Economic Feasibility of Desalination in California

Keith Gellerman

9/25/13

Department of Civil and Environmental Engineering
University of California, Davis

MS Plan II paper

Abstract

Water scarcity in California is a major issue. With increasing demands, new water sources are being explored and implemented. Desalination of brackish and seawater is becoming more popular, but costs are still high for high energy use, capital, and permitting. While most conventional water costs are lower than the cost of desalinated water, this could change. Although brackish desalination is already economical within California with alternative costs of \$500-\$900/acre-foot, seawater desalination is unattractive with costs ranging from \$900-\$2500/acre-foot or more. Decreasing costs from technological advances along with rising costs for conventional water sources could make seawater desalination attractive in some regions for some uses. In particular, several highly populated, coastal regions with wholesale water prices above \$800/acre-foot, seawater desalination could become financially attractive by the end of the decade if costs continue to decrease. However, for much of California, seawater desalination is unlikely to be economical.

1. Introduction

Increasing populations around the globe are raising demand for clean and reliable water. Providing water supports public health and safety through drinking water supplies and water for daily showers, toilets, food preparation and other uses. Most water supplies support other economic benefits. Water used in commercial agriculture in California amounts to 77% of total consumptive use (Cohen, 2009). It is also needed for industrial and commercial businesses as well as aesthetic landscaping (green lawns and vegetation) which increase property values.

Due to global warming, supplying water becomes a more difficult issue. Water supplies are expected to become less consistent and water stored from snowpack in nearby mountains is expected to decrease. From 1950 to1997, the snowpack in the Pacific Northwest has decreased by 50-70% and 15-30% in the Rockies (NRDC, 2004). Droughts are expected to be longer and harsher.

There are many ways to help meet these growing demands, but they usually come at higher costs. Groundwater is the most widely used, but without aquifer recharge, aquifers can be depleted and cause seawater intrusion, land subsidence, and growing pumping costs. Wastewater recycling can supply irrigation or directly or indirectly supply potable reuses. Water recycling comes with a “yuck” factor since much of the public does not want to drink water associated with human waste. Water conservation is very effective, but it can only be done to some extent. Lastly, desalination takes water with high salinity and removes the salt, to make fresh water. This is the most expensive alternative, but can also tap into essentially unlimited sources (oceans, seas, saline lakes, salty groundwater, etc).

This paper reviews the cost of treating saline water and shows at what point it may become economically attractive in California. It will also show at what price consumers may be willing to pay for desalinated water.

2. Background

3.1 Desalination Processes

Desalination is the process of removing salt and other minerals from saline water. This is

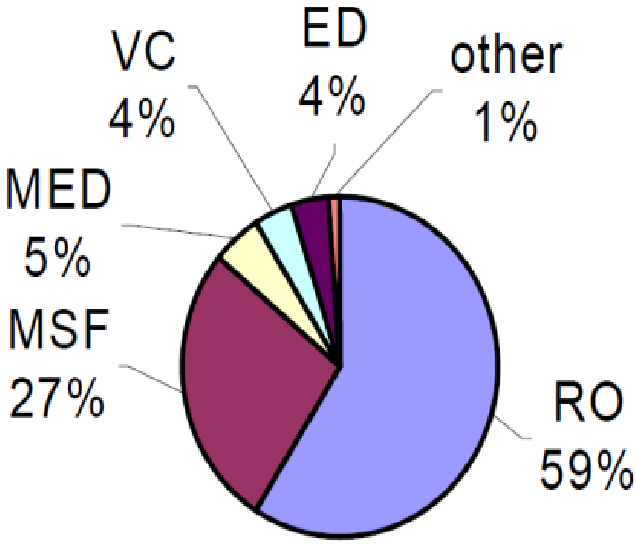

Figure 1: Percenta **Clayton, 2011)**

typically done by either distillation (thermal) and reverse osmosis (membrane) processes. The use of different processes is shown in Figure 1. Multi-stage Flash Distillation (MSF), Multiple-effect Distillation (MED), and Vapor-Compression (VC) are all distillation processes, while Reverse Osmosis (RO) and Electrodialysis (ED) are membrane processes. All of these processes use a form of pre-treatment which is typically sedimentation and filtration to remove most of the solids. Post-treatment is also needed, but varies by plant. Typical post-treatment adjusts pH, removes Boron and Calcium, and disinfects.

3.1.1 *Distillation*

Distillation essentially heats water until it evaporates, and recovers the separated steam as water in condensing chambers. Since the salt does not evaporate, the water in the condensing chamber is no longer saline. The two most common types of distillation are MSF and MED. MSF works by heating saline water in different chambers (each chamber hotter than the previous). Once at its maximum temperature, the seawater is pumped into different pressure stages (high pressure to low). These stages are operated at different pressures and temperatures based o the boiling point of water (at lower pressures water has a lower boiling point). The high temperature water then evaporates quickly because of the lower pressures. The evaporated water is then collected and condensed for removal. The brine (highly saline waste) is discharged after reaching the lowest pressure stage (Figure 2). MED is much simpler. The saline water is boiled and the evaporated steam is used to help heat the new saline water entering the system. The steam is cooled by influent water allowing it to condense into liquid water. Both MSF and MED are commonly paired with a power plants, so the waste heat from the power plant heats the water, while the water provides cooling for the power plant. It is also beneficial to pair with a power plant because of the ability to mix the brine from desalination with the exiting cooling water from the power plant.

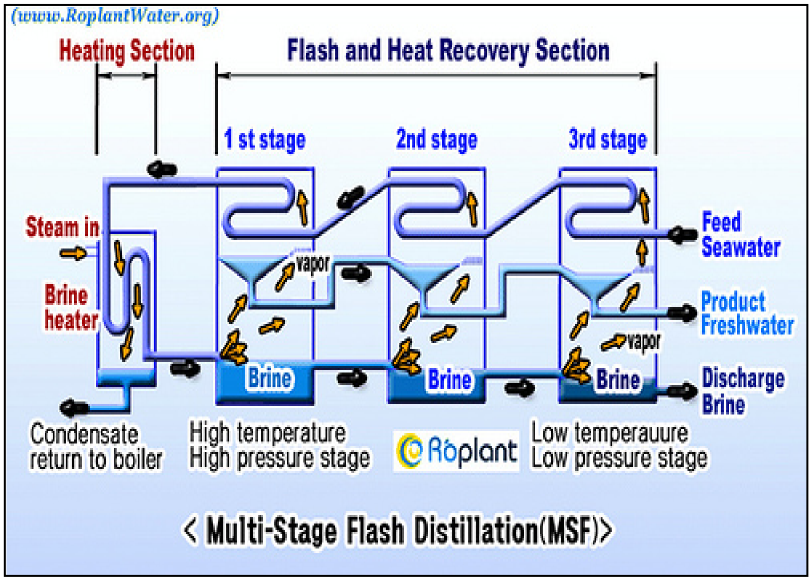

Figure 2: MSF Process (Roplant, 2002)

3.1.2*Membrane*

Membrane technology uses a membrane that prevents salt or other ions from passing through, while allowing water to pass. The two most common types of membrane desalination are Reverse Osmosis (RO) and Electrodialysis. RO takes saline water and uses high pressures to pass fresh water through a membrane, but not salt (See Figure 3). The water that passes through the membrane becomes the product and the water that remains becomes the brine. Electrodialysis is similar but instead of using pressure to separate the water and salt, it uses an ion exchange membrane which separates the ions to create fresh water. For membrane processes, it is also advantageous to pair with a power plant or wastewater treatment plants because of the ability to mix the brine from desalination with the exiting cooling water from the power plant.

