Desalination: Adapting to a changing climate and an increasing demand for freshwater

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Desalination:

Adapting to a changing climate and an increasing demand for freshwater.

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May 2023
Abstract
The state of California is just one place in the world that is experiencing an increasing demand for freshwater while also experiencing increasingly hotter conditions and longer periods of drought. There are a number of plants slated for development in the state of California but have been met with resistance from the public with concerns regarding their impacts to the surrounding marine environments. This paper provides background on desalination plants, provides evidence for a potential indicator species, identifies potential impacts to marine environments, and addresses stakeholder concerns and perceptions around desalination plants.

Introduction
The State of California just recently got out of a drought as a result of back-to-back storms, known as atmospheric rivers. Prior to these rain events in late 2022 and early 2023, California
had been experiencing prolonged durations of drought. The drought forced the State, County, and Cities to employ water use restrictions in an effort to prevent aquifers and reservoirs from being depleted to dangerously low levels. Some of the major reservoirs experienced historic lows as the drought droned on, but many have since returned to capacity or near capacity because of the 2022-2023 winter storms.

Although these storms have brought relief to the State’s water resources, there is still cause for California to identify alternatives to supplement water resources to support its various industries, as well as its citizens. As a result, cities, states, and countries have begun turning to the single resource that is in abundance – seawater. More specifically, these places are turning to desalination plants to solve their problems related to diminishing freshwater supplies. Desalination plants have been used in places like the Middle East since the 1930s, and have become a more popular potential alternative for consideration over the last couple of decades as climate change has altered precipitation patterns all over the world, making some places like California hotter and drier for longer periods of time. This paper will attempt to answer the research questions: 1) What are the impacts of desalination plants? 2) How have desalination plants been studied? 3) What are the public perception and barriers to the construction and operation of desalination plants?
Background
Modern desalination plants have been in use since the late 1920s, but began earlier than that when people learned that by boiling seawater and allowing that steam to condensate into another vessel, they would have freshwater to drink or use. The Middle East has a long history of utilizing desalination plants to provide freshwater to the region, but it has not been until more recently that places like the United States, Europe, and Australia have begun to seriously consider construction and operation of desalination plants. However, with the ever-increasing concerns about having available freshwater for industry, agriculture, and citizens because of recent prolonged drought conditions, desalination plants have become a legitimate investment in these regions. According to the United Nations’ guidelines regarding available freshwater, a territory that draws 25% or more of renewable freshwater resources is deemed to be a “water stressed” place. In addition to this, researchers have asserted that water scarcity will define the current century and play a role in a territory or nation’s overall security as freshwater availability becomes less reliable and the domino effects of food scarcity to impacts to global
economies (Ayaz et al 2022).

![Timeline of desalination plant development over time. a) 1881-boiling method to separate salts from water. b) 1928 – first land based desalination plant using multiple-effect distillation (https://www.preceden.com/timelines/332386-de)](image)

**Desalination Plants**

**Method: Thermal (Distillation)**

The desalination method that has been in use the longest is thermal (or distillation), and more specifically the multi-stage flash (MSF) process. This process brings in seawater (feedwater) from an intake valve, which is then heated in evaporation chambers to bring it to its gaseous state. After the feedwater has been evaporated into its gaseous state, it is then reverted to its original liquid form using condensation. This process produces two separate water streams. One stream is the “product stream,” where the water has a low salt concentration, and the other is the “brine stream” (brine), which is water with a high concentration of salts and other contaminants, such as those used for plant maintenance. The product stream will be further processed for public, industrial, and agricultural use, and the brine stream will be released back into the ocean (Gomes et al. 2022).
Method: Pressure
The desalination process increasingly used more often is reverse osmosis (RO). This method begins by processing the water through a pre-treatment system, which disinfects the water. Once the feedwater has been treated, it is processed through a semi-permeable membrane, separating the product stream from the brine stream (Gomes et al. 2022, Ayaz et al. 2022). It is important to note that depending on the desired outcome of the product stream and the quality of the feedwater itself, there can be upwards to 30 stages where the feedwater passes through these specialized membranes (Saliby et al. 2008).
**Desalination Plant Concerns**

The inherent issues that accompany this method of desalination include high capital cost to build and run and the brine stream (discharge) released from the plant. The high costs associated with this method of desalination are in relation to the membranes that are used. These membranes not only require specialized construction, but they also require a high level of maintenance and are typically replaced about every 5 years. In addition to this, reverse osmosis produces a brine stream with higher salinity than the MSF system and toxins, such as...
anti-scalants and anti-coagulants used to maintain the membranes are discharged into the ocean, which will be discussed further in the next section.

