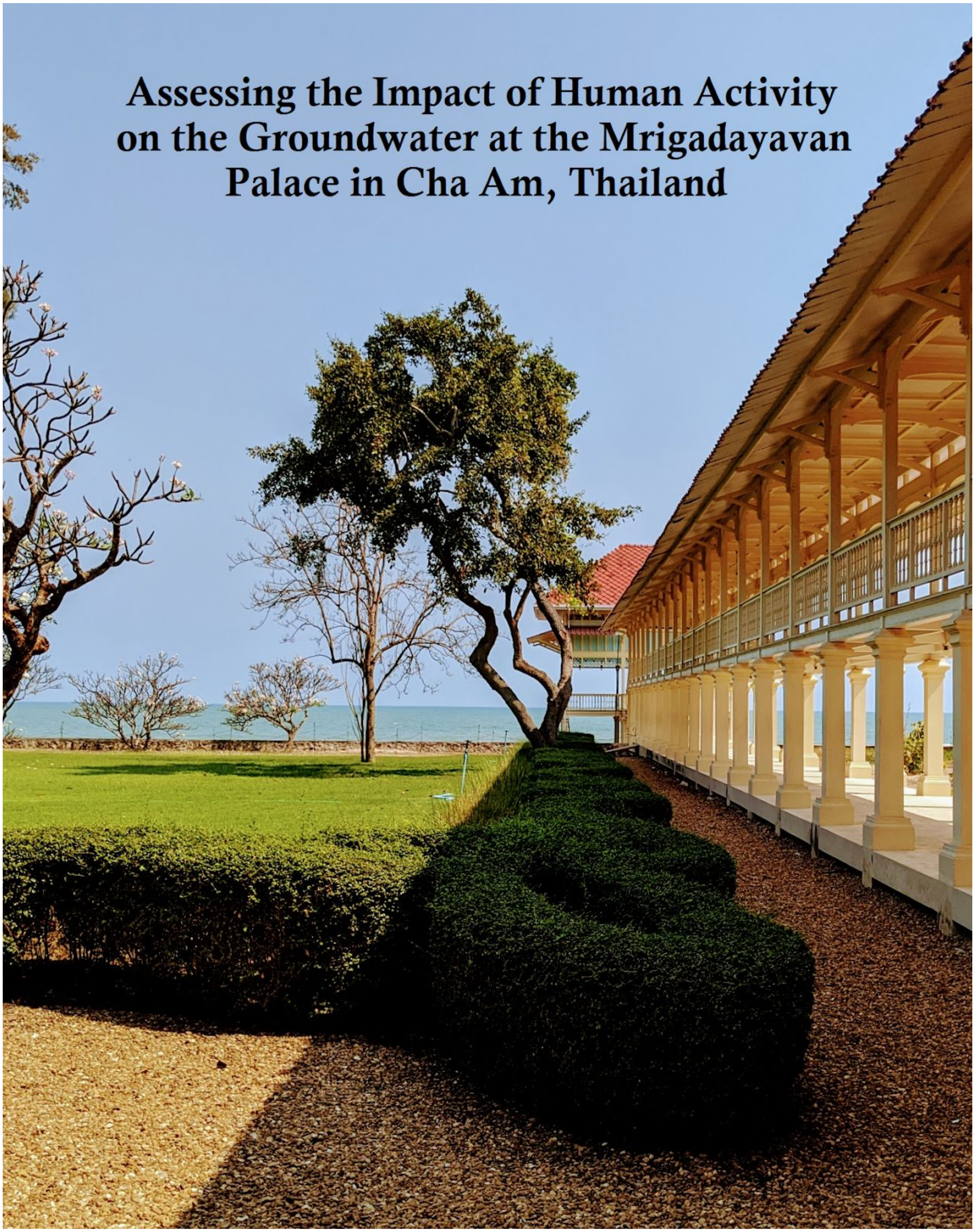
Assessing the Impact of Human Activity on the Groundwater at the Mrigadayavan Palace in Cha Am, Thailand



Assessing the Impact of Human Activity on the Groundwater at the Mrigadayavan Palace in Cha Am, Thailand

An Interactive Qualifying Project Report and Interactive Science and Social Project

Submitted to the faculty of
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Sponsored By:
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Abstract

The Mrigadayavan Palace Foundation aims to restore the Palace to its original condition by 2024. However, brackish groundwater prevents the restoration of the Palace grounds. By analyzing salinity data and interviewing community members, we found the likely cause of the brackish groundwater are the jetties feeding seawater to nearby mangroves. We recommend filling the jetties, spreading awareness of high local salinity, and implementing desalination methods to support the restoration efforts of the Foundation.

Executive Summary

Problem: The Mrigadayavan Palace was built in 1924 for King Rama VI. Following his death in 1925, the Palace was abandoned and suffered heavy damage from sea breeze and salt-spray. The Border Patrol Police began using the site as a training ground in 1965. In 1992 the Mrigadayavan Palace Foundation was established to manage operations and conservation, including restoring the Palace by 2024. They hope to become a global example of sustainable development, which requires self-sufficiency in terms of water sourcing. While architectural restoration has been successful, environmental restoration has been slow since the water on the Palace grounds is brackish, and the water of the surrounding grounds is saline. Therefore, the Palace is unable to use the onsite groundwater and needs to import freshwater, interfering with their restoration and sustainability goal.

Goal: The Mrigadayavan Palace Foundation, our sponsor, has asked us to identify the impacts of local human activity on the groundwater salinity at the Palace and its immediate surroundings. Our goal is to provide recommendations to decrease the salinity of the groundwater, as well as increasing local awareness of the issue.

Methods:

1. **Analyzed available data.** We received data on topographical and shoreline changes dating back to 1954, in addition to water salinity data for the months of November and December 2019 during our first sponsor meeting. We collected our own water and soil salinity data at the Palace in January 2020, and used it to determine the current groundwater salinity.
2. **Analyzed community awareness.** We interviewed 13 community members regarding their opinions of local infrastructure, like jetties, and their understanding of the salinity issue. Community members included people who reside and work in the area surrounding the Palace.
3. **Identify human impacts on salinity levels.** We mapped the location and salinity of 40 separate data values: 15 water salinity, 14 soil salinity, and 11 subsoil salinity.

4. **Identify remediation strategies.** Our recommendations for our sponsor aim to provide solutions to stop seawater intrusion, potential desalination methods that the Foundation could implement, and increase community awareness.

Findings:

1. **The groundwater salinity appears to be increasing.** Comparing our groundwater salinity measurements to the Foundation's earlier measurements proves the salinity levels are significantly increasing as time progresses, even over the course of three months.
2. **The jetties are likely causing the groundwater salinity levels to increase.** Mapping our salinity data—visually shown on aerial maps of the area—shows that areas closer to the jetties have a higher salinity level than areas midway between them. The former areas are saline, compared to the Palace grounds where the water is brackish (however this is the result of diluting the groundwater by irrigating with imported freshwater).
3. **Seawater intrusion is likely occurring.** Our soil salinity data showed that, in general, as soil samples were collected at a greater depth, the soil salinity increased. This led the team to believe that seawater intrusion was occurring as the soil in contact with the underground aquifers had a higher salinity than the topsoil in the same location.
4. **The surrounding community appears to be unaware of the high groundwater salinity levels.** Our research found 53.8 percent of interviewees (7 of 13 people) understand the definition of salinity. In addition, 53.8 percent noticed a decrease in vegetation in the area but were unsure why this is occuring. When asked about the jetties, 69.2 percent of participants were unaware of what jetties are or what purpose they serve. Of the three fishermen interviewed, two believed the jetties were harmful to their business as fishing is prohibited near them. However, the third fisherman believed that the jetties provided a safe place to dock his boat, and therefore thought of the jetties positively.

5. **Jetties are likely causing on and offshore pollution**.

   We observed piles of trash and polluted water around the jetties. The jetties were implemented to bring saltwater into the mangroves, however the water also flows back out into the ocean. Runoff from the mangroves pollutes this water and it is subsequently carried into the gulf.

6. **Jetties are likely negatively impacting beaches**. Through aerial imaging we are able to see that the shoreline has diminished since the installation of the jetties. This is likely due to the jetties changing the inflow and outflow of the tide.

Recommendations to our Sponsor:

1. Fill in or remove the jetties.
2. Advocate for infrastructure that supports a fishing based economy to be put in.
3. Install a water barrier.
4. Implement desalination technology on the Palace grounds to speed the restoration process.
5. Create an educational presentation and distribute a brochure regarding human impacts on salinity to raise awareness in the community.