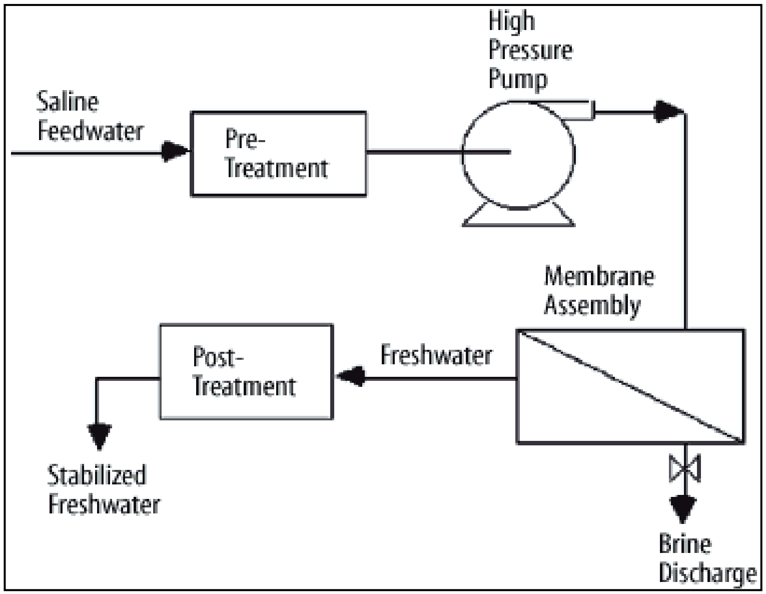

Figure 3: Reverse Osmosis Process (Use Water Wisely, 2012)

2.2 Problems and Limitations

3.2.1 Environmental Issues

Desalination is expensive. These high expenses are from capital expenses, energy requirements, environmental mitigations, and process inefficiencies. A major problem with desalination is brine disposal. Brine has a high salt concentration (greater than 50 ppt) and is typically disposed in the ocean or a nearby saline water body. This disposal creates many environmental concerns from increasing the salinity near the point of disposal. The high salt concentrations reduce oxygen levels in the water causing the plants and wildlife in the area to suffer (Ahmed and Anwar, 2012). Design considerations also need to be made with regards to the placement of the intake and brine disposal pipelines, because if they are too close to each other, the intake pipe may have a higher intake concentration, increasing the cost of treatment.

Brine disposal is also a problem for inland desalination (usually brackish desalination). Options for disposal include overland flow, which could harm plants in the area and would make local groundwater much more saline. Another option is to evaporate the water in the brine and dispose the remaining salt in a landfill, but this requires a lot of land and capital. Deep well injection is also considered, but could destroy an emergency water source. Another environmental problem is the plant intake where fish and other wildlife may be entrained. Several factors can influence the impacts of entrainment, like the depth of the intake pipe, the velocity of water entering the intake pipe, the location of the intake pipe and the type of intake pipe (Bourne, 2008). These problems typically require environmental permitting fees and mitigation expenditures.

3.2.2Capital and Energy Cost Issues

Table 1: Typical cost breakdown for RO desalination plants (Miller, 2003)

	Brackish Water (%)	**Seawater (%)**
Fixed Costs	54	37
Electric Power	11	44
Labor	9	4
Membrane Replacement	7	5
Maintenance and Parts	9	7
Consumables	10	3

Desalination plants are very expensive to build and operate. All desalination processes are very energy intensive. Table 1 shows that capital (fixed) costs are a sizeable portion of the water production costs for any form of desalination. Table 1 also shows that as the salt content increases, the amount of energy required to desalinate water increases. Desalination plants often receive government subsidies for about 10-40% of the capital costs (Hinkebein, 2004). Though desalination typically produces high quality fresh water, families, businesses, and farmers may not be willing to pay for the high cost. Desalination is currently the most expensive form of water supply alternative in California and almost everywhere else. The cost of desalination and other water alternatives will be discussed in a later section.

3.3 Progress in Desalination

Although desalination is an expensive water source, the cost is decreasing due to technological improvements. Desalination now can compete with conventional water sources in some cases (Reddy and Ghaffour, 2006). Over the past 40 years, the cost of desalinated water has dropped roughly 60-70% and is expected to continue to fall (AMTA, 2007). In addition, the cost of other water supplies has increased due to growing water scarcity, groundwater over-draft, and demand growth. Both factors increase the financial attractiveness of desalination.

3.4 Brackish vs. Seawater Desalination

Two types of water are desalinated: brackish water and sea water. Brackish water is found at fresh water and seawater interfaces or moderately saline lakes or groundwater basins. Brackish water is less saline than seawater with a concentration of 1-30 ppt. Seawater is between 30-50 ppt with an average of about 35ppt. The influent concentration of salt in the influent is important because in Reverse Osmosis (currently the most common desalination method), the higher influent salt concentrations require more pressure at the membrane (Table 2), which requires more energy. The cost of treating both types of water will be examined.

Table 2: Concentrations of Saline Water (Water Reuse Association 2011)

Source Water Quality and Pressure Requirements		
Source	**Associated Salinity, (mg/L)**	**Typical Pressure Range, psi (bar)**
Surface (Fresh) Water (MF/UF)	<500	15-30 (1-2)
Brackish Water (RO)	500 – 3,500	50-150 (3.4-10.3)
Brackish to Saline (RO/SWRO)	3,500- 18,000	150-650 (10.3-44.8)
Seawater, typical range		650-1200 (44.8-82.7)
• USA	18,000 – 36,000	
• Middle East	18,000- 45, 000+	

3. Lessons from International Desalination

4.1 Australia

Australia has recently emerged from a drought that lasted over a decade. This drought caused panic throughout the country and led to Australia's five largest cities spending $13.2 Billion on desalination projects (Onishi, 2010). But once the drought ended, adequate water supplies turned up, leaving the desalination plants to be operated on a part-time basis.

