Feasibility of Water Reuse in Solano County

by

Dakari Barksdale

BioResource and Agricultural Engineering

BioResource and Agricultural Engineering Department

California Polytechnic State University

San Luis Obispo

2014

Title	**:**	**Feasibility of Water Reuse in Solano County**
Author	**:**	**Dakari Barksdale**
Date Submitted	**:**	**June 6, 2014**

Stuart Styles

Senior Project Advisor **Signature**

7/6/14

Date

Art MacCarley

Department Head **Signature**

7/7/14

Date

ACKNOWLEDGEMENTS

I would like to first thank my family and friends who have given me their unrelenting support. I would not have been able to do this without their kind words and editorial skills.

Dr. Stuart Styles has also been a great help to me. He was always willing to give me more resources and put me in contact with experienced people.

Lastly, I would like to thank Felix Riesenberg, the engineers from West Yost, and all the utility directors that have helped me with data acquisition.

ABSTRACT

As a result of the increasing population and decreasing availability of fresh uncontaminated water, new water sources are needed. Surface water, groundwater, desalination, graywater and recycled water are all important water sources. Each one has unique advantages and disadvantages.

This senior project analyzes the feasibility of recycled water in Solano County. In order to better analyze the feasibility of recycled water, current water sources and desalination were examined. The price, availability, and environmental impact of each source were compared in this project. Information was gathered through field visits, phone calls, emails, presentations, conferences, personal interviews, classes, and internet research.

The results of this study indicate that recycled water is feasible in Solano County. Some cities are using or plan to use recycled water. On average the results show that the recycled water is cheaper than potable water by up to 58 percent. The initial cost of constructing pipelines for recycled water may be expensive, but in large droughts where fires run rampant and some water agencies are literally paying billions of dollars for desalination, this cost is negligible. In some areas implementation of recycled water would mean beneficially using the water rather than discharging it into the ocean.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF EQUATIONS

INTRODUCTION

Available Freshwater Water Sources

The earth is comprised mainly of water, but 97 percent of it is salt water (Anderson, 2003). Of the small percentage of fresh water, much of it is frozen in icebergs. About 1 percent of all the water on earth is fresh water in liquid form. It would be very nice to be able to use the salt water and implement it into municipal water, but desalination, the process of removing salt from water, is extremely expensive. So, humans are only able to easily use 1 percent of all the water on earth. One source of water that can be better utilized is recycled water.

Wastewater already has to be filtered in order to be dumped into rivers and oceans, so new pipelines could be added to transfer treated wastewater to urban, industrial or agriculture areas for reuse. Recycled water would increase the water availability in areas where the wastewater is discharged to the ocean. Water is already being indirectly reused in areas where treated wastewater is discharged into fresh water lakes or allowed into the ground.

The world population, including the population of Solano County, is on the rise. The population increase for Solano County can be seen in Figure 1. With this rise in people, comes a rise in water usage. This means more water must be pumped from the fresh water sources, such as Lake Oroville and Lake Beryessa. Excess pumping of the water in these areas is detrimental to marine life and in turn ails humans as well. Excess water withdrawal from the delta is not just a big concern for the Delta Smelt, a fish native to the Delta; it is a large concern for everyone since, "the Delta is the state's major water hub, supplying 25 million urban residents, approximately two million acres of farmland, and a unique ecosystem with more than 750 species of flora and fauna", (Madani and Lund, 2012).

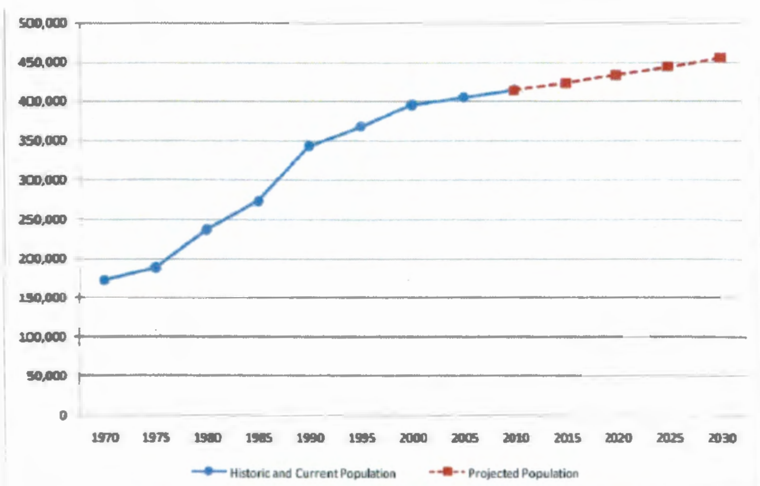

Figure 1 Population of Solano County (SCWA, 2010)

The current lack of precipitation and water usage has left many lakes and rivers dry. Cities in Solano County receive water from the Solano County Water Project and the State Water Project. The reservoir that services Solano County is the Lake Oroville reservoir; this lake as of February 19, 2014, was at 57 percent of its historical average (California Department of Water Resources, 2014). Figure 2 shows the current water level in solid blue, as compared to wet/dry years and the historical average year. The driest year in recorded California history was 1977 (calwatercrisis.org, 2007). The water level in 1977 is shown in Figure 2 as the red line; the Lake Oroville water level was below the water level of the driest year in recorded history. The water level then rose due to rain events, but it is still far below the average level. A picture of Lake Oroville can be seen in Figure 3. This is the worst drought in California history (Kostigen, 2014). Figure 4 on the following page shows the Alamaden Reservoir, which is located near San Jose. Water is not only pumped from rivers and lakes; some districts also utilize groundwater.

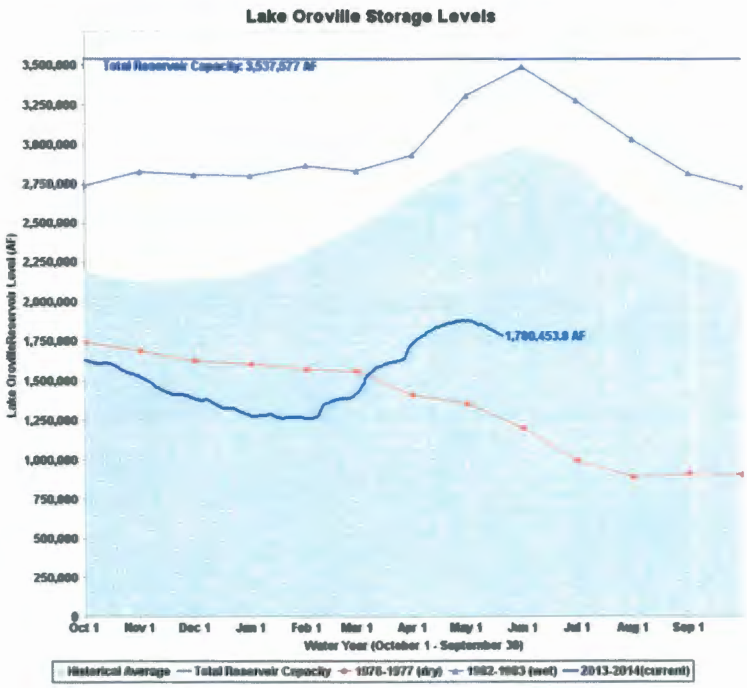

Figure 2 Lake Oroville Water Storage Levels (DWR, 2014)


Figure 3 Lake Oroville (ChicoER.com, 2014)

Figure 4 Alamaden Reservoir (Kostigen, 2014)

Surface waters, such as lakes and rivers, only comprise 2 percent of the available freshwater; while, groundwater comprises the other 98 percent of freshwater. Excess pumping from groundwater wells is detrimental as well. Pumping water from the ground at a rate faster than it can be replenished causes issues such as seawater intrusion and land subsidence. Seawater intrusion occurs when the elevation of seawater is greater than that of the groundwater. As water is pumped from groundwater wells, the elevation decreases which causes seawater to intrude into the aquifer. The Water Replenishment District of Southern California works to prevent seawater intrusion. Figure 5 shows their depiction of increased seawater intrusion due to groundwater pumping. If seawater intrusion is not managed, groundwater wells would pump salt water instead of freshwater. This has happened in some areas such as Monterey County where "historical pumping has lowered groundwater levels … which caused extensive seawater intrusion" (Monterey County Water Resources Agency, 2013).

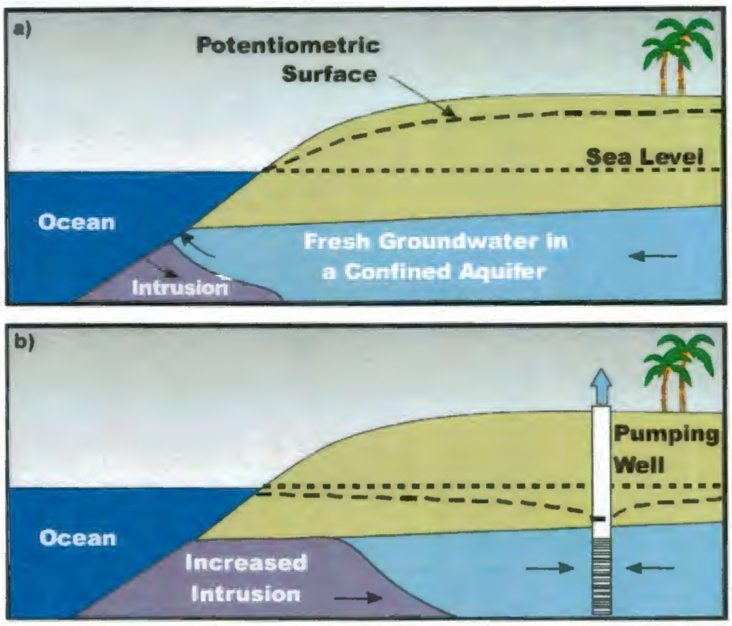

Figure 5 a) Seawater Intrusion with No Pumping b) Seawater Intrusion with Pumping (Water Replenishment District of Southern California, 2007)

Seawater intrusion can be inhibited by keeping the ground water level above the sea level; this can be done with recycled water by means of injection wells and infiltration ponds. Salt water can be found in aquifers at a depth 40 times the height of the fresh water above the sea level (Monterey County Water Resources Agency, 2013). This relation, known as the Ghyben-Herzberg relation, is due to the densities of fresh and salt water; it can be better seen in Figure 6.

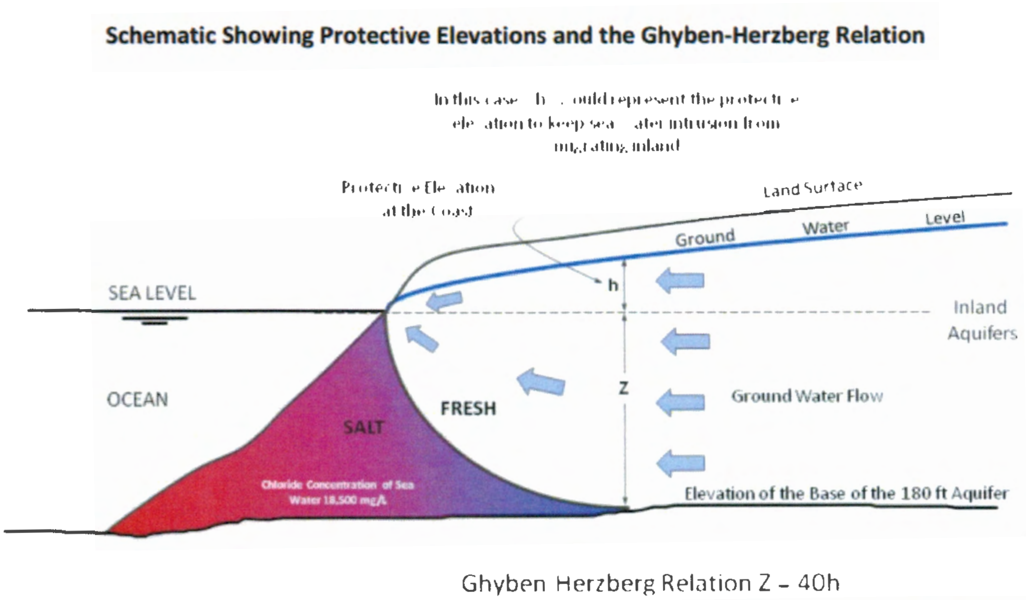

Figure 6 Seawater Intrusion Based on Ground Water Level (Monterey County Water Resources Agency, 2013)

Pumping groundwater at a higher rate than it can be recharged can cause the seawater to intrude the aquifers. If there is no seawater to intrude and fill the voids in the soil, the voids can collapse on themselves. This compacting of soil is called land subsidence. Subsidence affects over 17,000 square miles of land in America (U.S. Geological Survey, 2013). Excessive groundwater pumping has caused over 80 percent of land subsidence in America (U.S. Geological Survey, 2013). In 1977, Dr. Joseph Poland identified a portion of the San Joaquin Valley as the maximum subsidence location in America. Figure 7 depicts Dr. Poland next to a pole that shows the elevations of the land in 1977, 1955 and 1925; over 52 years the elevation decreased nine meters (29.5 feet). From this picture it is evident how land subsidence could be an issue.

Figure 7 Land Subsidence in San Joaquin Valley (USGS, 2013)

Water Shortages and the Effects

Large water shortages decrease the yield of crops, as seen in Figure 8 on the following page. To an extent, more water will produce more food; too much water can decrease yield. The increase in food supply will decrease cost. Water shortages force growers to cut back on water usage. Each year, growers are allocated a specific amount of water; in dry years, they are not allotted very much water. In order to grow crops they have to either stress their plants and possibly decrease their yield or pay more money to produce more crops with less water. When the growers suffer everyone suffers. The increase in cost for the growers creates an increase in cost for our food. California is the top agricultural producer in America producing $44.7 billion per year (Campbell and Durisin, 2014). Due to the lack of water up to 500,000 acres of California land will go unplanted; this reduces last year's principal crops by 12 percent (Campbell and Durisin, 2014). This hurts the California economy, the farmers and the consumers, who will have fewer choices and higher costs for food.

Water shortage does not only increase the cost of water for agriculture, but it also increases the cost of urban water. Increased water bills affect everyone in times of serious drought. In extreme droughts, extra water regulations are put in place so that water is not wasted. In past years, water regulations have been used in various parts of California to prevent people from watering their lawns and washing their cars.