Despite these issues as a result of using reverse osmosis, however, the technology is evolving to produce longer-lasting membranes and improved pre-treatment methods (including chemicals used). These improvements contribute to an overall low operational cost in terms of energy, both in respect to running the desalination plant and reducing energy used to produce the membranes since they would last longer (Ayaz et al. 2022). As a result of these improvements since reverse osmosis was first invented, it has become the most commonly used method around the world. In 1999, only 10% of desalination plants used reversed osmosis, whereas today, 84% of the plants around the world use RO.

Table 1. Table identifying the advantages and disadvantages of thermal and pressure desalination methods (Gomes et al. 2022).

<table>
<thead>
<tr>
<th>Desalination technology</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reverse osmosis (RO)</td>
<td>Easy adaptation to the implantation site. The plant can be adjusted to meet higher demand after implementation. Lower financial cost than thermal plants. Higher conversion efficiency for potable water</td>
<td>Membrane colmatation. Complex configuration. Specialized manpower for operation and maintenance. Increased use of chemicals during the process</td>
</tr>
<tr>
<td>Thermal distillation (TD) (MED/MSF)</td>
<td>Easy management and maintenance. Suitable for switching with renewable energy from intermittent sources. Less use of chemicals when compared to RO</td>
<td>High power consumption. It needs antifouling agents to prevent fouling on the evaporating surface. Cannot operate below 60% of capacity. Low conversion efficiency for potable water</td>
</tr>
</tbody>
</table>
Desalination Plant Impacts

Desalination plants provide a potential solution to the ever-growing need for freshwater around the world. However, these plants also have the potential to have detrimental impacts on the environment around them. More specifically, they have the potential to impact the marine environment in which the brine is released into. Some of these impacts to the marine environment include increased salinity, increased temperature, and increased concentrations of contaminants. Some studies have provided evidence that these impacts can impact marine flora and fauna while others have shown limited to no impacts. For the studies that found impacts to the marine environments, they also shed light on how impacts can be mitigated, which include new, developing technologies (RO membranes, improved desalination methods), plant design, and plant location.

Impact: Salinity

One of the primary concerns in respect to desalination plants is the brine discharged into the marine environment. Depending on the location and design of a desalination plant, the discharge distance from the plant can be as little as 50 meters (m) away from shore upwards to 100 m or more away from shore. The brine released can create a plume reaching anywhere from tens of meters to several kilometers away from the discharge point. The reach of the brine plume and the time it takes before the salt levels, specifically dissipates and reduces to the ambient level is dependent on the environment in which the discharge point is located. For example, one team of researchers discovered that the average increase in salinity from a brine plume was between 2 parts per million (ppm) to less than 0.5 ppm (Roberts et al. 2010). However, it is important to note that this research team came to these conclusions based on their literature review of peer-reviewed journal articles that focused on studies on desalination plants located in shallow, low wave energy environments of the Mediterranean Sea.

The increase in salinity above the ambient level in an area can have implications for the surrounding marine environment, including the benthic (seafloor) communities, as well as the surrounding flora and fauna. Due to the hypersaline nature of brine, it is denser than the water it is being discharged into. This means that in the water column, the salt solution will drop down towards the seafloor instead of being suspended in the upper sections of the water.
column. Organisms that live lower in the water column and on the seafloor, such as seagrass, receive an influx of salt that they are not adapted to. A laboratory study done on seagrass (*Poisidonia oceanica*) found that both stratified exposure of and exposure only to increased salinity at the basal (base) leaves of the plant had significant impacts on the survival of the plant that contributed to its mortality or deterioration (Roberts et al 2010). In addition to this, a study done on seagrass of the same genus, but different in Australia (*Poisidonia australis*) observed that when seeds of *P. australis* were exposed to different levels of brine solution over 2 and a half weeks - 0%, 25%, 50% and 100%. The seeds exposed to 100% brine solution failed to develop, whereas seeds exposed to normal seawater conditions developed shoots and leaves. The two other exposure conditions (25% and 50%) showed some growth, but it was overall stunted in contrast to the 0% exposure to brine (Campbell et al. 2019)