While the Perth Seawater Desalination Plant is producing water just under $1,500/acre-foot, most Australian plants are producing water from $2,500 to $3,500/acre-foot (Palmer and Porter, 2013). The Tugun Desalination Plant, which is currently in "stand-by mode", produces water at a cost of over $5,000/acre-foot (Killoran, 2013). A desalination plant in Adelaide is also suffering high costs for the plant. SA Water, the water provider for Adelaide, agreed to a 20-year contract that forces them to pay for expensive green energy for the plant (Kemp, 2012). This plant is expected to cost $130 million/year to operate at full capacity (~35 MGD) (ABC, 2010). This makes the operating costs alone to be about $3,300/acre-foot when operating at full capacity, which means it's even more costly when operating at less than 100% capacity. The plants hefty $1.8 Billion price tag increases the cost of water production to over $5,000/acre-foot (assuming a 30-year lifespan).

These extremely high costs for these plants are being paid for by customers and tax payers. While Australia's experience with desalination has been costly, the Middle East has proved that desalination can be economically feasible under the right circumstances.

4.2 Middle East

Most desalination use is in the Middle East, where over 50% of the World's desalination, with about half of that in Saudi Arabia (University of Wisconsin, 2005). Desalination in this region is economical due to the lack of other water sources, the low price of energy in the region, and the region's high wealth and willingness to pay for water. Since energy consumption is about 30-50% of the cost to produce desalinated water, cheaper energy helps lower total cost. Low energy prices allow Israel and Saudi Arabia to produce desalinated water for $800-$900/acre-foot. These regions also have low costs of environmental permitting and mitigation regarding intake pipe, brine disposal, and the air pollution abatement for an energy intensive plant.

The Middle East shows that desalination can be economically feasible if there is a lack of other water supplies and if energy is cheap enough. But what does this mean for California? The next section examines if desalination in California is feasible and if not, how it could become feasible.

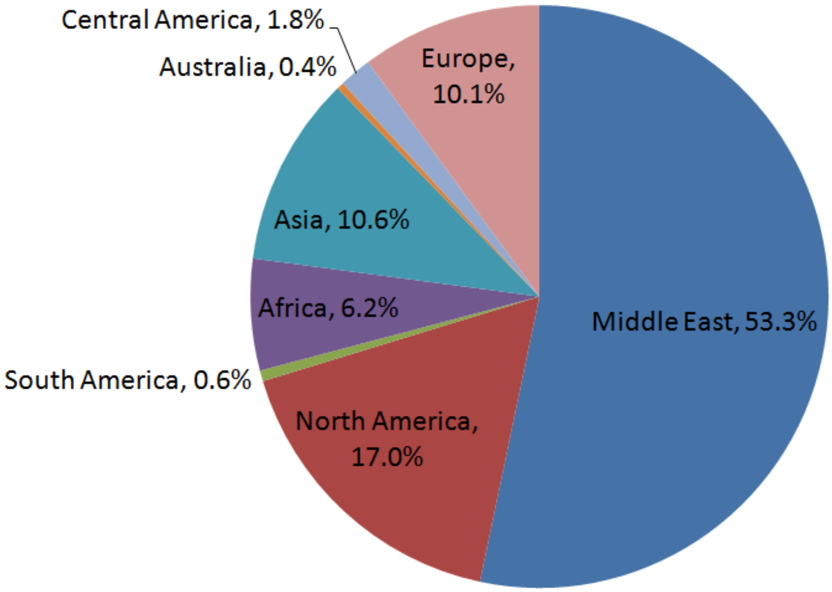

Figure 5: Output of Desalination Plants by Region (Clayton, 2011)

4. Review of Desalination in California and the US

5.1 Past and Current Plants

5.1.1 Charles Meyer Desalination Plant (Santa Barbara)

In 1991, Santa Barbara and neighboring cities Montecito and Goleta built a seawater desalination plant to help deal with a drought and have reliable water in case a disaster disrupts typical water supplies. This plant was built as a response to a drought that lasted from 1986 to 1991. Since 1991, rainfall has been adequate and there has been no need for the plant. The plant was only in operation for two weeks before the drought ended (Wall, 2013). The plant went offline in 1992 and has not been in operation since (Kuznia, 2008). Montecito and Goleta ended their involvement with the plant at the end of a five-year contract and the agencies' sold their portions of the plant (~60% of the capacity) (Fryer, 2010). The plant, for the most part, has remained intact and will only be brought back into commission if there is a severe drought or emergency.

A restart of the plant would cost approximately $20 million and would take at least 16 months (The Independent, 2009). In addition to the high capital costs, the operational costs (mostly energy) are expected to be over $1,400/acre-foot and this will put the overall cost of production well over $2,000/acre-foot when considering past and rehabilitation costs, if operating at full capacity. The city of Santa Barbara also spends $100,000 annually to keep the plant in operating condition. These high costs have made the Charles Meyer Desalination Plant a cautionary tale of desalination.

5.1.2 Marin Municipal Water District Desalination Project

In 2009, Marin Municipal Water District (MMWD) approved an EIR for a desalination project in San Rafael. The project is expected to have a capacity of 5 MGD with the option to expand to 15 MGD (Fryer, 2010). This plant will have varying water conditions, mainly salinity and temperature due to tide cycles and seasonal conditions. MMWD performed a pilot study to evaluate site conditions. The pilot study's data were used an analysis to find the costs of this plant's water. The analysis found that a 5MGD plant would have a cost of $3,009/acre-foot and a 10 MGD plant would have a cost of $2,430/acre-foot (Fryer, 2010). This analysis used MMWD's plan to operate the plant at 50% during wet years and 100% during drought years to reduce costs and energy use, where there are 23 wet years for every 2 drought years (Fryer, 2010). Operating the plant at 100% capacity at all times would significantly reduce the cost of producing water.

As of 2010, MMWD's board put the desalination project on hold due to a 15% drop in demand the past three years (MMWD, 2013). With such high projected costs for, the board likely realized desalination was not an economical when compared with water conservation and recycled water. MMWD is proceeding with caution when considering this plant to avoid ending up like the Charles Meyer plant.

5.1.3 Tampa Bay Seawater Desalination Plant

The Tampa Bay Seawater Desalination Plant is currently the largest desalination plant in North America with a capacity of 25 MGD (Fryer, 2010). This plant works with a Tampa Electric Company power plant, which warms the feed water and provides dilution for the brine. The plant had problems early in operation due to improper design and construction. The plant started operations in March 2003 and only seven months later the contractor for the plant filed for bankruptcy for not being able to successfully complete the plant (Tampa Bay Water, 2010). In 2004, the plant was put on standby and did not reach full expected capacity until December 2007 (Tampa Bay Water, 2010). These early problems with the plant significantly increased costs for the water.

