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Literature Review on Water Desalination Plant Production and Brine Disposal Methods

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Literature Review on Water Desalination Plant Production and Brine Disposal Methods

An Undergraduate Thesis Proposal

By

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Abstract

Water scarcity is an issue all around the world because people have a lack of clean and available drinking water. One way this issue can be eased and people can have more access to water is implementing water desalination plants around the world. Since most of the water on earth cannot be drunk, there are ways to turn the over abundance of salty waters we have on this planet into fresh, drinkable water to ease the water insecurity. There are many methods out there that can be used for water desalination, most of them involving membrane technologies. The most efficient and highly used method is Reverse Osmosis (RO). Once the salt water travels through the membranes and extracts the salts there are two outputs involved, the clean and desalinated water and then the concentrated salty brine water being rejected. The brine has to go somewhere, but most of the options used tend to have some negative impact on our environment. Exploring the most efficient brine disposal method in terms of output, energy, and environmental impacts is important when looking into how feasible large-scale water desalination could be in the future. It is a nice idea for there to be large plants constantly turning saltwater into freshwater, but everything comes with a price. The building and operation of these plants use up a lot of energy, releasing CO2 emissions into the air and the brine output from the RO process can harm the health of marine ecosystems. This research will explore the in and outs of water desalination processes, economic and environmental components and brine disposal or usage in order to evaluate what has to be considered for large-scale implementation in our future to help provide freshwater to the people who do not have consistent access to any.

Introduction

I am conducting research on water desalination methods in different countries, comparing the different processes and environments, looking into the economic impacts the implementation of water desalination plants has, and exploring methods of brine disposal or brine usage of the deposits the desalination plants produce. I am also focusing on established water desalination plants in the United States looking at their water production, energy efficiency, intake and outputs and brine disposal methods to evaluate how they contribute to the fight to reduce water scarcity. This research is important because 71% of the earth's surface is covered in water and less than 3% of that water is freshwater. The problem of water scarcity is an issue all around the world and it is only going to get worse. One thing I find so important for the future is that every person has access to clean water, that is why it is important to utilize the water we do have and turn saltwater into fresh, drinkable water through desalination methods. I am conducting this research in order to gain new knowledge on the topic and am looking into what impact the plants have on the water crisis and see if they can improve in any way.

Desalination is a method where we mimic the natural water cycle's processes of evaporation from oceans and subsequent condensation via a variety of technical processes to remove salt from brackish or salt waters producing clean water (Dongcuo 2014). There are many different desalination methods out there, so it is important to research the details of each process to see which process would work best for specific geographical and economic environments. "While lack of access to consistent safe drinking water is estimated to affect nearly 2 billion people worldwide, many of the efforts to solve this crisis have proven to be unsustainable" (Brunson 2013). It is important to solve the water insecurity crisis, but by reviewing different methods to determine which one is the most efficient and sustainable. Water desalination is a process that takes away minerals from saline water. It generally uses reverse osmosis technology to separate the water molecules from seawater, converting it to fresh and drinkable water. The reverse osmosis process reduces the amount of salt in the water by transferring it through semi-permeable membranes. There is a competing membrane process that has lower environmental impacts than reverse osmosis called Memstill. "Memstill has lower salt concentration increase in brine, efficient energy use, less pretreatment and chemical use during the operation and finally lower investment and operational costs compared to reverse osmosis technology" (Tarnacki 2011). This represents that there are always going to be new processes discovered with certain benefits and that work in certain environments, so it is important to research each water desalination process during this study.

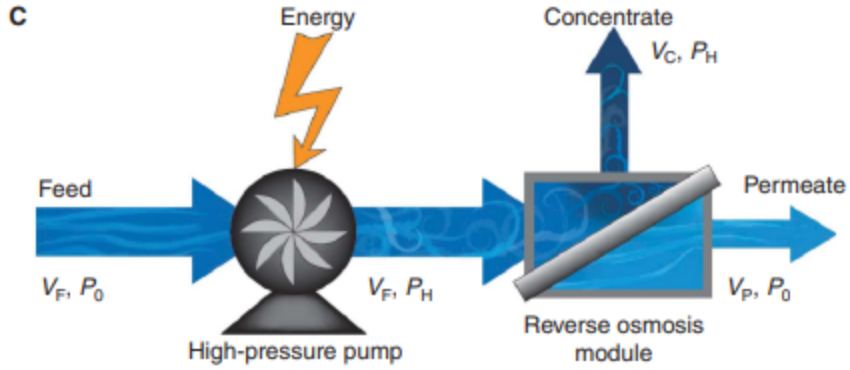
To examine the efficiency of a desalination method there are many components to look at, including recovery, rejection, and water and salt flux. Recovery is the proportion of feedwater that goes through the membrane to yield permeate and rejection is the amount of dissolved solids (brine) rejected from the membrane. The water and salt fluxes are important because they are the volumes of water or salt that passes through a unit of the membrane per unit of time (CEP 2014). Implementing desalination methods in your area is very costly with per unit production costs of water, cost of energy, thermal and electricity, constituting up to 48% of total cost for thermal seawater desalination and 32% for the RO seawater desalination process. At present, RO is the most energy-efficient technology for seawater desalination at industrial scale. The further improvement of RO membranes, possible but difficult, may result in a 10–30% reduction in

