AN EXAMINATION OF THE DESALINATION PROCESS AND FACILITY

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Thank you to my advisor and mentor Kelly Main, for guiding me throughout my undergraduate career. None of this would be possible without her support, patience, and dedication.

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Chapter 1 – Introduction

According to California's Department of Water Resources (2015), 95% of the total population in California - 37,034,027 - has been affected by the drought this year. Drought conditions have forced us to reevaluate our view and use of water. The purpose of this project is to evaluate desalination as a solution to the water crisis.

Water, as a resource, is becoming limited throughout California and it is necessary to examine alternative ways of providing water. Presently, the State has approximately one year of water supply left in its reservoirs, and the backup supply, groundwater, is rapidly depleting. In May 2014, an analysis showed that 100% of California was already under "Severe Drought" and that the 2014 drought is considered the worst in 1,200 years (California Department of Water Resources, 2015).

Being located near the coast, San Luis Obispo has the chance to capitalize on using the ocean as a nearby resource. Desalination has been used throughout the world for many years. Currently in the State of California, only Sand City, Santa Catalina Island, and San Nicolas Island have fully operational desalination plants. However, greater than 25 cities along the coast of California have recently proposed desalination facilities (Finley, 2014). Desalination is becoming a popular method to provide water for areas that are suffering from water shortages. This surge has required agencies and practitioners to have a steep learning curve.   Many areas throughout California are looking at alternative methods in providing water and best practices.

The role of a planner is providing community members with the necessary resources for today and the future. Water is a key resource and it dictates the success of a city. Presently, water use is exceeding replenishment rates and water reservoirs are depleting rapidly. Scientists have projected that the Sierra snowpack, the State's main water supply, will decrease by 25% by 2050 (Basu, 2014). With the anticipation of low levels of rain and snow in the future, it is possible that cities will be unable to provide water. Planners are starting to look at alternatives in providing water and desalination is viewed as a potential new water supply. This report will provide recommendations based on the examination and assessment of current desalination practices.

Chapter 2 - Background Literature

Desalination has been practiced around the world for over 50 years. Many countries, including the US, use desalination facilities to provide water where little to no fresh water is available. It is estimated that greater than 75 million people worldwide obtain fresh water by utilizing desalination practices (Betts, 2004, pg. 12). California's Water Plan calls for the production of 400,000-acre feet of desalinated water by 2030. On November 4, voters passed Proposition 1, which allows the State to sell $7.1 billion in bonds for water. Part of that, roughly $750 million, is going to be split among regional water districts for water related projects like construction of desalination plants (California Department of Water Resources, 2015).

Many view desalination as a solution to the water crisis. Some people view the ocean as an unlimited resource that can resolve any water issue through the process of desalination. Peter MacLaggan, head of the Carlsbad Desalination Project and Poseidon Water Company's Senior Vice President of California – Project Development, stated the following:

> "The Carlsbad desalination plant is an attempt to develop new water supplies within our boundaries that are locally controlled, drought-proof and not conditioned upon snow, rainfall and other climatic conditions. We have an endless supply of water in the Pacific Ocean and that's what we're all about in the desalination project" (Garske, 2013).

This chapter reviews the existing literature on the desalination process, the benefits, and the challenges.

The Process

Desalination is the process of taking saltwater and turning it into fresh water. There are many ways to do this, but two of the most popular ways are reverse osmosis and multistage flash. A substantial majority of the water produced through the practice of desalination, 90%, uses one of these two processes. The other 10% is produced using multiple effect distillation, electrodialysis, and/or vapor compression (Betts, 2004, pg. 16). This report will focus on the two main approaches, reverse osmosis and multi stage flash, since they are the most widely used and most successful for large quantity production. Facilities can process saltwater from multiple sources like oceans, seas, and/or brackish groundwater. Brackish water, or briny water, is water that has more salinity than fresh water, but not as much as seawater. Both processes start with pumping the saltwater to the plant. There are two methods for drawing saltwater into the system- pumping from below the sea floor and pumping directly from the ocean. The first method is more costly but taps into a water system that is less brackish or salty. The latter method is easier but can have a greater risk of impacting nearby marine life. The California Coastal Commission is studying both methods for feasibility and will report their findings before the end of the 2015 year (Starratt, 2004, pg. 4).

Multistage flash uses heat to boil the water and transform the saltwater into fresh water. The water is brought to a boil multiple times and the vapor produced is collected. The collected water vapor is fresh water and safe to drink. The multi-stage flash process is based on the idea of flash evaporation. The process uses a combination of heating and pressure reductions to remove the salt from the water through evaporation. The first stage is pumping the saltwater through trash rakes and screens to remove any debris. Then the saltwater is pumped into a chamber where the water is heated by boiling it or adding chemical additives that generate heat. The next stage is pumping the heated saltwater into the evaporator flash chambers. The evaporator is made of multi-stages, typically containing 10-28 stages in modern large plants. In each stage the introduction of saltwater into each chamber causes it to boil rapidly due to flashing or rapid heating. At each stage, or chamber, orifices and baffles are used to reduce the water pressure slightly which helps with the evaporation process. Also, at each stage, demisters are used to minimize carryover of brine droplets. If an acid is used to heat the water, an extra stage is required to remove by-products caused by the chemical reaction. In the final stages, the water vapor is cooled and condensed by using incoming colder saltwater which in turn absorbs the generated heat and initiates the start of the process. Lastly, the desalinated water is finalized by going through a post-treatment process that dissolves any remaining solids. The water is then pumped to a nearby water distribution facility and the brine, or byproduct, is discharged into the sea (Guity, 2003).

The amount of water produced depends upon the pressures maintained in each stage and the number of stages. An increase in stages can help improve plant efficiency and create better results. However, it can also increase overall plant costs as well.

Reverse osmosis involves pushing saltwater through a semi-permeable membrane that traps large molecules like salt. The pores of the membrane are extremely tiny and require a great deal of pressure to push the ocean or sea water through. Once the water has been pushed through, it is safe to drink. Reverse osmosis utilizes a system of high pressure centrifugal pumps to separate the salt from the water. Unlike multi-stage flashing, heating or phase separation change is not necessary in this process. The first step is pumping saltwater trough trash racks and screens to remove any debris. Then the saltwater flows through a multimedia gravity filter that removes suspended solids like silica or sand. The next step is passing the water through a micron filter to remove the smallest of particles. These filtration steps are necessary to protect the high pressure pumps and the reverse osmosis section of the plant. Then the water is pretreated with chemicals to eliminate undesirable constitutes that would cause membrane fouling. High pressure stainless steel pumps push the treated water through a semipermeable membrane, or reverse osmosis membrane, that restricts the passage of salts while permitting water to pass through. The most widely used and successful membrane configurations are spiral wound or hollow fine fiber. Each membrane uses cellulose triacetate and polyamide materials to catch salt particles. Lastly, the desalinated water is finalized after a post-treatment that includes disinfection, pH level adjustments, and removal of any dissolved

gases. The water is then pumped to a nearby water distribution facility and the brine, or byproduct, is discharged into the sea (Betts, 2004, pg. 21).