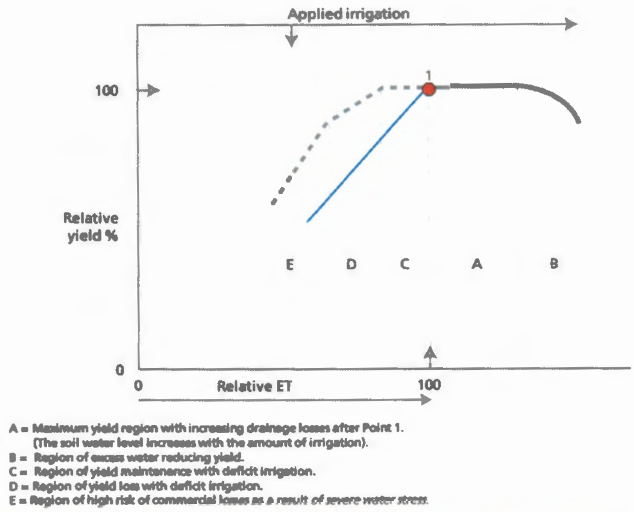

Figure 8 Yield vs Applied Water: dotted line is for fruit and nut trees and the solid line is for annual field crops (Fereres et al, 2011)

<u>Water usage of Solano County</u>

As seen in Figure 9 on the following page Solano County is located in Northern California between San Francisco and Sacramento. The county is comprised of 7 cities, Benicia, Vallejo, Suisun City, Dixon, Vacaville, Rio Visa, and Fairfield. In 2012, the county had an approximate population of 414,000 people (Solano County, 2012). The county produced about $292 million in agricultural revenue in 2011 (Solano County, 2012). The Solano County Water Agency (SCWA) provided 195,361 Acre Feet per Year (AFY) of water in 2010. These numbers are projected to increase to 217,700 AFY by 2020 (SCWA, 2010). This does not include all the water usage in Solano County it is only the water delivered by the State Water Project and the Solano Water Project. Customers can also use ground water or purchase water from other districts. There is also the unaccounted for 13,960 AFY of water lost during delivery (SCWA, 2010). Even in a normal year the Solano Project does not have enough water to meet demands of the county. The supply is slightly over 2000 AFY short of the demand in a normal year, and in a single dry year the demand exceeds the supply by 4,147 AFY. During a multidry (3 or more consecutive dry years) year period the demand exceeds the supply by 19,172 AFY (SCWA, 2010). This can all be seen in Tables 1, 2, and 3. The State Water Project (SWP) at most supplies Solano County with under 48,000 AFY, but even in a normal year the SWP typically only supplies Solano County with under 31,000 AFY, which is 64 percent allocation. During multiple dry years only 33 percent is allocated; on January 31, 2014, it was announced that the SWP allocation would be reduced to nothing (California Department of Water Resources, 2014). This was later raised to 5 percent. It is imperative that water is conserved and potentially reused to not only aid farmers and urban consumers, but to protect fish and for natural disasters such as fire. The drought allows for increased wildfires and makes it harder to contain them. In Big Sur on December 15, 2013, a seven day fire burned many homes forcing 100 people to evacuate while the fire scorched over 900 acres (Rice and Marquis, 2013).

Figure 9 Map of Solano County (Solano County, 2012)

Table 1 Solano Project Allocation in Normal Year (SCWA, 2010)

	2010	2015	2020	2025	2030
Supply Totals	205,277	205,277	205,277	205,277	205,277
Demand Totals	207,350	207,350	207,350	207,350	207,350
Difference (supply minus demand)	-2,073	-2,073	-2,073	-2,073	-2,073
Difference as % of Supply	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%
Difference as % of Demand	-1.0%	-1.0%	-1.0%	-1.0%	-1.0%

1 Assumes normal year supply is 99% of Solano Project contract amount.
2. Assumes demand is equal to contract amounts.

Table 2 Solano Project Allocation in Dry Year (SCWA, 2010)

	2010	2015	2020	2025	2030
Supply Totals	203,203	203,203	203,203	203,203	203,203
Demand Totals	207,350	207,350	207,350	207,350	207,350
Difference (supply minus demand)	-4,147	-4,147	-4,147	-4,147	-4,147
Difference as % of Supply	-2.0%	-2.0%	-2.0%	-2.0%	-2.0%
Difference as % of Demand	-2.0%	-2.0%	-2.0%	-2.0%	-2.0%

1. Assumes single dry year supply is 98% of Solano Project contract amount.
2. Projected normal is 99% of contract amount.
3. Assumes demand is equal to contract amounts.

Table 3 Solano Project Allocation in Muli-Dry Year Period (SCWA, 2010)

	2015	2016	2017	2018	2019
Supply totals	184,542	184,542	184,542	184,542	184,542
Demand totals	207,350	207,350	207,350	207,350	207,350
Difference (supply minus demand)	-19,172	-19,172	-19,172	-19,172	-19,172
Difference as % of Supply	10.0%	10.0%	10.0%	10.0%	10.0%
Difference as % of Demand	9.0%	9.0%	9.0%	9.0%	9.0%

1. Assumes single dry year supply is 89% of Solano Project contract amount
2. Assumes demand is equal to contract amounts.

LITERATURE REVIEW

Water Conservation

Many people think that adding new "water saving" appliances will fix the water crisis. They can definitely save water in most cases, but for some households it will not save any water and for a few houses it will actually use more water. This is due to the fact that people know their appliance saves water, so think they can flush the toilet more often or shower for longer. "When people know they are using a water-conserving appliance, they may use the appliance longer or more frequently", (Suero, Mayer, and Rosenberg, 2012). Figure 10 shows most of the households in Oakland, Seattle and Tampa saving water, up to 825,000 liters per household each year. The households that saved more water often had more people which increased their likelihood to save more water. The most occurring amount of water saved was 75,000 liters (19810 gallons). The California Building Industry Association (CBIA) states that a three bedroom single family home with four occupants uses 174,000 gallons of water per year (CBIA, 2010). Saving 19810 gallons each year would reduce the typical water use by less than 12 percent. According to a graph created by the University of California San Diego, based on Department of Water Resource data, 20 percent of California's water use is urban water use. Saving 12 percent of the 20 percent of water use would result in saving 2.4 percent of the total water use in California; urban water conservation is extremely important, but it cannot be the only solution.

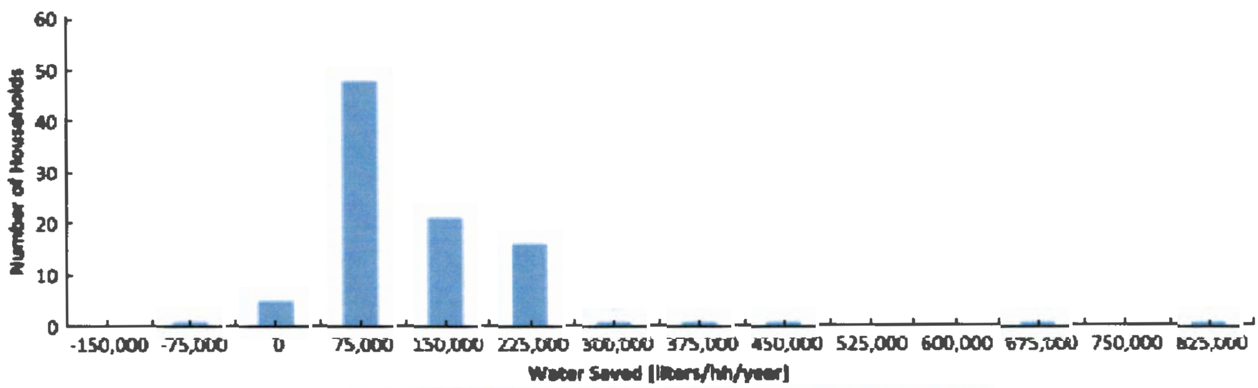

Figure 10 Water Saved per Household per Year (Suero, Mayer, and Rosenberg, 2012)

State Water Project

Many Northern California water districts have plenty of water. These districts, at times, have an excess of water and experience more difficulties with floods than droughts. This is partially due to the fact that 75 percent of California's rainfall falls north of Sacramento (CalWaterCrisis.org, 2007). The northern part of the state receives the majority of the rain and this is well known to the general public. It is also generally

known that the enormous population in Southern California requires most of the water. The people residing south of Sacramento account for 75 percent of the demand of California water (CalWaterCrisis.org). Due to disproportionate rainfall and water demand in the southern and northern parts of the state, the State Water Project (SWP) was created. This project is majorly responsible for the existence of 25 million people and 750 thousand acres of irrigated farmland (California Department of Water Resources, 2010). Although it is very true that water districts in Northern California would suffer very little from drought, we are not divided. We live in one state, one country and one world. Excess in Northern California should not be abused and misused; it should be delivered to those in need. Water is currently recycled in large quantities in Southern California because they suffer greatly from drought. If water is recycled in Northern California then more "clean water" can be delivered to Southern California. Many residents of Northern California may dislike this idea and blame the actors and celebrities residing in the deserts known as Los Angeles and San Diego, but Northern California residents can benefit from this as well, since Southern California residents are willing to pay extremely high costs for water.

The State Water Project has the rights to all the water that originates from the Sacramento and San Joaquin Rivers (SCWA, 2008). Although this water is close to Solano County and is stored in Lake Oroville, the lake Solano County receives water from, this water does not belong to Solano County. The State Water Project provides water mainly for Southern California, so it is not a dependable source for eliminating the water deficit in Solano County. The project is however being paid off by project beneficiaries, not the general taxpayer, so Northern California residents do not have as much to complain about. The State Water Project is extremely beneficial, but it is not perfect. So far this year it is unable to allocate water to its beneficiaries. Other means of increasing the water supply are needed.

Desalination

One solution to the drought is to simply increase the available water. This planet is covered mostly with water, although 97 percent of it is salt water, we do have the ability of removing the salt and obtaining the freshwater. The process of removing salt from water is called desalination. Desalination is performed in two methods distillation and reverse osmosis. Distillation is performed by changing water from the liquid phase to the gas phase; the steam is removed from the liquid water that contains impurities such as salt (Collentro, 2011). An example of a vapor compression distillation unit can be seen in Figure 11 on the following page. In this figure it can be seen that the seawater is pumped over the compressed steam tubes that cause the seawater to convert from liquid to gas. The steam is collected at the top of the unit and is compressed and circulated through the tubes to evaporate more seawater. Some of the seawater that does not evaporate is re-circulated in order to produce greater yields from the seawater.

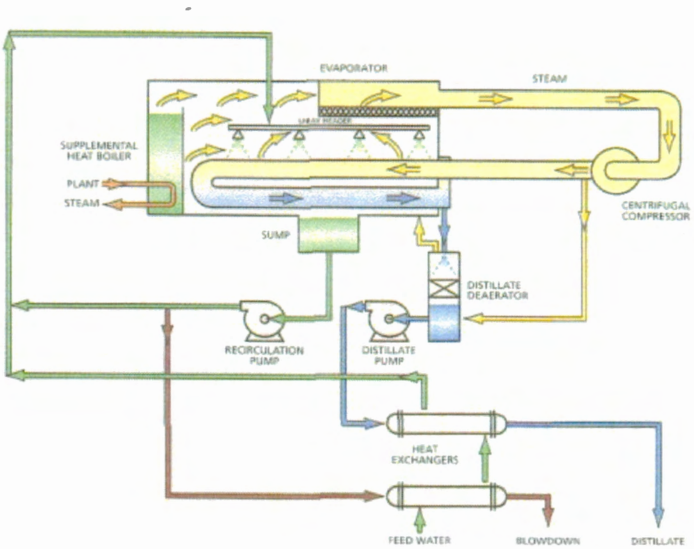

Figure 11 Distillation Process (Collentro, 2011)

Reverse osmosis, as the name states, is the reverse of osmosis. The flow of fresh water through a semi-permeable membrane, such as the root of a plant, is referred to as osmosis. Reverse osmosis occurs when a high pressure is applied to force brackish, or salty, water through a semi-permeable membrane. The membrane has holes large enough for water to pass through but small enough to keep most of the salt and impurities from also passing through. Figure 12 depicts a simplified example of reverse osmosis. Recovery rate for reverse osmosis desalination can be extremely low; the rates are dependent on the amount of salt in the water. Typical rates range between 25 percent and 50 percent. This equates to 2 to 4 gallons of seawater being used to make 1 gallon of freshwater. The wastewater from desalination is highly concentrated salt water, brine. The brine is often disposed of in the ocean, which can cause a degradation of the biological life in the ocean.

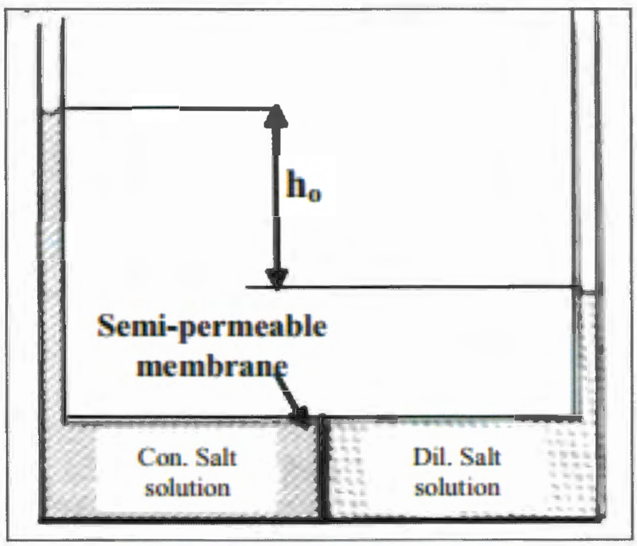

Figure 12 Reverse Osmosis (Rao, 2007)

Desalination plants are extremely expensive to build and maintain. Building a desalination plant in Long Beach will cost $250 million and the water would sell for $800 per AF (CaDroughtPrep.net, 2002). If Southern California residents are willing to pay this large sum of money to build a new plant, then it could be beneficial. It is highly feasible that the Southern California residents would pay more for the water that originates in Northern California. For each acre-foot, Long Beach residents pay $500 for imported water and $150 for groundwater (CaDroughtPrep.net, 2002). Groundwater and imported water supplies are exceeded by the demand, so Southern California cities are willing to pay extra money to supplement supplies. Northern California can supplement these supplies by recycling water and delivering more potable water to Southern California. This solution can be beneficial to both parties.

Solano Project

The Solano Project was created to compensate for the groundwater overdraft that occurred as a result of increased agriculture development and increased population. The Solano Project was created in 1959 to deliver water only to Solano County, since Yolo and Napa Counties did not want to be a part of the project (SCWA, 2008). The project was constructed for $38 million. The Monticello Dam is 304 feet tall, with a crest length of 1023 feet, and a capacity of 1.6 million AF. The Solano Project is a relatively reliable source, in comparison to the State Water Project, since it can still allocate 89 percent of contract amounts even in multi-dry year periods. However, this 89 percent allocation is still over 19,000 AF short of the 207,000 AF demand.

