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14. ABSTRACT
California's water supply is becoming insufficient to sustain the agricultural, industrial, and population growth. The solution is to supplement the current water infrastructure through desalination of sea or brackish water. California's existing sea water desalination plants primarily use reverse osmosis and produces only fifty percent freshwater from the sea water intake. Incorporating zero liquid discharge into existing and future desalination plants will increase freshwater production and reduce brine waste from returning to the ecosystem.

15. SUBJECT TERMS
Desalination, Reverse Osmosis, Forward Osmosis, Zero Liquid Discharge, Brine, California, Deep Well Injection, Surface Water Discharge, Evaporation Pond

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MASTER OF MILITARY STUDIES

Water Management in California

SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF MILITARY STUDIES

Major Sam S. Kalapala, USMC

AY 2020-21

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Executive Summary

Title: Water Management in California

Author: Major Sam Kalapala, United States Marine Corps

Thesis: The high cost and energy consumption associated with desalinization, along with the waste byproduct (often referred to as brine) that it produces raises the question: Is desalinization is a viable long-term solution to address water scarcity in California.

Discussion: Water management policies in California has enabled the over extraction from underground aquifers coupled with climate change and population growth has strained the water supply. Sources of water is mainly from seasonal rainfall and snowpack that recharge aquifers, rivers, and deltas along with importing water from the Colorado river all of which have become insufficient. The solution to the water scarcity issue is to desalinate sea or brackish water to supplement agricultural, manufacturing, and urban demand. Most common method that existing desalination plants along the California coast use is reverse osmosis (RO) however zero liquid discharge is a new technology that can produce a higher percentage of freshwater than RO. Although desalination is widely used in arid regions, the high cost to build and operate along with the brine byproduct that is toxic, questions if this is a viable long-term solution. Multiple efforts to address water scarcity is in effect such as conservation efforts, advances in technology, and desalination. Steps to mitigate the high cost of desalination include incorporating green energy, leveraging the capacity of other facilities such as power plants, and potentially public-to-public partnerships with military installations to build, operate, and maintain the facility.

Conclusion: Desalination is a viable long-term solution so long as the brine byproduct is appropriately disposed of to protect the ecosystem where brine is discharged. ZLD is a new technology that can produce a higher percentage of freshwater while disposing of brine more efficiently. ZLD is energy intensive however by incorporating green energy and sharing the input and output process with powerplant facilities will offset the cost to provide affordable and sustainable solution to communities.

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Preface

Throughout the course of writing this research paper, there were many rabbit holes that would have taken this paper in a completely different direction. The political climate in California that led to the current allocation of water rights is worthy of a separate research paper. The reason I chose to research desalination is because water scarcity is becoming a global problem and the application of desalination is the immediate solution for a lot of arid regions. I used California as a case study since I have lived in the state for some time and experienced droughts firsthand. Expeditionary military operations also require units to make water for sustainment and therefore is a vital aspect for mission success.

I close this preface with full acknowledgement for the guidance and mentorship provided by Dr. Matthew Slater from the Marine Corps Warfighting Lab. His insight into the significance of water scarcity issues in California framed my understanding of the environment, developed my analysis and recommendation for addressing the problem. I also would like acknowledge Dr. Lauren Mackenzie for her recommendations as the second reader and providing valuable feedback.

Introduction

California's water supply continues to be stressed due to climate change, population growth, and poor water management policies that allow over extraction of underground aquifers. As the population grows, it places greater demand on agriculture and manufacturing use, resulting "in higher levels of both water use and water pollution, thereby reducing the availability of water for drinking and recreation."[1] The sources of California's water is mainly seasonal precipitation and melting snowpack in the Sierra Nevada mountains that melt and recharges aquifers, rivers, and deltas, along with extraction from the Colorado River. [2] Over the years, these sources have become insufficient with droughts becoming more pronounced, with drastically reduced seasonal rain fall and snowpack and prompting the necessity for a sustainable alternate source.

The most prominent solution to the water scarcity issue in California is to desalinate sea or brackish water to supplement the dwindling water supply. The significant benefit to using desalination is "that it protects natural fresh water sources – rivers, lakes, and aquifers – from being depleted further."[3] Reverse osmosis (RO) is the primary method that desalination plants use to filter sea or brackish water along the California coast although, desalination technology is evolving to include other methods such as forward osmosis (FO) and zero liquid discharge (ZLD).

In California, there are currently 12 seawater desalination plants, some of which are off-line, and six more proposed plants due to come on-line. Each of these facilities address the issue

[1] Scott Moore, *Subnational Hydropolitics : Conflict, Cooperation, and Institution-Building in Shared River Basins* New York, NY: Oxford University Press, 2018. 24-25

[2] Hanasaki, Naota, Sayaka Yoshikawa, Yadu Pokhrel, and Shinjiro Kanae. "A global Hydrological Simulation to Specify the Sources of Water used by Humans." *Hydrology and Earth System Sciences* 22, no. 1 (2018): 789-817.

[3] Brian Richter, *Chasing Water A Guide for Moving from Scarcity to Sustainability*. 1st ed. Washington, DC: Island Press/Center for Resource Economics, 2014. 40

of brine waste differently and have their own limitations with energy consumption and varying water production levels. Communities that collaborate with military installations through public-to-public partnerships have benefited with cost sharing of construction, operation, and maintenance of desalination facilities.[4] Although San Nicolas Island desalination plant is the only military run facility in California, and does not support any municipalities, consideration for future plants will enhance relationships between military installations and communities by protecting water resources.

The proposal for this research paper is to address the high cost and energy consumption associated with desalinization, along with the waste byproduct (often referred to as brine) that it produces. Research has shown that brine is considered hazardous to the environment which raises the question: Is desalinization a viable long-term solution?[5] This research question will be addressed throughout the paper by discussing: [1] the current water management and allocation provided by the California Water Board, [2] the conservation and mitigation steps taken by state legislature to promote water conservation among farmers and consumers, [3] the methods of desalination such as RO, FO, and ZLD, and [4] the methods of disposing brine concentrate through deep well injections, evaporation ponds, and surface water disposal.

Zero Liquid Discharge is the recommended technology that has the potential to produce greater amount of useable water while reducing brine waste. This method incorporates either membrane based or thermal based treatment but is primarily thermal based method as it is most efficient in terms of output. Zero liquid discharge can be the solution for the new desalination plants to increase clean water out-put, reduce waste, and minimize environmental impact.

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[4] Beth E. Lachman, Susan A. Resetar, and Frank Camm. "Military Installation Public-To-Public Partnerships: Lessons From Past And Current Experiences". *Rand.Org*. (2016) 15-16

[5] Eran Raveh and Alon Ben-Gal. "Leveraging Sustainable Irrigated Agriculture Via Desalination: Evidence from a Macro-Data Case Study in Israel." *Sustainability* 10, no. 4 (2018): 974.