The design of reverse osmosis plants can greatly affect the cost of production. Various factors like membrane life, conversion or recovery ratio, power consumption, and feedwater temperatures can increase production costs. However, having a well-designed and efficient facility will help to reduce or avoid these issues (Betts, 2004, pg. 23). Also, in contrast to the multi-stage flash process, there is considerably less corrosion of materials due to fact that the water stays at ambient temperature levels throughout the process.

Within the past 10 years, there have been two major developments in the reverse osmosis process that have helped to reduce operating costs. First is the creation of membranes that can last for longer durations and operate more efficiently. Second is the use of energy recovery devices that utilize the pressure, from the stream of brine leaving the facility, to generate energy through the use of turbines (Betts, 2004, pg. 24).

Recently, there have been great technological advances in the desalination process that are helping to reduce operational costs and create a more efficient system. At the L.A. Conversation Corps' SEA Lab in Redondo Beach, a recently built desalination demonstration facility is used to test out membrane technologies, techniques for more energy efficient systems, and ways to reduce environmental impacts (Betts, 2004).

The Benefits

According to the World Health Organization, four out of ten people are affected by lack of water. Sometimes people are forced to get their water from contaminated sources that can cause serious health consequences, such as dehydration, muscle cramps, organ failure, and possibly death (Goodison, 2013).

Desalination can provide fresh water to anyone near a saltwater source. The world's surface is 70% water but 97% of it is too salty to drink. Only 0.5% of the total earth's water supply is available fresh water with the remaining 2% locked in icecaps (California Department of Water Resources, 2015). By installing a desalination facility, proponents argue that communities can create a safe, reliable, clean, fresh drinking water source.

For areas that are impacted by drought conditions, desalination can help to supplement depleted resources and/or meet increasing need. This is particularly helpful for California which is currently in a severe drought. The Pacific Institute estimated that 5% to 10% of California's water supply can come from desalination over the next two to three decades if all of the currently proposed seawater desalination facilities were built-out. However, various factors like funding, finding a location, and political opposition can affect this estimation (California Department of Water Resources, 2015).

Many cities throughout California have limited opportunities for "new" water sources and San Luis Obispo presently has no plans to acquire additional water resources. Desalination can help to meet existing or future water needs as well as being an addition to

water supply portfolios. Especially with uncertainties in future reliability of currently used water sources; desalination is regarded as a potentially reliable source (San Luis Obispo County Water Resources, 2015).

Many communities meet demands by importing water from outside sources. Particularly in Southern California, numerous regions are concerned about the reliability of importing water in the future. Even if these supplies are not currently being threatened, most communities would rather be self-sufficient and look to sources that are more “local.” Albeit San Luis Obispo does not currently import water, the reduction in available outside sources will take away any possible future options of importing for the City (Bourne, 2008, pg. 14).

Future uncertainties in water reliability concern both businesses and community members throughout the State. As drought conditions last for longer periods or occur more frequently, cities will possibly be restricted in their expansion because of water moratoriums that limit future developments. Countless areas throughout the Central Valley have experienced these types of moratoriums and were unable to develop due to water shortages (Finley, 2014).

Cities along the coast can occasionally experience contamination of groundwater sources due to saltwater intrusion. Saltwater intrusion is “the movement of saline water into freshwater aquifers, which can lead to contamination of drinking water sources and other consequences. Saltwater intrusion occurs naturally to some degree in most coastal

aquifers, owing to the hydraulic connection between groundwater and seawater" (Bourne, 2008, pg. 16). These sources become unusable and the damages cannot be reversed. With the use of desalination, these contaminated groundwater sources can be used once again. Also, since the water contains less salt than seawater, it requires less processing and therefore costs less and consumes less energy (Bourne, 2008, pg. 16).

During times of water shortages, many aquatic ecosystems throughout the State are threatened by reduced water flows. Desalination can provide less strain on existing fresh water sources and in turn reduce impacts to sensitive ecosystems. In some cases, allowing existing surface waters to sustain can help to restore some of the currently distressed aquatic ecosystems (Bourne, 2008, pg. 17).

Each of these benefits can help to improve water resources management, including both ecosystem restoration and public health. However, the use and role of desalination needs to be carefully examined and a variety of issues related to economic, environmental and other impacts, need to be addressed before decisions to use desalination can be made.

The Challenges

While desalination can potentially be a reliable, drought-resistant, high-quality water supply, various challenges have been identified and need to be addressed when proceeding with or designing a desalination facility.

One area of great concern is the impact to marine life surrounding the water intakes. The seawater that is pumped to the facility goes through a series of screens and filters

(Starratt, 2004). Large fish and organisms are pulled against the screens and filter while small organisms, like plankton, are pulled into the intakes. The majority of the large fish and organism die from the sucking pressure, while smaller organisms die throughout the desalination process. Severity of the impact is based off of factors such as water depth at the intake, the speed at which the water is being taken in, location, and type of intake. Various measures can help to significantly reduce these environmental impacts, like using intake pumps that lie beneath the sea floor. This method pumps from an area where marine life doesn't exist as well as accessing seawater that has a lower salinity. Many operating facilities at this time do not practice this technique because of high costs associated with drilling beneath the sea floor.

Another major environmental concern is the impact of the brine, or concentrated discharge. Every desalination process and facility produces some amount of brine that needs to be disposed of. Most plants discharge this salty concentrate back into the source from which the water originated. The increase in salinity levels at these discharge points can affect certain aquatic species negatively. Even small amounts of change can affect marine life and some areas have noticed a buildup of salt on the ocean floor. Various techniques, like diffusers, mixing strategies, or discharging into areas of low productivity, can help to lessen the impact. Facilities that pump from brackish groundwater sources need to use alternative methods, like discarding into landfills, to dispose the brine (Bourne, 2008, pg. 23).

Desalination requires a great deal of energy to operate large scale facilities. Both multistage flash and reverse osmosis processes require large amounts of energy either to constantly heat the water or to create a high enough pressure to push the water through the membrane. This is an issue from both an economical and environmental side. Economically, the large amount of energy needed causes operational costs to be tremendously high. High operating costs will require providers to charge higher rates than traditional methods of providing water. Environmentally, the large amounts of energy needed will require power plants to produce more in order to meet increased needs. In California, cities and counties are required to reduce GHG emissions 15% by 2020. Requiring more from power plants might inhibit cities and counties to meet this goal. However, there have been many updates to the process that have helped to reduce the amount of energy needed. One example is the creation and use of energy recovery devices that utilize the pressure of the stream of brine leaving the facility to generate energy through the use of turbines. Adding these devices throughout the facility can help to generate clean energy on site (Bourne, 2008, pg. 26).

Another challenge is determining the best location for the facility. Choosing a location encompasses multiple factors like land use compatibility, affects to recreation and tourism, impacts to wetland habitat, and environmental justice. A site will have to meet all regulatory requirements from Federal, State, and local agencies in addition to gaining support from the public sector. All of these need to be addressed through planning and design considerations to ensure the best possible site is selected (Betts, 2004, pg. 28).