actual energy consumption of RO desalination (Li 2018). One way to determine if it is feasible for water desalination plants to be built and operated in the United States is to look at countries where there is already successful implementation.

I looked into water desalination processes in Israel and found that their plants are the most energy efficient in the world and all their municipal water comes from the desalination plants (Tal 2018). One concern in Israel are the environmental impacts of the desalination processes. According to the article: "desalinating 1000 cubic meters of water (one million liters) per day consumes the rough equivalent of 10,000 tons of oil per year" (Tal 2018). This area of study is very interesting to me because a lot of people can agree that water desalination has its benefits in overcoming water scarcity issues, but other environmental impacts need to be considered when evaluating these processes. After many years of advocacy, there were five desalination plants developed to transform seawater into potable water in Israel. What I liked about the article on Israel is that it emphasized the benefits from the implementation of their desalination plants, but does not ignore the negative side of things. When most people advocate something that is "good for the environment" they focus on that thing's one goal, but never the other impacts it has. When I hear something about water desalination I think about how great that is that we are utilizing our natural resources, but I don't think about the CO2 emissions the plants release or how much oil they take to operate.

Another country who shows interest in the desalination process is China, where there is a plan for saline alkali water desalination in Southern Xinjiang. There is a high concern of the saline levels in their water and soil in this area and it is known to have a scarce amount of water resources so, "the development of recycling use of water resources and saline-alkali soils is the core technology of Xinjiang construction" (Fan 2019). The government wants to implement this project because it has an important effect on improving the ecological environment in Southern Xinjiang. It can alleviate the water shortage situation there and curb the saline-alkali soil effectively. Researching countries that have or are considering implementation of water desalination methods and plants is important to know what to look for and what questions to ask when it comes to implementation in our country.

Another thing I would like to focus on during this study is the economic impacts of water desalination. The main economic components that affect the price of desalinated water are capital and operational costs, production capacity, desalination technology, production capacity, and water salinity (Ziolkowska 2014). The topic of economic impacts on desalination is significant because in order to have a sustainable society the environment, the economy, and society all need to be considered. There is the area of energy consumption that I have explored, especially with reverse osmosis, since it is the most energy efficient desalination method. Despite this, reverse osmosis consumes more energy than the theoretical minimum energy required for desalination methods. There are ways to reduce the energy this process consumes, for example there is a staged membrane operation that can be implemented (shown below). This reduces the cost of the process by operating at a lower pressure in the first stage then it is pressurized to achieve the percent recovery desired (Elimelech n.d.).



The topic of water desalination is important to me because I am very interested in the water safety and quality field and have learned a lot about water scarcity in the past year or so. I have learned a lot about groundwater safety, aquifers, and water use in our state and was always curious why we don't utilize saltwater more. There are a lot of concerns with low groundwater levels, drought, or water scarcity issues when most of the world is made up of water. I always found that so interesting, the one thing this earth has more of has been a big concern for so long and that's because most of the water on earth isn't fresh. I always knew there were methods of turning saltwater into freshwater, but wondered why we don't utilize that more and that is why I chose this topic to research. I want to learn all about the different processes, how they compare, which one would be best based on locations, the effects on economy, and successful implementation. I think this research should take place because it is no surprise that the earth is overpopulated and our natural resources are being depleted in order to satisfy our population's needs. Every living thing needs water to live, humans use up so much water, not only for drinking but for recreation and for food and crop production. There should never be someone out there concerned about not getting enough water that day or concerned for the safety of the water they are drinking. That is what utilizing the technology we have and all the water we have to produce enough fresh water for the population is important. Before we can do that research has to be done on every aspect of this operation, it takes time, money, planning, land, etc. in order to build and operate water desalination plants, so this research is important to get the best results possible for everyone involved.