Current Water Management and Allocation in California

California has the largest state gross domestic product (GDP) in the United States, equating to 3.1 trillion dollars of which only 1.6 percent is from agriculture. It is impressive to note that less than 2 percent of the GDP is derived from farming; however, forty percent of the water market is allocated for agriculture. Fifty percent of water is allocated for the environment which is to ensure adequate supply for rivers and lakes feeding the natural habitat of wildlife, and only ten percent is for urban use according to the Public Policy Institute of California.

To put it into greater perspective, "about half of all produce sold in the United States comes from California (primarily from the megafarms in the Central Valley) productivity that is highly dependent on irrigation."[6] The ten percent allocated for the population will soon become insufficient as the number of households increasing consumption.[7] This is a duality because agriculture is somewhat of a detriment to California since it contributes to water shortages, however the U.S. is dependent on the food production to sustain the national population. To solve this issue, collaboration must be achieved from all levels of government to include private industry and academic institutions.

With so many competing interests there arises three coordination issues with the management of water and they are referred to as "institutional collective action dilemma."[8] The coordination is with functional, vertical, and horizontal levels of management and government that crosses responsibilities, authorities, and politics. The functional dilemma is the responsibility

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[6] Judith D. Schwartz, *Water in plain sight: Hope for a thirsty world*. St. Martin's Press, 2016.
[7] Anne R. Pebley "Demography and the Environment." *Demography and the Environment* 35, no. 4 (1998): 377-389.
[8] Scott Moore, *Subnational Hydropolitics : Conflict, Cooperation, and Institution-Building in Shared River Basins* New York, NY: Oxford University Press, 2018. 38

for managing the use of land and control of pollution introduced into the water system across all government stakeholders who have an interest in the natural resource.[9] The vertical dilemma is the responsibilities and authorities between the central government either state or federal, and the local governments who have competing interests.[10] Finally, the horizontal dilemma is the political nature of sharing a resource that flows from one jurisdiction to another as well as the economic impact of trying to place restrictions on what to grow.[11] These dilemmas create significant challenges when implementing water management policies as well as solutions such as desalinization.

Across California, the water management system is in conflict between special interest and environmental activism who take issue with the fact that 20 percent of the electricity consumed in the state is from pumping "the water over the mountains into Los Angeles."[12] The special interest is the private sector that seeks to make a profit from the distribution of water that was allocated at a time when the region was not in a drought.[13] A balance must be achieved to ensure an integrated water management policy that is "reasonable and just – reconciling upstream and downstream users."[14]

Current Water Conservation Efforts

At the state level, incentives that were once not available are now established to encourage farmers to switch to desalinated water, or partially supplement their water needs. This is a mitigation step to reduce water extraction from underground aquifers which are depleting

[9] Moore, *Subnational Hydropolitics, 38*
[10] Moore, *Subnational Hydropolitics,* 38
[11] Moore, *Subnational Hydropolitics,* 38
[12] Judith D. Schwartz, *Water in plain sight: Hope for a thirsty world*. St. Martin's Press, 2016.
[13] Maggie Back. *The Atlas of Water: Mapping the World's most Critical Resource*. 3rd ed. Berkerley: University of California Press, 2016. 41
[14] Back, *The Atlas of Water,* 13

faster than recharging. Farmers rely on uninterrupted water for their crops and therefore pull from aquifers that provide a steady source of water. However, new incentives such as tax reliefs, subsidized water, and policies to make farmers install rain collection systems encourage farmers to consider the alternate water source.[15]

Water conservation can also be implemented through changes in farming practices as illustrated by Australia's landscape rehydration project. This approach incorporates natural landscape to cool the area while improving soil content to increase water reliability.[16] Natural farming sequence will take some time to incorporate but is expected to be long lasting and sustainable. Past civilizations have suffered the cost of societal collapse due to poor land management from overgrazing of livestock and deforestation casing landslides and soil erosion. Poor land management contributes to the decline in agriculture output and becomes insufficient in sustaining the population.[17] To slow the pace of deforestation and reducing the impact to natural farming sequence, composite materials will substitute the demand for timber. History demonstrates that policy implementation may be the only way to change growing practices by enforcing new regulations that guarantee sustainable production while also ensuring a balance for framers to maintain profitable to stay in business. Implementing natural framing sequence is a disruption to establishing framing practices.

Another conservation method is through irrigation modifications by farmers that will also provide lower prices to the consumer. The three types of irrigation currently used are surface, sprinkler, and drip. Surface irrigation is the most common among farmers and is the process of flooding the crop area and using gravity to spread the water. This process is also the most

[15] Jose Aznar-Sánchez et al., "Aquifer Sustainability and the use of Desalinated Seawater for Greenhouse Irrigation in the Campo De Níjar, Southeast Spain." *International Journal of Environmental Research and Public Health* 16, no. 5 (2019): n/a.
[16] W. J. Hurditch "Sustainable Water and Energy Management in Australia's Farming Landscapes." *WIT Transactions on Ecology and the Environment* 200, (2015): 329
[17] Joseph A. Tainter. "Archaeology of Overshoot and Collapse." *Annual Review of Anthropology* 35, no. 1 (2006): 59-74.

inefficient method of the three. The second is a sprinkler system simulates rain drops on crops and is common among home lawn irrigation systems. The third and most efficient is the drip irrigation system that enables greater water management, energy reduction, and establishment of crops.[18] Desalinated water can supplement irrigation regardless of the type of irrigation system and alleviate depletion of underground aquifers.

Changes in population demographics, reflecting a rise in middle- and upper-class incomes, place an increased demand for higher end food products such as meat and other water thirsty crops, which in turn requires farmers and manufacturers to expend more water to meet demand.[19] California farmers also grow water thirsty crops for international markets as well, "for example, farmers in the arid Imperial Valley are shipping alfalfa to China to help feed that country's growing dairy herd."[20] China is also experiencing a middle-class boom that is demanding more meat in their diets and relying on international markets to fill the gap. Almonds are another source of massive water consumption, drinking an estimated 10 percent of the state's water supply, which comes out to a gallon of water per nut.[21] Almonds are a lucrative crop and California produces 80 percent of the world's production of almonds, adding to the state and national GDP but stressing the hydrological system.[22]

Although there is a rising population, there is a growing tendency that higher income people are aware of environmental impacts and use their purchase power to acquire premium products that are more efficient, thereby offsetting their water demand in other areas.[23] Water

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[18] Rajesha Kumar et al., "Desalination for Agriculture: Water Quality and Plant Chemistry, Technologies and Challenges." *Water Science & Technology* 18, no. 5 (2018): 1505-1517.

[19] Robert J. Wyman. "The Effects of Population on the Depletion of Fresh Water." *Population and Development Review* 39, no. 4 (2013): 687-704.

[20] Judith D. Schwartz, *Water in Plain Sight: Hope for a Thirsty World*. St. Martin's Press, 2016. 36

[21] Schwartz, *Water in Plain Sight*, 37

[22] Schwartz, *Water in Plain Sight*, 37

[23] Maggie Back. *The Atlas of Water: Mapping the World's most Critical Resource*. 3rd ed. Berkeley: University of California Press, 2016. 26

efficient appliances such as low flow toilets, tankless water heaters, dishwashers, and washing machine units become more efficient as they go up in price. Another example is construction material such as Trex composite decking that is made from recycled material. Trex is higher in price than wood but lasts much longer, does not require fossil fuel finishers like stain or paint, and does not require new lumber, leading to greater conservation of forests. Lower income populations will gravitate toward discount items that are not as efficient but meet their needs within their economic condition.[24] Yet, despite the conservation efforts mentioned, California is still experiencing water shortage unless additional resources are identified such as increasing the number of desalination plants or increasing the efficiency of existing plants.