The first recommendation is to fill in or remove the jetties. It is the fastest way to prevent the water salinity problems from increasing in severity. The risk of further seawater intrusion would be reduced if the saline water content and pressure in the jetties decreases. Filling the jetties is meant to allow the natural dune spring to return, where the streams are only open to seawater in certain months of the year.

The second recommendation is directed towards helping the community. The Palace is more likely to garner community support if they develop a stronger relationship with the community that surrounds them. Advocating for infrastructure to support the community's fishing-based economy will help improve the lives of local people and the Cha Am area, as a result.

The third recommendation is a backup plan if the removal of the jetties is not feasible. A water barrier will allow the PortAuthorities to control the inflow of salt water into the jetties.

The fourth recommendation includes implementing desalination technology on the grounds of the Mrigadayavan Palace to desalinate the groundwater. While removal of constant seawater penetration of the land may be a natural solution, it could take decades. If the Palace Foundation hopes to complete restoration in less than four years, the use of technology would increase the speed of the project significantly. Desalination methods include:

Desalination Method	**Cost**
Multistage flash desalination (MSF)	● Approximately 31.73 baht/m^3
Multi effect distillation (MED)	● 22 to 32 baht/m^3
Vapor Compression (VC)	● Lowest operating cost but expensive maintenance when compared to other methods
Electrodialysis (ED)	● Approximately 19 baht/m^3
Reverse osmosis (RO)	● 16.80 to 50.08 baht/m^3 for seawater ● 3.49 to 34.86 baht/m^3 for brackish water
Solar Desalination	● N/A, but relatively low cost
Groundwater Replenishment System (GRW)	● Around 29 baht/m^3

The fifth recommendation involves the sponsor educating the community on the issues that challenge both Palace grounds and the surrounding area. If the community has a better understanding of the decline in their living conditions, then they may be more likely to support changes to the local infrastructure. These changes can desalinate their groundwater, increase the amount of vegetation, decrease pollution, and improve the quality of their beaches.

Authorship Page

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1 - Introduction

Brackish water is the classification of salinity between fresh water and saline water. Brackish water is unsafe for human consumption and most of the range has too high of a salt concentration to use for agricultural purposes. These factors make contaminated and over salinated groundwater, a common issue worldwide. Increased salinization of groundwater is often more severe in coastal areas, as it is easy for saltwater to infiltrate the groundwater or soil in a process called seawater intrusion (Sae-Ju et al., 2018). Efforts to desalinate groundwater are typically centered around helping people, the environment, or both. Efforts in Cha Am, Thailand are primarily focused on improving the environment.

Cha Am is a coastal district in Phetchaburi Province along the southern peninsula of Thailand. The district borders the Gulf of Thailand, and its beaches are a popular tourist destination. The Mrigadayavan Summer Palace was built in 1924 for His Majesty King Vajiravudh (or King Rama VI), in the community of Bang Khwai. The Palace grounds originally contained a freshwater stream, or dune spring, and a long, white beach. Following King Vajiravudh's death in 1925 the Palace was abandoned until 1965 when the Border Patrol Police started occupying the site as a training ground. The Border Police, in tandem with the Thai Government's Fine Arts Department, made the first restoration efforts in 1987 after which the Royal Family established the Mrigadayavan Palace Foundation to take over the care and conservation of the Palace in 1992. The goal of the Foundation is to restore the Palace to its original 1924 condition by its centennial anniversary in 2024. The current state of the groundwater salinity is preventing the Foundation from maintaining the original vegetation in a sustainable fashion.

The Mrigadayavan Palace Foundation intends to present the Palace as a case study for sustainable development and restoration. One of the practices of sustainable development is self sufficiency regarding water sourcing and management. Previously, the Palace drew water from on-site wells for agriculture and landscaping purposes. However, as the water salinity was observed to be increasing in recent decades, the Foundation stopped drawing from the wells, as overpumping can exacerbate seawater intrusion. The Palace began importing water from nearby towns and using water from the Ta Sa-ded freshwater reservoir, located in the Rama VI Camp.

The Mrigadayavan Palace shares land with two other organizations, the Border Patrol Police, and the Sirindhorn Environmental Park.

The Sirindhorn Environmental Park planted mangrove forests to the north and south of the Palace in 1994. Mangroves require brackish water in order to thrive. However, when the forest was planted there was no source of saline water, only fresh water. Therefore, jetties and canals were dug in 2005 to provide seawater directly to the forest to mix with the natural fresh water . In addition to the jetties and canals, breakwaters and groynes were constructed to prevent coastline erosion that could potentially threaten the beaches, and therefore the tourism industry in the province. The Mrigadayavan Palace Foundation claims that the jetties and canals have caused the increased groundwater salinity in the area, because they are the only significant documented changes to the terrain and the natural topography of the land. The human activities impacting the increased salinity of the groundwater and the effect it is having on the environment surrounding the Mrigadayavan Summer Palace is the main focus of this Interactive Qualifying Project and Interactive Science & Social Projects (IQP-ISSP) team project.

In our efforts to assess the impacts of human activities on the salinity level of the local groundwater we developed four project objectives: determining the salinity levels on the Palace grounds (groundwater and soil), identifying community awareness of increased groundwater salinity and impacts of man-made infrastructure, analyzing the causes of increased salinity of the Palace groundwater, and creating recommendations to restore the groundwater. In this report, we explain groundwater salinity, justify the methods we used to accomplish these goals, describe our findings, and present the recommendations given to the Mrigadayavan Palace Foundation.

2 - Background

Groundwater salinity refers to the concentration of salt in water that is stored in underground soil, pores of rocks, or aquifers. There are four terms defining various levels of salt content in water, as seen in Table 1.

Table 1: Salt Content of Saline Water

Type of Saline Water	Total Dissolved Solids (mg/L)	Parts per Thousand (ppt)
Fresh water	0 - 1,000	0-0.5
Brackish water	1,000 - 10,000	0.5-30
Saline water	10,000 - 100,000	30-50
Briny water	> 100,000	> 50

High salt concentration in groundwater has both human and environmental causes and unleashes a variety of impacts on communities and their surrounding environments around the world. The Cha Am District of Thailand is experiencing the effects of increasing groundwater salinity, specifically around the Mrigadayavan Palace. Due to high salinity levels in the wells of the Mrigadayavan Palace, the desired vegetation is unable to grow without freshwater irrigation.

2.1 - Classification of Brackish Groundwater

The Australian Department of Water classifies brackish groundwater as having a concentration between 1,000 and 10,000 mg/L, or 0.5 and 30 parts per thousand (ppt). Brackish water is not suitable for watering most plants and is not considered viable drinking water. Groundwater salinity can be influenced by a variety of factors both natural and human.

2.1.1 - Causes of Increased Salinity

Groundwater salinity naturally increases four ways.

1. Salt water is evaporated from the ocean and precipitated inland, absorbing into the soil.
2. The weathering and breaking down of sediment.

3. Changes in terrain, both sea and ground, leave salt in the ground.
4. Storms such as hurricanes and tsunamis cause seawater intrusion.

2.1.2 - Seawater Intrusion

Seawater intrusion is the movement of seawater into fresh water aquifers due to natural processes or human activities. Seawater intrusion occurs when the water pressure decreases in freshwater coastal aquifers allowing saltwater to permeate inland. This pressure drop can occur naturally through weather events such as drought, but human interference is the most common cause of seawater intrusion. Through man-made changes in terrain, over-pumping of wells, and the construction of jetties and canals, humans can cause the pressure in coastal aquifers to decrease. A visual representation of seawater intrusion can be seen in Figure 1.