The type of study I am conducting is qualitative and I am performing a literature review of peer-reviewed articles on the topic. This will help me compile all the information I'll learn about water desalination by doing research and analyzing data. Some key factors to consider is the type of environment the areas I study are in because that plays a huge factor in this process. I have to look into the environment's location, climate, population, and economy in order to understand the environmental conditions that water desalination plants work most efficiently in. There would be many systems involved in water desalination plants that need to be considered. The public's opinion is important, the political and economic factors play a role, and the location that the plants would be operating in. The plants need a large amount of land, need a lot of workers to build the plants, and a lot of jobs will be created in order to keep the plants operating efficiently.

The main concern with sea water desalination is brine discharge that pollutes the water sources the plant is established in. According to research on impacts of brine disposal in the Persian Gulf: “This discharge of saltier waters impacts the marine ecosystem and may also affect dynamic and thermodynamic processes and when brine is injected, surface gravity waves irradiate from the locations and induce perturbations in other thermodynamic variables in the far field” (Campos 2020). With the negative impacts of brine deposits into the water there has been a lot of research done on how to dispose of the brine or on how to make useful products from it. With these negative impacts of brine disposal some states, like California have taken action: “Starting in 1972, the California State Water Resources Control Board adopted the Water Quality Control Plan for the Ocean Waters of California (Ocean Plan) as a regulatory oversight to address the environmental impacts of brine discharge” (Rodman 2018). There are processes to generate the brine wastes that are removed before the membrane process starts, which include acidification, addition of antiscalant chemicals, chlorination, and de-chlorination. For poor quality water, filtration, coagulation, flocculation, ion exchange, and carbon adsorption (Ahmed 2000). Brine water can contain many different elements including Al, Cr, Fe, Mn, Ni, Pb, and Zn. There is no way to reduce the product of brine into a simpler compound before it is deposited, but there is a way to collect the brine and utilize it after it has been discharged from the membrane method. One method of brine disposal that is very popular with reverse osmosis is the use of evaporation ponds. This is where the brine from the desalination discharge is deposited into a shallow evaporation pond and exposed to solar radiation. This method is perfect for high temperature and dryness areas to evaporate all the liquid from the pond leaving the residual salts that are removed periodically (Shalaby 2022). There are processes that lower the impact of brine disposal on the environment which are called Zero Liquid Discharge methods, which maximizes the recovery of freshwater and lowers the volume of concentrated water that is rejected. “By applying systems with zero liquid discharge (ZLD), there will be a potential for the recovery of the solid salts out of brine. The first step of the procedure is brine concentration, then crystallization, followed by dewatering of the solids. The budget of wastewater discharge is efficiently eliminated as well as producing solid salts by applying ZLD technologies” (Soliman 2021). An example of a process that recovers the salts for economic purposes and reduces the impacts on the environment is the SAL-PROC process is the use of technology for commercial salt recovery from brine. According to research on brine management, “SAL-PROC is an integrated process for sequential extraction of dissolved elements from inorganic saline waters in the form of valuable chemical products in crystalline, slurry and liquid forms. An analysis indicated that various types of salts, including gypsum, NaCl, Mg(OH)2, calcium chloride (CaCl2), CaCO3 and sodium sulfate (Na2SO4), can be produced from the reject brine of desalination plants” (Morillo 2014). This process helps ease the problem of brine disposal into our water and provide an economic benefit as well. There is a large commercial potential to the amount of salts that could be produced from the brine deposits from the reverse osmosis membrane. Below is an image from the research from Morillo that shows the specific steps of the SAL-PROC process.

Water desalination can be implemented to ease the pressure on our current water resources and work on solving the issue of water scarcity. This research on the different processes, successful implementation, and environmental and socio-economic impacts are all important areas of study to determine the most sustainable and efficient process of water desalination and brine usage for the United States to possibly implement in the future.

Research Questions

1. What is the most efficient use or disposal of excess brine from water desalination methods?
2. How efficient are the current practices for managing brine?
3. What are the production levels of large-scale plants in the United States?
4. What are the environmental and socio-economic impacts of implementing large scale seawater desalination?