Methods of Desalination

Desalination of sea or brackish water creates another source of water that does not interfere with the natural hydrologic cycle. California has an exceptionally large coastline and puling from the abundant ocean water creates minimal impact to the ecosystem so long as the wastewater discharge is treated to prevent toxins and harmfully high levels of saline from being introduced. In order to prevent this, desalination technology incorporates various conventional methods such as “reverse osmosis (RO), multi-stage flash distillation (MSF), multi-effect distillation (MED), electrodialysis (ED), electrodialysis reversal (EDR), nanofiltration (NF), etc. can be combined with emerging desalination technologies such as forward osmosis (FO), membrane distillation (MD), electrodialysis metathesis (EDM), etc.”[25]

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[24] Anne R. Pebley "Demography and the Environment." *Demography* 35, no. 4 (1998): 377-389.
[25] Argyris Panagopoulos. "A Comparative Study on Minimum and Actual Energy Consumption for the Treatment of Desalination Brine." *Energy* 212 (2020): 1.

These methods are further designated as either thermal based, such as MSF and MED, or membrane based. The advantage of thermal is the "high-purity freshwater compared to membrane-based technologies such as RO or FO."[26] The disadvantage of thermal base system is the high consumption of energy which is similar to a Zero Liquid Discharge (ZLD) system. Each method has limitations that either sacrifice efficiency or effectiveness with some methods requiring more energy powered by fossil fuels, other methods requiring additional chemical treatment, or other technical issues such as membrane fouling.[27] This adds to carbon emissions and increase climate change that is causing the water crisis in the first place.

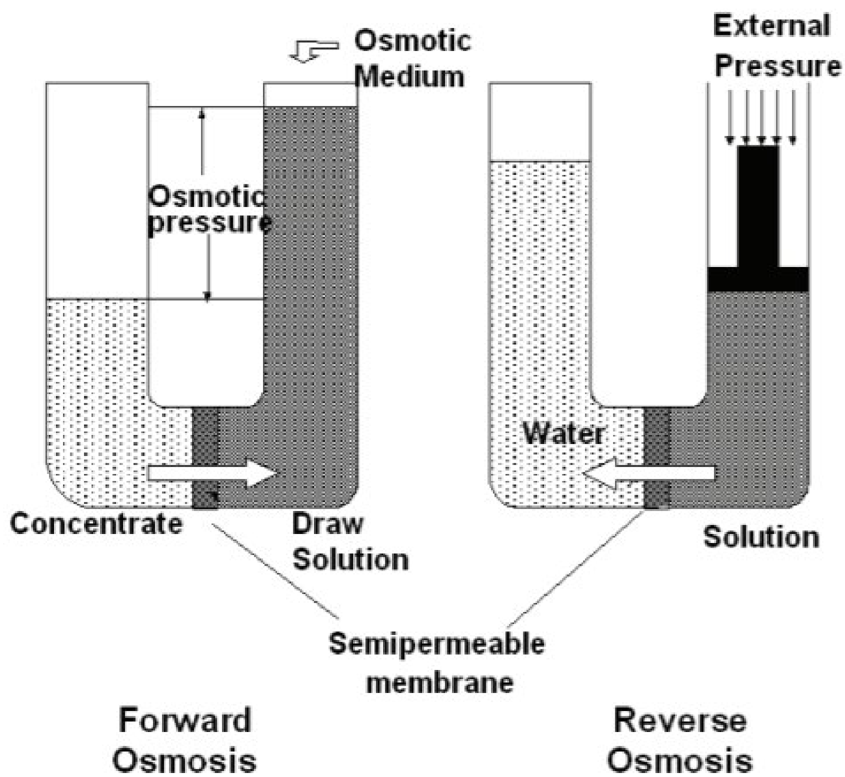

Figure 1: Comparison of FO and RO

[26] Panagopoulos, *Energy,* 5
[27] Rajesha Kumar et al., "Desalination for Agriculture: Water Quality and Plant Chemistry, Technologies and Challenges." *Water Science & Technology* 18, no. 5 (2018): 1505-1517.

Source: S. Adham, J. Oppenheimer, L. Liu, and M. Kumar. "Dewatering reverse osmosis concentrate from water reuse applications using forward osmosis." *Water Use Foundation Research Report* (2007).[28]

Of the desalination methods discussed, RO and FO are the most widely used. RO is one of the more effective methods of membrane technology however it is also energy intensive.[29] RO requires pressurization of the higher salt compartment "forcing water molecules to move through a semipermeable membrane in the compartment of lower salt concentration."[30] Figure 1 illustrates the RO process with the semipermeable membrane filtering the salt water into fresh water. Creating alternative solutions is to not only finding another water source but also to make it affordable for farmers and consumers. If the pressurized system that is required to operate an RO system in not cost effective, the cost will either be passed on to the consumer or the system must be replaced with something more affordable.

In an effort to address the energy requirement and make desalination using RO more cost effective, salinity gradient power (SGP) is a new technology currently being tested to supplement the power needs. This technology can potentially convert the high salinity of brine into a source of energy through electrodialysis; however, it is still in the development and testing phase and runs into the issue of scale.[31] Once the research and development hurdle has been overcome, using brine to power a desalination plant can have incredible effects in further reducing the environmental impacts and increase cost efficiency for widespread use.

[28] S. Adham, J. Oppenheimer, L. Liu, and M. Kumar. "Dewatering reverse osmosis concentrate from water reuse applications using forward osmosis." *Water Use Foundation Research Report* (2007): 2

[29] Sherub Phuntsho et al., "Fertilizer Drawn Forward Osmosis Desalination: The Concept, Performance and Limitations for Fertigation." *Reviews in Environmental Science and Biotechnology* 11, no. 2 (2012): 147-168.

[30] Panagopoulos, Argyris, Katherine-Joanne Haralambous, and Maria Loizidou. "Desalination Brine Disposal Methods and Treatment Technologies - " *Science of the Total Environment* 693, (2019): 8.

[31] Ali Altaee, and Nahawand AlZainati. "Novel Thermal Desalination Brine Reject-Sewage Effluent Salinity Gradient for Power Generation and Dilution of Brine Reject." *Energies (19961073)* 13, no. 7 (2020): 3

Forward osmosis on the other hand does not require a pressurized system to make the transfer of saline and therefore requires far less energy to operate. The drawback to FO is the lack of suitable membrane that will not foul after multiple uses and the solution that is produced is not potable water but suitable for agriculture.[32] Figure 1 illustrates the FO process where the concentrate of saline is pulled into the "draw solution through a membrane"[33]. Since the membrane is not required to sustain the higher pressure, the water produced is not suitable for consumption as it exceeds the minimum levels of purification. If potable water is the goal for FO, then additional treatment is necessary which will require more energy and at this point will be comparable to RO with energy consumption.