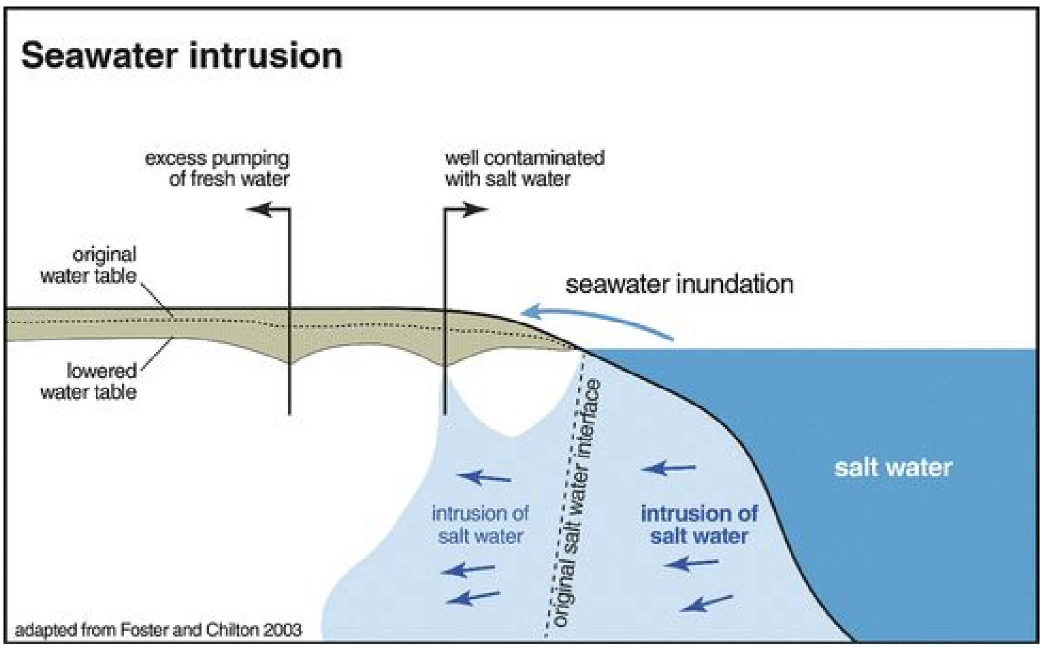


Figure 1: Example of Seawater Intrusion

Source: Integrated Groundwater Management

Impacts of Salinated Water on Infrastructure. Podmore (2009) states that salinated water has tremendous impacts on infrastructure and homes. One of the first places affected by salinated water is plumbing infrastructure such as water services, water tanks, and domestic water softeners. This leads to higher costs of plumbing and maintenance for the general population. Industries such as food, beverage, and paper production also suffer from increased water salinity, as water coolers, water treatment plants, and boilers are negatively affected by salinated water. Salinated water also tends to be damaging in terms of metal erosion and therefore has the potential to destroy storage tanks, railway tracks and reinforced concrete structures. These materials are used to create infrastructure that is important for the well being and security of an area and therefore should be taken seriously by regions facing this problem.

2.2 - Global Impacts of Over-Salinated Water

Salinated groundwater occurs throughout the world and can have a grave impact on communities both large and small, as well as the surrounding environment and ecosystem.

2.2.1 - Impacts on Societies

According to Watkins (2006) there is a global shortage of freshwater that can be used as drinking water. Freshwater has a salt concentration between 0 and 0.5 parts per thousand. Salinated groundwater further decreases the amount of potable drinking water. In regions such as Cha Am, Thailand, residents source their water from local reservoirs rather than pumping directly from the ground as overpumping can dramatically worsen the problem. Unfortunately, there is no one solution for desalinating groundwater because most desalination processes are designed for seawater and are inefficient to use on groundwater due to a lower salt-to-water ratio (Carreira et al., 2014).

2.2.2 - Impacts on Ecosystems

Berger et al. (2018) states that saline groundwater has a negative impact on ecosystems . Since vegetation is sensitive to changes in salinity, a change in the groundwater salinity of a region has the potential to kill entire populations of plants. Small animals and insects, who feed on those plants, will then have a limited food supply, causing their population to decrease. This then affects the food chain for larger animals. In extreme cases, overly salinated groundwater could cause an entire ecosystem to collapse.

2.3 - Groundwater Accessibility

Groundwater in Cha Am can be found in two types of rock layer, soft rock layer and hard rock layer. Soft rock layer groundwater is found in the plain along the coast while hard rock layer groundwater is found in the west of Cha Am and can be found in the gap caused by cracked rock layers at a fault. The groundwater layer can be found 20 to 200 meters deep. There are 255 groundwater wells that can be used in Cha Am (N. S. Consultant Co. Ltd., 2012).

2.3.1 - Groundwater Situation in Cha Am

The groundwater from Cha Am comes from various sources such as irrigation canals, lakes, farm ponds, rivers, canals and reservoirs. Cha Am receives very little rainwater due to its location in the rain shadow of the nearby mountains and thus annual rainfall amounts to only 853.3 milliliters states Sae-Ju et al (2015). The excess sodium chloride that exists in groundwater sites comes from ocean water since only bicarbonate and calcium ions exist in groundwater. On the east coast of Cha Am, 10-20 cubic meters of groundwater flow per hour (500-1500 mg/l of dissolved solids), to the south of Cha Am 2-10 cubic meters of groundwater flow per hour (<500 mg/l of dissolved solids), to the west less than 2 cubic meters flow per hour (<500 mg/l of dissolved solids) and finally to the north of Cha Am 10-20 cubic meters of water flow per hour are discharged to underground with varying concentrations of dissolved solids.

2.3.2 - Groundwater Regulation

The Groundwater Act in Thailand has been enforced since 1977 to prevent overexploitation of groundwater. Under its provisions, one may utilize groundwater only with an official permit from the Department of Groundwater Resources. Once permitted, the water must be used only in these 4 ways: consuming, production, material for production, and agriculture. Proper groundwater management should be carried out strictly in each utilization. For consumption, groundwater cannot be used unless there is no available connection to the surface water. For business and agriculture, groundwater can be used along with surface water in suitable ratio. In the case of no available surface water, people are allowed to use groundwater freely with no need for permission.

2.4 - Erosion and Coastal Infrastructure

Coastal erosion is caused by seawater loosening sand along the coast and washing it away from the shore. It is a natural process that can be accelerated by human interference. Rising water levels exacerbate this problem, but are not the only contributing factor. Removing mangrove forests, over using wells, mining sand, and building dams also aid in the destruction of coasts. The types of sediment and particles present on coastlines also determine how quickly and how severe erosion occurs. For example, beaches with fine sand erode far more quickly than beaches with large volcanic rocks.

2.4.1 - Jetties

According to the Surfrider Foundation (2015), jetties are structures that are built on the sides of a coastal inlet from piles of rocks or concrete. Typically they are meant to stabilize the location of the mouth of a river or stream from moving, however they can also be used to keep bodies of water open for navigation. There are two jetties constructed on the Mrigadayavan Palace grounds: one located to the North of the Palace and the other located to the South. While jetties can be beneficial, they can negatively change longshore currents, and tend to create an updrift and a downdrift beaches on either side. Furthermore, jetties can cause permanent damage to the equilibrium of beaches, affecting tidal circulation and wetland health.

Figure 2: Photo of North Jetty

Source: Photo by Natalie Cohn

2.4.2 - Beach Erosion Prevention

Erosion prevention structures can include seawalls, groynes and breakwaters. One of the most common methods for combating beach erosion is the construction of structures meant to protect beaches from the direct force of the ocean, according to Benoit et al. (2007). Beach nourishment, the deposition of externally sourced sand on beaches, is another process meant to slow coastal erosion. One advantage of this method is the low cost, however, as it is a temporary solution, it is a repeated cost. Furthermore, the Surfrider Foundation (2015) claims the introduction of non-native particles through beach nourishment, such as silt, can create turbid water and smother habitats, in addition to creating drop-offs that pose a danger to swimmers.

Vegetation can be planted to harden the soil thus retarding the coastal erosion process, however, this method is not applicable to beaches used for tourist activities.

Figure 3: Photo of Groyne Meeting a Breakwater in Front of the Bang Kwai Community

Source: Photo by Natalie Cohn

2.4.3 - Structures in Cha Am

The shoreline in Cha Am is around 200 kilometers long. According to the Thailand Land Development Department (2014), most of the soil in this area and in Cha-am is salty, making it unsuitable for agriculture. Originally, the topography of Cha Am was at a higher altitude than sea level. Now, due to bringing seawater inland to preserve man-made mangrove forests, the terrain has been altered to be below sea level. North of the Palace there are high rise hotels and beach houses. Figure 4 is an image that was taken from the northern jetty, facing north up the Cha Am coastline.