A study of the plant showed greatly varied costs of water. The first case took into account the first seven years of operations (2003-2009) and the second case only accounted for the two years after the rehabilitation. The actual cost (first case) of the plant's water is about $1,900, while the cost if the plant was initially designed and built correctly would be approximately $1,200 (Fryer, 2010). Though these costs seem promising, these costs do not necessarily represent the costs of desalination in California.

4.2 Future Plants

5.2.1 Carlsbad Desalination Project

The Carlsbad Desalination Project has just begun construction and is expected to be the largest desalination plant in the Western Hemisphere with a capacity of 50 MGD. The project is expected to be completed by 2016 and would supply about 7% of San Diego County's water (City of Carlsbad, 2013). Like the Tampa Bay plant, this plant is operated in conjunction with the Carlsbad power plant, which heats the feed water and dilutes the brine. Poseidon Water, the original developer and investor for the Tampa Bay Seawater Desalination Plant, is the developer for this project. Operating costs of this plant are expected to be higher than the Tampa Bay plant due to higher salinity of feed water (29 ppt vs. 33.5 ppt) (Fryer, 2010) and higher energy prices (10.5¢/kwh vs. 7.66¢/kwh) (EIA, 2013).

An analysis of this projected plant shows it is likely that the cost of producing water will range from $1,900-$2,100/acre-foot (Fryer, 2010). The low estimates of this project were based off of an interest rate of 5.2% for construction bonds, but Poseidon Water was able to secure an interest rate of 4.78% (SDCWA, 2013), which could lower the cost slightly. Also neglected in the estimates was a 10 mile pipe line that will be constructed to transport the water from the plant to the San Marcos aqueduct (SDCWA, 2013).

5.2.2 Huntington Beach Desalination Project

Poseidon Water is in the late stages of development for another 50 MGD plant in Huntington Beach (Poseidon Water, 2013). The plant is expected to be similar to its predecessors in Tampa and Carlsbad. Currently, there are no estimates of the cost of water for the plant, but it is likely to be similar to the Carlsbad plant that has a similar location and capacity. These two new plants are projected to deliver 113,100 acre-feet/year to coastal Southern California, but these plants may not be the best options.

5. Cost Analysis

The cost of desalination varies greatly. Several factors affect its cost, such as the type of plant, the size of the plant, the salt concentration of the influent, energy prices, and the location the water is transported. The next section compares costs for the two most common types of desalination are Reverse Osmosis and Multi-stage Flash Distillation.

6.1Type of Plant

6.1.1*Reverse Osmosis*

The unit cost of desalinated water drops as the capacity of the desalination plant gets larger (economy of scales). Figure 6 shows how desalination cost decreases as capacity increases and how the salt concentration affects the cost. Higher pressures are needed to remove salt as the concentration increases and higher salt concentrations increase the fouling of membranes. This fouling requires more backwashing and more frequent replacement of membranes, raising maintenance costs for RO.

6.1.2 *Multi-stage Flash Distillation*

The MSF process also has decreasing unit production costs as plant capacity increases. However, for MSF the concentration of salt in the influent water is not as important. Since MSF is a thermal separation process, the concentration has less of a role than in RO processes. This is true because MSF removes the water from the salt and the boiling point of seawater and fresh water are nearly the same (100˚C and 100.6˚C respectively). This makes the MSF process effective with seawater or higher salt concentrations and is rarely used for brackish water.

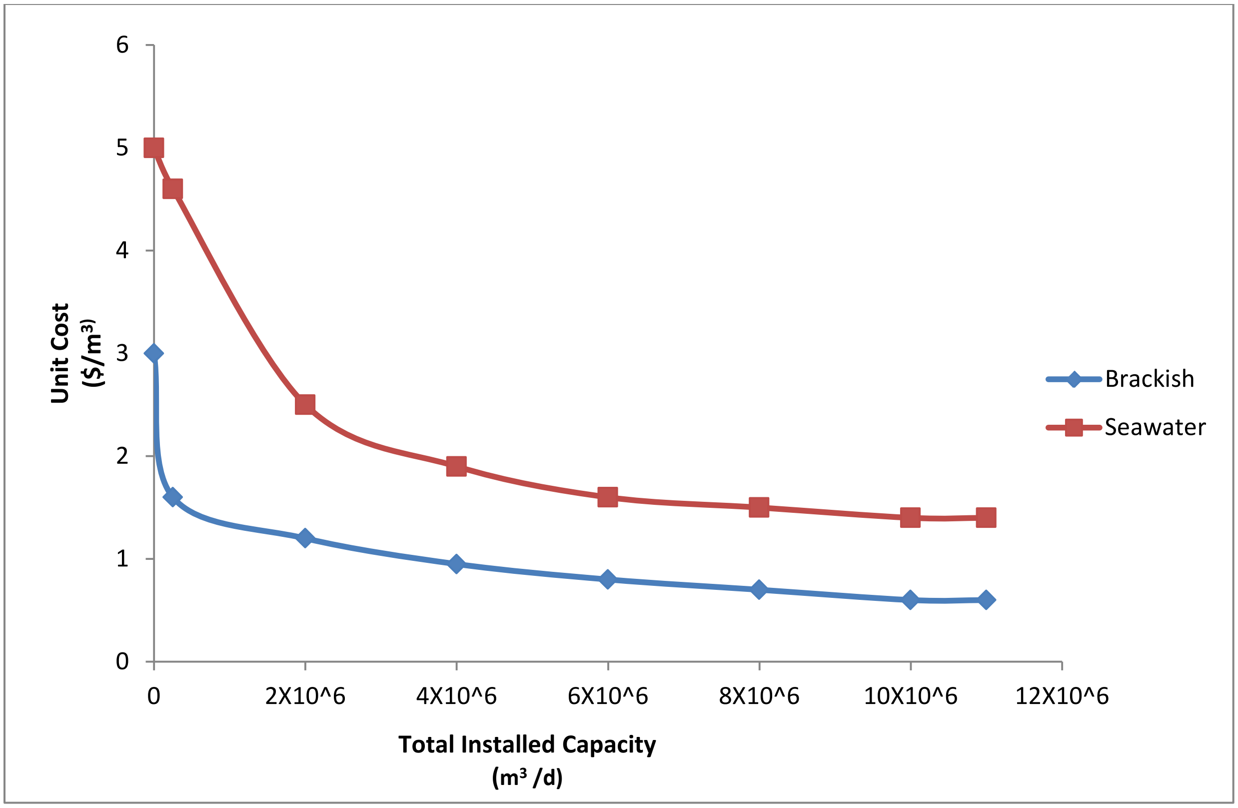

Figure 6: RO Unit Cost Compared with Total Plant Capacity (Zhou and Tol, 2004)
Note: This graph was recreated with approximated data from the reference stated above.