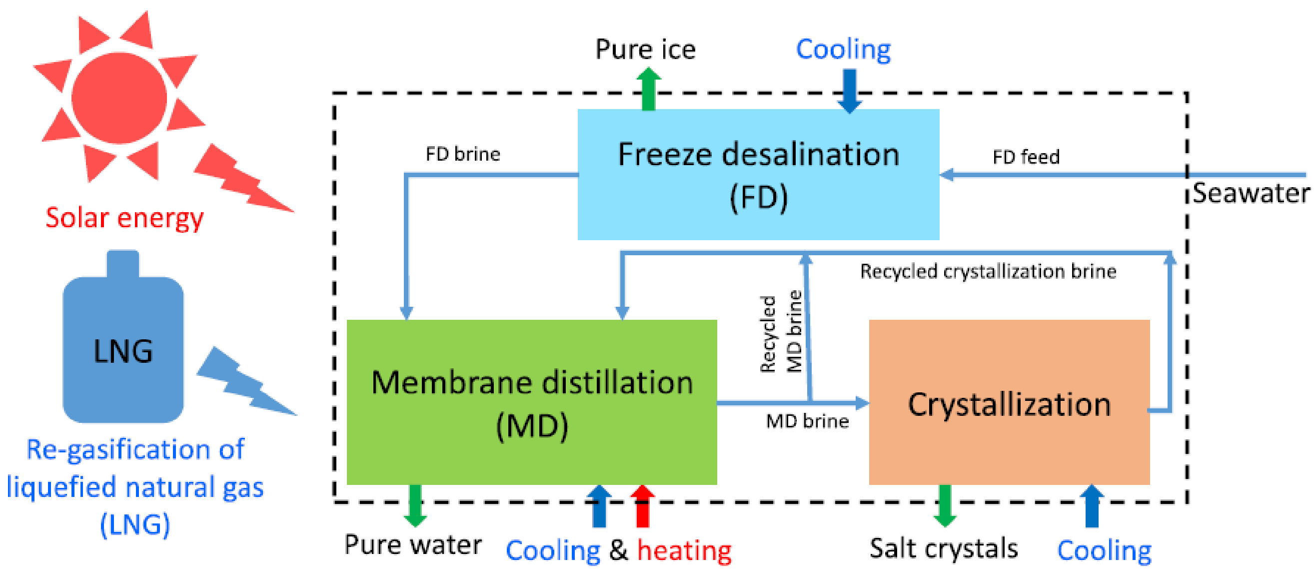

Figure 2: Zero Liquid Discharge

Source: Lu Jai Kang, Zhen Lei Cheng, Jian Chang, Lin Luo, and Tai-Shung Chung. 2019. "Design Of Zero Liquid Discharge Desalination (ZLDD) Systems Consisting Of Freeze

[32] Altaee, *Energies, 2*
[33] Nahawand AlZainati, Haleema Saleem, Ali Altaee, Syed Javaid Zaidi, Marwa Mohsen, Alaa Hawari, and Graeme J. Millar. "Pressure Retarded Osmosis: Advancement, Challenges and Potential." *Journal of Water Process Engineering* 40, (2021): 14.

Desalination, Membrane Distillation, And Crystallization Powered By Green Energies". *Desalination* 458: 66-75.[34]

As regulations become increasingly restrictive to reduce pollution as well as the rising costs associate with brine disposal, ZLD has become the best option to deal with both issues for a manufacturer.[35] On average the cost to dispose of brine can be as high as 33% of the desalination operation in addition to the rest of the overhead costs with whichever desalination method the plant is operating. Zero liquid discharge is normally a thermal-based technology that can produce the most amount of fresh water compared to any other methods of desalination. Two methods of treatment that are commercially available are brine concentrators (BC) and crystallizer. In BC the brine is heated to boiling where the water is turned into vapor and “then proceeds to a deaerator that removes non-condensable gases.”[36] What causes brine to separate from water is through the mixing and circulation of calcium sulfate (CaSO4) also referred to as a desiccant that removes moisture from the remaining concentrate and converted to crystals. Crystallizers also boil water to a vapor where the “vapor is compressed in a vapor compressor and heats the recirculating brine as it condenses on the heat exchanger.”[37] Illustrated in figure 2, once all the freshwater is extracted, the brine becomes a solid substance in the form of salt crystals which make it easier for disposal or reuse in other applications. Salt crystals can be used for creating chemicals such as sodium hydroxide (NaOH) or hydrochloric acid (HCI) which are used in either the medical or industrial sectors.

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[34] Kang Jia Lu, Zhen Lei Cheng, Jian Chang, Lin Luo, and Tai-Shung Chung. 2019. "Design Of Zero Liquid Discharge Desalination (ZLDD) Systems Consisting Of Freeze Desalination, Membrane Distillation, And Crystallization Powered By Green Energies". *Desalination* 458: 66-75.
[35] Enyu Liu, Yoke Lee Lai, Leong Ong Say, and Yong Ng How. 2020. "Treatment Of Industrial Brine Using Capacitive Deionization (CDI) Towards Zero Liquid Discharge – Challenges And Optimization". *Water Research* 183: 2.
[36] Argyris Panagopoulos, Katherine-Joanne Haralambous, and Maria Loizidou. "Desalination Brine Disposal Methods and Treatment Technologies - " *Science of the Total Environment* 693, (2019): 12.
[37] Pangopoulos, *Science of the Total Environment,*12

BC or crystallizer process are both energy intensive thermal technology, although the energy requirements can be supplemented with the use of solar panels, wave energy, or other renewable energy source. These are the most effective in obtaining the greatest percentage of freshwater and turning saline and other minerals into a dry form for disposal rather than returning it into a body of water. ZLD is the optimal solution for a region that has strong environmental regulations such as California in preserving the ecosystem and providing quality water. Additionally, California has abundance of renewable energy and if the desalination plant is strategically placed, it has the potential to incorporate multiple renewable energy sources simultaneously.

The use of RO, FO, or any other types of membrane or thermal desalination technology other than ZLD, only partially address the byproduct that is produced from these sources. In most of these methods the brine waste is ejected back into the original feed source by either diluting the solution through wells or mixing with other liquid discharges or retaining on land for evaporation. There are only a few organisms can survive on such high levels of saline and very few plant species as well.[38] Treatment of brine is costly and requires additional chemicals which make the residual sludge increasingly toxic. Failure to treat brine in California to a designated safe level, will result in fines or possibly closure of the facilities. The following methods are currently in use:

Methods of Brine Treatment

Brine is a hyper concentration of saline, waste minerals, and toxins which can be devastating to an ecosystem when left untreated and returned into the water source the

[38] Rajesha Kumar et al, "Desalination for Agriculture: Water Quality and Plant Chemistry, Technologies and Challenges." *Water Science & Technology* 18, no. 5 (2018): 1505-1517.

desalination plant feeds from. Brine treatment methods vary is application and are dependent on region and capacity to accommodate water treatment through put. The most popular methods are deep well injection, evaporation ponds, and surface water discharge.