Many agencies are concerned with cumulative impacts from increased numbers of desalination facilities. Currently there are three plants in operation and fifteen newly proposed plants along the coast. It is unknown what the severity of cumulative impacts might be on the ecosystem and marine life along the coast from the increase in operational plants. Some of the factors such as ocean or estuarine circulation patterns, facility capacity and design, and operational considerations can influence cumulative impacts (Bourne, 2008, pg. 28). Potential restrictions and increased monitoring will need to be incorporated into future permitting procedures to address this issue. For example, how to measure cumulative impacts or what potential restrictions to place on proximity and/or size of facilities (Bourne, 2008, pg. 29).

Ownership of the desalination facility is a possible concern. Some agencies are apprehensive about public water supplies being owned or controlled by private entities. It

will require careful planning in the early negotiating and permitting stages to ensure that private ownership will not affect communities negatively, such as charging unreasonably high costs. (Bourne, 2008, pg. 33).

Another area of concern is the possibility of contaminated feed-water. Many areas along the coast have experienced oil spills, chemical spills, algae blooms, or other hazardous events that have contaminated the ocean. Unlike groundwater, ocean water does not go through a natural filtration system that helps to remove any contaminants. The water being pumped to facility could require subsequent treatment processes to ensure that the water meets quality standards (Bourne, 2008).

Since many cities are starting to look towards desalination as an answer to the water crisis, State and local agencies are starting to generate new regulations and guidelines for these facilities. In May 2015, the California State Water Board implemented guidelines for building and operating desalination plants. This new regulation includes provisions on how water is taken into the plant and guidelines on how leftover brine should be returned to the ocean to help reduce impacts to marine life. Any existing or proposed facilities will have to comply with these new regulations. Along with these new guidelines, proposed desalination facilities will now have their intakes and discharges reviewed by the State Water Board Agency instead of only having regional boards review them. The intention of this new regulation was to address environmental issues and to provide possible techniques to reduce impacts (California Department of Water Resources, 2015).

Along with this State regulation, the Coastal Commission is generating information and guidelines to prepare for the surge of projects. Since the majority of the plants will be built within the jurisdiction of the Coastal Commission, the agency is now having to update their research on and approach to desalination. The agency is compiling studies on best practices and approaches that will have the least impact to marine life and the coast.

Another challenge for San Luis Obispo is that the City is landlocked, meaning it isn't located directly on the coast. By being over 5 miles from the coast, the City will not have the land to construct a desalination facility or have access to ocean water. Also, the City's water distribution center is located within city boundaries and will require that any treated water be pumped to the center.

Chapter 3 - Context: Water Supply and Use, San Luis Obispo County

The current conditions of San Luis Obispo's water supply are relevant to the consideration of desalination as an option for additional water. The City constantly monitors their water sources and provides real time data to the public on current reservoir conditions. This allows the City to better manage water supplies and to be aware of any issues. Also, it helps the City to initiate emergency protocols, when drought situations worsen, that require residents to reduce their water use (San Luis Obispo County Water Resources, 2015).

This chapter reviews the current water situation in the City of San Luis Obispo and how future factors will affect water supplies.

Existing supply

The City of San Luis Obispo uses a multiple water source concept to meet projected short and long-term demand. The sources are diversified as far as type (i.e. surface water and groundwater) and location (i.e. different watersheds throughout the area). This helps to reduce dependency on one single source and can lessen impacts from supply reduction or emergency situations like severe water shortages. There are five sources from which the City draws: Salinas Reservoir (Santa Margarita Lake), Whale Rock Reservoir, Nacimiento Reservoir, recycled water from the City's Water Reclamation Facility (WRF), and groundwater (San Luis Obispo County Water Resources, 2015).

Salinas Reservoir

The Salinas Reservoir, or Santa Margarita Lake, is located north of San Luis Obispo. The dam was built in 1941 to meet the water supply needs of Camp San Luis Obispo and, secondarily, the needs of the City. The reservoir captures water from a 112 square mile watershed and can store up to 23, 843 acre-feet. The water is pumped through the Cuesta tunnel, a tunnel through the mountains of Cuesta Ridge, then to the City's Water Treatment Plant by gravity (San Luis Obispo County Water Resources, 2015).

Whale Rock Reservoir

This reservoir is located near Cayucos and was created by constructing an earthen dam on Old Creek. Since 1961, it has provided water for the City of San Luis Obispo, Cal Poly State University, and the California Men's Colony. The dam captures water from a 20.3 square mile watershed and is pumped to the three agencies with the City owning 55.05%, Cal Poly owning 33.71%, and Men's Colony owning 11.24% (San Luis Obispo County Water Resources, 2015).

Nacimiento Reservoir

This reservoir is located north of San Luis Obispo and is a supply for groundwater recharge for the Salinas Valley. It also provides flood protection. The San Luis Obispo County Flood Control and Water Conservation District has an entitlement to 17,500 acre-feet per year (AFY) of water from the reservoir with

1,750 AFY designated for uses around the lake. The reservoir is owned and operated by the Monterey County Water Resources Agency (San Luis Obispo County Water Resources, 2015).

Recycled Water

This source is primarily used for landscape irrigation and construction dust; not for dinking. The water is pumped throughout the City in pipelines known as "purple pipe." This reused water is treated at the City's Water Reclamation Facility and is the City's first new source since 1961. Depending on the amount of wastewater entering the facility, the City can provide approximately 1,000 acre feet of recycled water for approved uses (San Luis Obispo County Water Resources, 2015).

Groundwater

The groundwater basin is located beneath San Luis Obispo. It is relatively small and can recharge quickly after normal rainfalls. However, it can lower quickly in below-average rainfall periods. Unfortunately portions of the groundwater basin is contaminated and requires additional treatment processes to remove contaminates. The City produces approximately 11 acre-feet per month from one well, which is roughly 2% of the City's total water use (San Luis Obispo County Water Resources, 2015).

Current use

San Luis Obispo Water Distribution Center currently serves the entire community within City limits. The multiple water sources the City uses meets 100% of the total water demand needed. Below is a diagram (Figure 1) showing the divide of water use

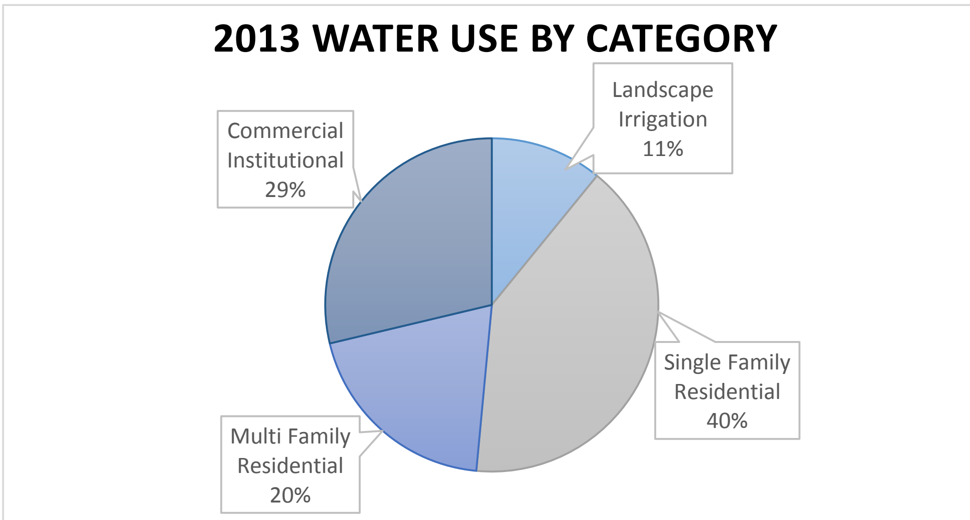


Figure 1 - Source: (San Luis Obispo County Water Resources, 2015).

by category with 40% to Single Family Residential, 29% to Commercial Institutional, 20% to Multi Family Residential, and 11% to Landscape Irrigation.   Figure 2, shows a breakdown of water uses within a single family home (San Luis Obispo County Water Resources, 2015).