6.2 Energy Use and Thermodynamic Limits

Reverse osmosis is now the more economical desalination process for water with salinity under 35 ppt, typical levels on the California coast. Seawater RO plants have five unit processes that consume energy: raw water intake, pre-treatment, reverse osmosis, post-treatment, and brine disposal. Of these unit processes, reverse osmosis is the most energy intensive. Much research is being done to lower the energy use of seawater reverse osmosis, but there are theoretical thermodynamic limits to remove salt from water. Current pilot plants have shown the capability of only using 1.8 kwh/m^3 of treated seawater with 50% recovery (Elimelech and Phillip, 2011). With the remaining four processes using approximately 1 kwh/m^3. This puts the energy use at about 4.6 kwh/m^3 of product, similar to other findings (Hanak, et al. 2011) that state 4.5 kwh/m^3.

The absolute minimum energy required for separation is represented by the equation:

$$-W=\int RT \ln a_w \, dn$$

where W is the free energy of mixing, R is the ideal gas constant, T is the absolute temperature, a_w is the activity of water, n is the number of moles of water (Seminat, 2008). Given this equation, the absolute minimum energy required to separate salts from seawater is about 0.79 kwh/m^3 of treated water with a very low recovery rate (Seminat, 2008). Theoretical minimum for energy use in reverse osmosis with a typical 50% water recovery is 2.12 kwh/m^3 of product (Elimelech and Phillip, 2011). This is optimistic because plants are finite in size and cannot be operated in as a “reversible thermodynamic process” (Elimelech and Phillip, 2011). The practical minimum energy use for reverse osmosis is roughly 3.12 kwh/m^3 of product. Energy use can be lowered to 2.56 kwh/m^3 using a two-stage process in series, but that is uneconomical due to much higher capital costs. The theoretical minimum energy use could range from 3.12-4.12 kwh/m^3 (absolute minimum to practical minimum) when factoring in the other unit processes used in desalination.

The price of energy is the also important. Current energy prices are about 10.5 cents/kwh (U.S. Energy Information Administration, 2013). The current lower bound energy costs for seawater desalination is between \$580 - \$600/acre-foot. This puts the cost of energy between \$404-\$534 /acre-foot of product. This makes an average difference in price of \$120/acre-foot. If energy prices are to increase to 12 cents/kwh, the cost of desalinated water increases to the range of \$462-\$610/acre-foot of product.

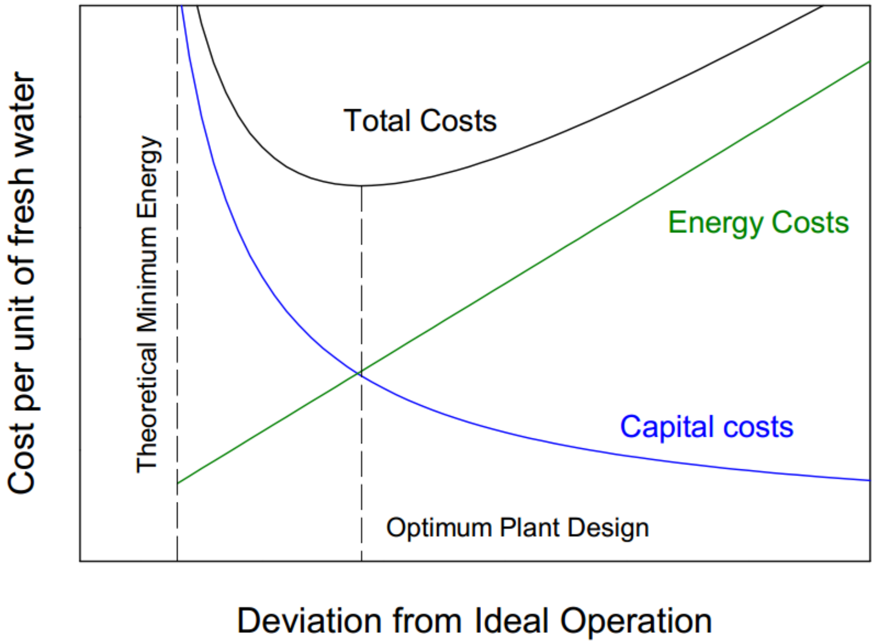

Figure 7: Trade offs between capital costs and energy use for a practical plant design (Miller, 2003)

Even with lower energy consumption, capital costs typically rise when using more energy efficient processes. Figure 7 shows that capital costs increase exponentially as the theoretical minimum energy use is approached. It is likely that the theoretical minimum energy use is not reached on any full-scale plant and if so will not improve the cost of the desalinated water.

6.3 Trends for Desalination

The unit cost of desalinated water has decreased steadily over the past 50 years due to technological advances. Both processes have made great strides in reducing costs. The MSF process reduced its cost about 88% from 1960 to 2000 with an average decrease of 5.3% annually (Zhou and Tol, 2004). Reverse Osmosis has decreased the unit cost of desalinated water by about 70% since the 1970’s, about a 3.5%/year reduction in cost for both seawater and brackish water (AMTA, 2007). Since technological advances should continue, the unit cost of water should continue to drop. Though the curves are flattening, there has been an increase in funding for desalination research due to an increase in desalination plant growth. These combined should continue to reduce unit costs. However, there are likely to be substantial physical limits to how low desalination costs can become.

6.4 Cost of Alternative Water Supplies

Table 3: Cost of Water by Source in California (PPIC, 2009)

Costs of new water supply sources in California ($ per acre-foot per year)

Method	Low	High
Conjunctive use and groundwater storage	$10	$600
Water transfers	50	550
Agricultural water use efficiency (net)	145	240
Urban water use efficiency (gross)	230	635
Recycled municipal water	300	1300
Surface storage (state projects)	340	1070
Desalination, brackish	500	900
Desalination, seawater	900	2500

Sources: Department of Water Resources, 2009a; Department of Water Resource, 2007: low estimate for surface storage; Department of Water Resources, 2005a: conjunctive use; author estimates: water transfers.

To see if desalination is economical, it must first be compared to the price of other water supply sources. Table 3 shows that the unit cost of desalination is still much higher than other alternatives. However, brackish water can be economical. These costs vary case by case as seen by the large range of costs. Urban water costs are much higher than the agricultural water costs, because of higher urban willingness to pay for quality and reliability. In many cases, the price of water per acre-foot exceeds $800 in many urban areas of California. The price of urban water varies greatly throughout California. The highest prices are in dense urban populations, such as places in the Los Angeles metropolitan area and the San Francisco Bay area (Table 4). In these locations, the cost of desalinating brackish water is within a reasonable cost range, but the cost of seawater desalination still exceeds the average price. Since these prices are averages, they are likely to fluctuate during wet and dry years. These prices could increase with increased demand and less water due to global climate change.