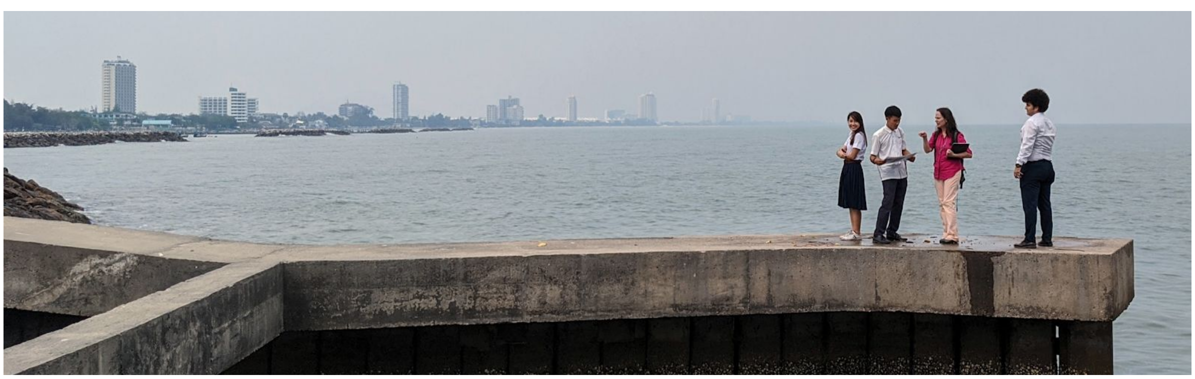


Figure 4: Photo of the North Jetty in Relation to Northern Cha Am

Source: Photo by Natalie Cohn

Preventive action to protect the beaches has begun to take place along the Cha Am coast, and erosion control structures are being built. Among these are breakwaters, large rock walls that run parallel to the shoreline in an effort to provide calm water for harbors, and groynes, structures running perpendicular into the ocean from the shoreline meant to interrupt sand movement in the longshore flow, according to the Surfrider Foundation. However, groynes can cause updrift and downdrift of sand, making a once straight shoreline become uneven. Furthermore, they claim that once groynes are implemented, an entire beachline will need to be covered in them as there will always be beach erosion in the form of downdrift off of the last groyne structure.

2.5 - Mrigadayavan Palace

The Mrigadayavan Palace was the summer palace of His Majesty King Vajiravudh. King Vajiravuh was born on the first of January in 1880, the 29th son of H.M. King Chulalongkorn (Sirikulchayanont, 2003). The Mrigadayavan Palace, registered as a site of cultural heritage in 1981, is open to the public as a museum and attracts 350,000 to 400,000 visitors a year (Svasti, 2016). It is an immersive experience to many people studying the arts and sciences in addition to tourists as it offers lessons in the cultural history of Thailand and environmental restoration.

Figure 5: Photo of Mrigadayavan Palace

Source: Hua Hin Destinations

2.5.1 - The Mrigadayavan Palace Foundation

According to the Palace website, following the first attempt at restoration, the Mrigadayavan Palace Foundation was founded under the patronage of Her Royal Highness Princess Berjaratana to manage operations, funding, and restoration projects around and inside the Palace grounds. Funding for any restoration or conservation efforts comes entirely from donations, admission prices, and gift shop sales as mentioned on their website. The Mrigadayavan Palace Foundation offers tours and educational experiences to many Thai students because to the Thai people, studying history is key to being a good citizen, as it promotes national identity and loyalty through vivid and inspiring stories. The saline groundwater is preventing the Palace Foundation from sustaining the original vegetation that the Palace grounds hosted when the groundwater was fresh. This is impeding the Foundation's ability to fully restore the grounds.

2.5.2 - Previous IQP-ISSP Findings

In 2017, a team of students from Worcester Polytechnic Institute and Chulalongkorn University researched water quantity and quality and coastline erosion at the Palace. The team examined man-made structures near the Palace to determine what effect they had on the groundwater, shoreline, and surrounding environment. In addition, they analyzed the groundwater, observed the region's water source, and interviewed the surrounding community to evaluate the impact of brackish groundwater on the daily lives of local people.

What we learned from their project:

- The groundwater is brackish, near saline, in areas closer to the jetties.
- The number of wells in the area surrounding the Palace is undocumented. Unsupervised use of wells can lead to seawater intrusion.
- Locals have been affected, but do not understand the jetties have caused the problems nor do they know the other negative effects of jetties.
- Deliverables: informational video and a sign put up in the Palace (was not found when we visited the Palace).
- Recommendations: The Foundation should start tracking the groundwater salinity levels on the grounds and the area within the jetties.

This information provided us with data on the groundwater salinity levels in 2017, allowing us to document changes. Their community interviews also guided our decisions on what questions to ask locals on salinity impacts.

2.6 - Sirindhorn Environmental Park

Sirindhorn Environmental Park is an educational center for the rehabilitation and conservation of natural resources, environment, and energy. The park was initiated by the interest of Her Royal Highness Princess Maha Chakri Sirindhorn to recover mangroves and return a balanced ecosystem to nature. The princess was instrumental in the planting of several types of mangroves and requested a study to find the best way to maintain and continue planting the mangroves in the area. During her stay in 1998, the princess observed abandoned land and poor soil conditions that had poor vegetation. With this observation, the princess initiated soil rehabilitation in the area to restore lush vegetation in the area.

In 2003, Sirindhorn Environmental Park was officially established by the cooperation of the Border Patrol Police, Huai Sai Royal Department Study Center, and the Mrigadayavan Palace Foundation to present to HRH Princess Maha Chakri Sirindhorn on the occasion of her 4th cycle birthday anniversary. Under the patronage of HRH Princess Maha Chakri Sirindhorn, the park is managed by the foundation of The Sirindhorn International Environmental Park (SIEP). The park continues to operate as a model for reforestation and rehabilitation of mangroves while encouraging the cultivation of the sufficiency economy philosophy. There are several educational centers within the park for people to learn, train, and adapt to their living. Examples of the learning topics are renewable energy, wastewater management system, the Princess mangrove plantation, and coastal erosion protection as reported on the park's official website. The mangrove plantation on the SIEP grounds may also be at risk because of the over salinization of the groundwater.

2.7 - Potential Solutions for Brackish Water

A brief summary of common large scale water desalination methods is described.

2.7.1 - Seawater Barriers

Seawater barriers, or hydraulic barriers, are a series of injection wells positioned along the coastline between the ocean and a groundwater aquifer. They act as a dam, and are meant to create a barrier that ensures ocean water cannot penetrate the aquifer. The wells input imported freshwater into the domestic water supply to raise groundwater elevations to at or above the original elevation of the aquifer.

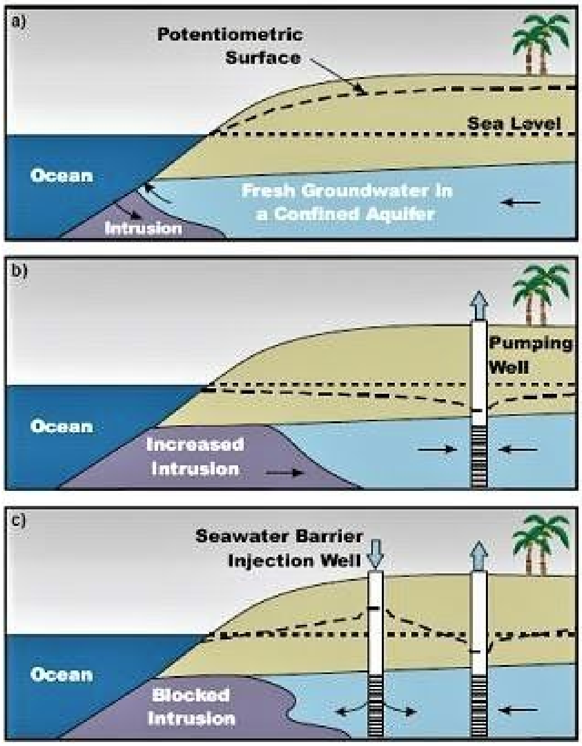


Figure 6: Image of Seawater Barrier

Source: West Basin

In Figure 6: a) is a naturally occurring environment with limited seawater intrusion; b) shows increased intrusion due to overpumping of groundwater in the aquifer; and c) depicts an injection well that increases pressure in the aquifer to block intrusion because the potentiometric surface is above sea level (West Basin, 2020).

Mixed hydraulic barriers are hypothesized to control seawater intrusion. Ebeling et al. (2019) observed and studied 542 remediation scenarios for six cross-sections of a hypothetical shallow, unconfined, homogeneous coastal aquifer. These characteristics were selected based on a number of coastal aquifers from real-world case studies related to seawater intrusion. The simulation was designed to represent a typical withdrawal of groundwater that would cause active seawater intrusion and provide information about the state of intrusion for beach barrier type. There are two types of hydraulic barriers: positive and negative. Both are parallel to the coastline, however positive barriers rely on the injection of freshwater or treated water, while negative barriers extract groundwater. Both positive and negative barriers can be used simultaneously, and the order of their placement in proximity to the coast can be switched.

Regardless of order, the combination creates a viable mixed hydraulic barrier (Ebeling et al., 2019).