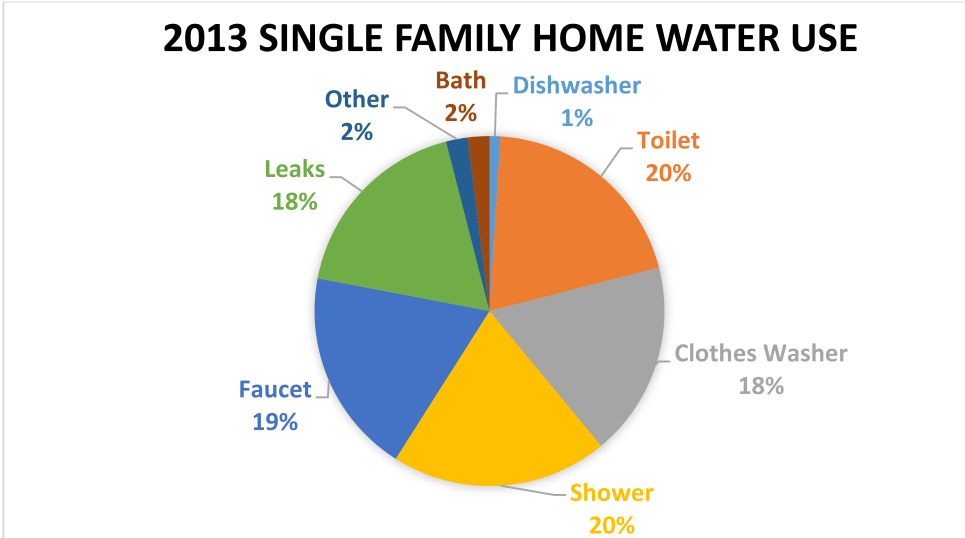


Figure 2- Source: (San Luis Obispo County Water Resources, 2015).

The City primarily uses two reservoirs to serve as the main water supply: Salinas & Whale Rock. Below is a table (table 1.1) showing information on current amounts of water and total storage capacity. The Salinas Reservoir is at 16.18% of its' total and Whale Rock is at 42.07% of its' total. The City describes these sources as "Primary water supply" which is defined as the amount of water needed to serve the build-out population. The build-out population includes the current population and possible future growth of the population. The "Reliability Reserve" is defined as a buffer to future unforeseen or unpredictable long-term shortages to the City's main water supply. Water sources under this definition may not be used by proposed developments as a permanent water source and is intended to serve only existing populations during times of significant water shortage. The last category is "Secondary Water Supply" which is defined as the amount of water remaining from the City's available water resources above those amounts needed to meet the primary water supply and reliability reserve. This category is mainly used to meet peak water demand periods or short-term loss of the City's main water supply. All three of these categories

were designed to ensure that San Luis Obispo will have sufficient water supply for current or future populations as well as in times of water shortages (San Luis Obispo County Water Resources, 2015).

Table 1.1 – 2015 Salinas and Whale Rock Reservoirs

	Salinas Reservoir	Whale Rock
Current Storage (Acre Feet)	3,857.90	16,394.50
Capacity (Acre Feet)	23,842.90	38,966.50
% of Total	16.18	42.07
Water Elevation (FT)	1,254.13	169.00
Max Water Elevation (FT)	1,300.74	218.30
Seasonal Rainfall (Inches)	10.5	n/a

Source: (San Luis Obispo County Water Resources, 2015).

Current approaches to water conservation

Water conservation practices have been mandated for many cities throughout California (California Department of Water Resources, 2015). For example, implementing restrictions on washing vehicles or offering incentives for planting drought-resistant lawns, shrubs and plants. San Luis Obispo has taken action, through water conservation techniques, to address issues of drought and general limitations on water availability. After a serious drought from 1986 to 1991, the City created a contingency plan to address immediate and short-term water shortages. The plan was designed to take action when there is a projected three year supply of water remaining from available water resources.

Essentially, the plan creates a surcharge for water users who exceed either their historical water use or average water use for the area.

In 2009, the California Senate passed a bill that required water agencies to reduce water use 20% by 2020. This decision was based on a three-year drought, 2007 to 2009, rated by California officials as “critically dry.” After reviewing current best practices by water purveyors, environmental groups, and industry stakeholders, these were determined to be the best conservation practices (California Department of Water Resources, 2015):

- Water conservation pricing and rate structures
- Technical assistance for water customers
- Incentives for indoor and outdoor water saving technologies
- Public information and outreach
- Water audits

In April 2015, Governor Brown signed an Executive Order that required cities and towns across California to reduce water use by 25%. This conclusion came after California experienced the worst three-year drought in State’s history. The order listed a variety of measurements to be implemented, as well as “carrot and stick” methods to help change current water behavior. The order focuses on four main ideas: Saving water, increasing enforcement, streamlining government response, and investing in new technologies (Zeman, 2015, pg. 3).

The first section of the executive order discusses practices on how to save more water now. Some of the practices include replacing lawns throughout the State with drought-tolerant landscaping, requiring campuses, golf courses, cemeteries and others to significantly reduce their water use, and creating a rebate program to replace old appliances with more water and energy efficient models. Also, there will be more pressure on new homes and developments to install water-efficient systems for both inside and outside the homes or developments (Zeman, 2015, pg. 6).

The second section is designed to encourage water conservation and discourage water waste. This section was meant to focus on agricultural water users and force local water agencies to take more action in reducing water use. Some of the practices include better monitoring of water used by farmers as well as creating plans to help agricultural communities prepare for the possibility of drought next year. Also, it calls upon local agencies to enforce updating standards and better reporting of water usage and supplies (Zeman, 2015, pg. 7).

The third section focuses on creating a more efficient system to address emergency drought situations. Some of the practices include temporary relocation for families who have wells that have run dry, streamline permitting and review of emergency drought salinity barriers, and prioritization of any pending water infrastructure projects (Zeman, 2015, pg. 9).

Lastly, the final section looks to encourage new technological practices to help make California more drought resilient. This mainly focuses on incentivizing promising new technology that helps to be more water efficient. For example, additional State funding is being allocated to the Pacific Institute who is researching various cell membrane materials that are more resilient and require less maintenance, which in turn can lower operational costs. This program is directed under the California Energy Commission (Zeman, 2015, pg. 12).