![Figure 4. Results of brine exposure study of *Poisidonia australis*.](image)

**Impact: Temperature**

Another concern regarding the discharge from desalination plants is the increased temperature of the brine into the marine environment. This concern is more specifically tied to the thermal distillation process related to the multi-stage flash desalination method because heating the
feedback is part of the processing. The brine discharged from thermal desalination plants has been found to be 10 to 15 degrees Celsius higher than the ambient temperature of the receiving waters (Roberts et al. 2010). This increase in temperature, depending on how quickly the brine dissipates when discharged, can contribute to reduced dissolved oxygen and nutrient availability. The change in temperature can contribute to a change in the flora and fauna communities that originally inhabited an area prior to the operation of a desalination plant. The impacts from these changes need to be studied and understood better on a scientific level, but the impacts these changes could have to local fisheries and to those who recreate near these discharge locations could be significant and have greater immediate and/or long-term implications to the health of the marine environment (Roberts et al. 2010).

Impact: Toxins

Researchers performed a literature review to learn about toxins released by desalination plants and discovered that contaminants, such as copper, chlorine, and anti-escalants and anti-foulants were discovered. These contaminants were discovered when researchers performed studies on benthic samples in the Arabian Gulf, where upwards to twenty-one desalination plants are in operation. However, these findings are not restricted to the Arabian Gulf, but were also observed in benthic samples taken near an unspecified desalination plant in Florida. The researchers learned that this plant had discharged upwards to 45 kg of copper for each day of operation in the 1960s and 1970s, which resulted in copper levels five to ten times higher than the ambient level of the receiving waters, exceeding the toxicity threshold for many native species (Table 2) (Roberts et al. 2010). It is important to highlight that the researchers performing a literature review of various studies looking at impacts of desalination plants to the marine environment had a difficult time getting an in-depth understanding of the testing methodologies used because they were not provided or were unclear. Despite this, the overall data provides evidence that brine discharge with elevated metal contents has the potential to have detrimental impacts on marine life.
Ecological Impacts

Research indicates that marine organisms can be directly impacted by desalination plant discharge for the reasons described above – increased salinity, increased temperatures, and the introduction of toxins. Organisms that have been observed to be impacted include seagrasses, phytoplankton, and invertebrate and fish communities surrounding outlets (Roberts et al. 2010). Laboratory and field-based studies have been performed to learn more about which conditions affect marine flora and fauna the most and how. For example, laboratory studies have been performed to observe the effects of increased salinity on seagrass (*P. oceanica*). Some of these experiments showed that *P. oceanica* displayed reduced growth, a greater occurrence of necrotic lesions, and premature deterioration. These responses occurred when the seagrass was exposed to salinities of 39 parts per thousand (ppt), which is a minor increase from the ambient salinity level for the study region located in Alicante, Spain. However, when *P. oceanica*, epifaunal mysids, and echinoderms were exposed to salinities of 40 to 45 ppt, an increase in mortality for all species was observed. In contrast to this, studies done on seagrass (*Poisonia australis*) in Western Australia’s Shark Bay found that the growth and leaf production of seagrasses performed their best at 42.5 ppt, and mortality and deterioration

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**Table 2. Summary of contaminants from desalination brines in marine ecosystems (Roberts et al. 2010).**