PROCEDURES

Water Price Survey. The water prices for the various cities were all found on the internet. Even within each city, prices varied greatly. The lower prices typically were for single family homes where very little water was used, and the higher prices were the water prices for industrial, commercial, or construction purposes. The costs that the water treatment plants pay to treat the water is not entirely dependent upon the amount they distribute, so the correlation between treatment costs and water rates is not direct, therefore the correlation between potable water and recycled water cannot be direct. By utilizing the highest and lowest water prices for each city a range of price comparisons was made. This range is more useful than an average, because the average price may not reflect the actual cost of treating and distributing drinking water. The amount of water used at each water rate category (example water rate categories are: Single Family Low Water Usage, Restaurant high usage) is very different, so an average cannot be used to determine water costs. If an average were to have been used, it would have to be weighted based on the amount of water used in each category. However, the amount of water used in each category cannot be easily found and is always changing due to droughts, floods and conservation.

Water Source. The drinking water sources were found via phone calls and from water quality reports. Drinking water sources are important, because the depletion of each type of water source has a different kind of impact and has different availabilities. Surface waters are less available during a drought, while groundwater may remain unaffected by a drought. Depleting surface waters detrimentally impacts marine life, while depleting groundwater leads to subsidence. Subsidence is the sinking of the earth's surface which can greatly degrade the integrity of the structures in the affected area. The effect of using groundwater or surface water is not easily quantified and was thus disregarded in this analysis. However, the survival of our environment is very important. It is often stated that the depletion of the Delta only harms the 3 inch long Delta Smelt. The depletion of the Delta not only harms the Delta Smelt, but all the wildlife that thrive in wetlands. "More than one-third of the United States' threatened and endangered species live only in wetlands" (EPA, 2012). Subsidence due to the depletion of groundwater is more easily quantified based upon the costs required to reconstruct the structures that have be deteriorated due to the sinking of the earth. In Figure 7, as previously stated, it can be seen that in 1925 the land was nine meters (29.5 ft) higher than it was in 1977.

WWTP Survey. The information needed for analyzing the cost of wastewater treatment was gleaned from site visits to the Vallejo and Vacaville treatment plants, phone calls to Rio Vista, Dixon, and Benicia treatment plants, and from an online brochure from the Fairfield-Suisun Sewer District. The pertinent information that was gathered includes the daily flow rate, treatment level, and discharge point.

The daily flow rate is important, for it shows how much water can be produced/reproduced to offset drinking water usage. The treatment level is very important because there are regulations regarding what water can be reused based on the

level that it has been treated. For example, tertiary treated water can be reused for food crops where the water contacts the edible portion, but secondary treated water cannot be reused for this. In figures 13 and 14 shown below one can see in detail all the uses for secondary and tertiary treated water.

RECYCLED WATER USES* ALLOWED IN CALIFORNIA

Recycled Water Use	Treatment Level: Disinfected Tertiary Recycled Water	Disinfected Secondary 2.2 Recycled Water	Disinfected Secondary 23 Recycled Water	Undisinfected Secondary Recycled Water
Irrigation for:				
Food crops where recycled water contacts the edible portion of the crop, including all root crops	ALLOWED	NOT ALLOWED	NOT ALLOWED	NOT ALLOWED
Parks and playgrounds				
School grounds				
Residential landscaping				
Unrestricted-access golf courses				
Any other irrigation uses not specifically prohibited by other provisions of the *California Code of Regulations*				
Food crops, surface-irrigated, above-ground edible portion, not contacted by recycled water		ALLOWED		
Cemeteries			ALLOWED	
Freeway landscaping				
Restricted-access golf courses				
Ornamental nursery stock and sod farms with unrestricted public access				
Pasture for milk animals for human consumption				
Nonedible vegetation with access control to prevent use as a park, playground or school grounds				
Orchards with no contact between edible portion and recycled water				ALLOWED
Vineyards with no contact between edible portion and recycled water				
Non food-bearing trees, including Christmas trees not irrigated less than 14 days before harvest				
Fodder and fiber crops and pasture for animals not producing milk for human consumption				
Seed crops not eaten by humans				
Food crops undergoing commercial pathogen-destroying processing before consumption by humans				
Ornamental nursery stock, sod farms not irrigated less than 14 days before harvest				
Supply for impoundment:				
Nonrestricted recreational impoundments, with supplemental monitoring for pathogenic organisms	ALLOWED[3]	NOT ALLOWED	NOT ALLOWED	NOT ALLOWED
Restricted recreational impoundments and publicly accessible fish hatcheries	ALLOWED	ALLOWED		
Landscape impoundments without decorative fountains			ALLOWED	
Supply for cooling or air conditioning:				
Industrial or commercial cooling or air conditioning involving cooling tower, evaporative condenser, or spraying that creates a mist	ALLOWED[3]	NOT ALLOWED	NOT ALLOWED	NOT ALLOWED
Industrial or commercial cooling or air conditioning not involving cooling tower, evaporative condenser, or spraying that creates a mist	ALLOWED	ALLOWED	ALLOWED	

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General Information Section 11 Introduction to Water Recycling

Figure 13 Recycle Water Uses - Part 1 (Watereuse.org, 2000)

RECYCLED WATER USES* ALLOWED IN CALIFORNIA

This summary is prepared by WateReuse Association of California, from the December 2, 2000, Title 22 adopted Water Recycling Criteria, and supersedes all earlier versions.

Recycled Water Use	Treatment Level: Disinfected Tertiary Recycled Water	Disinfected Secondary 2.2 Recycled Water	Disinfected Secondary 23 Recycled Water	Undisinfected Secondary Recycled Water
Other Uses:				
Groundwater Recharge	ALLOWED under special case-by-case permits by the RWQCB[4]			
Flushing toilets and urinals	ALLOWED	NOT ALLOWED	NOT ALLOWED	NOT ALLOWED
Priming drain traps	ALLOWED	NOT ALLOWED	NOT ALLOWED	NOT ALLOWED
Industrial process water that may contact workers	ALLOWED	NOT ALLOWED	NOT ALLOWED	NOT ALLOWED
Structural fire fighting	ALLOWED	NOT ALLOWED	NOT ALLOWED	NOT ALLOWED
Decorative fountains	ALLOWED	NOT ALLOWED	NOT ALLOWED	NOT ALLOWED
Commercial laundries	ALLOWED	NOT ALLOWED	NOT ALLOWED	NOT ALLOWED
Consolidation of backfill material around potable water pipelines	ALLOWED	NOT ALLOWED	NOT ALLOWED	NOT ALLOWED
Artificial snow making for commercial outdoor use	ALLOWED	NOT ALLOWED	NOT ALLOWED	NOT ALLOWED
Commercial car washes, not heating the water, excluding the general public from the washing process	ALLOWED	NOT ALLOWED	NOT ALLOWED	NOT ALLOWED
Industrial process water that will not come into contact with workers	ALLOWED	ALLOWED	ALLOWED	NOT ALLOWED
Industrial boiler feed	ALLOWED	ALLOWED	ALLOWED	NOT ALLOWED
Nonstructural fire fighting	ALLOWED	ALLOWED	ALLOWED	NOT ALLOWED
Backfill consolidation around nonpotable piping	ALLOWED	ALLOWED	ALLOWED	NOT ALLOWED
Soil compaction	ALLOWED	ALLOWED	ALLOWED	NOT ALLOWED
Mixing concrete	ALLOWED	ALLOWED	ALLOWED	NOT ALLOWED
Dust control on roads and streets	ALLOWED	ALLOWED	ALLOWED	NOT ALLOWED
Cleaning roads, sidewalks and outdoor work areas	ALLOWED	ALLOWED	ALLOWED	NOT ALLOWED
Flushing sanitary sewers	ALLOWED	ALLOWED	ALLOWED	ALLOWED

Figure 14 Recycle Water Uses - Part 2 (Watereuse.org, 2000)

The discharge point is also of importance, because some locations are already reusing the water. Discharging the water to a lake can be considered a way to reuse water. The water in a lake percolates into the groundwater and can be pumped out from the ground to be used for drinking water. If the treated wastewater is discharged to a lake and is left to have a long enough residence time, it can be used again as a drinking water source. Treated wastewater that is discharged to a river may have some percolation that will recharge the groundwater, or it may quickly reach the ocean and mix with salty seawater. Water that is discharged directly to the ocean is not at all beneficially used. Once this water mixes with the salty seawater it is hard to utilize. Groundwater and surface waters can be rather easily utilized, but utilizing seawater requires high energy costs and is not feasible in all areas.

Phone/Brochure. Three of the cities in Solano County were called in order to gather data on their wastewater treatment plants. Two plants were visited. The remaining treatment plant, the Fairfield-Suisun Sewer District, had a very detailed brochure that provided all the pertinent information for this analysis, so the utilities directors here were not called.

Desalination Plant Tour. Desalination prices and data were collected during a tour of the Morro Bay Desalination Plant. This tour provided information such as water costs, regulations, and water quality. The water from Morro Bay's Desalination Plant costs around 2,100 dollars per acre-foot (Hanson, 2014). An acre-foot is a volume of water; this amount of water is enough to supply water to three families for a year (Dublin San Ramon Service District, 2010). Regulations have made it unfeasible for some places, such as Morro Bay, to use Seawater Desalination. Because of this, Morro Bay, like many other places, has resorted to only desalinating brackish water. Brackish water is water that contains much lower salt levels than seawater.

Desalination Presentation. The desalination presentation by Samuel Kramer gave valuable information regarding the cost efficiency of large desalination plants. This added information helped in the comparison of potable water, recycled water, and desalinated water.

METHODS

The cost of drinking water was compared to the cost of recycled water using a spreadsheet. Drinking water costs could be found online for each city. Recycled water prices were estimated by accounting for pumping cost and construction costs.

The cost of pumping recycled water in each city in Solano County was estimated by utilizing the following factors: flow rate, elevation change, electricity costs, assumed pump efficiency (70 percent), and assumed motor efficiency (70 percent). According to engineeringtoolbox, pumping costs can be estimated by using Equation 1 (engineeringtoolbox).

$$Pumping\ Cost = \frac{0.1308 * MGD * Elev * (\frac{\$}{kWh})}{pump\ efficiency * motor\ efficiency} \quad (1)$$

The water flow rates were calculated by converting million gallons daily (MGD) to hundred cubic feet per year (hcf/year) and to acre-feet per year (AF/year) by using Equations 2 and 3.

$$\frac{hcf}{year} = \frac{Million\ Gallons}{Day} * \frac{1{,}000{,}000\ gallons}{Million\ Gallons} * \frac{365\ days}{year} * \frac{1hcf}{748\ gal} \quad (2)$$

$$\frac{AF}{year} = MGD * \frac{1121\frac{AF}{year}}{MGD} \quad (3)$$

Water sources were found by researching water quality reports for each city.

Flow rates, discharge points, and treatment levels were found by visiting the treatment plants, calling the operators, and by looking online.

Elevations were determined using United States Geological Survey (USGS) topographic maps of each area. The locations of the wastewater treatment plants were found in order to determine the elevation of each treatment plant. These elevations were all close to zero feet, so zero was chosen for simplicity. The highest point on the topographic map that was near any urban or rural areas was chosen for the high elevation. The difference between these elevations was used in the pumping cost calculation.

Discharge benefits were determined based upon the discharge point of the treated wastewater. Ocean discharge is believed to have no benefit; whereas, discharge to a wetland is considered to be beneficial.

Electricity costs were found on the Pacific Gas and Electric Company website. Peak prices were chosen for simplicity. Since the initial assumption of this project was that reusing water is not feasible, assumptions were made to support this. Recycling water was considered infeasible unless proven feasible when using assumptions that do not support it. This is similar to the statistical initial hypothesis method.

Constructions costs were very roughly estimated, as they can vary based on location due to confounding factors. Ten million dollars was chosen as a baseline cost since the Dublin San Ramon Services district spends close to this amount each year in upgrades. The upgrades cover more than just pipeline construction however.

RESULTS

The average cost of drinking water in Solano County was between $2.07/hundred cubic feet and $3.42/hcf; the calculated average cost of recycled water in Solano County is $1.04/hcf. Recycled water was not cheaper in every city as water rates in some cities were very low. However, this data shows that recycled water can cost up to 58 percent less than potable water, in Solano County. This is supported by data from the Dublin San Ramon Services District. In Dublin and San Ramon, the recycled water is approximately 10 percent less expensive than potable water in a normal year and 29 to 58 percent less in a shortage (Dublin San Ramon Services District, 2010). The potable water prices used for this report were the most current prices found online, so many of them reflect the effects of the 2013-2014 drought. This is partly why the difference in cost is so great between the recycled water and the potable water in some areas. Each city's website was used to find their water rates.

The method of determining the pumping cost and the volumetric flow rates can be seen above in the methods section. In order to determine the recycled water prices, the pumping costs were doubled. This provided a simple way to account for friction costs and any other miscellaneous costs. The recycled water costs were calculated using Equations 4 and 5.

$$\frac{\$}{hcf} = \frac{2 * Pumping\ Cost/year}{hcf/year} \tag{4}$$

$$\frac{\$}{AF} = \frac{2 * Pumping\ Cost/year}{AF/year} \tag{5}$$

The recycled water price subtracted from the potable water price gave an estimate of the savings in dollars per hundred cubic feet (hcf). Since many cities would not be able to recycle all their treated wastewater, the entire volume of treated wastewater could not be considered saved water. In this project it was assumed that only 25 percent of the treated wastewater would be reused. The savings per year were calculated by offsetting drinking water with 25 percent of the treated wastewater. The annual savings were presented as thousands of dollars, see Equation 6.

$$Savings\ per\ year = \frac{Savings}{hcf} * 25\ percent * \frac{hcf}{year} * \frac{1\ thousand\ dollars}{1{,}000\ dollars} \tag{6}$$

Percent savings per unit is the amount that the recycled water is cheaper than the potable water shown in a percent. The percent savings per unit was calculated using Equation 7 on the following page:

$$\textit{Percent savings per unit} = \frac{1 - \textit{Recycled Water Price}\left(\frac{hcf}{year}\right)}{\textit{Potable Water Price}\left(\frac{hcf}{year}\right)} \quad (7)$$

The payback period was calculated by analyzing the time it would take to pay off the initial costs using the annual savings from recycling water. This period is only an estimate and neglects the effects of interest and inflation. Equation 8 shows how payback period is calculated.

$$\textit{Payback Period} = \frac{\textit{Construction Costs}}{\textit{Savings per Year in dollars}} \quad (8)$$

Tables 4 and 5 show the calculated recycled water costs and the comparisons to drinking water. This data is based on the data collected for this project.