Deep well inject is the method of drilling deep into the ground, well below any freshwater aquafer in order dispose of the brine concentrated solution. As illustrated in figure 3, the depth of the well can range from 500 meters to 1500 meters depending on location of plant and depth of freshwater aquafer. This method has been used for 20 years with minimal impacts to the environment. Over time, the feed tubes must be inspected for corrosion or clogging to prevent seepage into freshwater aquafer. This method has relatively moderate cost with site survey, deep excavation, and feed pump if required. This method is also suitable for any size of desalination plant and ideal for inland operations.

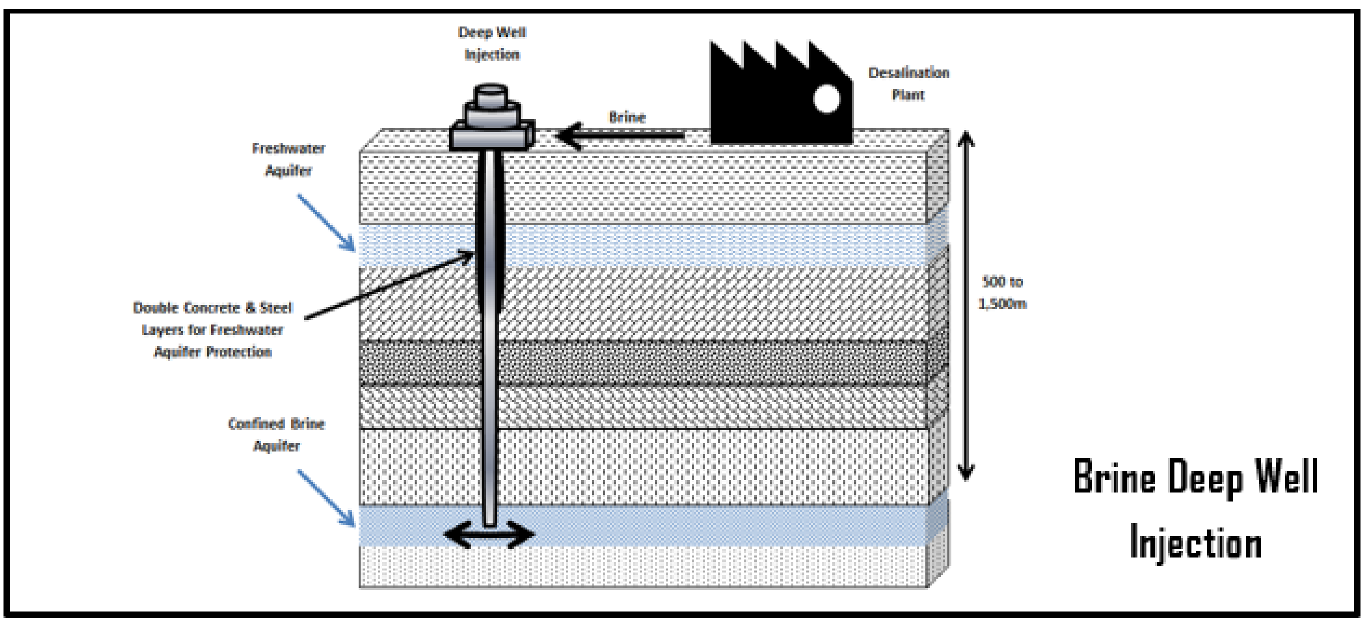

Figure 3: Brine Deep Well Injection

Source: Brine Deep Well Injection". 2021. *Lenntech.Com*.[39]

The risk to this method is the possibility of pressurized brine migrating vertically due to fractures in the well, brine injection rate outpacing ground saturation rate and no longer being able to hold the solution, or brine leakage into nearby freshwater wells that do not have any protective liner or casing. Once brine solution is injected into the ground, it is irreversible if such issues to arise and therefore a thorough site survey is critical to ensure a planned well is isolated and large enough to store the anticipated volume of brine injection.

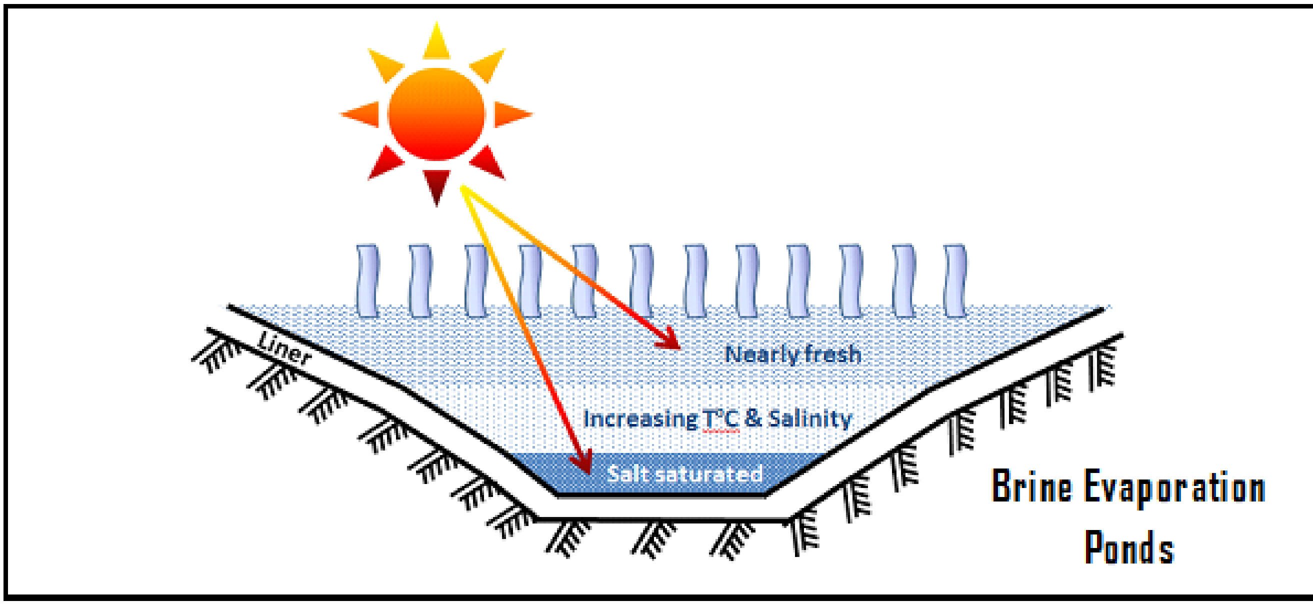

Figure 4: Brine Evaporation Ponds

Source: Brine Deep Well Injection". 2021. *Lenntech.Com*.[40]

Evaporation ponds as illustrated in figure 4, is an open holding reservoir where brine concentration solution is discharged into the pond. The process utilizes solar heat to evaporate

[39] "Brine Deep Well Injection". 2021. *Lenntech.Com*. https://www.lenntech.com/processes/brine-deep-well-injection.htm.
[40] "Brine Evaporation Ponds". 2021. *Lenntech.Com*. https://www.lenntech.com/processes/brine-evaporation-ponds.htm#ixzz6jq1O6smP.

the water molecules, leaving only the salt and minerals to harden and crystalize for reuse or disposal. The pond is lined with impenetrable material to prevent seepage into the ground. Liner integrity must be inspected to prevent contaminating any underground aquifers or surrounding vegetation that is sensitive to saline levels in the soil. Leak detection system must be installed to monitor liner integrity and catch the issue before significant contamination occurs. Additionally, potential risk exists for ponds to overflow and cause contamination during rainy seasons and is another reason for limiting this method to dry arid regions with minimal rain fall and ample sunshine such as California.