Factors affecting future supply and use

There are two main factors that can possibly affect future supply and use: population growth and climate change. According to the US Census Bureau, San Luis Obispo's population is 46,377 people and the City provides water to that entire population. The City of San Luis Obispo has grown a little over 1,000 people, or 2% growth, in the last decade which is shown on the table below (table 1.2). In addition, the overall total water used per year has decreased approximately 500-acre feet, even with the growth in population (San Luis Obispo County Water Resources, 2015). Since population growth in San Luis Obispo has been minimal over the past 10 years, only increasing by roughly a thousand people, it does not pose much of a threat to the future water supply. Also, cities can regulate and limit how large their city grows, which means they can more easily monitor their supply and demand.

Table 1.2 – Annual Water Totals and Population

Year	Population	Total Water Use (acre feet)	Per Captia (gpcd)	Rainfall (inches)
2004	44,298	6,239	125.7	21.0
2005	44,687	6,098	121.8	20.8
2006	44,559	6,000	120.2	17.2
2007	44,433	6,494	130.5	12.7
2008	44,579	6,359	127.3	18.1
2009	44,829	6,134	122.2	18.9
2010	44,948	5,489	109.0	36.0
2011	45,418	5,285	103.9	18.9
2012	45,308	5,541	109.2	21.5
2013	45,541	5,892	115.5	3.8

Source: (San Luis Obispo County Water Resources, 2015).

However on a larger scale, California projects an overall growth of 600,000 people in the next year, and the California Department of Finance has predicted that the total population in 2050 will be roughly 60 million people which is almost double of the current State population (California Department of Finance, 2014). Even if San Luis Obispo's population growth is minimal, the anticipated overall State growth might impact local water supplies through increases over water battles or limitations on purchasing any additional water supply sources. In general, California's rapid population growth will put increased strains on already overstretched public works and natural resources.

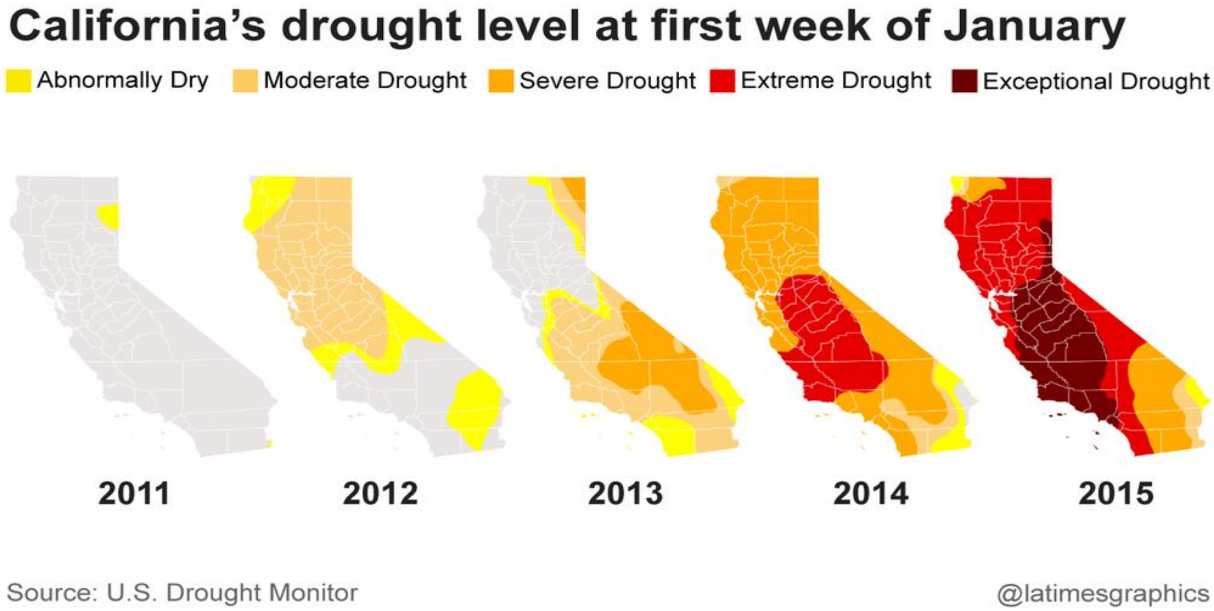
Climate change is an enormous threat to San Luis Obispo's future water supply. Climate change is having serious impacts on snowpack, sea level, and weather patterns which in turn affect the water supply in California.

Snow-pack acts as a natural storage device collecting large quantities of water in the form of snow and slowly releasing it during spring and summer months. But effects of

climate change have resulted in the reduction of snow fall and warmer temperatures cause what we do get to melt quickly. On January 3, 2015, the State conducted its' first snow survey of the wet season and found more bare ground than snow. Statewide, the snowpack water content is just 20% of its' regular amount for this time of year. The Sierra Nevada snowpack is the State's main water supply and provides about one-third of the water Californians use each year. In 2014, NASA's Airborne Snow observatory estimated that there was approximately 58 billion gallons of water content in the Sierra snowpack. But estimates for 2015 show only 25 billion gallons of water content. Scientists projected that the Sierra snowpack will have a loss of at least 25% by 2050 (Basu, 2014).

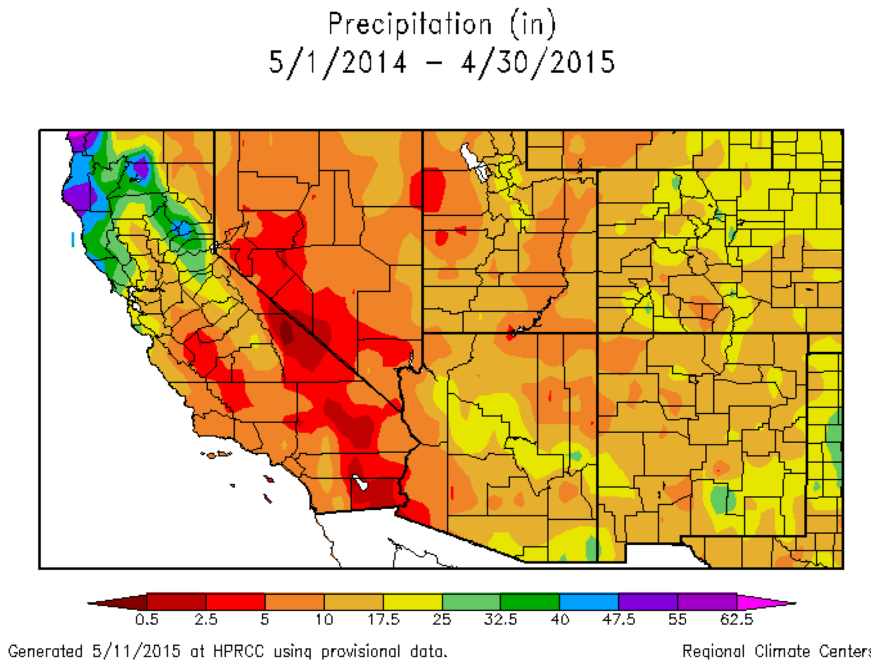
The rise in sea level threatens groundwater sources because saltwater is denser and pushes inland beneath freshwater aquifers which in turn becomes contaminated with salt. Seawater contains about 35,000 parts per million of salt. Drinking saltwater can be detrimental to our health because the body can't process large quantities of salt. Similarly saltwater cannot be used for agricultural or industrial uses (Basu, 2014).