Methods

The research design I am using for this project is meta-analysis. The approaches that I am using for this project are description and comparison research methods. The design of meta-analysis research is evaluating existing information to better understand and develop a research problem. I am looking at ecological and mathematical data during my research process. Looking into how much each water desalination method costs is important to deepen my understanding on this issue and to find a realistic solution to it. Comparing the economic data in this study is important to see how possible methods of desalination could impact the United States with large scale implementation. One article I did a literature review states that: "The Perth Seawater Desalination Plant is the largest in the world outside of the Middle East, with a daily capacity of 144 mega liters. It provides 17% of the water needs for the city's 1.6 million residents" (Tal 2018). One of the desalination plants in Perth could provide water for that large amount of people, that is why I am curious about the data of established desalination plants in the United States. Implementing large plants like that is very costly, so it is important to look at the costs of building and maintenance of established plants and compare that to the amount of resources and people in the United States to see what is economically feasible.

I am using the comparison research approach during this study by looking into the details of each desalination method and comparing them to one another based on costs, effectiveness, and geographical location. I am looking at the relationships between each method and how they have an impact on the environment and economy when implemented in order to determine the most effective desalination method for the United States. This is important because the methods' effectiveness can change with geographical location and with the amount of people working on the plant and maintaining it. Descriptive and comparative research was conducted in exploring the different methods to dispose of the rejected brine after the plants desalinate the water. Reviewing the largest water desalination or wastewater treatment plants in the United States was to evaluate what the outputs of desalinated water are compared to outputs of reject brine for each plant. Research was also conducted about the details of what each desalination plant does with the reject brine, since there are many options on where to put the brine after the clean water is recovered. Comparing each brine disposal method for the already established plants is a good way to get a sense of what the most efficient disposal method is and seeing how geographic location and desalination techniques may impact the method of disposal.
I am using the descriptive approach in my research as well because I am gathering data from each process and observing or measuring the behavior of each one. This is important with the environmental side of my study, to observe the impacts each desalination method has on the

environment. For this research I am using a systematic literature review method to gather my data. I am gathering research articles about the different methods, their economic impacts, how much freshwater can be produced, and the environmental harm possible when using these methods. I am also researching the established water desalination plants in the United States to gain knowledge on what characteristics of a plant succeeds. Looking at the established plants will help me determine how much each desalination plant contributes to the fight against water insecurity. The data I am collecting is more qualitative than quantitative, even when I compare amounts of water collected or economic costs. I will be using thematic analysis to analyze the data I collect from the research articles I review. This will help me find the most efficient characteristics a water desalination plant can have.

Results

Comparison of water desalination methods

From the literature review on the different water desalination methods that plants have established the top two regarding energy, cost, and production are Reverse Osmosis (RO) and the Memstill process. Reverse osmosis has been established as the top method for desalinating water, especially in the last few decades there has been decreased operational costs from higher energy efficiency from improved membranes and better energy recovery systems (Tarnacki 2011). Memstill is a fairly new water desalination process that is RO's highest competitor in production. The biggest comparison the two have is that Memstill has a lower environmental impact with lower salt concentration in the brine that is disposed of. Memstill also requires less pretreatment of water, no chemical use during the operation, and lower operational and investment costs. Even after all the advantages Memstill has over Reverse Osmosis, RO is the main process for water desalination based on recovery rate of water. The main function of a water desalination plant is to produce fresh, drinkable water from contaminated or saltwater, and since Reverse Osmosis has a much higher recovery rate compared to Memstill, it is the chosen process for water desalination methods.

Table 1. Comparison of the main characteristics of Memstill and Reverse Osmosis processes. This table compares the statistics of these two processes to evaluate which one is most efficient. These results are based on assumption but can change based on the energy source and operation of the specific plants.

	Memstill process	RO process
Membrane material	PTFE	Active layer – polyamide (composite membrane)
Module design	Plate and frame	Spiral wound
Housing, spacer	Steel, PP, PE	Steel, PP
Recovery rate	10%	42.5%
Chemicals	No use	ClO, H_2SO_4, $NaHSO_3$, $FeCl_3$
Energy demand (electrical)	0.75 kWh	4–6 kWh[a] (incl. pre-treatment)
Energy demand (thermal)	20–200 MJ[a]	–

[a]Depending on the available energy source, configuration and operation.

The economics of water desalination

Water desalination is a great concept with the amount of water that is not drinkable on this planet, but there are many factors that determine the development of desalination plants to not be feasible. The costs of building and operating a water desalination is the biggest environmental factor in this process. The cost of desalinating water is represented as a function of capital costs and operational and maintenance costs. For evaluation of the economics of water desalination in our Country, I researched the details of one of the largest plants in the United States, the Carlsbad Desalination Plant in San Diego, CA.