Table 4 Feasibility Analysis Program - Part 1

	Vallejo		Benicia		Fairfield		Suisun	
Drinking Water Price ($/hcf) Range	$5.01	$7.80	$1.65	$3.29	$2.06	$3.21	$1.11	$2.05
Water Source	Surface		Surface		Surface		Surface	
Effect of using source	Limited Supply		Limited Supply		Limited Supply		Limited Supply	
Effluent discharge point	San Pablo Bay		San Pablo Bay		Suisun Marsh		Suisun Marsh	
Elevations of the area (ft)	0	600	0	600	0	700	0	700
Flow rates (MGD) @ wwtp (dry)	12		2		12.2		12.2	
Highest water treatment	Secondary		Secondary		Tertiary		Tertiary	
Discharge Benefits	None		None		High		High	
$/kWh	0.226		0.226		0.226		0.226	
Pumping Cost/hour	$434.44		$72.41		$515.29		$515.29	
Pumping Cost/year	$3,805,658		$634,276		$4,513,933		$4,513,933	
Annual Volume (hcf/yr)	5,855,615		975,936		5,953,209		5,953,209	
Annual Volume (AF/yr)	13,452		2,242		13,676		13,676	
Recycled Water Price ($/AF)	$565.81		$565.81		$660.12		$660.12	
Recycled Water Price ($/hcf)	$1.30		$1.30		$1.52		$1.52	
Savings ($/hcf)	$3.71	$6.50	$0.35	$1.99	$0.54	$1.69	-$0.41	$0.53
Recycled Water Used (%)	25%	25%	25%	25%	25%	25%	25%	25%
Savings per Year (thousands)	$5,431	$9,508	$85	$486	$809	$2,520	N/A	$794
Percent Savings per Unit	74%	83%	21%	60%	26%	53%	-37%	26%
Construction Costs (assumed)	$10,000,000		$10,000,000		$10,000,000		$10,000,000	
Payback Period (years)	1.8	1.1	117.0	20.6	12.4	4.0	N/A	12.6

Table 5 Feasibility Analysis Program - Part 2

	Vacaville		Rio Vista		Dixon		Solano County (Ave)	
Drinking Water Price ($/hcf) Range	$0.41	$1.70	N/A	N/A	$2.20	$2.47	$2.07	$3.42
Water Source	Surface/Ground		Groundwater		Groundwater		-	
Effect of using source	Limited/Subsidence		Subsidence		Subsidence		-	
Effluent discharge point	River		River		Percolation pond		-	
Elevations of the area (ft)	0	500	0	150	0	100	-	
Flow rates (MGD) @ wwtp (dry)	7.5		1.75		2.5		7.2	
Highest water treatment	Tertiary		Secondary		Secondary		-	
Discharge Benefits	Slight		Slight		High		-	
$/kWh	0.226		0.226		0.226		-	
Pumping Cost/hour	$226.27		$15.84		$15.08		$256.37	
Pumping Cost/year	$1,982,113		$138,748		$132,141		$2,245,829	
Annual Volume (hcf/yr)	3,659,759		853,944		1,219,920		3,495,942	
Annual Volume (AF/yr)	8,408		1,962		2,803		8,031	
Recycled Water Price ($/AF)	$471.51		$141.45		$94.30		$451.30	
Recycled Water Price ($/hcf)	$1.08		$0.32		$0.22		$1.04	
Savings ($/hcf)	-$0.67	$0.62	N/A	N/A	$1.98	$2.25	$0.92	$2.26
Recycled Water Used (%)	25%	25%	25%	25%	25%	25%	25%	25%
Savings per Year (thousands)	N/A	$564	N/A	N/A	$605	$686	$1,733	$2,426
Percent Savings per Unit	-164%	36%	N/A	N/A	90%	91%	2%	58%
Construction Costs (assumed)	$10,000,000		$10,000,000		$10,000,000		$10,000,000	
Payback Period (years)	N/A	17.7	N/A	N/A	16.5	14.6	5.8	4.1

DISCUSSION

Although wastewater reuse may not be necessary for all locations, it is a great tool for reducing human water usage. Counties in Northern California are mostly water rich and do not have to suffer very much in a drought. However, counties in Southern California are suffering so greatly that they are investing billions of dollars into new water sources, such as desalination. If Northern California used less of the freshwater supply, there would be more water available for Southern California and less money would have to be spent on desalination. According to a report by California Drought Preparedness, the proposed $250 million dollar desalination plant in Long Beach would produce water that would sell for $800 per acre foot. The imported water in this area costs $500 dollars per acre foot and the groundwater is only $150 dollars per acre foot (CaDroughtPrep, 2002). The desalination plant in Carlsbad is expecting to sell water for over $2000 per acre foot (Shoenberger, 2014). The Carlsbad project was allocated $530 million dollars in a private activity bond (water-technology.net, 2014). Desalination is extremely expensive, and this cost can possibly fall on the entire state.

Since everyone can end up paying for these projects, it is in everyone's best interest to work together. Increasing the water supply with less expensive measures, such as recycled water, benefits everyone. For irrigation usage, recycled water also has the added benefit of containing nutrients, such as nitrogen. The nutrients in the water reduce the need for fertilizers (Dublin San Ramon Services District, 2010). Using recycled water to offset irrigation water usage, the greatest water usage in California, would not only benefit growers due to reduced fertilizer costs but would benefit all of California. As depicted in Figure 15, 77 percent of California's water is used for agriculture and 13 percent is estimated to be consumed for urban residential use (Cohen, 2009).

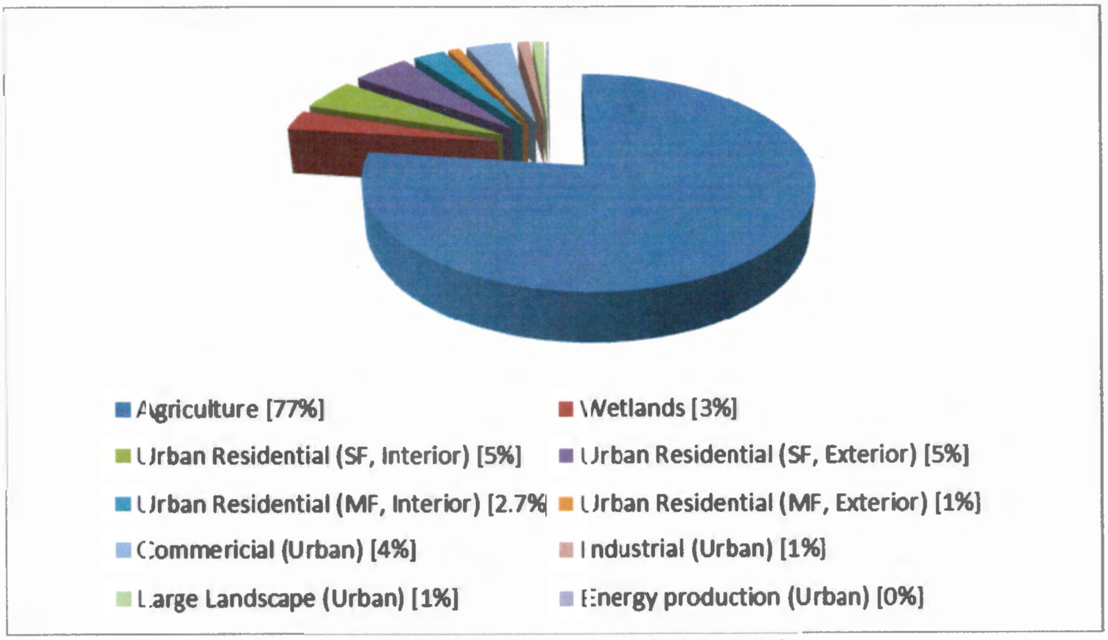

Figure 15 California Water Usage (Cohen, 2009)

Recycled water is a dependable source that can be used or wasted. The only added cost of utilizing recycled water, after initial costs are covered, is pumping cost. Secondary treatment is required for all wastewater treatment plants, so the cost of treating the wastewater would not change if the water was being recycled or not. However, desalination is expensive while in use and while not in use. Reverse Osmosis Desalination plants cannot be turned off during wet years, left untouched when desalination is not needed, and then later turned back on again in times of drought. Instead, the desalination plant must be turned off when it is not needed and then maintained and tested until it is needed again. In Southern California, counties, such as San Diego, are paying up to $1 billion dollars to supply enough water to account for 7 to 10 percent of the total need (Garrick, 2014). This 7 to 10 percent of the total need in San Diego is equivalent to 50 million gallons of water each day. The desalinated water would serve cities in San Diego County, a densely populated area. In Vallejo, California, a city in the Bay Area, 12 million gallons of water are treated each day in the summer time, when there is less water. Not only could recycled water in Vallejo produce over one-fifth of the water produced by the $1 billion dollar project, it could produce it for almost one-fourth of the cost. Vallejo has a population of 118 thousand people, while San Diego has a population of 1.3 million people (city-data.com, 2012).

Desalination also has a detrimental environmental impact. Seawater desalination recovery rates are typically maximized around 50 percent. This means that 50 percent of the seawater is desalinated and can be used as potable water, and 50 percent of the seawater becomes brine, more concentrated salt water. The brine is then pumped back into the ocean. If the brine is not dispersed properly, it can cause an adverse effect on the marine life in the discharge area. Treated wastewater is at times discharged to lakes, rivers and wetlands, where it is considered to be somewhat beneficially reused. By reusing treated wastewater for urban and agricultural uses, the marine life in the lakes, rivers, and wetlands may suffer. Recycled water could be used mainly when the treated wastewater is discharged to the ocean, where it is in no way beneficially used. With this in mind, the analysis of reusing water in Solano County shows that implementing recycled water in Vallejo is the most feasible, but it is possible everywhere else in the county as well. Some water is currently being recycled in Fairfield for landscape irrigation (Riesenberg, 2013). Vacaville is currently upgrading their treatment plant to utilize tertiary treatment, and is planning to reuse some of the water for irrigation in the summer months. Although the initial costs may be high for some cities to utilize recycled water, it is pertinent that measures are taken early, so that rash decisions can be avoided when droughts are uncontrollable.

RECOMMENDATIONS

The main recommendation is to install purple pipelines, recycled water pipelines, when other projects are being constructed. According to Felix Riesenberg, Fairfield Assitant Public Works Director, the initial construction cost of pipelines and plant upgrades are main limiting factors in many recycled water projects (2013). This cost can be greatly reduced by installing purple pipes, when existing pipelines are being replaced or when trenches are being dug out for other projects.

This analysis does not include greywater. Greywater reuse allows households to utilize their own wastewater. Instead of the wastewater treatment plants treating the water and pumping it back out for reuse, households could use the water from their sinks and showers for their toilets and lawns. Figure 16 shows a model of a typical greywater reuse unit.

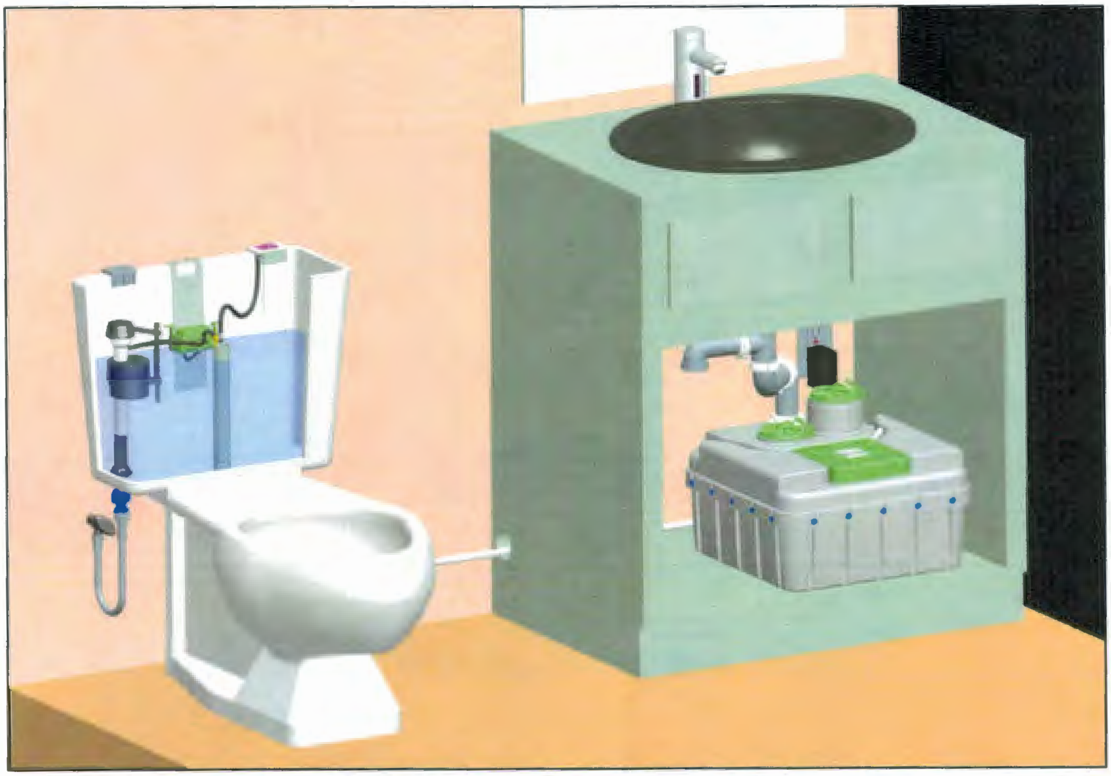

Figure 16 Graywater System (Aqus, 2010)

REFERENCES

1. Anderson, J. 2003. The Environmental Benefits of Water Recycling and Reuse. Water Science Technology: Water Supply 3(4):1-10

2. Boissevain, P. 2014. Personal Communication. Polly Boissevain, Engineering Manager, West Yost, Walnut Creek, California

3. California Department of Public Health. 2014. Chromium-6 in Drinking Water: MCL Update.

4. California Department of Water Resources. 2014. California Data Exchange Center, Lake Oroville.

5. California Department of Water Resources. 2014. State Water Project Allocation – Zero Percent. DWR 9625.

6. California Drought Preparedness. 2002. Water Shortages. <http://www.cadroughtprep.net/watshort.htm>, referenced 2014.

7. CalWaterCrisis. 2007. California's Water: A Crisis We Can't Ignore. <calwatercrisis.org>, referenced 2014.

8. Campbell E. and Durisin M. 2014. California Farms Going Thirsty as Drought Burns $5 Billion Hole. Bloomberg.

9. Chico Enterprise Record. 2014. Low Water Levels at Lake Oroville. <http://media.chicoer.com/2014/01/03/photos-low-water-levels-at-lake-oroville/#1>, referenced 2014.