Variable weather patterns have led to serious drought conditions in California. Droughts are defined as a condition of water shortage for a particular user in a particular location. The magnitude of the drought can vary from one region to the next. Many parts of California — including Sacramento and Los Angeles — marked calendar year 2015 as the driest on record. Drought is directly tied to water supply conditions, but different criteria is used to judge this like rainfall/runoff totals, amounts of water in storage, or expected supply from a water wholesaler. Most areas throughout California are defined as either



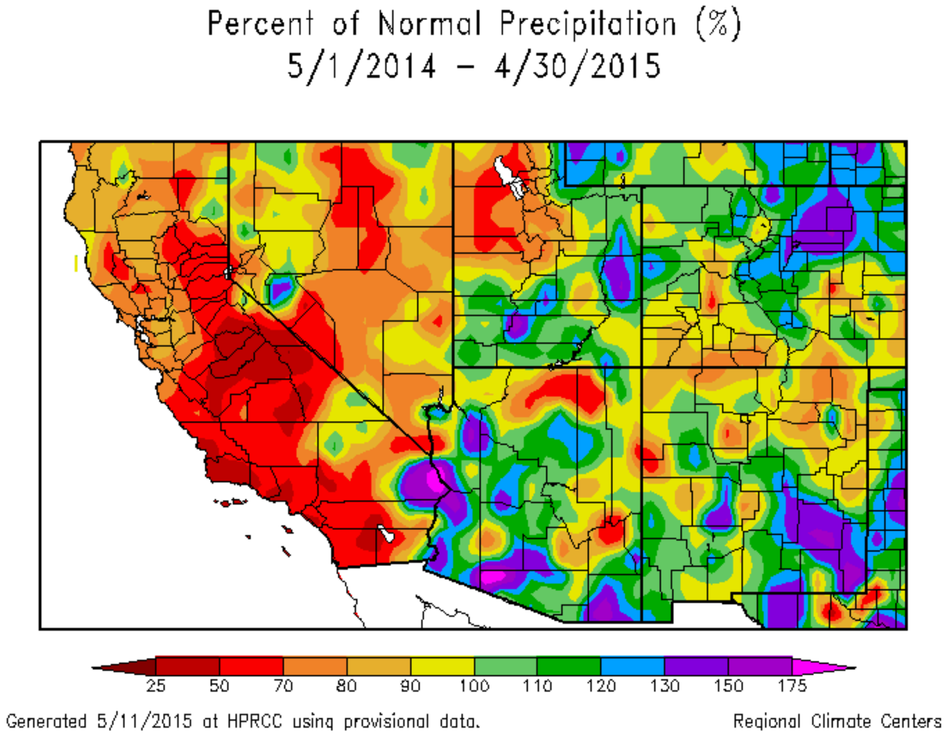
being in an extreme or exceptional drought (Finley, 2014). Over the past year San Luis Obispo has moved from extreme to exceptional drought conditions. Drought conditions worsen over time because water use exceeds its yearly snow/rainfall replenishment. Drought impacts become exacerbated as carry-over supplies in reservoirs are depleted and water levels in groundwater basins decline. Storage in large reservoirs that typically help California survive dry seasons is 72% below average for this time of year. The State's two biggest reservoirs, Shasta and Oroville, are both at 57% of historical levels for the date (Finley, 2014). The current drought has been ongoing for the past four years and it unknown if or when it will end.

San Luis Obispo relies on rainfall to replenish reservoirs and groundwater basins but this year has had record low rainfall totals. The rainfall total for 2014 was 9.69 inches, while predictions for 2015 are less than five inches total.



Source: California Department of Water Resources, 2015

The total rainfall for the past year has been 68% below normal precipitation. San Luis Obispo’s two main reservoirs, Salinas and Whale Rock, are at a total capacity of 16% and 42% respectively (San Luis Obispo County Water Resources 2015). If drought conditions persist and water use continues to exceed replenishment rates, then reservoirs and groundwater basins could potentially be an unreliable source.



Source: California Department of Water Resources, 2015

With future uncertainties and current conditions worsening, cities and counties will need to look towards alternative water sources in addition to increasing water conservation practices.

Chapter 4 - Methods

This chapter reviews the methods used to address questions raised in Chapters 2 and 3 of this project, regarding desalination and its potential use to address water shortages. In order to accomplish the goals of this report, research was conducted around five main questions, already discussed in Chapters 2 and 3 and repeated here. Research was conducted by reviewing current literature published in professional journals, existing desalination facilities, periodicals, books, organizations, and websites.

Question: What are the current issues with water?

It is necessary to establish existing issues with water availability and meeting the needs of a growing city. By answering this research question, it will give the necessary background to ascertain the issue of water shortage and the need for a solution.

Question: Do the benefits outweigh the costs?

This question is designed to understand if the desalination facility will provide enough water to address any issues. It is necessary to determine if the desalination production will be worth it since there are various environmental impacts caused by the process.

Question: What are the indicators and characteristics of a successful desalination facility?

In order to determine if a desalination facility is successful, it is necessary to understand the criterion used in evaluating success. Answering this question helps to

establish the successes and failures of current practices. Also, it assists planners in executing a plan that addresses the issues and successfully uses best practices.

Question: Can the environmental impacts be mitigated?

This question helps to identify existing environmental impacts and techniques used to lessen or avoid these impacts. It is important to understand how the process affects the environment and what can be done to minimize the impact. It also looks at current practices and determines if other measures could be taken to lessen damages.

Question: What is the planner's role in water as a resource?

By understanding the planner's role in providing water, it will help to create a resource that meets the needs of the community in an informative and practical way. It will also help to strengthen the development and implementation of a desalination facility.

Chapter 5 – Case Studies

The Carlsbad desalination plant is the largest in the Western Hemisphere. After twelve years of planning and over six years in the State's permitting process, the Carlsbad Desalination Project has received final approvals from every required regulatory and permitting agency in the State. The idea for a desalination facility came after a rough five year drought that left officials wanting a reliable, drought-proof water resource. The project will cost $900 million, funded by bond sales, to build the seaside plant and 10 mile pipeline. It will draw in approximately 100 million gallons of ocean water a day and run it through a reverse osmosis filtering system. This will produce 50 million gallons of drinking water per day, which roughly serves 300,000 people. The City planned to have the plant open and operational by 2016 but due to the severity of recent drought conditions the completion date has been moved up to November 2015. By 2020, it is anticipated that it will account for 7% of the region's water supply (Carpio, 2015).

Poseidon Water Company is constructing the desalination facility in Carlsbad and specializes in developing and financing water infrastructure projects, primarily seawater desalination and water treatment plants. Poseidon's projects are implemented through a public-private partnerships that provides a water supply for public use through private financing for construction and operation of the treatment facilities.

A 30-year Water Purchase Agreement is in place between the San Diego County Water Authority (SDCWA) and Poseidon for the entire output of the plant. The City of

Carlsbad, located within the San Diego Water Authority district, will be the location of the plant and a recipient of the treated water (Garske, 2013).