In 2012 an agreement between Poseidon Resources and the San Diego County Water Authority (SDCWA) was made for the approval of Poseidon Resources to buy up land for the design, build, and eventual establishment of the Carlsbad Desalination Plant. The plant is funded through debt, bonds, and private equity, with the total engineering, procurement, and construction costs being $594 million (Smith 2015). The purchase agreement made between the two parties for the purchase of this land established the economics and the numbers the plant needs to meet in order to be profitable, pay the debt back, and continue operating. For the plant to be successful there has to be a water unit price established to estimate the costs and prices for the desalinating and then transport of the water. The components that determine the water unit price include the fixed charges, like debt service, and variable charges like electricity costs.

Table 2. Represents the estimate for a possible bond rate of 5.60% taking in the unit price of the water and delivery areas in acre feet. Telling us what components go into pricing the water in order for the plant to return the equity capital 30 years after establishment (Smith 2015).

Unit Price Component	Water	Delivery
	48,000 AF	56,000 AF
Fixed Charges		
Debt Service	$551	$472
Equity Return	$280	$240
Pipeline Installment	$238	$204
Fixed Operating Charge	$400	$343
Fixed Electricity Charge	$73	$63
Sub-Total	$1,542	$1,322
Variable Charges		
Operating	$101	$101
Electricity	$442	$442
Poseidon Management Fee	$10	$10
Sub-Total	$553	$553
Water Unit Price	$2,095	$1,875
Other SDCWA Costs	$193	$165
All-in Cost of Water	$2,288	$2,040

The purchase agreement states that the Carlsbad plant can be reevaluated for possible buyout if they become short on their debt payments, fails acceptance training, Poseidon Resources becomes bankrupt, deliveries less than 75% of the amount stated in contract, and the drinking water standards are not met. Looking into what costs and funding goes into the beginning steps of a large scale desalination plant is important to understand how these plants affect our economies.

Brine discharge and disposal methods of water desalination plants

Reverse osmosis has been proven to be the most efficient and most popular method of water desalination, but after the process is finished the plant rejects a concentration of brine water. This has been the biggest issue with the water desalination processes, but many of the large-scale plants have explored options on what they can do with the brine to dispose of it in the safest and cleanest way possible. The methods of brine disposal can depend on the geographical location of the water desalination plant, the output of clean water and concentrated brine water, and the desalination method used by the plant. To look into the different methods of brine disposal, research was conducted on some of the largest implemented reverse osmosis plants in the United States. For this portion I looked at five desalination plants shown in the table below.

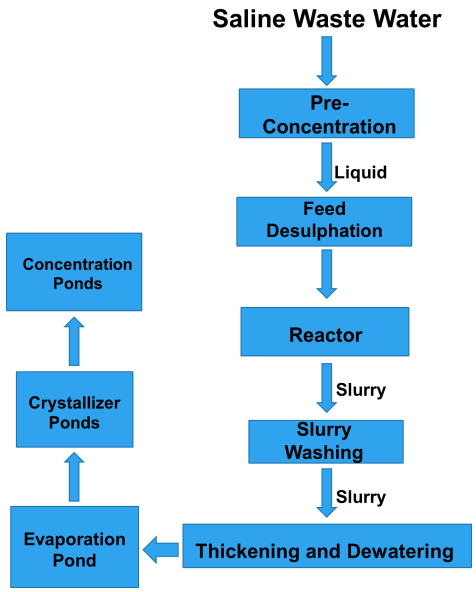
Table 3. A compiled list of five of the largest water desalination plants in the United States. This shows how much clean water compared to concentrated brine water is produced after the RO process and shows the different methods of brine disposal. Representation that there are many different ways to dispose of the brine post desalination that have different costs and benefits. Brine management is still a work in progress and there is not a perfect disposal method yet.

Water desalination plant	Location	Treated water produced, million gallons per day (MGD)	Brine water produced, million gallons per day (MGD)	Brine water disposal
Yuma Desalination Plant (Bureau of Reclamation 2012)	Yuma, AZ	73 MGD	30 MGD, combination of RO product and MODE blend water	Through the MODE (Main Outlet Drain Extension) to the Colorado River
Carlsbad Desalination Plant (San Diego 2022).	San Diego, CA	50 MGD	50 MGD	Into the Pacific Ocean through the Encina Power Station Channel
Tampa Bay Seawater Desalination Plant (Tampa Bay Desalination Plant 2022).	Tampa Bay, FL	44 MGD	19 MGD	The brine is moved through a discharge canal where it is diluted to Tampa Bay's salinity level and then it is deposited into the Bay
Kay Bailey Hutchinson WTP (Kay Bailey WTP n.d.).	El Paso, TX	27.5 MGD	4.675 MGD	Brine is piped through storage tank and then the concentrate is disposed of through deep-well injection