10. City-Data.com. San Diego, California < http://www.city-data.com/city/San-Diego-California.html>, referenced 2014.

11. City-Data.com. Vallejo, California <http://www.city-data.com/city/Vallejo-California.html>, referenced 2014.

12. City of Benicia. 2012. Consumer Confidence Report of Drinking Water Quality.

13. City of Benicia. 2014. Water Rates and Charges. <http://www.ci.benicia.ca.us/vertical/sites/%7B3436CBED-6A58-4FEF-BFDF-5F9331215932%7D/uploads/Water_Rates_and_Charges.pdf>, referenced 2014

14. City of Fairfield. 2012. Consumer Confidence Report 2012 Drinking Water.

15. City of Fairfield. 2013. 2013 Utilities Rates Table. <http://www.fairfield.ca.gov/civica/filebank/blobdload.asp?BlobID=8256>, referenced 2014.

16. City of Rio Vista. 2011. Water Quality Report for Calendar Year 2011.

17. City of Rio Vista. 2008. Water Rates. <http://riovistacity.com/wp-content/uploads/file/Finance/2008-2013%20Water%20Rates.pdf>, referenced 2014.

18. City of Vacaville. 2011. Drinking Water Quality Report to Consumers.

19. City of Vacaville. 2014. Water Services Charges. <http://www.cityofvacaville.com/modules/showdocument.aspx?documentid=3243>, referenced 2014.

20. City of Vallejo. 2012. Annual Water Quality Report.

21. City of Vallejo. 2013. Municipal Water System Rate Table. <http://vallejo.hosted.civiclive.com/UserFiles/Servers/Server_13423/File/Public%20Works/Water/Rate%20Table%20FY13-14.pdf>, referenced 2014.

22. Cohen, Y. 2009. Graywater – A Potential Source of Water. UCLA Institute of the Environment Sustainability

23. Collentro, W. 2011. Distillation. Journal of Validation Technology 17.3 (Summer 2011):17-23

24. Cooley, J. 2014. Personal Communication. Jeff Cooley, Utilities Operations Manager, Vacaville Utilities Department, Vacaville, California

25. Desalination.com. 2013. Office of Saline Water – Desal R&D Funding, USA. <http://www.desalination.com/museum/office-saline-water-desal-rd-funding-usa>, referenced 2014.

26. Dixon-Solano Water Authority. 2012. Drinking Water Quality Report.

27. Dixon-Solano Water Authority. Water Rates. <http://www.discoverdixon.org/images/stories/images-content/water%20rates%20may%201%202010.pdf>, referenced 2014.

28. Dublin San Ramon Services District. 2010. Frequently Asked Questions About Recycled Water. <http://www.dsrsd.com/wwrw/recycledwaterfaq.html>, referenced 2014.

29. ENGETEC. 2008. Wastewater Treatment. <http://www.engetec.info/pb/wp_6aa03213/wp_6aa03213.html?0.5>, referenced 2014.

30. Fairfield-Suisun Sewer District. FSSD Treatment Plant Facts.

31. Fereres et al. 2011. Yield Response to Water of Fruit Trees and Vines: Guidelines. FAO Vol 4.

32. Garrick, D. 2014. Desalination Plant on Course for 2016. UT San Diego

33. Hanson, D. 2014. Personal Communication. Damaris Hanson, Engineer, Morro Bay Public Services Department, Morro Bay, California

34. Kaiser, J. 2014. Personal Communication. Jennifer Kaiser, Public Information and Outreach, Vallejo Sanitaion & Flood Control District, Vallejo, California

35. Kostigen – Kostigen, T.M. 2014. Could California's Drought Last 200 Years? National Geographic

36. Kramer, S. 2014. Personal Communication. Samuel Kramer, Engineer, IDE, Huntington Beach, California

37. Madani, K. and Lund, J.R. 2012. California's Sacramento-San Joaquin Delta Conflict: From Cooperation to Chicken. ASCE Journal of Water Resources Planning and Management 138:90-99

38. Monterey County Water Resources Agency. 2013. Protective Elevations to Control Sea Water Intrusion in the Salinas Valley

39. Pacific Gas and Electric Company. 2014. Peak Day Pricing. <http://www.pge.com/en/mybusiness/rates/tvp/peakdaypricing.page?>, referenced 2014.

40. Purgatoire River Water Conservancy District. Water Conversions. <http://www.prwcd.org/water_conv.html>, referenced 2014.

41. Rao, S.M. 2007. Reverse Osmosis. Resonance. May 2007

42. Rice, D. and Marquis, D. 2013. Driest Year Ever in California Sparks Fire, Water Fears. USA Today.

43. Riesenber, F. 2013. Personal Communication. Felix Reisenberg, Assistant Public Utilities Director, Fairfield Public Utilities, Fairfield, California

44. Shoenberger, P. 2014. Personal Communication. Paul Shoenberger, General Manager, Mesa Water District, Costa Mesa, California

45. Solano County. 2012. County Facts & Figures <http://www.co.solano.ca.us/about/county_facts_n_figures.asp>, referenced 2014.

46. Solano County Water Agency. 2008. History. <http://www.scwa2.com/Projects_North_Bay_Aqueduct.aspx>, referenced 2014.

47. Solano County Water Agency. 2008. North Bay Aqueduct. <http://www.scwa2.com/Projects_North_Bay_Aqueduct.aspx>, referenced 2014.

48. Solano County Water Agency, Urban Water Management Plan. 2010. Final Draft.

49. Strandberg, J. 2014. Personal Communication. Jim Strandberg, Geologist, West Yost, Walnut Creek, California

50. Suero, F.J., Mayer, P.W., and Rosenberg, D.E. 2012. Estimating and Verifying United States Households' Potential to Conserve Water. ASCE Journal of Water Resources Planning and Management 138:299-306

51. Suisun-Solano Water Authority. 2012. Drinking Water Quality Report.

52. Suisun-Solano Water Authority. 2014. Water Rates. <http://www.suisun.com/wp-content/files/Utility_Services_Rate_Sheet.pdf>, referenced 2012.

53. The Engineering ToolBox. Electric Water Pump. <http://www.engineeringtoolbox.com/water-pumping-costs-d_1527.html>, referenced 2014.

54. United State Environmental Protection Agency. 2003. Wastewater Technology Fact Sheet. Office of Water.

55. United Stated Environmental Protection Agency. 2012. Wetlands and People. <http://water.epa.gov/type/wetlands/people.cfm>, referenced 2014.

56. United States Geological Survey. 2013. Land Subsidence.

57. Water Replenishment District of Southern California. 2007. Battling Seawater Intrusion in the Central and West Coast Basins. WRD Technical Bulletin Volume 13

58. Water-Technology.net. 2014. Carlsbad Desalination Project, San Diego California, United States of America. <http://www.water-technology.net/projects/carlsbaddesalination/>, referenced 2014.

59. Wateruse.org. 2000. Recycled Water Uses Allowed in California. <wateruse.org/h2o>, 2014

60. Yost, J. 2014. Personal Communication. Jim Yost, Co-Founder, West Yost, Davis, California

APPENDIX A

HOW PROJECT MEETS REQUIREMENTS FOR THE BRAE MAJOR

HOW PROJECT MEETS REQUIREMENTS FOR THE BRAE MAJOR

Major Design Experience

The BRAE senior project must incorporate a major design experience. Design is the process of devising a system, component, or process to meet specific needs. The design process typically includes the following fundamental elements. Explain how this project will address these issues. (Insert N/A for any item not applicable to this project.)

Establishment of Objectives And Criteria. Project objectives and criteria are established to meet the needs and expectations of the Solano County Water Agency. See "Design Parameters and Constraints" section below for specific objectives and criteria for the project.

Synthesis and Analysis. The project will incorporate pipeline hydraulics, economics and environmental concerns.

Construction, Testing and Evaluation. The economic evaluation of replacing and/or installing pipelines will be conducted.

Incorporation of Applicable Engineering Standards The project will utilize EPA standards for water quality.

Capstone Design Experience

The engineering design project must be based on the knowledge and skills acquired in earlier coursework (Major, Support and/or GE courses).

Incorporates Knowledge/ Skills from these Key Courses.

- ENVE 438 Water and Wastewater Treatment
- BRAE 403 Engineering Economics
- BRAE 312 Hydraulics
- BRAE 331 Irrigation Theory
- Econ 201 Survey of Economics
- BRAE 414 Irrigation Engineering
- ENGL 149 Technical Writing

Design Parameters and Constraints

The project should address a significant number of the categories of constraints listed below. (Insert N/A for any area not applicable to this project.)

Physical. N/A

Economic. The cost of implementing a new pipeline must not outweigh the savings from recycling water.

Environmental.	Benefits of the project will be to reduce wastewater disposal and increase clean water availability.
Sustainability.	Water reuse increases the sustainability of water use.
Manufacturability.	No manufacturing required, but creating a program to help determine when to replace pipelines could help many districts with the computations and would provide supporting evidence for pipeline installation.
Health and Safety.	Health and Safety will not be decreased due to wastewater reuse, because water should be treated to the EPA requirements.
Ethical.	N/A
Social.	Many people may dislike using wastewater to irrigate the landscape and agriculture.
Political.	Reduced wastewater disposal, but increased spending on pipelines.
Aesthetic.	Purple pipelines will be used to indicate treated wastewater.
Other.	The objective of the program would be to allow anyone to be able to analyze the efficiency of installing a new pipeline.

APPENDIX B

CITY OF VALLEJO WASTEWATER TREATMENT PLANT SITE VISIT MEMO

MEMORANDUM

DATE: 3/21/14

FROM: Dakari Barksdale

SUBJECT: Vallejo Wastewater Treatment Plant Tour

At 9 a.m. on Friday, March 21, 2014, Jennifer Kaiser led me on a tour of the Vallejo Wastewater Treatment Plant. The plant is located at 450 Ryder Street in Vallejo. It is located on the San Pablo Bay waterfront. Since the Vallejo Wastewater Treatment Plant (Vallejo WWTP) is surrounded by industrial buildings, it would be hard to expand and add new development such as tertiary treatment. Although this plant is located right next to the water, the effluent must be pumped out two miles from the treatment site to the Carquinez Strait. This increases the cost for the Vallejo WWTP, but this may change in the near future due to a change in regulations.

This plant on average treats 11-12 million gallons daily (MGD) during dry weather. The plant is rated to handle a maximum flow of 60 MGDs; when this maximum flow rate is exceeded then the water is pumped into the storage tank, depicted in Figure 17. If the flow rate is too extreme, then an overflow can occur. Overflows occur in times of intense rain; the overflow consists of rainwater and sewage. The rainwater seeps into sewage drains and increases the flow rate to the treatment plant. This mixture of water is discharged during overflows. This is detrimental, since untreated sewage is discharged to the environment. However, the mixing of rainwater and sewage dilutes the sewage so that the impact of the overflow is lessened. Vallejo has not had an overflow in 6 years.

Figure 17 Storage Tank at the Vallejo WWTP

The sewage that is treated at the Vallejo Wastewater Treatment plant starts by being pumped by influent pumps, shown in Figure 18. Each pump is capable of pumping 16-18 MGDs, so during average dry weather flow only one of the pumps is needed at a time. The sewage then travels through the mechanically cleaned bar screens, seen in Figure 19. These screens remove all the large inorganic debris that should not be present in the sewage system, but this debris is hard to keep out of the water. The sewage that passes

through the bar screens then passes through the grit chamber and is then clarified in the primary clarifiers. Grit chambers remove grit, which is comprised of sand, gravel, cinder and other materials such as eggshells and coffee grounds (EPA, 2003). The primary clarifier, depicted in Figure 20, slows the water, allowing the heavy particles to settle to the bottom. These particles at the bottom of the clarifier, referred to as sludge, are constantly scraped out and collected for dewatering and disposal.

Figure 18 Influrnt Pumps

Figure 19 Mechanically Cleaned Bar Screens

Figure 20 Primary Clarifier

The water that leaves the primary clarifier passes through the trickling filter and the aeration basin. Both of these processes remove contaminants from the water using biology. The microbes present in the wastewater are capable of cleaning the water with sufficient time, but the wastewater in the aeration basin is blended with the sludge from the secondary clarifiers to increase the amount of microbes in the water and therefore

speed up the process. Air is pumped through the water to promote the growth of the microbes and subsequently decrease the contaminants in the water. The wastewater passes through the secondary clarifier after it passes through the aeration basin. The secondary clarifier is much like the primary clarifier. However, the sludge from the secondary clarifier is recycled, by using it in the aeration basin, whereas the sludge from the primary clarifier is dewatered and disposed of. A schematic detailing the air and water flows in a typical secondary wastewater treatment plant can be seen in Figure 21. Figure 22 depicts the schematic screen used by plant operators to ensure that the plant is functioning properly. After the water passes through the secondary clarifier it passes through the contact chamber where the water comes in contact with chlorine. The water is then de-chlorinated so that the biological life at the discharge point is not killed. The sludge that is not reused in the aeration basin is dewatered on site in the solids handling part of the treatment plant. The sludge is dewatered on a conveyor belt. As it can be seen in Figure 23, the sludge is squeezed between two conveyor belts. Once the sludge is dewatered, it is sent off to be used as fertilizer for crops. The only crops that can use this sludge are crops that are to be eaten by animals that will not be consumed by humans, such as horses (Kaiser,2014). The Vallejo Wastewater Treatment plant recycles the sludge created during the treatment process but has not yet implemented a large scale recycling plan for the treated wastewater. The majority of the treated wastewater is discharged to the ocean; the rest is used to grow a small garden of native plants on site. This garden can be seen in Figure 24.