<table>
<thead>
<tr>
<th>Reference</th>
<th>Location/region</th>
<th>Matrix/species/community</th>
<th>Summary of findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hoepner and Lattmann, 2002</td>
<td>Red Sea (21 plants)</td>
<td>Discharge</td>
<td>Estimate that up to 2708 kg Cl, 36 kg Cu, 9478 kg anti-foulants released from desalination plants into the Red Sea each day</td>
</tr>
<tr>
<td>Crockett, 1997</td>
<td>McMurdo, Antarctica Kuwait</td>
<td>Sediments</td>
<td>Found higher concentrations of copper, lead and zinc in sediments near a combined waste water desalination plant outfall relative to control areas</td>
</tr>
<tr>
<td>Saeed et al., 1999</td>
<td>Key West, Florida</td>
<td>Seawater samples</td>
<td>Compared concentrations of hydrocarbons in waters around plant outlets and inlets</td>
</tr>
<tr>
<td>Cheshar, 1971</td>
<td></td>
<td></td>
<td>Copper concentrations in waters surrounding plants were five to ten times higher than background levels, and occasionally present at concentrations exceeding toxic thresholds to native organisms. Estimate that up to 45 kg of copper was discharged from the plant for each day of normal operation</td>
</tr>
<tr>
<td>Paquin et al., 2000 USA (28 plants)</td>
<td>Discharge</td>
<td></td>
<td>In a review of chemical data from 28 plants, up to 60% of samples exceeded water quality criteria for Cu at the time of collection. However, the authors state that a lack of clean techniques in earlier studies may have biased results, and that less conservative criteria were not exceeded</td>
</tr>
<tr>
<td>Romeril, 1977</td>
<td>Jersey, England</td>
<td>Epibiosis</td>
<td>Found greater accumulation of copper in algae and limpets around desalination plant compared to a reference location approximately 3 miles from the discharge</td>
</tr>
<tr>
<td>Sadiq, 2002</td>
<td>Ras Tanajib, Saudi Arabia</td>
<td>Sediments</td>
<td>Concentrations of Cd, Cu, Hg, Ni, P and Zn elevated in sediments within 100–250 m of outfall, concentrations decreased away from outfall out to 3 km</td>
</tr>
</tbody>
</table>
occurred when the salinity levels reached between 50 and 65 ppt (Roberts et al. 2010). While these differences in salinity tolerances do not allow scientists to establish a global salinity limit for the *Poisidonia* species, it provides evidence that seagrass could possibly be used as an indicator species for regional salinity limits of brine discharged into receiving waters by desalination plants. For regions that may not have this species of seagrass, these findings provide a basis to potentially identify endemic flora that could be used as an indicator species to help detect whether a desalination plant is operating at optimal levels.

In addition to the studies focusing on seagrass tolerance to salinity, contaminants such as lead, zinc, and copper were tested in the sediments and receiving waters surrounding the discharge location of desalination plants. In Key West, Florida, researchers estimated that the plant discharged copper at levels that exceeded toxic thresholds for native species. To better understand the potential impacts of brine on marine fauna, researchers used a bioassay study to observe the potential impacts of brine on echinoderms ascidians, gorgonian corals, and stone crabs. These individuals were placed in cages, transplanted to the study area, and monitored for changes. The study found that when exposed to as little as 3% of brine solution added to their cages, the echinoderms died within days. However, it is important to note that the researchers observed that when the corroded copper-nickel trays at the desalination plant were replaced, the survival of all the species increased rapidly. Therefore, impaired survival of these species, specifically the echinoderms, was attributed to the copper released into the receiving waters with the brine. These impacts to marine fauna have been largely mitigated with improved desalination plant maintenance and operation practices.

Although these studies provide important information in respect to the potential impacts of brine on marine environments, it is necessary to point out the studies reviewed did not always provide the details of their study design. In addition to this, a common point of criticism of studies reviewed was not only that study designs were vague or not provided, but that the research lacks comprehensive before-and-after and long-term studies. This is a problem considering how long desalination plants have been in operation and the increased focus on desalination plants as either permanent or supplemental sources of freshwater globally. Not
only do more studies need to be done, but these studies need to be designed to be replicated and somehow standardized to enable scientists to compare study designs and results.

Case Study
Carlsbad Desalination Plant
The Carlsbad Desalination Plant is located in Carlsbad, California at the southern end of the Agua Hedionda Lagoon and adjacent to the Encina Power Station. Brine is the issue of greatest concern due to its potential impacts to the marine environment upon discharge into receiving waters as discussed above. As a result, the California State Water Boards amended their California Ocean Plan (2015 Amendment to Water Quality Control Plan) (Ocean Plan) to include guidelines addressing desalination plant limits for brine discharge. The Ocean Plan restricts the increase of salinity from brine to 2 salinity units above ambient conditions up to 100 m from the discharge point. Most of the desalination plants currently in operation in California operate at a smaller scale than the Carlsbad Desalination Plant. As a result, the California State Water Boards made an exception for the Plant and allows an increase in 2 salinity units up to 200 m away from the discharge point. It is important to note that the power plant, Encina Power Station, which has been in operation since 1954, is adjacent to the Carlsbad Desalination Plant. As such, infrastructure such as the intake valve and discharge conveyance have been in place since it began operations. The Carlsbad Desalination Plant diverts approximately 10% of the post-cooling seawater released by the power plant and uses it as the Plant’s feedwater for processing. Once the feedwater has been processed and separated into the separate product stream and brine stream, to dilute the brine prior to discharge it is mixed with the rest of the post-cooling water from the Encina Power Plant. The discharge conveyance for the Carlsbad Desalination Plant and power plant is a channel that is 10 to 15 meters wide between two rocky walls and extends approximately 50 meters offshore (Petersen et al. 2019).