Reviewing what methods of disposal these plants use represents what the most popular and efficient brine management methods are. Some plants may just dump the concentrated brine back into the seawater without any alterations done to it or plants can dilute the brine to make it the correct salinity level then dump it back into the water. There are also different ways you can dispose of the brine into seawater that eases the harm it causes to the environment. These are some of the alternatives that help ease the effects on the environment, but there are ways to use the brine as well, like dilution or using high water current to your advantage.

Having an efficient method of brine disposal is important to help decrease the harmful effects that are put onto the environment from brine exposure. Some of the solutions for the brine issue include mixing sea water before being pumped out to reduce the effects, dispose of the brine with the highest water current, and use the brine for commercial salt uses. There is a newer process called the SAL-PROC membrane method that turns the concentrated brine water into commercial salts that can be used for economic purposes. “SAL-PROC is an integrated process for sequential extraction of dissolved elements from inorganic saline waters in the form of valuable chemical products in crystalline, slurry and liquid forms. An analysis indicated that various types of salts, including gypsum, NaCl, Mg(OH)2, calcium chloride (CaCl2), CaCO3 and sodium sulfate (Na2SO4), can be produced from the reject brine of desalination plants” (Morillo 2014). The step by step process for this procedure is shown in the figure below.

Figure 1. This figure shows the most popular process of turning salty brine from the desalination plants into commercial salts that can be sold on the market.



Discussion

One purpose of this project is to evaluate the established water desalination plants in the United States and see how they are contributing to the water crisis relief, and affecting our economy. Since water scarcity has grown over the years, the need for more water desalination plants has also grown. I did this by looking at some of the largest water desalination plants in the U.S. to see what their inputs, outputs, energy consumption, and amount of people they provide for are.

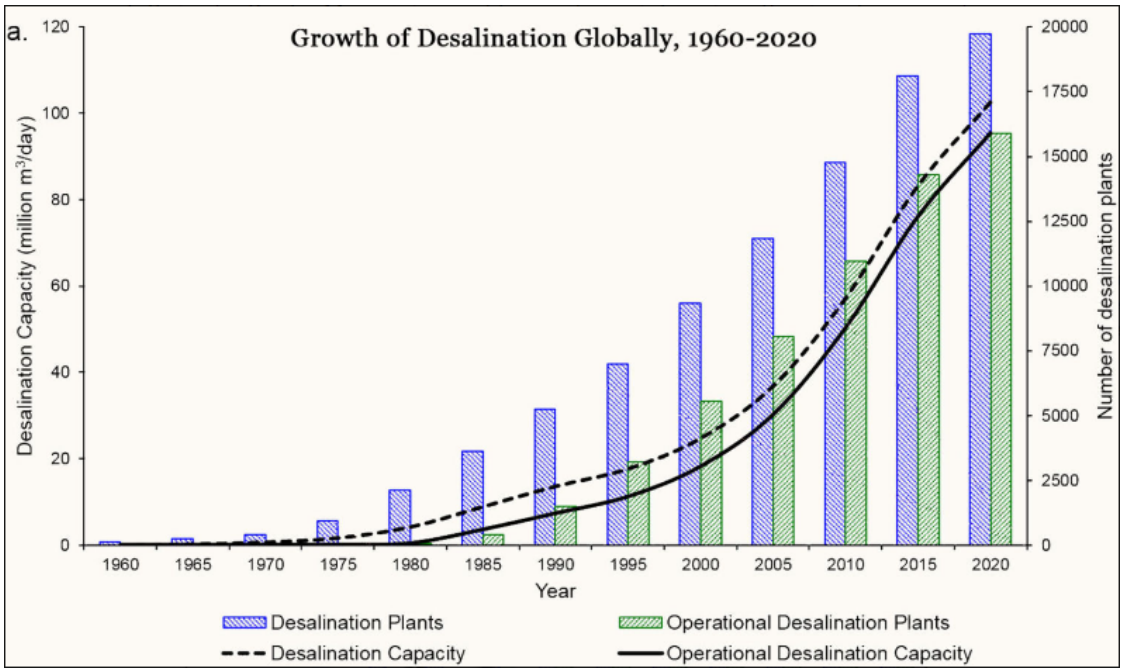


Figure 2. Desalination has been growing steadily in the last decade. JONES ET AL, SCIENCE OF THE TOTAL ENVIRONMENT, 2019.