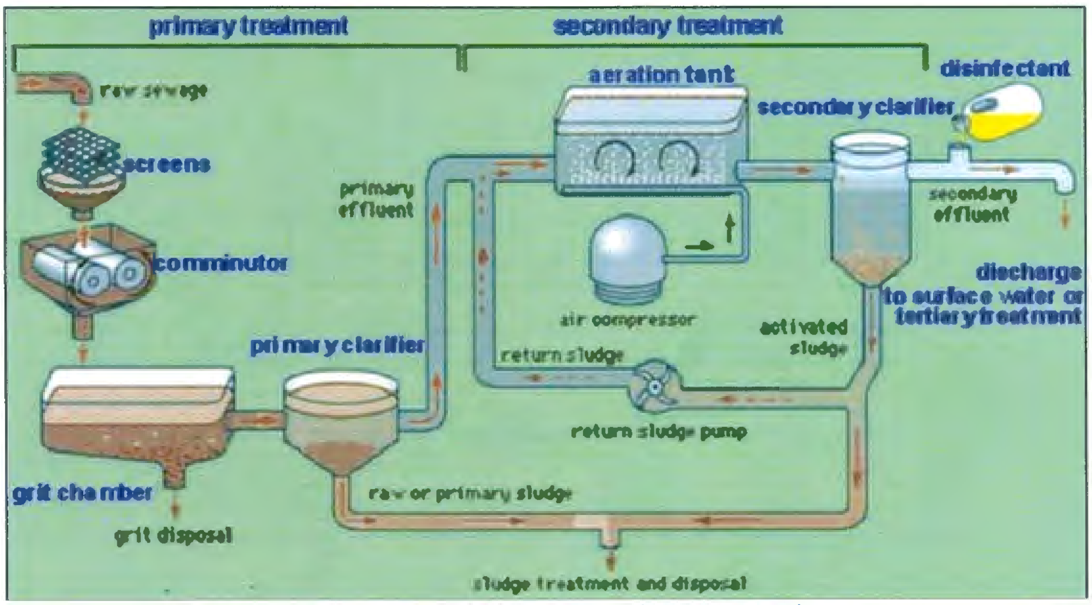

Figure 21 Typical WWTP Schematic (ENGETEC, 2008)

Figure 22 Control Screen in Vallejo WWTP

Figure 23 Sludge Thickening Conveyor Belt

Figure 24 Recycled Water Plant Nursery

APPENDIX C

CITY OF VACAVILLE WASTEWATER TREATMENT PLANT SITE VISIT MEMO

MEMORANDUM

DATE: 3/25/14

FROM: Dakari Barksdale

SUBJECT: Vacaville Wastewater Treatment Plant Tour

On March 25th, 2014, Jeff Cooley from the Vacaville Utilities Department gave me a tour of Vacaville's Easterly Wastewater Treatment Plant. This plant was very different in comparison to the Vallejo and San Luis Obispo plants. The Easterly Wastewater Treatment Plant covered a much greater area than the Vallejo treatment plant and thus had greater capability for improvements and upgrades. In fact, the Easterly Wastewater Treatment Plant was constructing a tertiary treatment train. By upgrading to tertiary treatment, Vacaville has the ability to recycle their water for nearly any use other than drinking water. Their current plans include reusing the water to supplement irrigation water in the summer time. The treatment processes used for this plant included perforated screen filters, grit cyclones, primary clarifiers, aeration basins, secondary clarifiers, sludge thickeners, and anaerobic digesters. The Easterly Wastewater Treatment Plant used a smaller area for their primary clarifier by making it square and incorporating it with the aeration basin. The primary clarifier in Vallejo was a circular basin that was separate from the rectangular aeration basin. The primary settler for Vacaville was square and allowed the water to directly flow from the settler to the aeration basin. It also used water to remove the scum, the materials that are lighter than water, from the surface of the water rather than a mechanical arm, like what was used in Vallejo. Figure 25 shows water being used to remove the scum in the primary clarifier. The water being used was not drinking water but was instead some of the water that had recently been treated at the plant; this water is referred to as 3-water, by the plant operators. The sludge, which consists of the materials that are denser than water, is removed with mechanically driven scrapers as seen in Figure 26. Aeration basins account for a large bulk of the annual treatment costs. Easterly Treatment plant was able to reduce the annual budget by upgrading to new more efficient modular blowers. The new blowers provide a 40 percent reduction in energy costs compared to the existing ones (Cooley, 2014). The secondary clarifier in Vacaville, similar to the clarifiers at the Vallejo Wastewater Treatment Plant, utilized mechanical arms. Figure 27 shows how the mechanical arms remove the scum from the surface of the water.

Figure 25 Primary Filter with Scum Removing Water Sprayers

Figure 26 Scrapers along Bottom of Empty Primary Clarifier

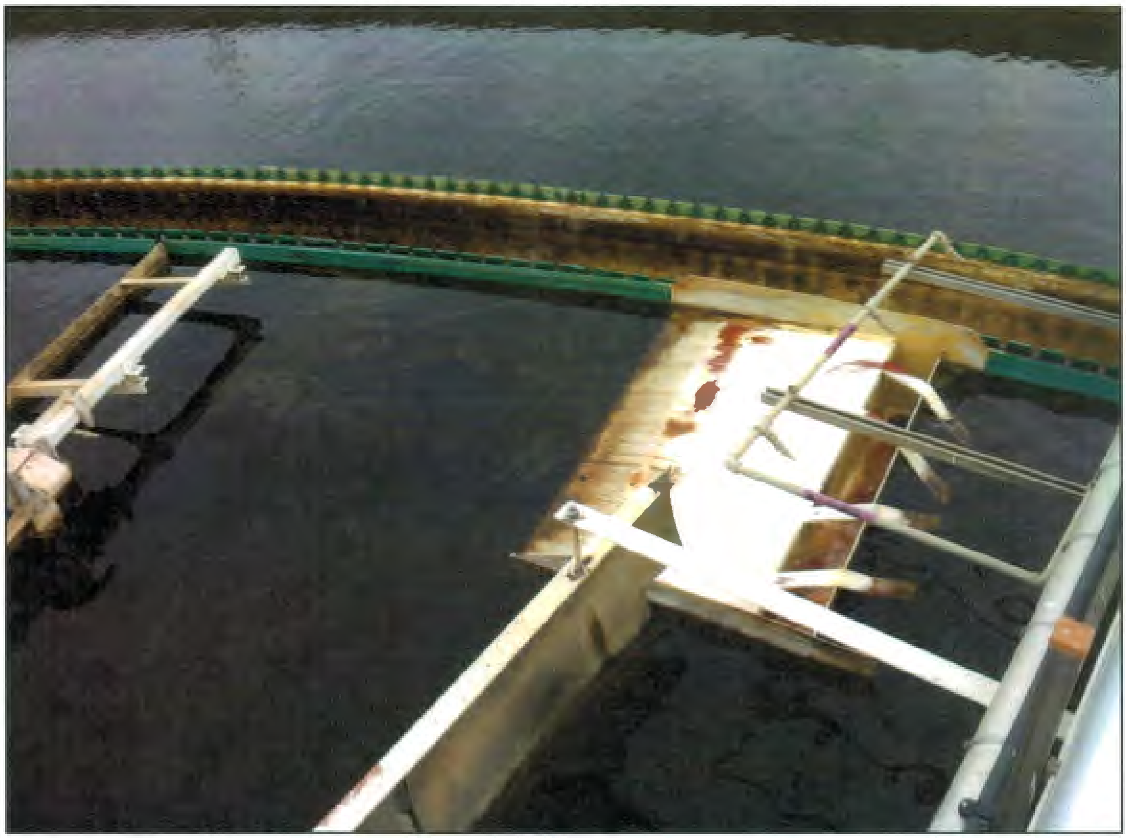

Figure 27 Mechanical Scum Removal in Secondary Clarifier

The water that passes through the secondary clarifier is then disinfected with chlorine. This water slowly flows through the chlorine contact chamber, seen in Figure 28. The longer the water is in contact with the chlorine, the more contaminants are killed. Once the water is sufficiently disinfected, the water is de-chlorinated so that the environment downstream is not harmed. Also, in efforts to preserve the environment, dissolved oxygen (DO) has to be present in the treated wastewater. In Figure 29, motors can be seen in the water, these motors are there to added oxygen to the water if the DO levels are too low. Since the lab results have never shown that the DO levels were too low, the motors have never been used. The lab shown in Figure 30, runs many tests to makes sure the treatment plant is meeting all the regulations.

Figure 28 Chlorine Contact Chamber

Figure 29 Dissolved Oxygen Motors at Tail-End of Treatment Plant

Figure 30 Vacaville WWTP Onsite Testing Lab

Some of the sludge that is removed from the secondary clarifier is returned to the aeration basin. The microbes in this sludge help clean the water. The rest of the sludge from the secondary clarifier and all the sludge from the primary clarifier are dewatered on site. The sludge is first mechanically pressed on conveyor belts, and then is put in an anaerobic digester. Figure 31 shows the sludge on a conveyor belt. The anaerobic digester removes more of the water from the sludge, thus reducing its volume. After the sludge is thickened in the anaerobic digester, it is dried more in the sun, until the moisture content is low enough for the local landfill to dispose of it. The Easterly treatment plant has an agreement with the local landfill that allows the landfill to send its leachate, all the liquid that drains from the trash, to the Easterly treatment plant if the landfill disposes of the solids from the Easterly treatment plant.

Figure 31 Sludge in Conveyor before Dewatering

APPENDIX D

ASSOCIATION OF CALIFORNIA WATER AGENCIES CONFERENCE

MEMORANDUM

DATE: 5/6-9/14

FROM: Dakari Barksdale

SUBJECT: Association of California Water Agencies Conference

The Association of California Water Agencies (ACWA) holds water conferences twice a year, in the spring and in the fall. This year's spring conference was held in Monterey. West Yost, a company based in Davis, sponsored my attendance. This conference provided information on current issues regarding California's water supplies. Some of the topics included, groundwater, subsidence, data collection, water rates, desalination, recycled water, water quality, water rights, and a lot of political issues related to water. The contamination of groundwater and the subsidence due to groundwater were a major concern in most of the areas that had a lot of agriculture. Data collection was of major importance around the delta. Many data collection sites along the delta are collecting data too infrequently. The flows of the delta change quickly, and in order to get more accurate estimates of salt and contaminant concentrations, data should be collected more often. When data is not collected with high frequency, aliasing can occur. Aliasing can cause data to be misinterpreted. In Figure 32, aliasing occurs and creates a graph (blue line) that is different from the actual data (red line). Utilities directors and other officials who are in charge of making water rates have a difficult time setting water rates. Water rates are not set based solely on the cost to produce water in certain quantities. The cost of treating water is not completely variable based on the flow rate through the plant. Water costs are mainly fixed costs with very little variable cost (Boissevain, 2014). Water rates are often setup to encourage conservation, by charging lower rates to the households and companies that use little water. However, speakers at the ACWA conference stated that some citizens will conserve so much water that the water agency will lose money.

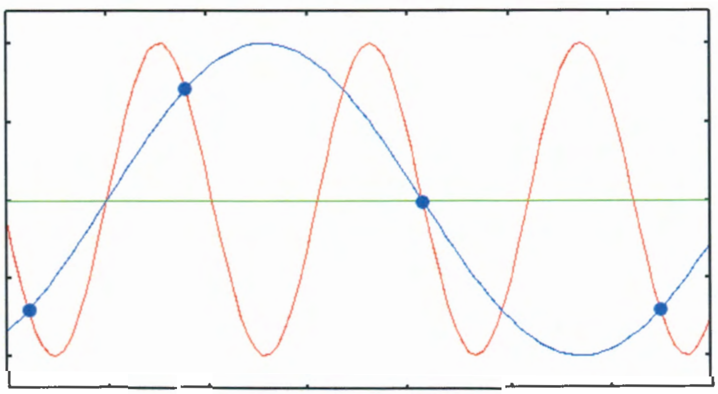

Figure 32 Aliasing Example

As a result of the 2013-2014 drought, desalination has recently been implemented on a larger scale in California. Groups such as CalDesal are gaining more fame and importance in the water community as more counties are starting to implement desalination. Currently, a desalination plant is being built in Carlsbad, California. At 54

MGD, this desalination plant will be the largest plant in the Western Hemisphere. Companies such as Poseidon were attempting to sell desalination to water agencies at the conference. Some of the utilities directors, such as Bert Michalczyk, the general manager of the Dublin San Ramon Services District, are part of the subcommittee of ACWA that is involved with recycled and potable reuse. This group was formed to increase water reuse in California. Bert Michalczk, has implemented recycled water as a large portion, approximately 18 percent, of the Dublin-San Ramon water supply (Dublin San Ramon Services District, 2010). This district has been developing a recycled water system since the 1990's (Dublin San Ramon Services District, 2010).

Water quality was also of great concern at the conference due to new regulations on contaminants such as chromium-6. A regulations package for the proposed maximum contaminant level (MCL) was submitted to the Office of Administrative Law, on April 15, 2014 (California Department of Public Health, 2014). Changes in water quality regulations often result in major construction costs at some water treatment facilities, and if a water agency does not have the money, they get fined by the State or Federal government (Strandberg, 2014). Increasing a water supply by acquiring water rights is extremely difficult (Yost, 2014). This process is a political process that requires much more than engineering calculations. For water agencies to increase their water supply it can be very difficult due to the politics involved. Obtaining permits and abiding by all the regulations can be very difficult, and it explains why so many lawyers must work with engineers in each water agency.

APPENDIX E

MORRO BAY DESALINATION PLANT TOUR

MEMORANDUM

DATE: 4/29/14

FROM: Dakari Barksdale

SUBJECT: Morro Bay Desalination Plant Tour

On April 29, 2014, I toured the Morro Bay Desalination Plant with faculty and staff from California Polytechnic State, San Luis Obispo. Damaris Hanson from the Morro Bay Public Utilities Department was in attendance as well. She gave information on water costs, contaminant levels, and regulations. The operators gave information on the layout of the plant, the tests performed, operating pressures, and the required maintenance for the plant. The Morro Bay Desalination Plant has two treatment trains, one for treating seawater and one for groundwater. Currently, Morro Bay is only treating brackish groundwater. The regulations on the brine discharge from the seawater treatment train are keeping the Morro Bay Desalination plant from desalinating seawater. The groundwater in Morro Bay is high in nitrates, so Morro Bay uses reverse osmosis. This treatment process costs 2,100 dollars per acre foot. The city of Morro Bay would rather use water from the State Water Project, since it is cheaper. However, as a result of the drought, they are only allocated 5 percent of the water they pay for. Even worse, they are not able to access the 5 percent of their allocation or the water they stored in the State Water Project reservoirs. This water is unavailable since the State Water Project officials do not want to turn on the pumps to deliver the water to Morro Bay; using these pumps for a small amount of water is extremely inefficient (Hanson, 2014). So under these conditions, Morro Bay is forced to use desalination. Figure 33 shows one of the brackish water desalination trains.