The study by Ebeling et al. (2019) discovered that hydraulic conductivity and the regional freshwater flow are often the most impactful aspects of determining how quickly remediation can occur. Increasing the hydraulic conductivity by one order of magnitude accelerated the remediation time by upwards of 90 percent from traditional remediation methods in which total restoration can take up to 100 years. The success of the simulations also depended on the situational variances, such as the distance from the coast at which the barrier was placed. The study concluded that mixed hydraulic barriers hold great potential as a more efficient solution for coastal aquifers contaminated by seawater intrusion in the correct circumstances. As of this study, mixed hydraulic barriers had not been used in a real-world situation, however it remains a possible solution that may be able to greatly shorten the remediation timeline if the conditions at the Palace are favorable.

An example of a successful implementation of hydraulic barriers exists in Los Angeles, California. The region west of the Rocky Mountains and, most notably, Southern California receive less than fifteen inches of annual rainwater, the desert area getting less than five inches per year (Xiao, 2018). In addition to water shortages, the coastal southern region of the state faced many issues regarding seawater intrusion in the 1940s, causing many of the freshwater wells to be abandoned (Seawater Barrier, *Public Works*, n.d.). In 1943, the California government deemed immediate action be taken, and three seawater barrier projects, listed largest to smallest, began in Los Angeles County: (1) the West Coast Basin Barrier Project; (2) the Dominguez Gap Barrier Project; and (3) the Alamitos Barrier Project.

The projects have all been successful in restoring fresh groundwater to Los Angeles County. West Basin Municipal Water District is now working with Water Replenishment District of Southern California (WRD) to increase the usage of recycled water that is being injected into the West Coast Barrier Basin to provide a higher quality, more reliable source of water to the local aquifer and conserve imported water supplies.

2.7.2 - Other Methods of Desalination

According to Kress (2019), desalination can generally be broken down into two methods: (1) membrane processes, and (2) thermal processes. In membrane processes, now the more popular method of desalination, claiming upwards of 65 percent of global desalination efforts, a membrane is used to separate dissolved salts from water. Thermal processes were the main desalination method until 2005 when the cost of membrane technology decreased in cost and increase in efficiency (Kress, 2019). The thermal process involves heating water until the condensed vapor is pure water. There are also various types of hybrid systems that combine membrane and thermal technology, in addition to novel technologies that are being used.

Thermal technology is meant to mimic the natural water cycle—artificially produced water vapor condenses as freshwater according to Banat’s 2007 assessment of desalination technologies for Jordan University of Science and Technology. Thermal desalination is typically used for desalination of seawater or highly salinated water. They are typically used for desalinating large quantities of water, as creating a phase change for water requires a large amount of energy. Commercial facilities are typically multistage processes and include Multi Stage Flash (MSF), Multi Effect Distillation (MED), and Vapor Compression (VC). These methods are best used in locations where there is excess heat waste or energy costs are low. Membrane technology requires shaft power or electrically energy to pass water through a membrane, allowing it to have lower energy requirements. However, while the costs continue to lower, membranes need frequent replacement. Electrodialysis, for brackish water, and Reverse Osmosis (RO), for saline and brackish water, are examples of membrane desalination technology. These methods are best used in locations where flow rates are low and energy costs are fairly high.

Alternatives to these include solar humidification, membrane distillation, freezing, and conventional desalination powered by renewable energy sources.

2.7.3 - Issues with Isotopes

To further complicate the restoration of fresh groundwater, desalination must be designed to impact the specific isotopes in the water as well as accommodate several other natural environmental conditions unique to the location. Isotopes are elements of the same atom with the same proton number but different neutron numbers and this causes a slight variance in each isotope's mass. The isotopes within soil and groundwater vary greatly throughout the world, and there are a number of different remediation methods that are used to remove specific isotopes from contaminated water. The existing conditions and environmentally contributing factors can also impact how the desalination process will work. All of these aspects together mean that desalination efforts are often very unique to the location where they are implemented in order to optimize their efficiency (Carreira et al., 2014).

3 - Methodology

The goal of this project is to determine the impact of human activity on the groundwater of the Mrigadayavan Palace and desalination methods to restore the fresh groundwater in order to make the palace self sufficient in terms of where they get their water from. To accomplish this goal, the team developed the following objectives:

1. Determine salinity levels of groundwater and soil on the Palace grounds.
2. Identify community awareness of increased groundwater salinity and impacts of the mangrove and jetties.
3. Analyze the causes of increased salinity on the Palace groundwater.
4. Identify strategies to restore fresh groundwater.

3.1 - Objective 1: Determine salinity levels of groundwater and soil on the Palace grounds

The Mrigadayavan Palace Foundation has been conducting monthly salinity testing of the groundwater throughout the Palace grounds for four years. The data from the previous months was presented and explained to the team during the initial sponsor meeting. Information on the salinity levels of the groundwater, regional maps of the jetties, and diagrams explaining the on-land water cycle in Cha Am were also given to the team. Initial charts and diagrams provided by the Foundation are available in Appendix A. These charts show the change in salinity levels over time.

We visited the Mrigadayavan Palace from January 20th to the 22nd to collect water and soil samples, interview the local community, and talk more in depth with the Palace Foundation about their own research. From the information received we were able to come to a better understanding of the severity of the problem and the ideal ways to restore the groundwater and raise awareness in the community.

We conducted our own testing of the groundwater salinity using a YSI Salinometer set from Chulalongkorn University. The YSI Salinometer measures the conductivity of the water and converts the conductivity measurement to a salinity measurement in parts per thousand. The probe of the salinometer was submerged 0.5 meters below the surface of the water. The team mapped where on the Palace grounds the samples were taken, and the results were later compared to the data given by the Mrigadayavan Palace.

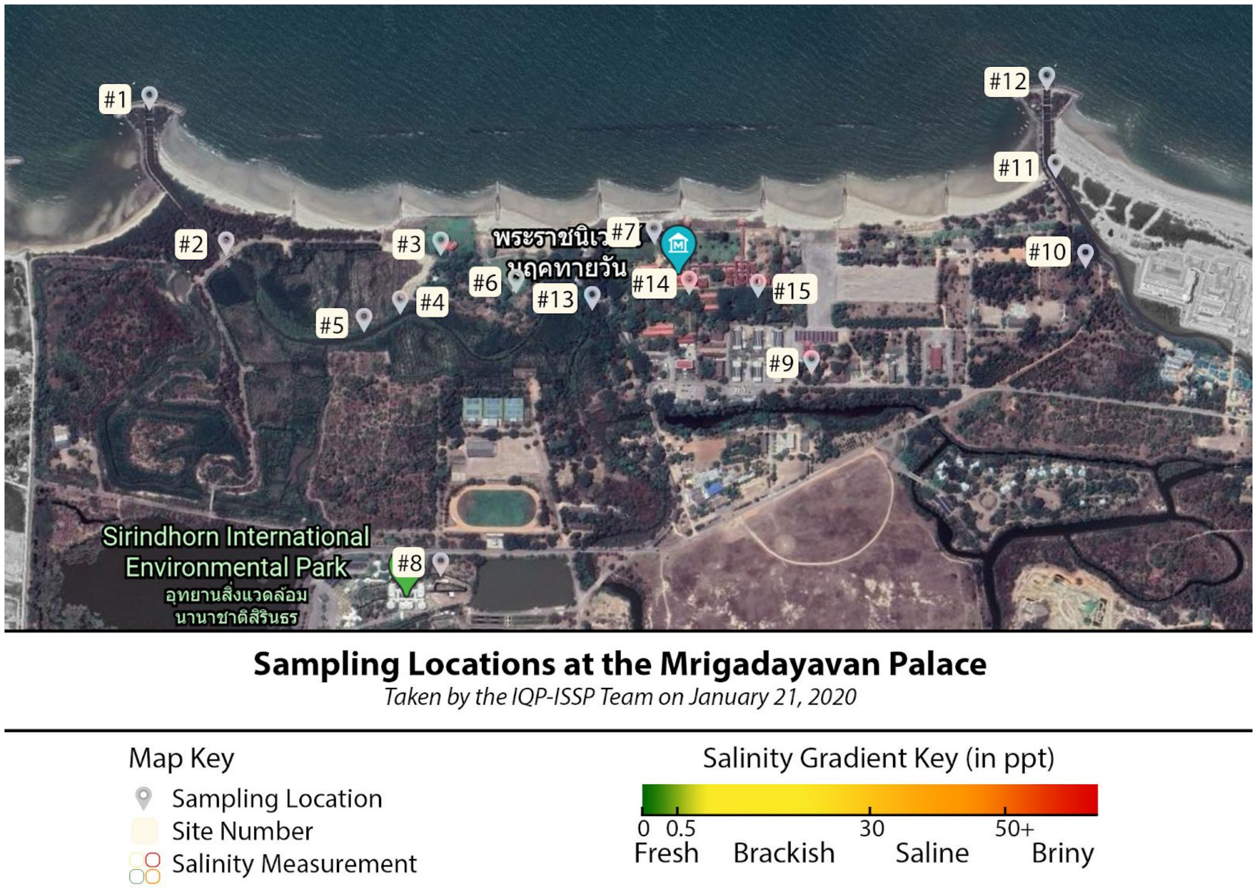


Figure 7: Map of Water Sampling at the Mrigadayavan Palace

To test the salinity levels of water sources around the Palace grounds, the team evaluated fifteen sites, but only obtained water salinity data at fourteen locations (location #6 did not have a body of water to sample), as indicated on Figure 7.