One large issue that we discussed earlier was the effect of brine discharge from the desalination plants. When brine is disposed of into the sea-waters it causes negative impacts on marine life, depletes the oxygen in the water, disturbs the food chain, and kills sea water plants (Connecta't 2022). There are two methods in reducing the amount of environmental harm these desalination plants cause, either carefully disposing of the toxic brine before the water is treated or solutions for the brine disposal after the water is treated. Some of the solutions for the brine issue include mixing sea water before being pumped out to reduce the effects, dispose of the brine with the highest water current, and use the brine for commercial salt uses. These are some of the alternatives that help ease the effects on the environment, but there are ways to use the brine as well. You can reduce the plume effect of the brine by mixing diffusion dilution, discharge the brine onto surface water, use evaporation ponds to collect the salt, use land application for crops with irrigation purposes, de-icing roads, or use it as dust control (Connecta't 2022). These are just some of the general ways discussed on how to handle the large amount of brine discharge.

RQ1: The most efficient disposal of excess brine is diluting it with seawater to make it a healthy salinity level and then disposing of it back into the body of water. This practice is used by the desalination plant in Tampa Bay. There is also a method to turn the excess brine into commercial salt products that could be sold, called SAL-PROC shown in figure 1.

RQ2: The most efficient water desalination method in the terms of energy, economy, and the environment is Reverse Osmosis (RO). Table 1 in the results section shows the comparison of the two most popular desalination methods. Even if RO has a much larger demand for energy in kWh the recovery rate of water under the RO process is much higher to make it more efficient.

RQ3: Table 3 in the results section shows which brine disposal methods are used by the RO largest desalination plants in our country. This clarifies the most current and efficient brine disposal practices that are used in the country on a large scale.

RQ4: The main environmental impacts are caused by the disposal of brine into our bodies of water. High concentrations of brine in our waters harm marine life, deplete the oxygen in the water, disrupt the food chain, and kill seawater plants. The main economic components that affect the price of desalinated water are capital and operational costs, production capacity, desalination technology, production capacity, and water salinity (Ziolkowska 2014).

Conclusion

One purpose of this project is to evaluate the established water desalination plants in the United States and see how they are contributing to the water crisis relief, and affecting our economy. Since water scarcity has grown over the years, the need for more water desalination plants has also grown. I did this by looking at some of the largest water desalination plants in the U.S. to

see what their inputs, outputs, energy consumption, and amount of people they provide for are. Based on peer-reviewed journal articles and data from resources provided by established desalination plants, reverse osmosis and safe brine disposal methods are necessary to ease the water insecurity issue we have. Water security levels can be improved by the combination of RO membrane desalination and the disposal of brine into the oceans, after being diluted to safe saline levels. If I would have done this project any differently, I would gather more information and data on our future water needs to evaluate what water production levels are needed.

References

Ahmed, Shayya, W. H., Hoey, D., Mahendran, A., Morris, R., & Al-Handaly, J. (2000). Use of evaporation ponds for brine disposal in desalination plants. Desalination, 130(2), 155–168. https://doi.org/10.1016/S0011-9164(00)00083-7

BRUNSON, BUSENITZ, L. W., SABATINI, D. A., & SPICER, P. (2013). In pursuit of sustainable water solutions in emerging regions. Journal of Water, Sanitation, and Hygiene for Development, 3(4), 489–499. https://doi.org/10.2166/washdev.2013.136

Bureau of Reclamation, L. (2012, July). Lower colorado region. Retrieved November 21, 2022, from https://www.usbr.gov/lc/yuma/index.html

Campos, Vieira, F., Cavalcante, G., Kjerfve, B., Abouleish, M., Shahriar, S., Mohamed, R., & Gordon, A. L. (2020). Impacts of brine disposal from water desalination plants on the physical environment in the Persian/Arabian Gulf. Environmental Research Communications, 2(12), 125003–. https://doi.org/10.1088/2515-7620/abd0ed

CEP, B. (2014, July 02). Desalination as adaptation: Energy Intensive, but sometimes necessary. Retrieved May 4, 2022, from https://www.bard.edu/cep/blog/?p=6217

Connecta't. “Brine Disposal: How Do Efficient Desalination Plants Get Rid of This Toxic Remnant?” *Home.es - Keiken Engineering*, 19 Apr. 2022, https://www.keiken-engineering.com/news/brine-disposal-how-efficient-desalination-plants-get-rid-of-toxic-remnant.