Figure 33 Morro Bay Brackish Water Desalination Train

APPENDIX F

DESALINATION PRESENTATION

MEMORANDUM

DATE: 5/15/14

FROM: Dakari Barksdale

SUBJECT: IDE Desalination Presentation

On May 15, Samuel Kramer, an employee of IDE, gave a presentation on desalination. In this presentation he discussed the different types of desalination plants, the different contract types, and the sizes and locations of some of the largest desalination plants in the world. The largest desalination plant in the world is located in Soreq, Israel. Three desalination plants in Israel each produce 165 million gallons daily (MGD), 120 MGD, and 104 (MGD). Between these three plants, Israel can produce 389 million gallons daily. In the Western Hemisphere, the desalination plants are not as large; the largest plant being only 54 (MGD). This 54 MGD plant, in Carlsbad, is currently being built by IDE and will be operated, in June of 2016, by IDE. The Carlsbad desalination plant will utilize the intake from the nearby power plant. The power plant will use the water to cool the generators; after the water cools the generators, a portion of it will be desalinated. Then the brine, the saltier wastewater of the desalination process, will be mixed with the un-desalinated water that was used to cool the power plant. The un-desalinated water used to cool the power plant mixes with the brine at a 5 to 1 ratio, thus decreasing the salt concentration of the brine. This mixture is then dumped back in the ocean. On some seawater intakes, jellyfish are sucked up and cause clogging. To limit this, bubbles are used to reject the jellyfish. Annually, America spends $2 billion dollars on desalination (Kramer, 2014). With increased research, desalination could become cheaper and more feasible. JFK stated, "It is essential, therefore, that we make every effort at this time to search for low-cost processes for converting sea and brackish water into fresh water to meet our future water needs and those of our neighbors throughout the world. I know of no Federal activity that offers greater promise of making a major contribution to the ultimate economic well-being of all mankind than this [desalination] program" (Desalination.com, 2012).

APPENDIX G

USGS Topographic Maps

Figure 34 Benicia Topographic Map (USGS, 2012)

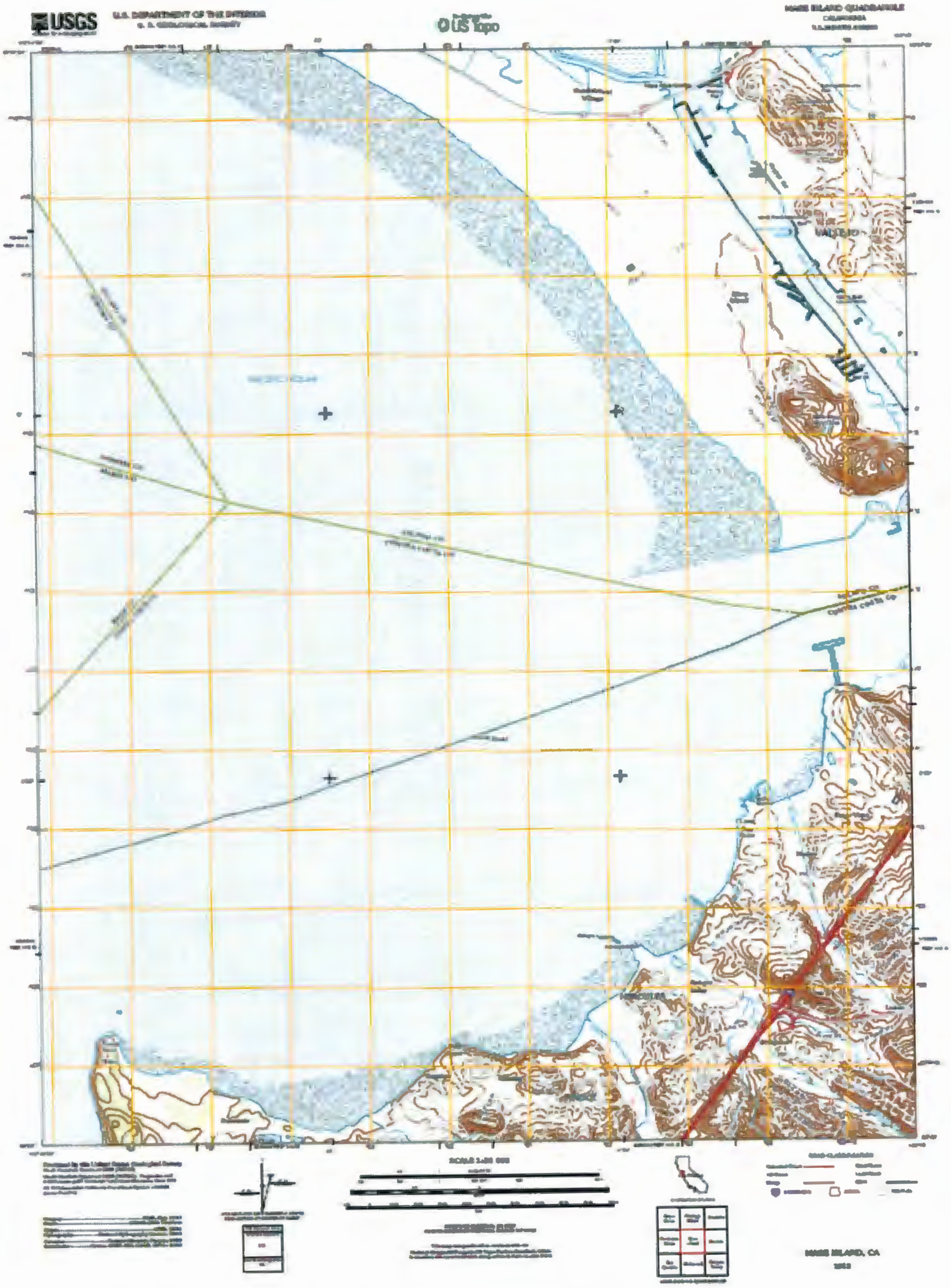

Figure 35 Mare Island (USGS, 2012)

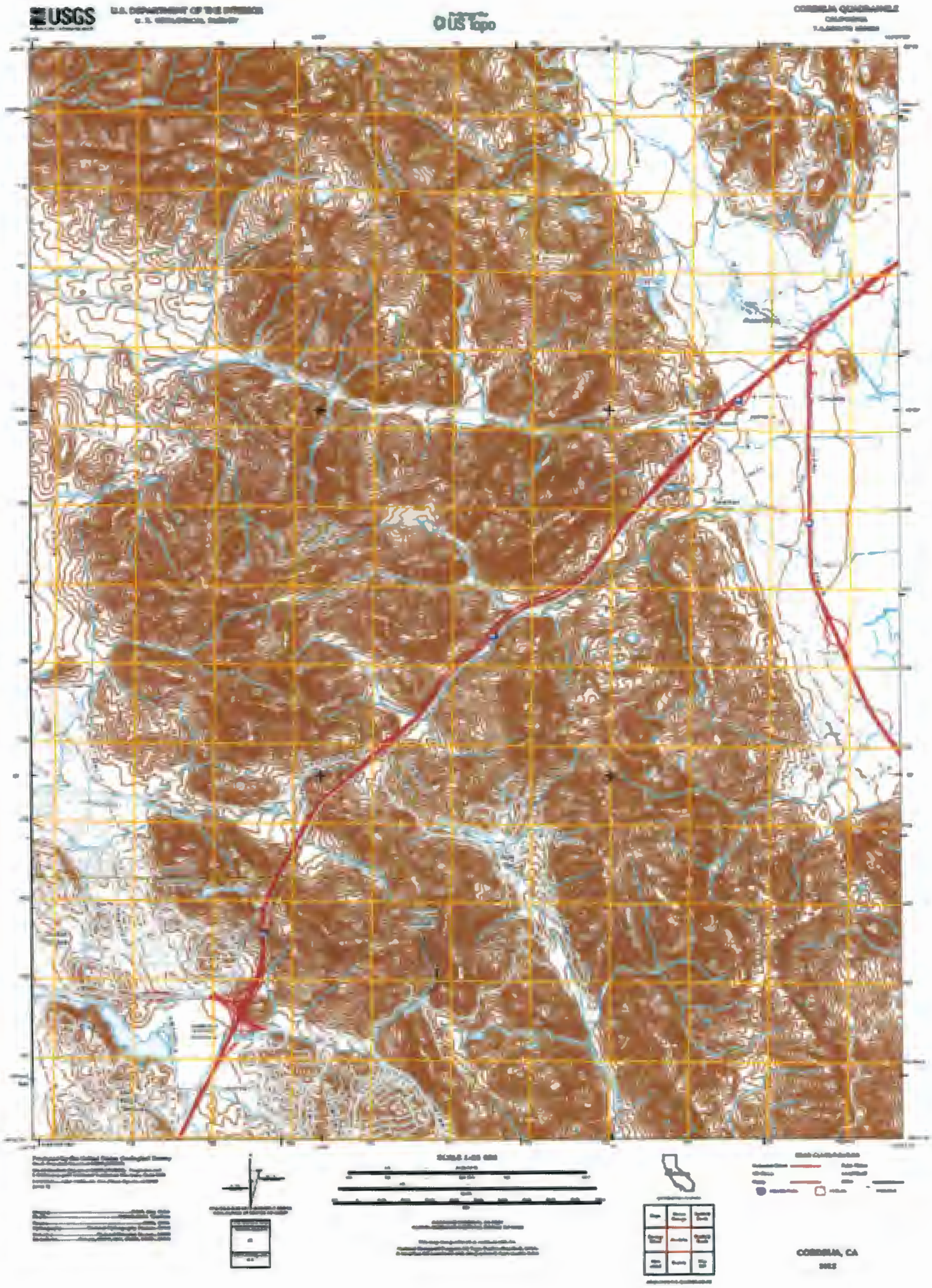

Figure 36 Cordelia (USGS, 2012)

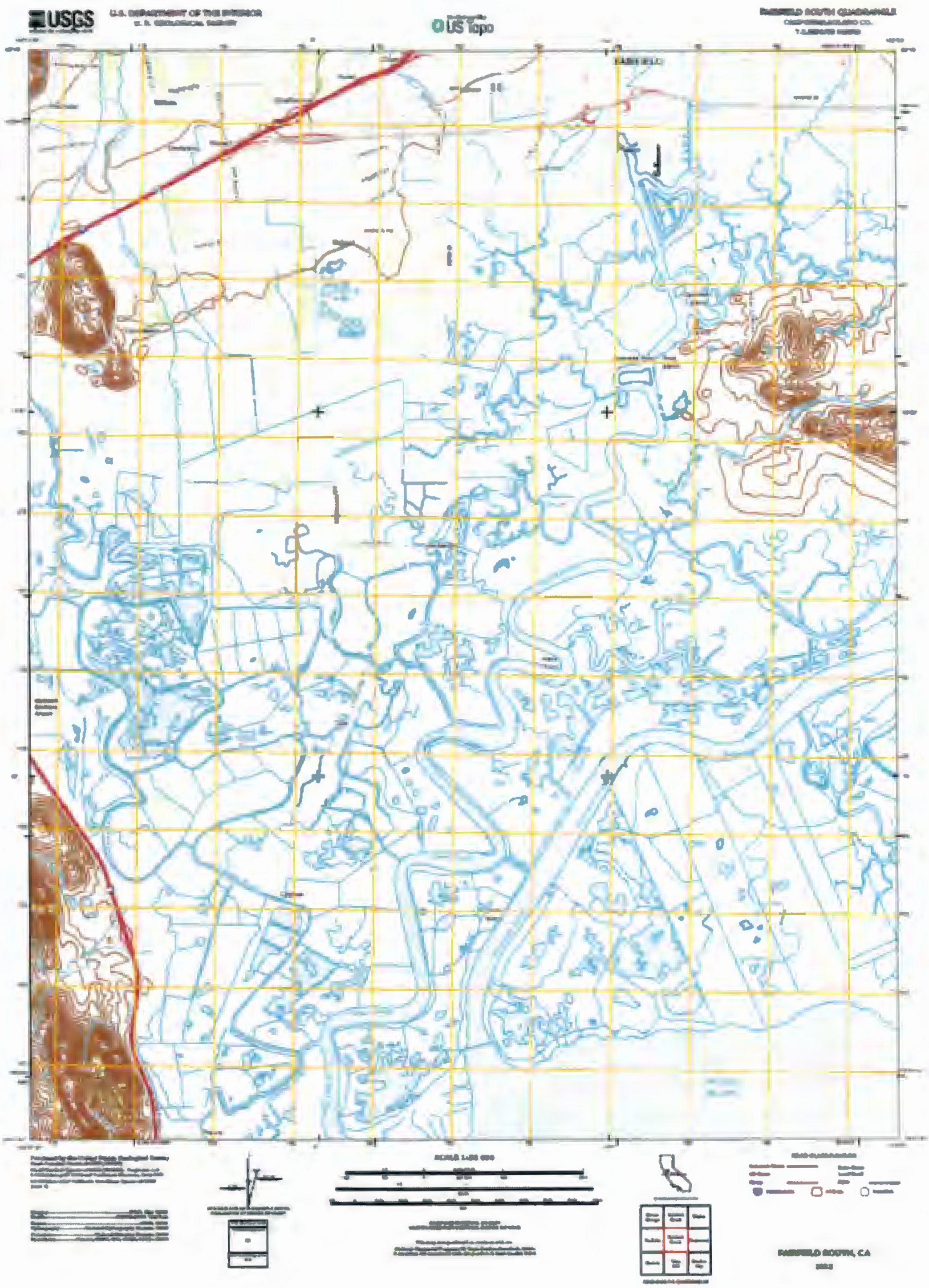

Figure 37 Farifield South (USGS, 2012)