According to Salinity Notes, in order to accurately test for water salinity, the salinometer has to be washed with freshwater to clean it of any impurities sticking to the detector node before a measurement is taken. Once the salinometer is in water source, the detector node should fully be immersed to get an accurate reading. It is recommended for the salinometer to be moved around a bit to mix the water for the most correct values. The salinity value measured by the salinometer takes fifteen seconds to stabilize once the device starts reading the salinity. Washing after taking a measurement is recommended to clean the device and prepare for next use. We collected samples at four different wells, three on the Palace grounds and one on the grounds of the nearby Sirindhorn Environmental Park. Samples were also collected from the two jetties on the Palace grounds, and streams throughout the grounds.

By taking our own water salinity data we could properly determine if there are any flaws in either of the salinometer testings. While there is always room for human error in testing, such as not fully cleaning the device between tests, we also took into consideration the fact that the Palace was doing irrigation during our visit. Performing this testing with a different salinometer can bring us to one of two conclusions, if the numbers are similar we can conclude unbiased data and if they are different we would have to do further research as to why.

We also collected soil and subsoil samples at the Palace. Thirteen of the fourteen soil samples were taken at the same locations where water samples were collected. From these fourteen locations there were seven subsoil samples collected as well. According to Vineyard Activity Guides, salt content in soil increases vertically. Therefore to accurately determine the concentration of salt in soil, two samples have to be taken for each testing location: one from the top soil, 0-10 centimeters from the surface, and the other from the subsoil, 20-30 centimeters from the surface. These samples were tested at the Faculty of Agriculture, Kasetsart University and the results were available to us after 3 weeks. Samples #8, #9, #12, and #13 were unable to be tested due to insufficient quantities. These samples assisted us in better understanding the severity of the problem and gave insight to the potential causes of the increased groundwater salinity based on the amount of sodium chloride in each sample. Subsoil samples having a high amount of salt, could indicate the presence of seawater intrusion.

3.2 - Objective 2: Identify community awareness of increased groundwater salinity and impacts of the mangrove and jetties

In order to collect more information on the community awareness and understanding of the problem we decided to interview locals. By learning the opinions of these people we can discover more information about the local area and the values of the community.

3.2.1 - Interviewing Local Community Members

First, the team focused on interviewing the stakeholders, which includes: fishermen (A), merchants (B), teachers (C), and nearby residents (D) in the Bang Kuai community, adjacent to the Palace grounds. Border Policemen (E), merchants outside the Palace (F), and Sirindhorn Environmental Park employees (G) were also interviewed. A map of specific locations of interviews can be seen in Figure 8. The prepared questions aimed to provide a thorough assessment of both the community's activities that could affect the groundwater's salinity and how they receive local information as this guided the team to the most effective way to raise awareness to the people on the knowledge related to increased groundwater salinity. Additional questions about the mangrove forest and jetties were included because the team was evaluating the impacts these features have on the groundwater salinity. However, the main motivation for the interviews was to assess community awareness of the increased levels of salinity in Cha Am's groundwater. The specific list of interview questions for the community are listed in Appendix B.

Collecting these interview responses gave us a more broad understanding on how the stakeholders, community members and Environmental Park, view the effects of the jetties. As all our questions are opinion questions we can not conclude these as scientific proof, but just as general knowledge given to us from a selective group of individuals.

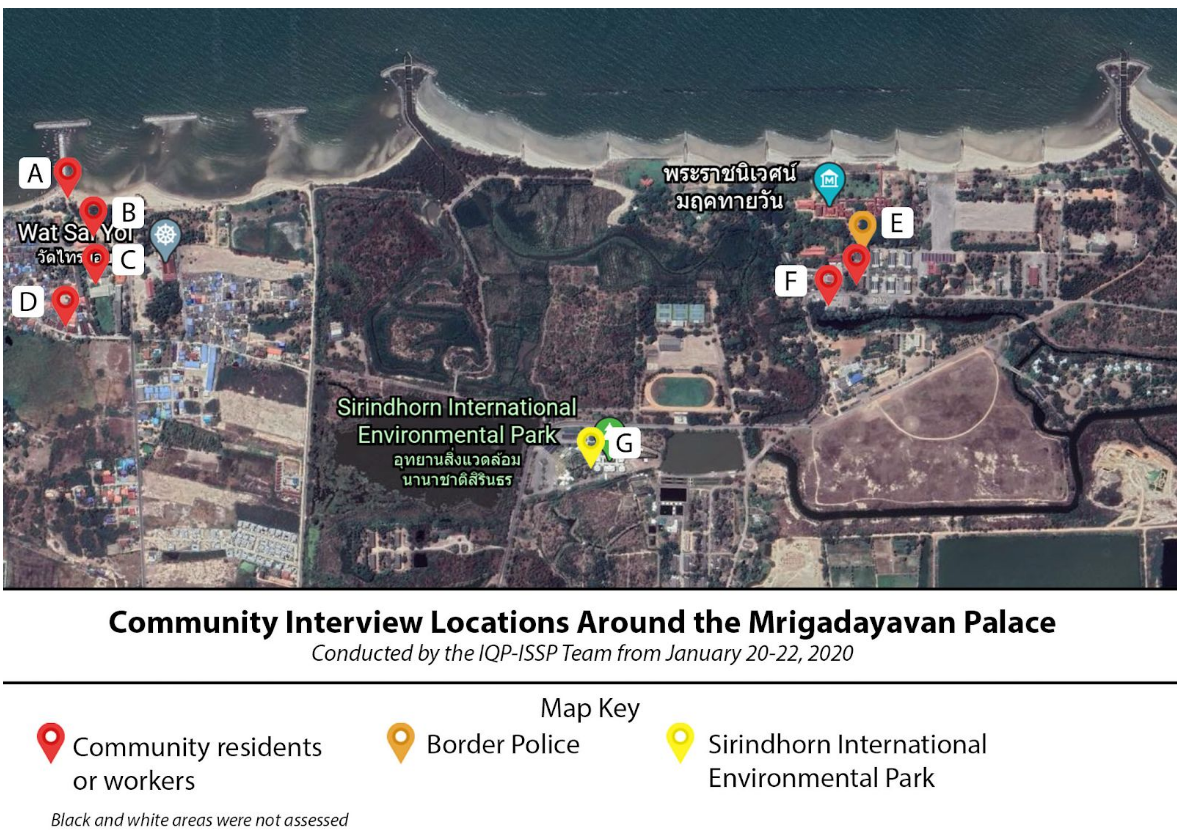


Figure 8: Map of Interview Locations

3.2.2 - Documenting Community Perspectives On Local Man-made Infrastructure

We spent a week analyzing the information contained in the reponses. The general understanding that the community had about groundwater salinity, the local environmental changes, and the impact man-made infrastructure have on salinity levels is discussed in the next chapter. The team looked for common responses across the interviews that may be an indication of common opinions or views within the community. The interview responses were categorized based on knowledge of groundwater salinity, knowledge of man-made infrastructure, and general knowledge about the community and area. Assessing within these categories have allowed us to determine the community's perspectives on the structures.

3.3 - Object 3: Analyze the causes of increased salinity on the Palace groundwater

The team wanted to analyze the conditions at the project site and the surrounding area so that we could better determine the local causes of increased groundwater salinity. This was done by interviewing local community members and caretakers of the mangroves in order to better understand the human activities in the area that could impact the salinity levels. By analyzing and graphing all data taken, we are able to determine the likely causes of the problem.

3.3.1 - Interview Caretakers of Mangroves

The team conducted interviews with the nearby Sirindhorn International Environmental Park who are responsible for the mangrove forest planting and continued care. To prevent potential conflict between the Park and the Palace, the team only asked questions regarding the species and local forests. The specific list of interview questions for the Park are listed in Appendix C. The responses from these interviews have been categorized based on whether they indicate positive or negative effects from the mangroves or if the mangroves are doing well in the current conditions.