Researchers discovered that with the introduction of the brine discharge from the Carlsbad Desalination Plant, the salinity levels rose by 2.7 salinity units above the ambient level and that the brine plume extended upwards to 600 meters away from the discharge location. The salinity level measure and distance of the plume both exceed that which is outlined by the California Ocean Plan. However, a promising finding from these studies was that no significant
impacts to the marine environment or flora and fauna were observed. These observations were attributed to the Plant discharging their brine into an environment where the power plant had already may have contributed to alterations to the coastal communities, and the flora and fauna may have been able to adapt due the ongoing anthropogenic disturbances since the 1950s. Last, they observed that although Carlsbad Beach has high wave energy therefore high mixing potential, the lack of brine dilution and efficient mixing and dissipation was highlighted as a point of improvement for future desalination plant projects along the California coast. In all, the team provided three primary recommendations for future desalination plant proposals and development: 1) location of discharge point with diffuser systems and/or higher dilution prior to discharge, 2) identify locations where anthropogenic disturbances have already occurred (e.g., powerplants and wastewater treatment plants), and 3) studies performed before-and-after desalination plant operations and studies designs that can be more easily cross compared with other research done on desalination plants.

![Diagram](image.png)

*Figure 5. Different diffuser designs to maximize mixing and dissipation of brine discharge (Admad and Baddour 2014).*
Stakeholders
Tainan Desalination Plant (Tainan, Taiwan)

The country of Taiwan is the world’s leader in semiconductor chip manufacturing. The demand for these chips skyrocketed during the COVID-19 pandemic, which coincided with Taiwan experiencing their worst drought in 50 years. As a result, Taiwan’s Water Resource Agency (WRA) built a small temporary emergency desalination plant to meet water demands involved with making semiconductor chips in Hsinchu, also known as Taiwan’s Silicon Valley. Taiwan then identified the city of Tainan, where semiconductor chips are also produced, as at-risk for entering a water scarcity emergency because of the drought that Taiwan was experiencing in addition to other factors, such as siltation of reservoirs, which reduces water storage capacity throughout the country. The drought Taiwan experienced is generally atypical of the country’s usual weather patterns, which includes a typhoon season that begins in May and lasts until October. The typhoon season would typically provide enough water to recharge reservoirs and other water sources, such as aquifers, but the increasing frequency of droughts has resulted in reduced water storage, which has led the country to impose water use restrictions and has diverted available water from household and agricultural use towards semiconductor chip manufacturing instead. The combined widespread effects of the drought and increased demand for semiconductor chips are what led Taiwan to propose the construction of a desalination plant in the city of Tainan to meet the increasing demand for freshwater. However, the proposal for the construction of the Tainan Desalination Plant was met with resistance from stakeholders, especially from those concerned with the potential impacts the desalination plant could have on whose livelihoods are intimately tied to the health of the marine environment. The Tainan Desalination Plant construction was delayed because of stakeholders raising concerns.

A group of researchers wanted to better understand the thoughts and concerns of the stakeholders resisting the Tainan Desalination Plant, and so they designed a study to do this. The study largely utilized interviews and questionnaires to obtain information, and efforts were made to capture the perspectives of a wide breadth of people with different backgrounds. What the research team found was that there were five key elements that influenced people’s
perceptions about desalination plants, and whether they were inclined to accept or reject the desalination plant proposal (Liu, T.-K. et al. 2022). These five elements include:

1. Water Resource Development Dilemma
2. Combating Variability to Match Demand
3. Potential Environmental Impact of Desalination
4. Stakeholders Position on the Development of Desalination Plants
5. Environmental Impact Assessment (EIA) and Public Participation