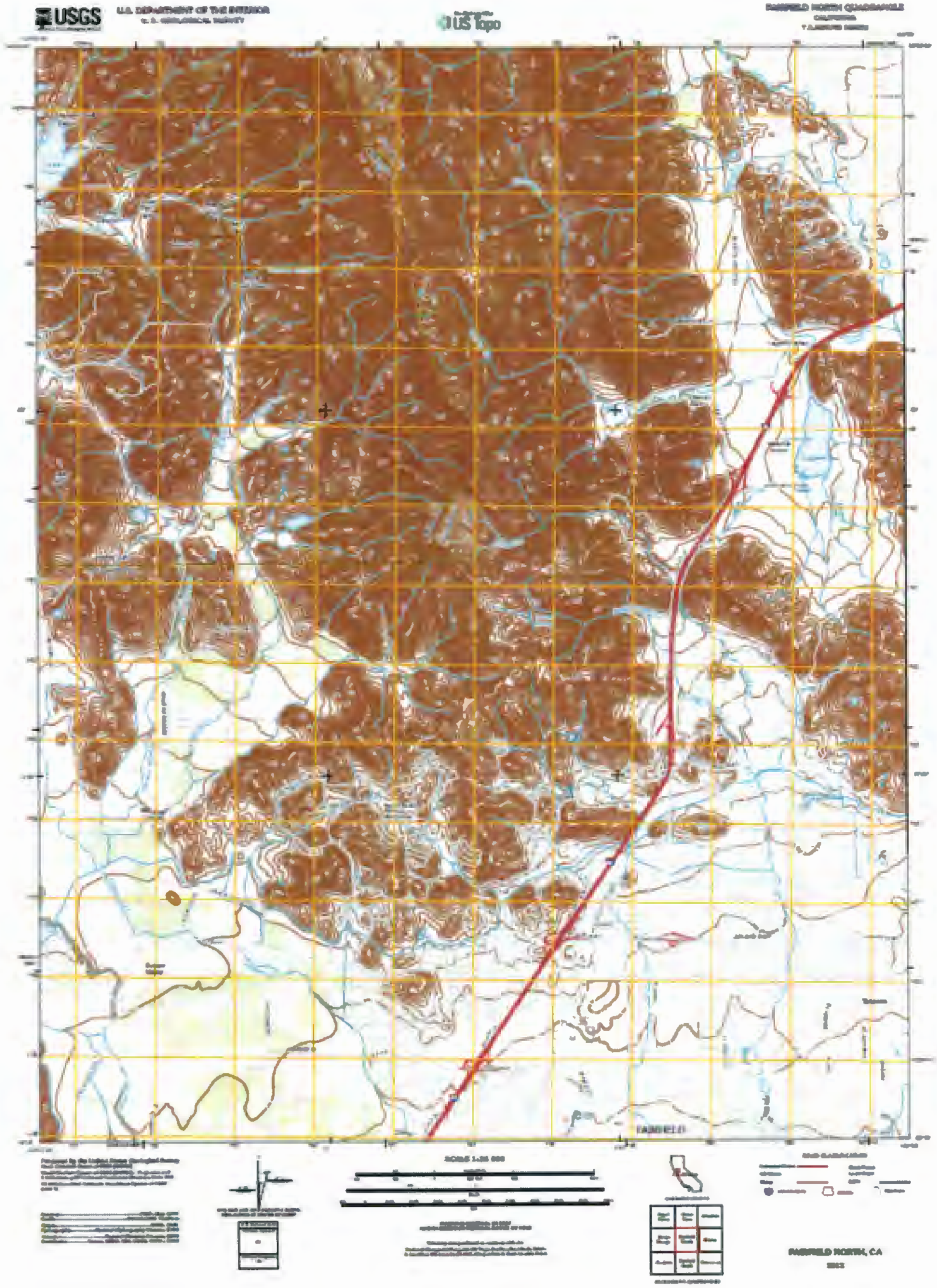

Figure 38 Fairfield North (USGS, 2012)

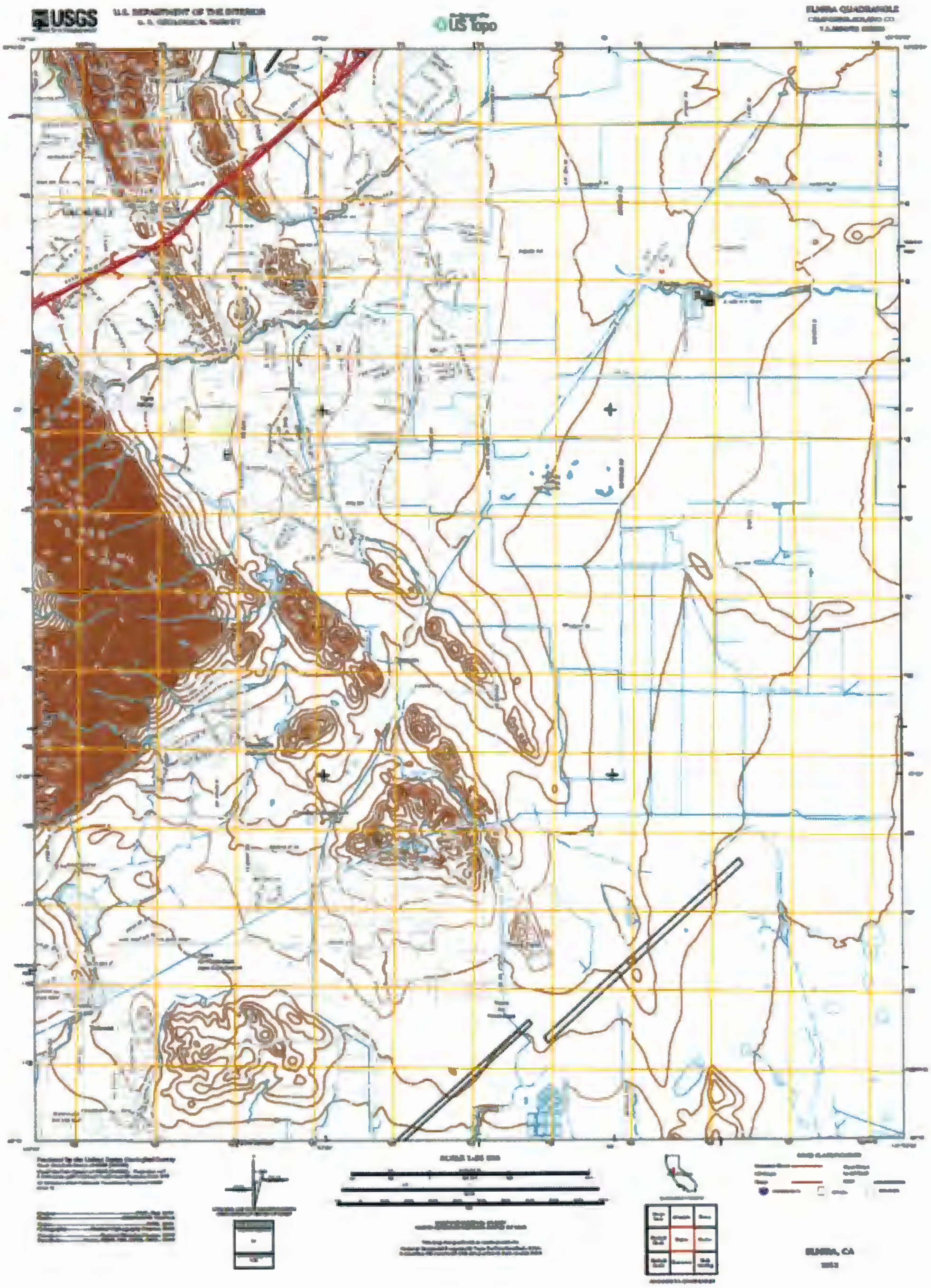

Figure 39 Elmira (USGS, 2012)

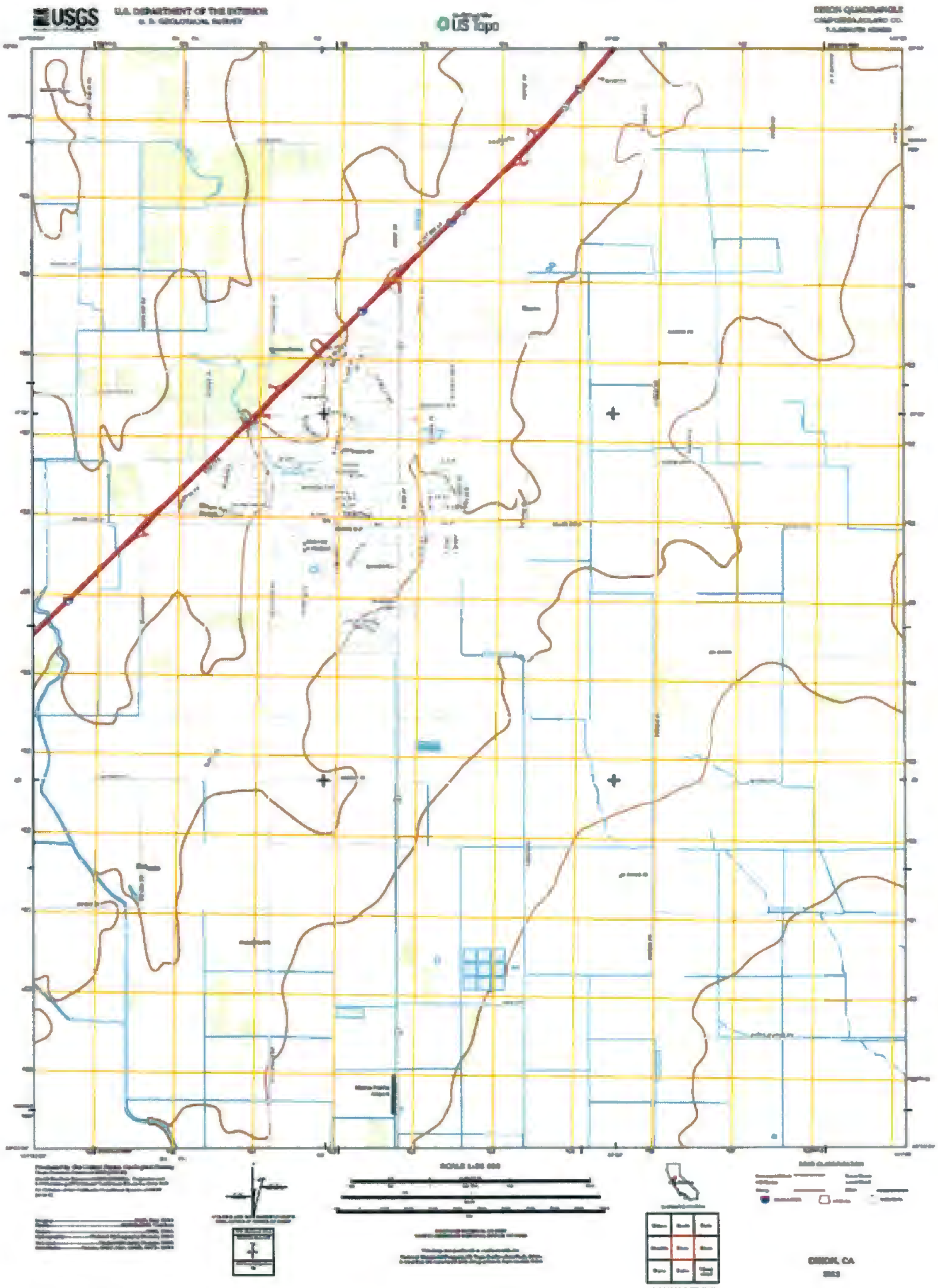

Figure 40 Dixon (USGS, 2012)

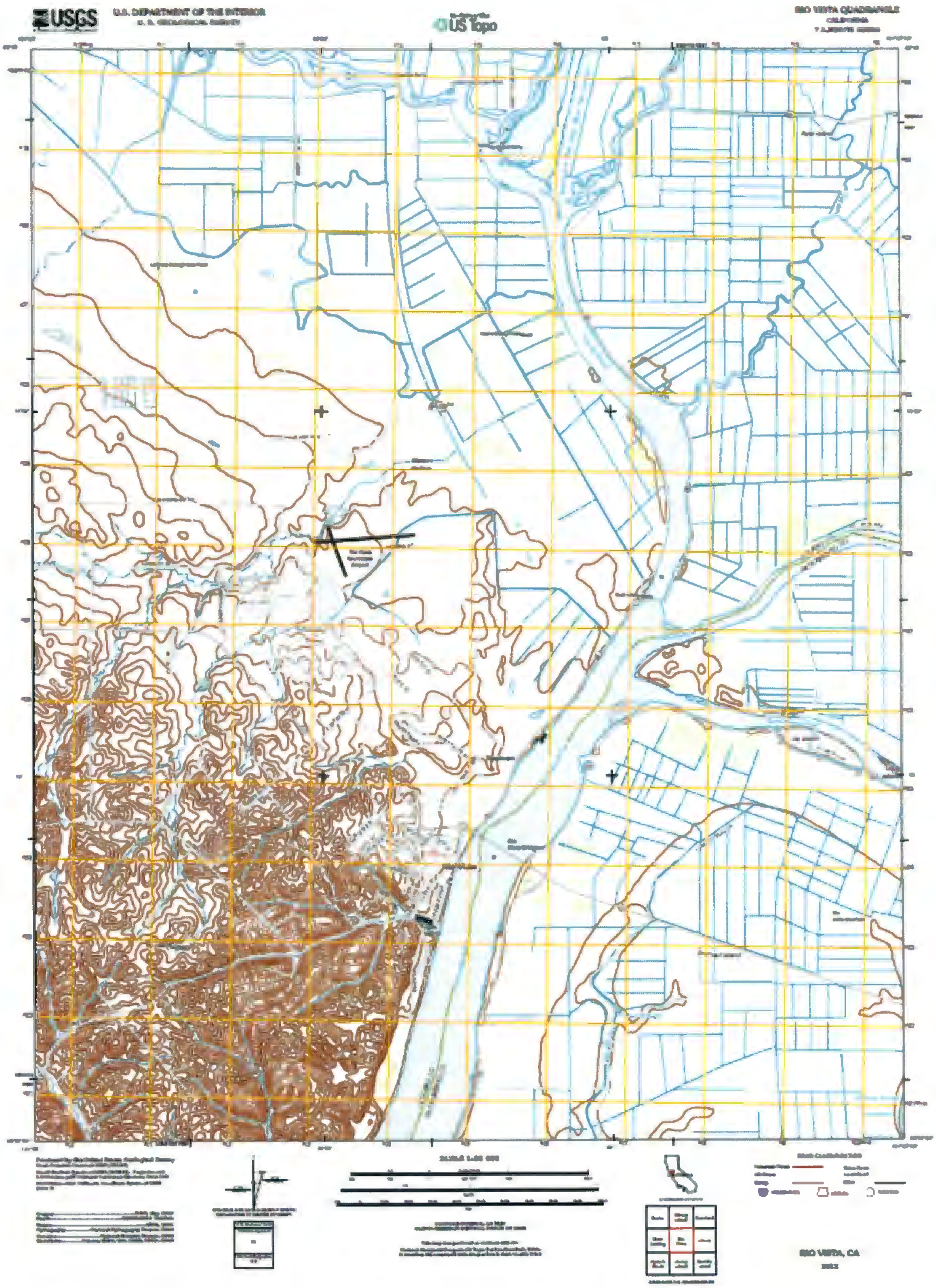

Figure 41 Rio Vista (USGS, 2012)