Evaporation pond is highly dependent on the climate which will dictate the rate of evaporation. One of the major costs associated with this method is the price of land, which in California will continue to rise along with population and agriculture as dependent variables. Given that desalination plants are to provide water for either urban centers or agriculture, this method will compete for space and will quickly become limited to the available land which will dictate capacity as the surrounding areas grow.

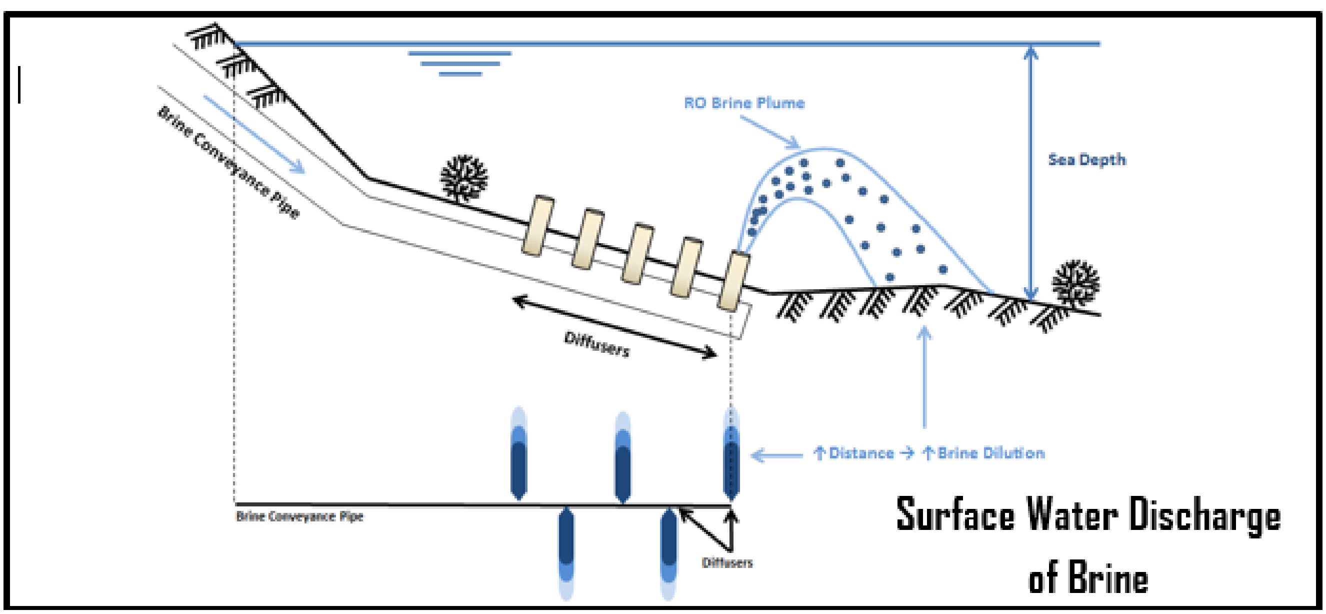

Figure 5: Surface Water Discharge of Brine

Source: Brine Deep Well Injection". 2021. *Lenntech.Com*.[41]

Surface water discharge is the method of dispelling brine concentrate back into a body of water which is usually the ocean or bay that the desalination plant is drawing from.[42] This is a cost-efficient method if the pipes that are utilized do not require trenching, otherwise underwater trenching can significantly increase cost. The necessity in trenching outfall pipes is to ensure appropriate clearance below the surface to prevent from being struck by passing vessels. A more cost-effective way is to lay the pipes on the ocean floor and anchor it down with a weight such as concreate blocks. This method relies on tidal current to carry the brine concentrate out to sea to further dissolve the saline with the rest of the body of water.

Location of the brine outfall pipes must be carefully selected as to ensure no endangered species are within the already fragile ecosystem where brine will be discharged. The tide current must be sufficient to carry the discharged brine, and the system must be deep enough to ensure no passing ships would strike the pipes. Distance between ocean or bay intake must also be considered as to not create circular system where brine is reinjected into the desalination process.

The brine outfall can be split into multiple tubes with enough dispersion to reduce concentration in a particular zone and to reach current strong enough to promote mixture. Additional planning consideration must be made for construction of any new costal desalination plants to have sufficient distance from existing plants. This is to mitigate the possibility of too many outfalls converging into one tidal zone area. Although this is a reliable method, inspection

[41] "Surface Water Discharge Of Brine". 2021. *Lenntech.Com*. https://www.lenntech.com/processes/surface-water-discharge-of-brine.htm.

[42] Kifah M. Khudair, and Eraibi A. Noor. "Environmental Impact of RO Units Installation in Main Water Treatment Plants of Basrah City/South of Iraq." *Desalination* 404, (2017): 270-279.

of outfalls should still be conducted to ensure there are no pipe leaks prior to reaching the mixing area where brine is ejected into the plume.

Existing Seawater Desalination Facilities

California current has 12 desalination that are located along the coast stretching from Monterey down to Carlsbad as the droughts primarily impact Southern California in the densely populated areas. As illustrated in figure 6, these facilities fall under the management of Monterey County, Los Angeles County, Orange County, and San Diego County. These facilities primarily use RO as the method to desalinate either seawater or brackish water and incorporates one of the previously discussed brine disposal methods. Two of the sites are closed and one scheduled to be decommissioned due to permits and new policies however, the facilities still occupy valuable property within the municipalities as they are in proximity to the ocean and connected to the water supply system.

Finding new locations for facility sites will be challenging when competing for space, permits, and accessibility to ocean water, all factors which drive cost to build and operate. To offset cost, the existing infrastructure can be used to retrofit new technology, making them more cost efficient and in compliance with new environmental regulations. One cost mitigating factor for some of the existing facilities is the proximity of desalination plants to power plants that share the energy requirement for water intake and discharge.

Another cost mitigating factor is for municipalities that are resident to operational military bases. In a public-to-public partnership, cost sharing to construct, operate, and maintain a desalination facility and reduce the burden on finding a suitable location. An example of such partnership is with the Forth Bliss and El Past Water Utility (EPWU) company; the facility is built on the base, but the ownership and operation is conducted by the utility company. This base facility "treats brackish groundwater and helps protect water quality in the aquifer, and provides additional potable water to EPWU customers, i.e., the community and Fort Bliss."[43]

[43] Beth E. Lachman, Susan A. Resetar, and Frank Camm. *Military Installation Public-to-Public Partnerships: Lessons from Past and Current Experiences.* RAND Arroyo Center Santa Monica United States, 2016.