3.3.2 - Analyze Interview Answers

The interviews with the community provided the team with insight on local activities and changes that could not be found through the collection of quantified data. From finding comparisons in the interview questions, the team learned important information about the community. This assisted with identifying problems with the groundwater and vegetation in the community, understanding their knowledge on the jetties, and where they get their information from. From here the team found suitable ways to educate the community on the impacts happening around them.

3.3.3 - Graphing Salinity Levels

After gathering all available groundwater salinity data, a graph was created to show the change in salinity over time. From examining this graph the team had found the rise and falls in the salinity pattern and further looked into those time periods. We determined the time frame that the salinity began to increase, and compared it to the information about significant weather, environmental, societal, or infrastructure changes.

3.4 - Objective 4: Identify strategies to restore fresh groundwater

Identifying solutions to restore fresh groundwater will be found through the analysis of case studies researched by the team for background information, and the completion of the previous four objectives.

3.4.1 - Identify Potential Processes to Raise Awareness in the Community

We researched possible recommendations to give the Palace Foundation on how to approach educating the community on the need to remove the jetties and mangroves. If the data says otherwise, the team will create recommendations on how the Palace Foundation can inform the community on the impact individuals can have on their local environment and how to protect it. By raising awareness in the stakeholders, people can understand what is happening in their community and may change their own actions to assist in the progress of restoring their environment. Moreover, the team will ensure the Palace Foundation has a finalized event or informative signs to educate its community on the dangers of increasing groundwater salinity.

3.5 - Research Ethics

The IQP-ISSP team plans to protect those who chose to participate in interviews. The team did not ask for names of the participants. The only identifying information that is being published is the participant's occupation. No details of this person will be given to anyone that is not a member of the IQP-ISSP team, and responses will be discarded following the conclusion of research. The full consent form can be seen in Appendix D.

4 - Results and Analysis

In this chapter we describe our results and explain our findings based on our analysis of data we collected.

4.1 - The Groundwater Salinity Appears to be Increasing

The team tested the water salinity at 14 different locations. Results of the salinity testing are visible in Figure 9. When compared to the previous salinity data that we received from the palace, there is a general increase in the salinity of the groundwater.

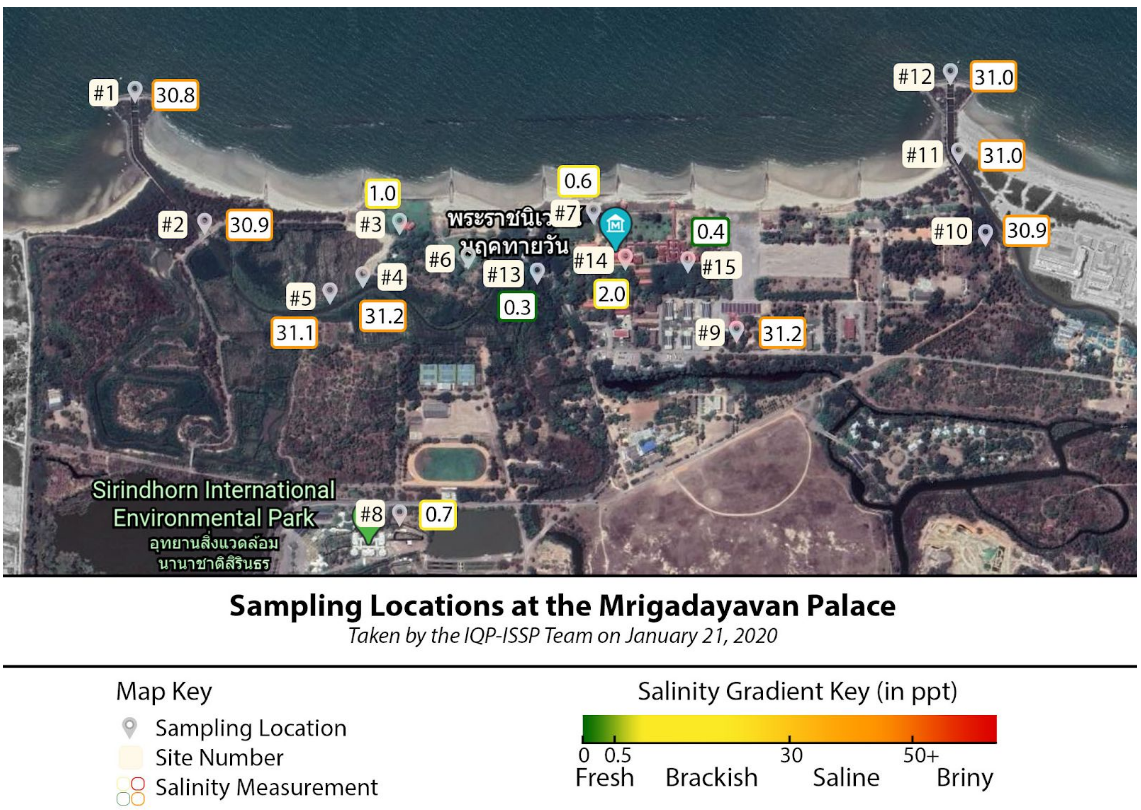


Figure 9: Map of IQP-ISSP Groundwater Salinity at the Mrigadayavan Palace

It is important to note that in the data provided by the Palace, there is freshwater at the site labeled “Original Well”. In our data there are two freshwater sites at points #13 and #15, we believe this was due to irrigation taking place during our site visit. The freshwater wells on the Palace grounds have not succumbed to seawater intrusion as they are protected wells, meaning water is not pumped from them. By not pumping from the wells, the water pressure in the well does not change and the seawater is unable to penetrate the aquifer. While the wells are close to brackish, continued protection keeps the salinity level below 0.5 ppt. The wells that are not protected contain brackish water as the seawater has penetrated the aquifer. These wells are in a lower brackish state, they lie within 0.5-2 ppt. This decrease in salinity can be seen in greater detail in Figure 10. Other than this, there has been a small overall increase in the groundwater salinity from early November 2019 to late January 2020.

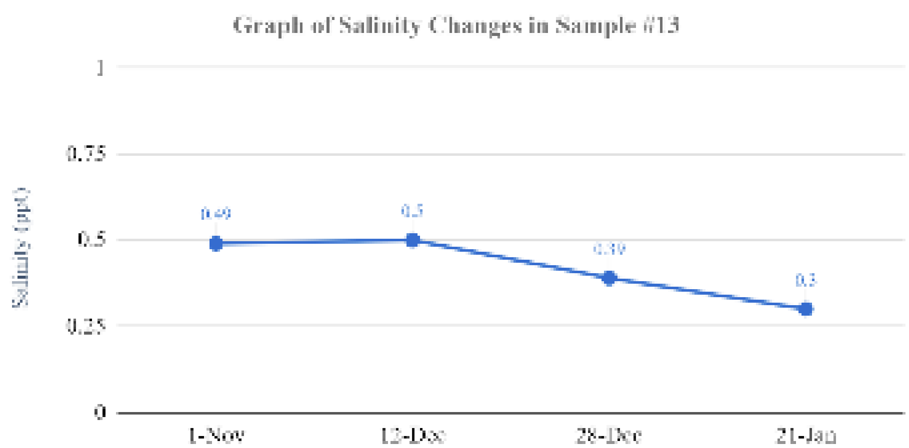


Figure 10: Graph of Increased Salinity at Sampling Point #13

4.2 - The Jetties are Likely Causing the Groundwater Salinity to Increase

By analyzing the graphs made for each location we can see the level of salinity change over time. From the graphs we could see an increase in salinity in the areas around the jetties, likely due to the inflow of seawater. These areas are now beyond brackish as they have surpassed 30 ppt, they are saline.