*Water Resource Development Dilemma*

Taiwan faces a unique problem when it comes to creating additional reservoirs. The terrain of the area makes it difficult to find a location for a new reservoir (Figure 5), which contributes to high levels of soil erosion resulting from typhoons. This high level of soil erosion is directly related to the constant increase in siltation behind reservoirs. Furthermore, the siltation contributes to decreasing storage capacity of the reservoirs, which then requires regular dredging using mechanical excavation, mud pumps, hydraulic slag removal, and bypass tunnels. However, these methods are met with skepticism because the dredging will never catch up with the amount of sediment that is built up behind the reservoirs and stakeholders believe that sediment from the reservoir were discharged downstream through the bypass tunnel, which they believe altered the downstream ecology and had detrimental impacts to the environment (Liu, T.-K. et al 2022).
Combating Variability to Match Demand

Stakeholders expressed a preference for Taiwan’s Water Resource Agency to investigate all other means and methods of meeting water demands before settling on desalination plants. Some of these include construction of water conveyance pipelines that can be used to transport water from one place to another when resources are reaching dangerously low supply levels. These conveyance pipelines would include water level monitoring systems, as well as water management systems to help understand where and when water needs to be sent. Taiwan has implemented these systems, but the efficiency and expansion of these systems is met with various challenges, the most significant one being costs related to this type of project.

In Taiwan, like in other places around the world including the United States, the cost of water is kept artificially low. The reasons for this are not identified, but it is reasonable to assume that the cost of water is kept low because it is essential for everyone on a biological level, but to also allow people to enjoy things like green lawns and pools, and to keep agricultural and industrial costs low. In addition to this, it appears that water is kept at an artificially low cost because people also do not have a full understanding of the value of freshwater, especially in regions where water supplies have historically has been constant, like Taiwan. However, the low price
of water makes it difficult to promote water conservation and to fund improvements to existing water-related infrastructure to fix things, like leakages, to prevent water supply loss in the system (Liu, T.-K. et al 2022).

**Potential Environmental Impact of Desalination**

One of the most important topics when it comes to desalination plants is the potential impacts they could have on the surrounding coastal environment. These impacts could have compounding effects on those who rely on the coast for their livelihoods (fishing and aquaculture) and recreate in and along the coast. The stakeholders in Tainan understand that desalination plants can provide a solution to water shortages, but the potential impacts cannot be overlooked. As discussed above, the primary concerns stakeholders have about desalination plants is the brine released into the waters. Therefore, stakeholders would like the government and developers to not only provide scientific data regarding the potential impacts to the coastal environment, but also provide a compensation scheme for local fishermen and aquaculture farmers if their livelihoods are impacted by the brine discharged by the desalination plant. In addition to this, stakeholders are conscientious of the fact that desalination plants will require a lot of energy to process the seawater. In addition to this, Taiwan’s electric supply (80% of total power generation) is produced using fossil-fuel powered power plants. Stakeholders interviewed by the researchers expressed their concerns regarding the electricity used to power these desalination plants because of the method used to produce electricity and the relationship between burning fossil fuels and its contribution to climate change (Liu, T.-K. et al 2022). They expressed concerns about furthering contributing to climate change and exacerbating the issues that accompany it, such as the drought they were experiencing in 2020.

**Stakeholder’s Position on the Development of Desalination Plants**

The researchers found that most stakeholders interviewed were neutral or approved of desalination plants. Those who opposed the Tainan Desalination Plant were largely fishermen or people whose income were tied to the coast in some way. The primary concerns of stakeholders discussed in relation to their position to desalination plants focused on three main things: water demand and shortage, cost of desalinated water, and pollution control of brine.
Stakeholders held positive views on and a preference for using desalination plants during the dry season or to supplement water supply when there is a shortage but were not set on using them full-time as the primary source for their water supply. In addition to this, the cost of water produced from desalination plants was about two times greater ($1 USD) than the current cost ($0.53), which could be prohibitive to households. This cost issue also contributed to the preference for limited use of desalination (Liu, T.-K. et al 2022). Last, as mentioned before, stakeholders are deeply concerned about the impacts of brine pollution that would be discharged into the marine environment and the effects that could have on people’s livelihoods and recreational uses. These were three outstanding items that the research team were able to identify as primary concerns and issues that the government and developers would need to address if they are to gain public support for the construction of desalination plants.