Carlsbad's population is currently 112,299 with an expected growth of 4.63% by 2017. This growth in population and past experiences with water shortages has led the City to look towards alternative methods for water sources. Currently the City imports 70% of its water from outside sources and the remaining 30% comes from local groundwater basins. The City has determined that immediate and pressing water needs cannot be accomplished without some investment in saltwater desalination. By building this desalination facility, the City hopes to accomplish four main goals (Carpio, 2015):

- Provide a local source of potable water to supplement imported water supplies;
- Improve water supply reliability;
- Improve water quality;
- Complement local and regional water conservation and water recycling programs.

The following sections will provide an overview on the location of the facility and the benefits and challenges associated with the desalination plant.

Location

The City of Carlsbad looked at several sites to determine that the best location for the desalination facility is the Aqua Hedionda Lagoon. The lagoon is a 388 acre man-made,

shallow coastal embayment along the Pacific Ocean. Currently on the site is the Encina Power Station that is expected to be decommissioned in the coming years. Since the power plant used seawater to cool the reactors, it was an ideal location for the desalination facility because it could use the power plants existing methods of pumping and discharging water to and from the facility. Also, the location helped achieved the City of Carlsbad Redevelopment Plan goals of converting and relocating the power plant. The desalination facility will only use a six acre parcel and leave the majority of the property for potential recreational or redevelopment activity at some future date (Voutchkov, 2008, pg. 9).

Source: City of Carlsbad, 2014

The other major component of the project is the construction of the outtake pipeline that pumps the drinking water to the distribution center. The conveyance pipeline is a 10-

mile, 54-inch water delivery pipeline that will travel eastward from the seawater desalination plant through Carlsbad, Vista and San Marcos to the San Diego County Water Authority's Second Aqueduct connection facility in San Marcos (Garske, 2013).

Another factor in choosing this site was its vicinity to the ocean. Since desalination plants require large quantities of saltwater, it is essential to be as close as possible to the source because pumping saltwater long distances is extremely costly. Saltwater is very corrosive and the pipelines used to pump the ocean water require a great deal of maintenance. Having a multitude of pipelines pumping ocean water increases operational cost of the facility and in turn increases the overall cost of the product.

Source: City of Carlsbad, 2014

Benefits

The decision to build the plant came after officials believed that there were numerous benefits associated with the desalination facility. The Carlsbad City Council found that “the desalination plant serves an extraordinary public purpose.” The following section will review some of the benefits of building the Carlsbad Desalination Plant, like creating a new water supply, boosting local economies, and accomplishing City goals.

Leading authorities argue that desalination produces a high quality drinking water that will compare favorably with existing supplies. Many worry that water produced from the desalination process will not be the same quality as fresh water sources like groundwater basins. However, the water produced is highly filtered with a low mineral content. Numerous areas are experiencing high mineral concentrate in the water pumped from groundwater basins due to accumulation. Since reservoir levels are at an all-time low, the water being pumped is essentially from the bottom of the basin, where minerals have accumulated over time. This requires suppliers to further treat the water because high mineral content can be perceived as tasting unpleasant and can lead to mineral build-up in pipes (Rock & Mclean, 1995).

The water produced will meet the requirements of various State and regional plans. The California Department of Water Resource's Water Plan specified that regions needed to create 275,000 acre feet of desalinated water by 2025. The Metropolitan Water District of Southern California's Plan indicated that 150,000 acre feet of desalinated water needed to be produced each year by 2020 in the Southern California region. The San Diego Water Authority's plan identifies the need for 56,000 acre feet of seawater desalination per year from the Carlsbad project by 2016. This project will provide 56,000 acre feet per year of new water supply for the San Diego region and will meet the requirements of all State and regional plans (Voutchkov, 2008).

The Carlsbad Desalination Project officials argue that it will help to boost the local economy. The City estimates that the facility will generates up to $5.3 million per year in

increased property and business tax revenues. Also, the project will create 2,300 construction jobs and 500 new permanent jobs. Although the City isn't financially struggling, the increase in revenue can help to update other areas of weakness for the City (Carpio, 2015). However, according to Michael Hiltzik's article, Desalination plants aren't a good solution for California drought, the San Diego County Water Authority will be paying $110 million a year regardless if the region needs the plant's water or not. This suggests that during periods of heavy rainfall where reservoirs are overfilled and the desalination water is not need, the San Diego County will still be paying for water it does not use. Water bills in the region are projected to rise by an average of $5 to$7 a month to cover the cost of the desalination facility. But, the County suggested that it might pay that much in the future for other imported water and are looking to desalination as a long term investment to mitigate a continuing water crisis (Hiltzik, 2015).

Similar situations have occurred, for example Santa Barbara invested $34 million into a desalination plant during the 1980's, only to have the plant mothballed and partially dismantled after heavy rains had returned. Today the City is contemplating restarting the facility by investing $40 million to update the plant, plus spend $5 million a year in operating costs. This could cause the average monthly bill to increase from $78 to $108 (Hiltzik, 2015). Conversely, in some areas, like San Luis Obispo, City Council members have approved an increase to water rates to maintain water funds because water conservation practices have caused decreases in revenues (Lambert, 2015). On a global perspective,

average water prices for U.S. cities are especially low and on average are half the cost compared to Australia and European nations (Little, 2015).

To mitigate some of the environmental impacts, representatives of the desalination plant have offered to help preserve and restore the coastal environmental. The project will preserve the 300 acre lagoon and its recreational and marine life resources by implementing a Monitoring and Management Plan. This plan identifies the need to monitor impacts to marine life in the lagoon and provide status updates to the Coastal Commission. Also, it will restore 66 acres of coastal wetlands in South San Diego Bay and plant 5,000 trees in areas damaged by local wildfires (Voutchkov, 2008). However, few studies have monitored the long term environmental impacts of a desalination plant as large as the Carlsbad facility (Little, 2015).

In addition, the project will help to achieve the goals of the Coastal Act to maintain, restore and enhance public access and recreation and maintain, restore and enhance the marine environment through the preservation of more than 15 acres of lagoon and ocean front land for public purposes. Also, this helps to satisfy the requirements of the permit issued by the Coastal Commission (Carpio, 2015).

Ultimately the biggest benefit of the project is that the City will have created a new water supply to help ease the water shortage impacts from the drought. The San Diego Water Authority argues that, within a decade, desalinated water will become less expensive, particularly as fresh water supplies become more limited and therefore more

costly to import (Little, 2015). Southern California's other imported source, the Colorado River, is shared by six other states and every gallon produced is either owned or claimed by someone (Little, 2015). By having this new source it will help the City to be less dependent on outside sources and can provide a sizeable amount of water for its' residents.

Challenges

With any large project there can be some negative impacts associated with it. The Carlsbad Desalination Plant had some issues that needed to be addressed before approval of the project was given. One of the main issues with the facility is its' environmental impacts to the marine life and GHG emissions.