Dongcuo, S., & McCarthy, E. (2014, July 02). Desalination as adaptation: Energy Intensive, but

sometimes necessary. Retrieved May 8, 2022, from https://www.bard.edu/cep/blog/?p=6217

Elimelech, M., & Phillip, W. (n.d.). The future of seawater desalination: Energy, technology, and the ... Retrieved May 8, 2022, from https://www.science.org/doi/10.1126/science.1200488

Fang, Tu, W., Mu, L., Sun, Z., Hu, Q., & Yang, Y. (2019). Saline alkali water desalination project in Southern Xinjiang of China: A review of desalination planning, desalination schemes and economic analysis. Renewable & Sustainable Energy Reviews, 113, 109268–. https://doi.org/10.1016/j.rser.2019.109268

Kay Bailey Hutchison WTP. (n.d.). Retrieved November 21, 2022, from https://www.epwater.org/our_water/plants/kay_bailey_hutchison_wtp

Li, Siddiqi, A., Anadon, L. D., & Narayanamurti, V. (2018). Towards sustainability in water-energy nexus: Ocean energy for seawater desalination. Renewable & Sustainable Energy Reviews, 82(P3), 3833–3847. https://doi.org/10.1016/j.rser.2017.10.087

Morillo, Usero, J., Rosado, D., El Bakouri, H., Riaza, A., & Bernaola, F.-J. (2014). Comparative study of brine management technologies for desalination plants. Desalination, 336, 32–49. https://doi.org/10.1016/j.desal.2013.12.038

Rodman, Cervania, A. A., Budig-Markin, V., Schermesser, C. F., Rogers, O. W., Martinez, J. M., King, J., Hassett, P., Burns, J., Gonzales, M. S., Folkerts, A., Duin, P., Virgil, A. S., Aldrete, M., Lagasca, A., Infanzon-Marin, A., Aitchison, J. R., White, D., Boutros, B. C., … Achilli, A. (2018). Coastal California Wastewater effluent as a resource for seawater

desalination brine commingling. Water (Basel), 10(3), 322–. https://doi.org/10.3390/w10030322

San Diego Regional Water Quality Control Board. (2022). Carlsbad Desalination Plant. Retrieved November 21, 2022, from https://www.waterboards.ca.gov/sandiego/water_issues/programs/regulatory/carlsbad_desalination.html#:~:text=The%20Carlsbad%20Desalination%20Plant%20is%20currently%20using%20cooling%20water%20from,the%20Encina%20Power%20Station%

Shalaby, Sharshir, S. W., Kabeel, A. ., Kandeal, A. ., Abosheiasha, H. ., Abdelgaied, M., Hamed, M. H., & Yang, N. (2022). Reverse osmosis desalination systems powered by solar energy: Preheating techniques and brine disposal challenges – A detailed review. Energy Conversion and Management, 251, 114971–. https://doi.org/10.1016/j.enconman.2021.114971

Smith, R. (2015, January 23). *Economic Perspective on San Diego County water authority's Carlsbad Desalination Project*. Journal of Water | Powered by Stratecon Inc. Retrieved December 11, 2022, from https://journalofwater.com/jow/economic-perspective-on-san-diego-county-water-authoritys-carlsbad-desalination-project/

Soliman, Guen, F. Z., Ahmed, S. A., Saleem, H., Khalil, M. J., & Zaidi, S. J. (2021). Energy consumption and environmental impact assessment of desalination plants and brine disposal strategies. Process Safety and Environmental Protection, 147, 589–608. https://doi.org/10.1016/j.psep.2020.12.038

Tal. (2018). Addressing desalination's carbon footprint: The Israeli experience. Water (Basel),

10(2), 197–. https://doi.org/10.3390/w10020197

Tampa Bay Seawater Desalination. (2022, June 02). Retrieved November 21, 2022, from https://www.tampabaywater.org/tampa-bay-seawater-_desalination

Tarnacki, Melin, T., Jansen, A. ., & Van Medevoort, J. (2011). Comparison of environmental impact and energy efficiency of desalination processes by LCA. Water Science & Technology. Water Supply, 11(2), 246–251. https://doi.org/10.2166/ws.2011.052

Ziolkowska. (2014). Is Desalination Affordable?—Regional Cost and Price Analysis. Water Resources Management, 29(5), 1385–1397. https://doi.org/10.1007/s11269-014-0901-y