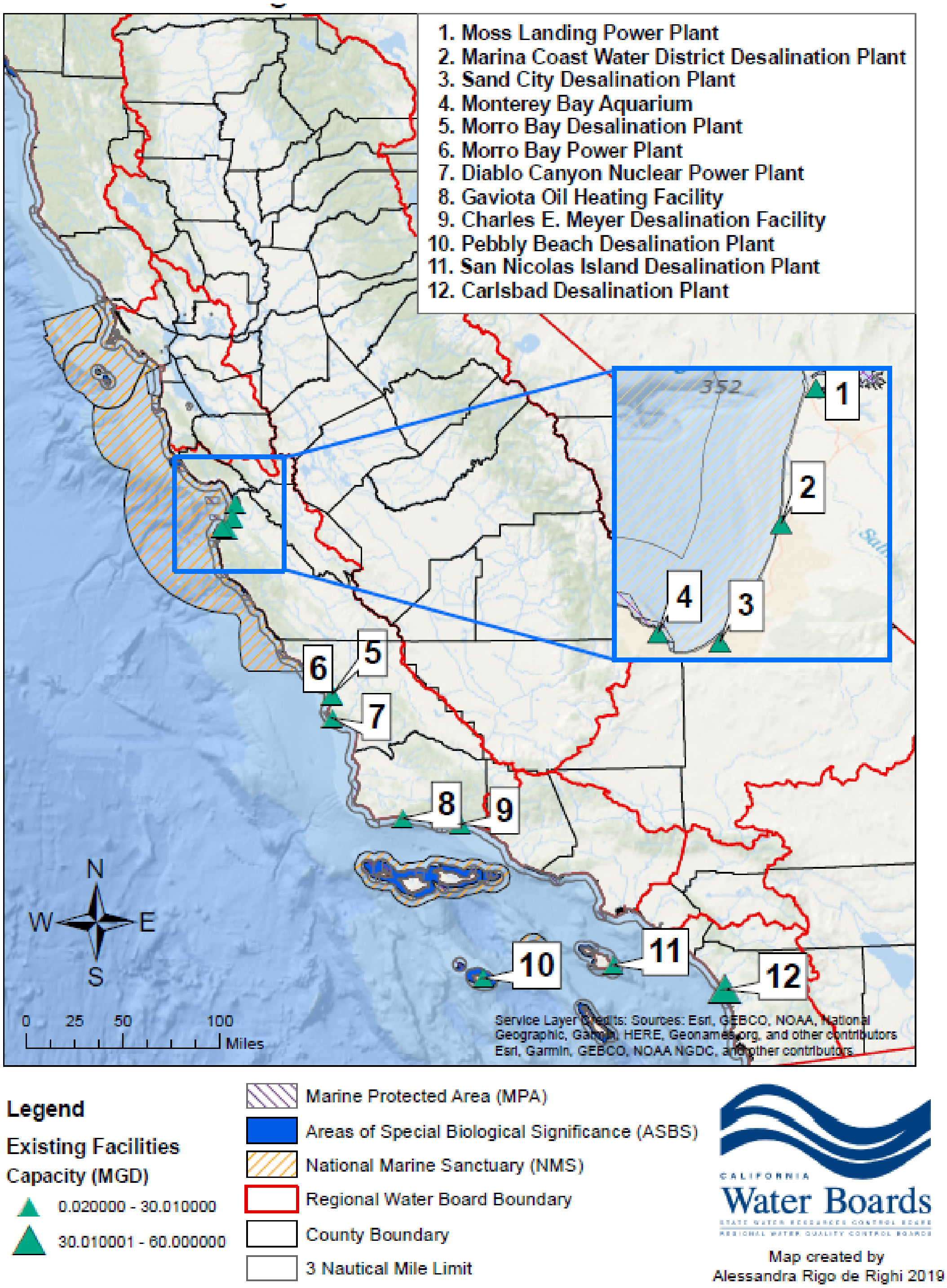

Figure 6: Existing Seawater Desalination Facilities

Source: de Righi, Alessandra Rigo. "Existing Seawater Desalination Facilities." n.d. Map. *California Water Board.*[44]

[44] de Righi, Alessandra Rigo. "Existing Seawater Desalination Facilities." n.d. Map. *California Water Board.*

As power plants also undergo modernization to become more efficient and reduce carbon emissions, this will only further benefit the desalination system. There are currently six new desalination plants proposed and scheduled to come on-line in the near future. Three of these facilities are around the San Francisco Bay area, one in Los Angeles County and two in Orange County. This paper will not address these new facilities however it is proposed for future research papers. A recommendation for these future desalination facilities is to use the synergistic relationships that existing facilities have been able to leverage with power plants along with incorporating developing green technology. Additionally, facilities that are in proximity with operational military base is another opportunity manage cost, land, and protect aquifers.

Moss Landing Power Plant

The Moss Landing Power Plant located in Monterey Bay utilizes water from the harbor to cool its power plant system while also feeding the desalination plant. The water first enters a pre-treatment filtration system to remove organic material prior to entering the RO system. [45] The symbiotic relationship between the powerplant and desalinations plant is also through the disposal of the brine solution. The brine concentrate is blended in with the plant's discharge to bring the saline levels to an acceptable amount and mitigating any impact to the Monterey Bay ecosystem.

Marina Coast Water District Desalination Plant

[45] Brad Damitz, David H. Furukawa, and Jon Toal. *Desalination Feasibility Study in the Monterey Bay Region*. Association of Monterey Bay Area Governments, 2006. 26.

The Marine Coast Water District Desalination Plant is no longer operational; however, when it was it utilized RO technology on an exceedingly small scale only producing .27 million gallons per day (MGD). This plant was initially built in 1996 intended to supplement the overdrawn groundwater well that resulted in saltwater instruction. At the time of operation, the plant recovered 52% of freshwater with the remaining brine pumped into a deep well along the coast. The brine would mix with the surf in order to dilute the high salinity content.[46]

Sand City Desalination Plant

The Sand City Desalination Plant also located in Monterey Bay was designed to pull brackish water from an aquifer under the beach instead of seawater which protected sea life from impingement. The purpose of this desalination plant is to reduce "the use of the Carmel River and Seaside Groundwater Basin."[47] This plant uses RO to provide the city with water transported and purchased from Cal-Am water company. This desalination plant disposes of the brin solution using a shallow well under the beach to dilute the saline levels with tide.