It is widely accepted that the large amount of energy required to operate the facility will in effect create an increase in GHG emissions for the area. The facility will operate continuously, 24 hours a day for 365 days per year, to produce the amount of drinking water needed. According to Amanda Little's article, Can Desalination Counter California's Drought, a great deal of energy is needed to pump freshwater long distances from Northern to Southern California. Nevertheless, desalination will still use about thirty percent more energy, compared to importing freshwater, to desalinate ocean water and deliver it to households (Little, 2015).

In 2006, California introduced a bill to reduce GHG emissions to 1990 levels by 2020. This required the facility to look at ways to offset the net carbon footprint associated

with the project's operations. To address this issue, the facility developed several practices to reduce their carbon footprint. First the facility is installing solar panels on the roof and spent $1 million on funding re-vegetation in the area. Secondly, the company is purchasing carbon offset to zero-out the project's net carbon footprint. Thirdly, the project will seek LEED certification though green designs and sustainable practices. Lastly, the plant will use energy efficient measures and onsite renewable resources (Voutchkov, 2008). One such feature is the use of an energy recovery system that allows recovering and reusing 33.9% of the energy associated with the reverse osmosis process. However many are concerned that the plant will still effect climate change, especially since the shutdown of the San Onofre nuclear power plant has caused Southern California to become more dependent on fossil-fueled electric generation (Hiltzik, 2015).

The other major impact is the intake and outtake system for the facility. Pumping water to the facility can impact the surrounding marine life by pumping fish and organisms through the filters and screens. At the same time it could be argued that diverting large amounts of freshwater from rivers can be more environmentally damaging then desalination. In general, scientists in California are more concerned about what is pumped to the plant since California law dictates that discharged water be diluted to no more than 20% higher salinity then the ocean water itself (Little, 2015). To lessen this impact the plant will place their intake pumps underneath the seafloor where little to no marine life exists. Studies have shown that the brine discharge, or outtake, can impact marine life by creating toxic salt levels in the water. To mitigate this impact the facility will dilute the

discharge water to California legal standards, before it is pumped back into the lagoon (Carpio, 2015). Nevertheless, environmental groups argue that desalination plants are extremely bad for the environment and that utilities and customers will not conserve as much if they perceive the ocean as an endless supply for desalination facilities (Little, 2015).

According to authorities of the project, these mitigation measures have satisfied the requirements of the Environmental Impact Report and have drastically reduced the environmental impacts caused by the facility.

Other challenging areas include the permitting process and public approval. It took the project 6 six years to complete the permitting process, which required review from Federal, State, and local agencies. Many community members and environmental activists have opposed the project because of its' environmental impacts. There have been 14 lawsuits filed against the plant but none were successful (Carpio, 2015). The company has tried to address these concerns by having open discussions about the project and describing the measures taken to reduce environmental impacts.

The prevalence of desalination has caused many agencies and researchers to reevaluate and redevelop current practices. Nevertheless, many of these challenge can be mitigated with technological advances and improvements to the desalination process.

Chapter 6 – Desalination Recommendations

This chapter presents recommendations based on the discussion and assessments in previous chapters. The recommendations below are designed for a potential desalination facility in the San Luis Obispo area. Recommendations have been developed on the assessments of existing success and strategies.

Most desalination facilities are constructed near existing power plants. Proposed facilities are co-located with existing power plants for two reasons: existing infrastructure and land use compatibility. Power plants along the coast use ocean water to cool the reactors and have established intake and outtake systems. It is more cost effective and easier to construct if the pumping system has been established. Also, power plants, like Diablo Canyon Power Plant, have pipelines that run to the City of San Luis Obispo. Using these existing lines is cost effective and can be more environmental sound by reusing rather than building new. Another reason is that desalination facilities have similar characteristics of a power plant to the extent that they both have similar issues of land use compatibility and permitting requirements. Using the existing location of the power plant will help to avoid issues of finding a new location and will potentially make approval of the project easier.

Although San Luis Obispo is landlocked, there are a few possibilities for the City to still use desalination as a way of providing water. San Luis Obispo County or City can use, lease, or purchase land on the coast to construct a desalination facility and then pump the treated water to San Luis Obispo's water distribution facility or to other cities within the

county. Another possibility is considering a partnership with nearby cities, like Cambria or Morro Bay, that have existing desalination plants that can be updated or expanded to serve a greater area. Also, San Luis Obispo County or City can create a lease agreement or a public-private partnership with Diablo Power Plant, owned by PG&E, to expand their existing desalination facility to serve both the power plant and other cities in the County, like San Luis Obispo City. Similar to Carlsbad's 10 mile pipeline, San Luis Obispo can construct a pipeline that will pump the treated water from the desalination facility to the water distribution center in San Luis Obispo.

The issue of reducing the amount of brine into the ocean can be resolved through these practices. The current methods of disposing of brine leaves high concentration levels of salt which settles on the sea floor and is toxic to marine life. One proposed solution is diluting the brine before it is discharged into the ocean. By diluting the discharge, it lessens the impact to surrounding marine life and prevents buildup on the ocean floor.   Another proposed solution is the disposal of brine to landfills. Many scientists are looking into ways of using salt to help breakdown trash and can be a cleaner technique than using other toxic chemicals.

Secondly, the issue of pumping water to the facility can be mitigated through these methods. Pumping seawater through subsurface, or underneath the sea floor, intakes is more beneficial than open wells. It better protects marine life since little to no life exists under the sea floor and the water being pumped has a slightly lower salinity which makes processing it easier. This method isn't widely used because the cost of installation is

extremely high.   However, this initially large cost can help to prevent future legal action or opposition from environmental groups.

Thirdly, the issue of intense energy use can be alleviated through these techniques. Using energy recovery systems utilizes the desalination process as a generator for onsite energy. The steam produced or brine stream can be used to generate energy though turbines, which reduces the need for electricity and is a clean energy source. Also, applying existing practices, like the use of solar panels, can be an easy and cost effective method. Advances in technology and improvements to the desalination process have helped to make the system more efficient and in turn helped to reduce energy consumption levels.

Lastly, the *California Desalination Planning Handbook* (Bourne, G. 2008, 39) has assembled a list of design characteristics to help with the permitting process. These are based on responses from permitting agencies and successful experiences addressing these concerns. The following factors can help to facilitate a successful permitting process:

- Inland facilities or facilities away from the shoreline are typically easier to permit than coastal facilities.
- Subsurface seawater intakes are likely easier to permit than open-water intakes.
- Publicly-owned facilities are likely easier to permit than privately-owned.
- Facilities with known service areas are likely easier to permit than facilities with unknown or extensive service areas.

- Facilities that are part of a coordinated local or regional water portfolio are likely easier to permit than facilities proposed by a single, independent entity.
- Proposed desalination projects that have undertaken a thorough, transparent planning process will more likely be easier to permit than those which have not
- Early and ongoing coordination with permitting agencies and the public is likely to make the process easier than with little or no coordination.

Desalination is becoming the future for water sources and many cities throughout California are looking at it as a solution to drought conditions. The development of the desalination facility needs to be evaluated for both its advantages and disadvantages. No one facility fits all and methods used have to be customized to the area. However, attention to design and planning can help to ensure that the facility will be both environmentally friendly and beneficial to community members.

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