6.5 Water Scarcity

Having a reliable water source is necessary for economic growth and well being. As demand for water increases, the cost of water often increases. There is not a shortage of water in California, but rather a shortage of cheap water. Water demand in California is expected to increase as population increases, which increases both urban water use and agricultural (food for growing population). Climate change also plays a role by decreasing natural storage. Reducing the snowpack in the Sierra Nevada's means the water will now melt earlier in the year, instead of melting during summer when the demand for water is high.

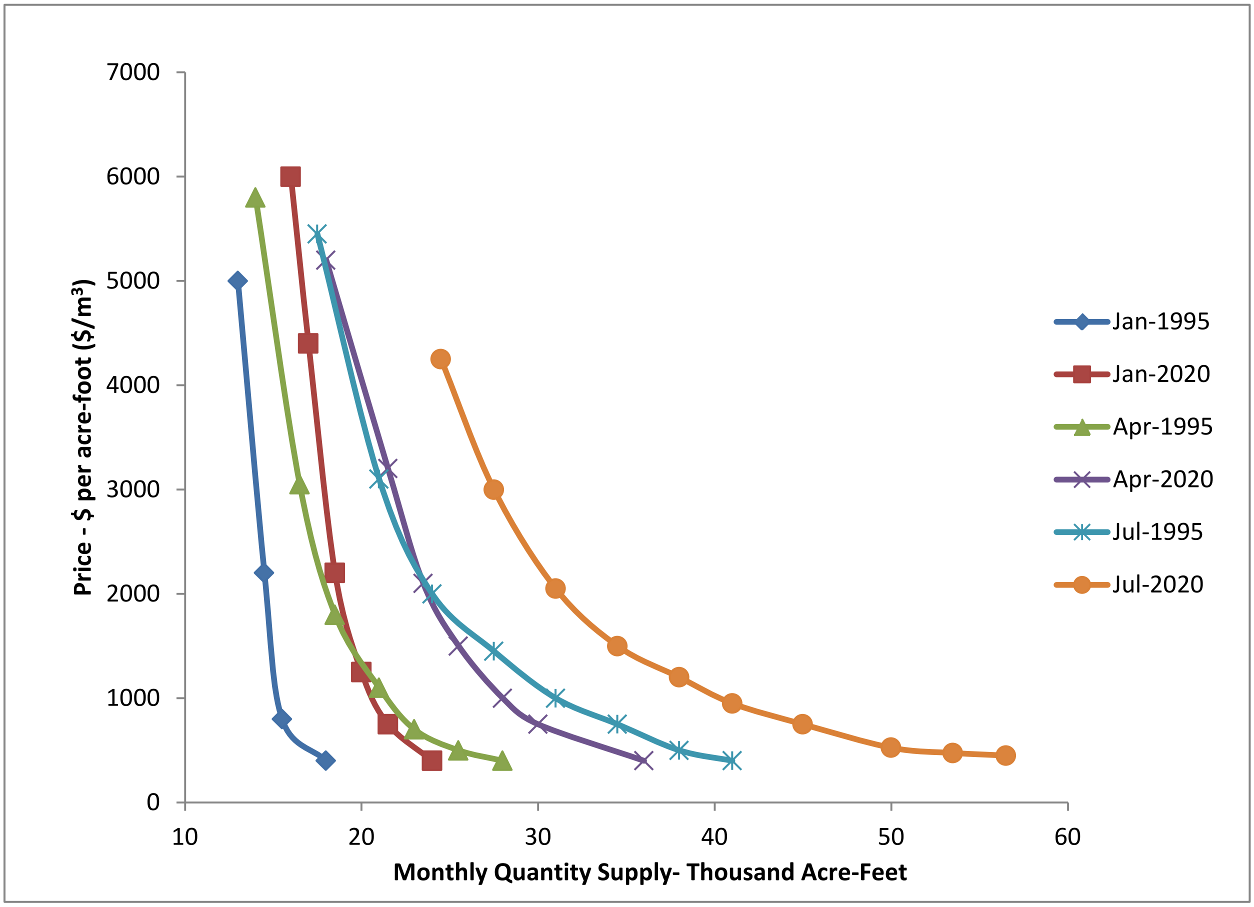

Figure 8: Price Increase of Water in Santa Clara County with Decreasing Supply (Jenkins et al., 2003)
Note: This graph was recreated with approximated values from the reference above.

Figure 8 represents how much water could cost consumers if demands are not met because of a scarce available supply. The scarcity of water will increase the cost of available water supplies. Looking at Figure 8, an increase in demand and decrease in water supply can affect the price of water. If the Santa Clara Valley was only able to deliver 38 TAF of water in July 2020, the marginal price would be roughly $1200/acre-foot.

By 2020, California's economy could lose $1.6 B annually due to water scarcity (Jenkins et al., 2003). Nearly all of this economic loss occurs in southern California. The Central Valley experiences very little scarcity, while the San Francisco Bay Area experiences water scarcity in about 30% of the years and southern California experiences significant scarcity every year and very high scarcity in drought years (Jenkins et al., 2003).

6.6 Regions

Where the water supply is used also affects its cost. If the water has to be transported over mountainous regions or long distances, the price can increase significantly. Since almost all desalination occurs near the ocean, that water's initial elevation is at sea-level (0 feet). However, there are inland regions that have limited water supplies. Transporting water over 60 miles (100 km) could increase the cost of desalinated water up to 10% (Zhou and Tol, 2004). This could push a high lower-bound price of $900 to $1000, increasing desalinated water cost away from being economical.

6. Results

Currently in California, brackish desalination is economically feasible for water supply in some cases, while desalination of seawater is almost never cost effective except in extreme cases. With a lower bound cost of $500/acre-foot, brackish desalination is a proven technology in inland Southern California (PPIC, 2009). Seawater desalination is not cost effective with a lower bound of $900/acre-foot, which still significantly exceeds the highest water rates in California. This does not mean ocean desalination will never be economical.

Table 4: Urban Water Coast by Region (DWR, 2005)

Urban Water Costs for Typical Single Family Households

(Selected Cities and Water Purveyors)

Hydrologic Region	**City**	**Fixed Charge**	**Incremental Cost**
San Francisco Bay	San Jose	$11.33	$852.00
	Livermore	$8.45	$ 744.00
	South San Francisco	$10.62	$ 835.00
South Coast	Ojai	$15.35	$833.00
	Simi Valley	$9.70	$ 784.00
	Long Beach	$13.00	$843.00
	Thousand Oaks	$10.70	$892.00
	Coronado	$6.50	$761.00

Desalination can play a role during droughts. Since desalination is a drought proof alternative, it can be economical during major droughts when water scarcity is driving the cost of water up although capital costs for infrequent desalination might become prohibitive. For example water scarcity in the Santa Clara Valley can drive the price of water from around $700/ acre-foot to $1200/acre-foot. Since seawater desalination has an unlimited supply, the cost of desalination is fairly stable and depends mostly on energy prices (not on precipitation). If Southern California loses $1.6 B annually by 2020 due to water scarcity, desalination may become cost effective during non-drought situations. Having a reliable source of water like desalinated seawater, could help provide security for California’s water supply.