*Environmental Impact Assessment (EIA) and Public Participation*

The process for construction infrastructure, such as desalination plants, in Taiwan consists of a two-phase process: environmental impact statements, and reviews. However, the researchers found that this alienated stakeholders and community members because public hearings are not held until after the development planning work has already been completed. When the process is conducted in this manner, the public does not feel like their participation is valued or necessary, and the timeframes of the public hearings has been short, preventing people from being able to attend or take time to understand what they have learned and provide feedback. The researchers discovered a desire by stakeholders and the community to have more involvement in the public hearings process before development plans are finalized. To do this, the researchers learned that more frequent and convenient times for public meetings prior to the development plan being finalized, and requiring developers to present and communicate their scientific data related to desalination plants so that all people in the community can understand, were the primary requests by the interviewees.

*Conclusions*

The decision to build and operate desalination plants comes with a number of considerations from the development process and engaging and winning over stakeholders to the potential
impacts on the marine environment and how to mitigate them. Various studies have observed significant impacts to the marine environment because of brine discharge while others have observed little to no impacts. As a result, what the research indicates is that desalination plants have the potential to impact marine environments and that these potential impacts vary depending on location of the plant itself (co-located with a power or water treatment plant), the discharge point (distance from plant, wave energy, use of diffusers), method used (thermal vs. pressure), and how well scientific studies are designed and their duration (short term vs. long-term, before-and-after, etc.). Furthermore, engaging the public, especially stakeholders whose livelihoods are dependent on marine resources, has a greater chance of generating support for the development of desalination plants when done thoroughly, respectfully, and with great care and consideration for the community in which a desalination plant is being proposed to be built in.

Recommendations

Desalination Plant Location

The location of the desalination plant will play an important role in reducing the potential for impacts to the marine environment from brine discharge. As one research team observed, little to no significant impacts to the marine environment were observed at the Carlsbad Desalination Plant location, which they believe is due to the Plant being co-located next to the Encina Power Plant and the marine communities already being altered by human activities. In addition to this, the location of the discharge point plays a role in reducing impacts from brine. The three elements that influence are: distance from shore or the facility, wave energy, and diffuser system designs. The research indicates that discharge locations situated farther away from the shore with high wave energy are likely to dissipate the brine and bring the salinity levels back down to ambient levels more efficiently. However, in situations where it is not possible to do this, using specially designed diffuser systems to most effectively disperse the brine could help reduce impacts from brine discharge.
Laboratory and Field-based Research

A theme throughout the literature regarding desalination plants and their impacts on the marine environment was the need to improve scientific studies and designs to better understand what the potential impacts of desalination plants are on marine environments. An emphasis on before-and-after studies was expressed along with a desire for long-term studies, as well as studies that can be more easily compared and analyzed across each other.

Stakeholder Engagement and Participation

To garner support from stakeholders and the community, state and/or local governments must allow participation prior to the finalized development plan of a desalination plant. By doing this, the public has ample opportunity to learn what data and information the government and developers have collected and make their concerns regarding the potential impacts known. Without this ability for the public to participate in the development process, public support will likely be low and met with resistance, which could cause delays, which is what happened when the Tainan Desalination Plant was proposed.

Improved Desalination Technologies

Efforts to find ‘cleaner’ ways to implement desalination plants are essential to build confidence in and support of them. Major improvements have already been made since desalination plants were first implemented by developing new technologies, like the reverse osmosis membranes. The use of these membranes reduces the need to use energy to heat the feedwater, whereas most thermal desalination methods use fossil fuels to do this. This helps eliminate the burning of fossil fuels, which is a contributing factor to climate change resulting in the need for desalination plants around the world where water is or becoming a scarce resource. However, it is important to note that some power plants that generate electricity use fossil fuels to do this, which is what stakeholders in the Tainan Desalination Plant case study pointed out. In addition to this, the Tainan Desalination Plant stakeholders pointed out the potential for using solar energy due to Tainan’s location.
Additional technology developments include developing longer lasting membranes for reverse osmosis so that they do not have to be replaced as frequently as they currently are (approximately every five years), more efficient desalination methods (such as microbia desalination cells or MDCs), and more environmentally friendly chemicals used for pre-treatment of the feedwater and plant maintenance (Kokabian and Gude 2019, Roberts et al 2010, and Petersen 2019).
References


