amounts of the major plant nutrients (in pounds) that are present in a ton of grapes. Assuming a typical yield of 3-5 tons per acre, there are about 9-15 pounds of nitrogen removed from the vineyard each year with the harvested crop. By comparison, the amount of nitrogen potentially delivered to vineyards annually using NSD recycled water is not exceptionally high (14-21 pounds per acre), but it may be enough to be of concern to some growers and winemakers, especially on sites that are already fairly vigorous. Many vineyards in Carneros and the MST region are currently fertilized with nitrogen at rates approaching or exceeding these levels, but others are not, or they may not be fertilized with nitrogen every year. There are some vineyards that rarely (if ever) receive nitrogen additions.

Table 15. Amount of nutrients in one ton of grapes.*

Nutrient	Pounds per ton of fruit		
	Average	High	Low
N	2.92	4.12	1.80
P	.56	0.78	0.44
K	4.94	7.38	3.18
Ca	1.0	1.86	0.54
Mg	0.2	0.32	0.10

* Data from literature as compiled by Larry Williams, Dept. of Viticulture and Enology, UC Davis.

Where there are concerns about the additional nitrogen that would be applied in conjunction with the use of NSD recycled water, growers should consider the use of cover crops to help mitigate the potential effects on excess vigor. Cover crops can compete with the vines and help to control their growth. The choice of cover crop species is important in this regard. Legume cover crops fix atmospheric nitrogen which will increase the supply of nitrogen to the vines. Cereals and other grasses do not fix nitrogen. They compete with the vines for water, nitrogen and other nutrients. Growers concerned about nitrogen in the NSD recycled water should plant grass cover crops and avoid the use of legumes.

Another mitigation measure for growers concerned about nitrogen in the NSD recycled water is to have a secondary source of water available for irrigation. This water could be blended with the NSD water, or used alternatively, in order to control the amount of nitrogen applied to the vineyard during the course of the season. A secondary source of water may also be desired for use in spray tanks later in the season once fruit is present on the vines.

Drip System Maintenance Issues

Clogging of drip emitters is a significant maintenance issue with drip irrigation. Clogging of emitter flow passages may be caused by chemical precipitates formed from water constituents such as calcium, bicarbonate, and iron.

Calcium ions can combine with bicarbonate ions to form precipitates of calcium carbonate (lime). Waters with a pH greater than 7.0 and levels of bicarbonate exceeding 2 meq/L have the potential to cause lime precipitate clogging problems. An equivalent level of calcium must be present for this precipitation to occur. The calcium can be naturally present in the water or it may be added to the drip system when products such as gypsum or calcium-containing fertilizers are injected into the irrigation water. Acidifying the water to lower the pH to below 7.0 will prevent calcium carbonate precipitation and re-dissolve any calcium carbonate already precipitated.

Iron levels exceeding 0.5 to 1.0 mg/L can result in iron precipitates that can clog drip emitters. Iron precipitation is a more difficult problem since the water pH must be less than 4.0 to prevent iron precipitates from forming. Lowering irrigation water pH to below 4.0 is impractical in most instances. Precipitated iron is also extremely difficult to re-dissolve making drip system remediation from iron clogging challenging.

Evaluation of NSD Recycled Water for Drip Irrigation Clogging

Average levels of bicarbonate and calcium in NSD recycled water are 2.1 meq/L and 1.6 meq/L respectively. The NSD recycled water pH is 7.5 and the iron concentration is 0.1 mg/L. These levels indicate little risk of iron precipitate clogging, and a low risk of calcium carbonate clogging (Table 16). The bicarbonate level is relatively low as is the calcium in the NSD water (1.6 meq/L). If a calcium source (gypsum or calcium-containing fertilizer) were added to the irrigation water, the calcium carbonate precipitate clogging risk would be slightly increased but would still be low.

In comparison, the average bicarbonate level of three wells monitored in the MST region was 2.8 meq/L, and the average of three wells monitored in the Carneros region was 4.8 meq/L (Table 17). The NSD recycled water, therefore, has a lower calcium carbonate precipitate clogging risk than those wells monitored in the MST or Carneros regions.

Table 16. Water characteristics important in drip irrigation chemical precipitate clogging, and NSD recycled water levels.

Water Characteristic	Initial Level of Concern	NSD Recycled Water Season Average	Risk of Clogging
Bicarbonate (meq/L)	2 meq/L or greater	2.1 meq/L	Low
Iron (mg/L)	1 mg/L or greater	0.1 mg/L	Very low
pH	7.0 or greater	7.5	Low

Table 17. Comparison of selected water characteristics important in chemical precipitate clogging of drip irrigation systems. Values shown are for NSD recycled water, 3 irrigation wells monitored in the MST region, and 3 irrigation wells monitored in the Carneros region.

Water Characteristic	NSD Recycled Water Season Average	MST wells (3)	Carneros wells (3)
Bicarbonate (meq/L)	2.1	2.8	4.8
Iron (mg/L)	0.1	0.7	0.1
pH	7.5	7.6	7.7

The chemical precipitate clogging risk associated with the NSD recycled water is low, and is less than that of irrigation wells monitored in the MST and Carneros regions, which, on average, had higher levels of bicarbonate and slightly higher pH.

The use of NSD recycled water for drip irrigation would pose a very low risk of iron precipitate clogging and a low risk of calcium carbonate precipitate clogging.

Organic Grapevine Production with Recycled Water

The National Organic Program (NOP) includes the Federal regulations that establish national standards for agricultural products labeled as organic. These standards are known as the National Organic Standards. Congress authorized the USDA to establish the NOP in the Organic Food Production Act of 1990. Organic producers in the United States must now be certified according to the NOP Rule. Growers develop production and handling practices with one of a number of certifiers, such as the California Certified Organic Farmers (CCOF), to qualify their produce as meeting the USDA requirements. Individual certifiers are prohibited from making additional requirements to the USDA standards in the NOP.

The use of recycled water for vineyard irrigation is not restricted in the NOP. Therefore, organic grape growers are free to use this water in organically certified vineyards, as long as it is agriculturally suitable for the intended use.

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