Projections can give an idea when seawater desalination might become an economical option for non-drought situations. Based on the lower bound cost for seawater desalination of $900/acre-foot and the retail prices for large urban areas that are currently above $800/acre-foot

(Table 4), seawater desalination is closer to becoming economical. These areas are coastal regions in the San Francisco Bay area and the Southern California (See Table 4).

Desalination has thermodynamics that limit cost reduction potentials. Energy use in seawater desalination is expected to reduce a maximum 20% (Hanak, et al., 2011). A 20% reduction in ocean desalination cost would lower costs to approximately $780/acre-foot. With increasing alternative water costs and desalination costs dropping, desalination could become economical in some regions as soon as the end of the decade. Figure 9 shows that minor increases in water prices in urban areas in Southern California and small reductions in desalination costs could make soon make desalination economically attractive in those regions.

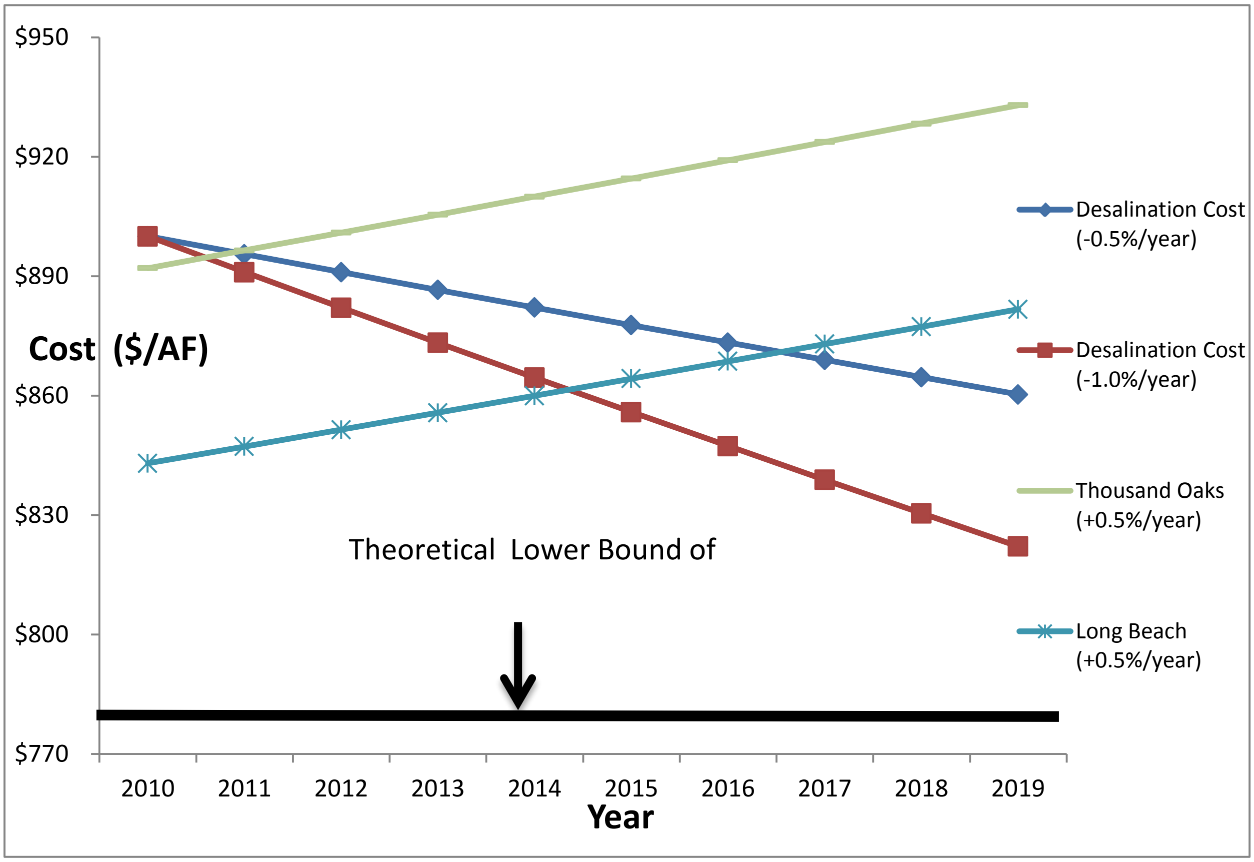

Figure 9: Water Prices Increase vs. Decreasing Cost of Desalination by Year (Projected)

The most financially attractive places for seawater desalination are urban areas near the ocean that depend on imported water. With water scarcity occurring every year in Southern California, it seems to make the most financial sense if most desalinated water production occurs in highly populated, coastal areas in that region. A densely populated area has the economies of scale to build larger plants which keep the cost of production down. Using desalination in areas where environmental effects are limited also can also reduce costs significantly. Utilizing the desalinated water for urban use only takes advantage of the high value for an urban water supply.

This does not mean desalination will be the most financially attractive option. Recycled municipal wastewater will almost always be cheaper than desalination and is also a drought-proof alternative. Treating wastewater with a RO processes requires much less energy than seawater due to much lower TDS. Table 3 shows that recycling wastewater is approximately $1,000/acre-foot cheaper than seawater desalination. Recycling wastewater also provides an environmental benefit by decreasing the flow of wastewater into a water body, while desalination is environmentally detrimental. It also has an advantage for inland areas where brine disposal is an issue. There is really no advantage that desalination has over recycled wastewater, except that it is more widely accepted by the public to be a clean drinking water source.

7. Conclusions

In 1962, President John F. Kennedy said "*If we could ever competitively, at a cheap rate, get fresh water from salt water, that it would be in the long-range interests of humanity which would really dwarf any other scientific accomplishments*". Desalination has come a long way since its beginning in the 1960's but still not as cheap as expected. While brackish desalination is currently economically feasible in some parts of California, seawater desalination needs to become cheaper to be implemented more in the State. With technological advances and increasing water demand, seawater desalination could become economical by the end of the decade for some regions. This may be optimistic because recently planned and constructed plants in California are producing water at or above $2,000/acre-foot, which is significantly higher than any other water alternative. This Cheaper options, like recycled water, should be considered first.

Desalination is not a "fix-all" solution to California's water issues. The problem will take many other measures to insure that California's health, safety, and economy improve. Water conservation, wastewater recycling, and increased storage capacity need to be used with desalination to meet California's growing demands.