Monterey Bay Aquarium

The Monterey Bay Aquarium operates a small desalination plant that produces .04 MGD of non-potable water in order to support the basic daily operations of the aquarium. This desalination plant is one of the very first in California that is still in operation today. The brine is discharged along with the effluent that dilutes the brine to "ambient salinity, and the effects of the brine effluent are considered to be negligible."[48]

[46] Damitz, *Desalination Feasibility Study*. 91.
[47] Damitz, *Desalination Feasibility Study,* 29.
[48] Damitz, *Desalination Feasibility Study,* 26

Morro Bay Desalination Plant

The Morro Bay Desalination Plant is currently closed due to a gas leak that polluted the beach well, which caused the city's permit for the wells and outfalls to be pulled. Any operation of the desalination plant is in violation of the Coastal Commission which maintains the city in a water stressed situation as the city has no reservoir or storage capacity of its fresh water. When this plant was in operation, it used RO to desalinate the brackish water from the beach wells, disposing the brine through tidal current mix.[49]

Morro Bay Power Plant

Much like the Morro Bay Desalination Plant, the power plant is also closed; however, the Morrow Bay Ocean Fresh Water coalition are advocating for the plant to reopen as a full-time desalination plant. The proposed method would utilize RO in providing fresh water supply and dispose of the brine through surface water discharge which is a cost-effective method for the city.[50] Wave energy is proposed to power the plant to reduce carbon emissions.

Diablo Canyon Nuclear Power Plant

The Diablo Canyon Nuclear Power Plant is the last operational nuclear plant that is scheduled to be decommissioned in 2025. California has decided to move away from nuclear energy as it sees it as a potential hazard given the state is prone to earthquakes. The desalination plant uses the overflow of seawater pulled to cool the nuclear reactors which has no indication of

[49] Damitz, *Desalination Feasibility Study,* 87
[50] Damitz, *Desalination Feasibility Study,* 81

radiation. [51] The plant utilizes multiple treatment technologies consisting of "ultrafiltration (UF), electrodialysis reversal (EDR), double-pass reverse osmosis (RO), vacuum and mixed-bed ion exchange to produce high-purity water."[52] The high saline brine is used to flush the desalination system to reduce bacteria and mixed with the nuclear plant's discharge, diluting the water to ambient levels.

Gaviota Oil Heating Facility

The Gaviota Oil Heating Facility has a symbiotic relationship with the desalination plant that pulls seawater to supply fresh water to Santa Barbara county. The plant uses RO as its method of water purification and further treats the water with choline to make the water drinkable. The oil facility is powered through steam from water that is purified from the desalination process and further "deionized and use for injection into the gas turbines for nitric oxide emission control."[53] Brine is treated with mixing the facility's wastewater outflow to dilute the solution to normal levels and discharged into the Santa Barbara channel.

Charles E. Meyer Desalination Facility

The Charles E. Meyer Desalination Facility supplements freshwater to the city of Santa Barbara that also pulls from two reservoirs and groundwater. The facility is considered state of the art with many technologically advanced intakes and monitoring system to minimize marine life impingement. RO technology is used to filter the seawater, then the brine is sent to an energy

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[51] Debu Majumdar. "Desalination and other non-electric applications of nuclear energy." In *Workshop on Nuclear Reaction Data and Nuclear Reactors Physics, Design and Safety, Trieste, February*. 2002. 6.
[52] Ted Prato, Erik Schoepke, Lance Etchison, Tom O'Brien, Brian Hernon, and Kirt Perry. "Production of high purity water from seawater." In *American Desalting Association 2000 North American Biennial Conference and Exposition*. 2000. 2.
[53] Santa Barbara County Air Pollution Control District. 2018. "Gaviota Oil Heating Facility Point Arguello Project Stationary Source". Santa Barbara: Air Pollution Control District. 20

recovery system that uses the high saline solution to reduce energy consumption. The brine is then mixed with the city's wastewater which dilutes the solution and then discharged back into the ocean.[54] Although the desalination plant is fully operational, it is still considered as a standby option during periods of drought.

Pebbly Beach Desalination Facility

The Pebbly Beach Desalination Facility provides fresh water to the city of Avalon through the RO process. The facility does not provide the water immediately upon filtration as this site is considered supplemental, instead the fresh water is stored in tanks until required. This facility out of all the other existing seawater desalination plants still in operation produces the most amount of waste that is untreated and discharged back into the ocean. Although it produces the most waste, it is still within the mandate limits which is "permitted to discharge up to 0.720 MGD (500 GPM) of reject brine, saltwater bypass (untreated seawater), filter backwash from the desalination process."[55]

San Nicolas Island Desalination Plants

The San Nicolas Island Desalination Plant is located on the Navy Base that is off limits to civilians. The plant utilizes a small RO desalination plant to supply water to the island inhabitants and without it the only other way to bring water to the island is on a barge. The fresh water that is extracted is stored in tanks for use as needed and the brine is ejected in a beach well that mix with the tide to stabilize the saline levels.

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[54] "Santa Barbara - Desalination". 2021. *Santabarbaraca.Gov*. https://www.santabarbaraca.gov/gov/depts/pw/resources/system/sources/desalination/.

[55] California Regional Water Quality Control Board. *Proposed Reissuance of Waste Discharge Requirements*. Public Notice No. 16-045., 2017. NPDES No. CA0061191. 1.

Carlsbad Desalination Plant

The Carlsbad Desalination Plant draws water from the Encina Power plant's boiler cooling system where both plants are co-located. The desalination plant is one of the most advanced plants with "solar power generation system on its approximately 50,000ft² rooftop, pressure exchanger-based energy recovery system and variable frequency drives and energy efficient motors for all pumps."[56] The desalination plant uses RO to treat sea water and is stored at the facility for distribution to the community. Similar to other plants that are co-located with power plants, the brine reject is mixed with the power plant's discharge, reducing the salinity of the brine to mandated levels.

Conclusion

Water management in California is complex with many competing interests for water rights and allocation. The strongest advocates are mega farmers who rely on steady water for crops, politicians and special interests who encourage the sale of water intensive products to domestic and international consumers, and environmental activists who seek to preserve and reduce consumption of this natural resource to even lower levels. Conservation efforts alone will not curb the constant depletion of the underground aquifers which currently outpaces recharge rate and therefore an alternate source must supplement the water shortage. Therefore, desalination is the most plausible solution so long as the disposal of brine is effectively implemented.

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[56] "Carlsbad Desalination Project, San Diego, California". 2021. *Water Technology*. https://www.water-technology.net/projects/carlsbaddesalination/.

The most widely used method with existing seawater desalination plants in California is RO. Membrane desalination is proven technology that has been used for decades and the most common issue is the fowling of membrane. Unless coupled with another desalination method, RO technology can only produce on average only half of the fresh water pulled from either sea or brackish water intake. The existing facilities dispose of the brine reject by diluting the brine with either power plant effluent discharge, deep or shallow well injects by the beach that gets mixed with the tied, or surface discharge. Energy requirements have also been supplemented with the use of solar, electrodialysis, and steam from the symbiotic relationship with powerplants.

Existing desalination plants can be improved with integrating ZLD technology to capture the most amount of water while also removing toxic chemicals and minerals from the ocean. This can be mutually beneficial for ocean health as well as supplying ample usable water for local populations. Although ZLD require more energy for the thermal process, renewable energy sources can supplement the additional requirements as is the case with the Carlsbad desalination plant which has renewables incorporated. Desalination plants using ZLD technology and renewable energy to power the plant can be the long-term solution to California's water issue to meet current and future demand.

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