References

1. ABC News. "$130m annual cost to run desal plant". ABC News. 2010. Retrieved from: http://www.abc.net.au/news/2010-12-01/130m-annual-cost-to-run-desal-plant/2358158
2. Ahmed, Musfique. Anwar, Rifat. "An Assessment of the Environmental Impact of Brine Disposal in Marine Environment". International Journal of Modern Engineering Research. Volume 2, Issue 4. 2012.
3. American Membrane Technology Association. "Membrane Desalination Costs". Feb. 2007.
4. Bourne, Gregory. "California Desalination Planning Handbook". California State University, Sacrament, Center for Collaborative Policy. Feb. 2008.
5. Busch M., Mickols W.E. "Reducing energy consumption in seawater desalination." Desalination Volume 165, pp 299-312. August 2004.
6. City of Carlsbad. "Seawater Desalination". City of Carlsbad. 2013. Retrieved from: http://www.carlsbadca.gov/services/departments/water/pages/seawaterdist.aspx
7. Clayton, R. "Desalination for Water Supply." Foundation for Water Research. May 2011.

8. Cohen, Yoram. “Graywater-A Potential Source of Water.” UCLA Institute of the Environment and Sustainability. 2009. Retrieved from: http://www.environment.ucla.edu/reportcard/article.asp?parentid=4870
9. Department of Water Resources. “California Water Plan Update 2005.” Volume 4, pp. 35. 2005.
10. Elimelech, Menachem, Phillip, William A. “The Future of Seawater Desalination: Energy, Technology, and the Environment.” Science Volume 333, pp 712-717. August 2011.
11. Fryer, James. “An Investigation of the Marginal Cost of Seawater Desalination in California”. Residents for Responsible Desalination. March, 2010.
12. Hanak et al. “California Water Myths”. Public Policy Institute of California. 2009. Retrieved from: http://www.ppic.org/content/pubs/report/R_1209EHR.pdf
13. Hanak et al. “Managing California’s Water: From Conflict to Reconciliation. “Public Policy Institute of California. 2011.
14. Hinkebein, Thomas. “Desalination: Limitations and Challenges”. Sandia National Laboratories. 2004. Retrieved from: http://www.ncbi.nlm.nih.gov/books/NBK83737/
15. The Independent. “High Price for Desal Plant”. The Independent. 2009. Retrieved from: http://www.independent.com/news/2009/may/21/high-price-desal-plant/
16. Jenkins, Marion W., Lund, Jay R., Howitt, Richard E. “Using Economic Loss Functions to Value Urban Water Scarcity in California.” AWWA Volume 95. 2003.
17. Kemp, Miles. “Water customers pay for mothballed desalination plant’s costly green electricity deal”. Aledaidenow. 2012. Retrieved from: http://www.adelaidenow.com.au /news/south-australia/water-customers-pay-for-mothballed-desalination-plants-costly-green-electricity-deal/story-e6frea83-1226537887265
18. Killoran, Matthew. “Desal plant hemorrhaging money”. Goldcoast.com.au. 2013. Retrieved from: http://www.goldcoast.com.au/article/2013/06/06/452794_gold-coast-news.html
19. Kuzina, Rob. “Santa Barbara Council Tables Decision on Desalination Plant” Noozhawk. 2008. Retrieved from: http://www.noozhawk.com/article/080508_santa_barbara _council_tables_decision_on_desalination_plant
20. Marin Municipal Water District. “Long-Term Water Supply” Marin Municipal Water District. 2013. Retrieved from: http://www.carlsbadca.gov/services/departments/ water/pages/seawaterdist.aspx
21. Miller, James. “Review of Water Resources and Desalination Technologies”. Sandia National Laboratories. March, 2003.
22. Natural Resource Defense Council. “Current Science on Global Warming and Western Water”. 2004. Retrieved from: http://www.nrdc.org/globalwarming/gww/agww.asp
23. Onishi, Norimitsu. “Arid Australia Sips Seawater, but at a Cost”. The New York Times. 2010. Retrieved from: http://www.nytimes.com/2010/07/11/world/asia/11water.html?_r=1&

24. Palmer, Neil. “Cheap seawater desalination”. National Centre of Excellence in Desalination. 2013. Retrieved from: http://desalination.edu.au/2013/07/cheaper-seawater-desalination/#.UjNoedK3-So
25. Pique, G.G. “SWRO Desalination: A Viable Long-Term Solution to Water Scarcity.” Environmental Protection. October 2010. Retrieved from: http://eponline.com/articles/2010/10/14/swro-desalination-a-viable-longterm-solutiontowaterscarcity.aspx?admgarea=features
26. Poseidon Water. “Huntington Beach Project”. Poseidon Water. 2013. Retrieved from: http://poseidonwater.com/our_projects/all_projects/huntington_beach_project
27. Reddy, K.V., Ghaffour. “Overview of the cost of desalinated water and costing methodologies.” Desalination. Volume 205, Issues 1-3. March 2006. Retrieved from: http://www.sciencedirect.com/science/article/pii/S0011916406013890
28. Roplant. “Thermal Technologies”. Roplant. 2002. Retrieved from: http://www.roplant.org/index.php?pid=7&sid
29. San Diego County Water Authority. “Carlsbad Desalination Project”. San Diego County Water Authority. 2013. Retrieved from: http://www.sdcwa.org/issue-desal
30. Semiat, Raphael. “Energy Issues in Desalination Processes”. Israel Institute of Technology. 2008.
31. Tampa Bay Water. “Tampa Bay Seawater Desalination Plant”. Tampa Bay Water. 2010. Retrieved from: http://www.tampabaywater.org/documents/fact-sheets/desal-fact-sheet.pdf
32. U.S. Energy Information Administration. “Table 5.6.B. Average Retail Price of Electricity to Ultimate Customers by End-Use Sector.” June 2013. Retrieved from: http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_06_b
33. Use Water Wisely. “Desalination, An Expensive Yet Abundant Water Source.” Highpoint, Inc 2012. Retrieved from: http://www.usewaterwisely.com/totm0706.cfm
34. University of Wisconsin. “Desalination.” University of Wisconsin, Eau Claire. 2005. Retrieved from: http://people.uwec.edu/piercech/desalination/index.htm
35. Wall et al. “The History of Water in Santa Barbara”. Wordpress.com. June, 2013.
36. WateReuse Association Desalination Committee. “Seawater Desalination Power Consumption.” WateReuse Association. November 2011.Retrieved from: http://www.watereuse.org/sites/default/files/u8/Power_consumption_ white_paper.pdf
37. Zhou, Yuan and Tol, Richard S.J. "Evaluating the costs of desalination and water transport”. Water Resources Research Volume 41 Issue 3. December 2004

Acknowledgements

I would like to thank my advisor, Jay Lund, for all of his guidance and advice with my project. I would also like to thank my project’s committee members Alissa Kendall and Stefan Wuertz, for their help with this report. Lastly, I would like to thank all of my family, friends, classmates, and coworkers that have helped me throughout my time in graduate school.