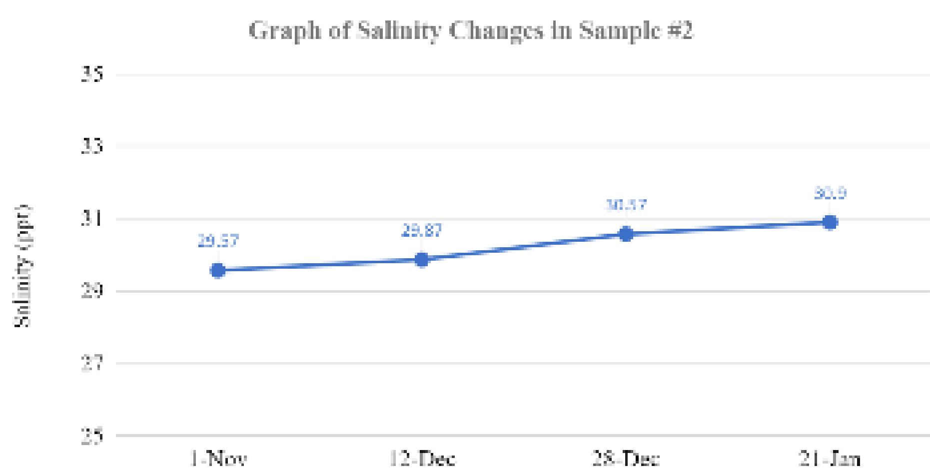


Figure 11: Graph of Increased Salinity at Sampling Point #2

The gradient maps show similar information. The areas around the jetties have higher salinity levels surrounding them (orange in color) that show how they are more affected. While the palace grounds show a brackish state, yellow, with some freshwater areas, green.

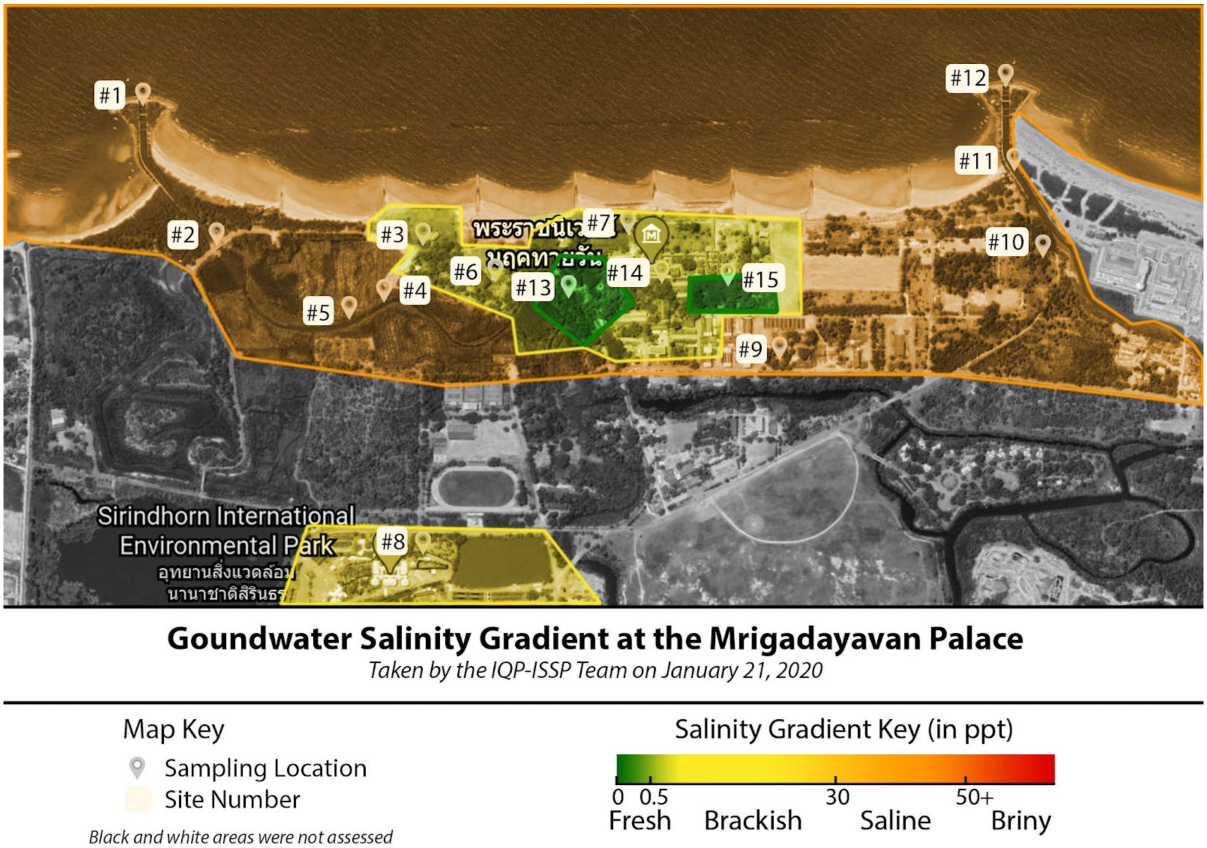


Figure 12: Map of IQP-ISSP Groundwater Salinity Gradient at the Mrigadayavan Palace

4.3 - Seawater Intrusion is Likely Occurring

Our soil sample results show that three of the topsoil sample sights yield fresh groundwater, but the remaining seven samples that were tested were all brackish. Topsoil samples at site location #2 and #11 were likely under 0.5 ppt because they were located directly next to the concrete jetty structures which prevented the seawater from being able to seep into the soil.

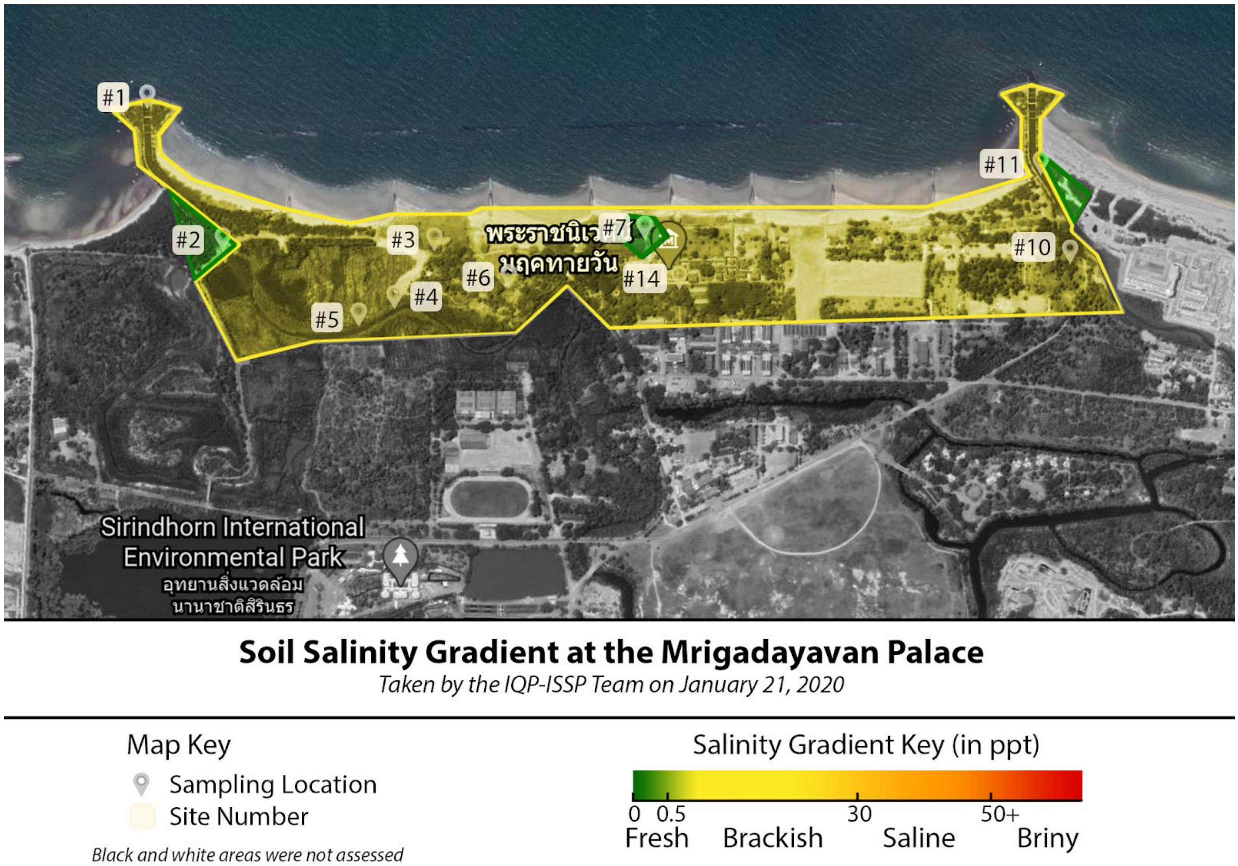


Figure 13: Gradient Map of Soil Salinity

We believe that the results of the subsoil testing prove the presence of seawater intrusion. Subsoil sample #7 is located at the protected well and is the only freshwater subsoil sample. The remaining subsoil samples are brackish. Had just the topsoil been brackish we would have concluded the presence of sea spray. However, since the subsoil is also brackish we believe that the seawater being brought in from the jetties is penetrating the aquifer.

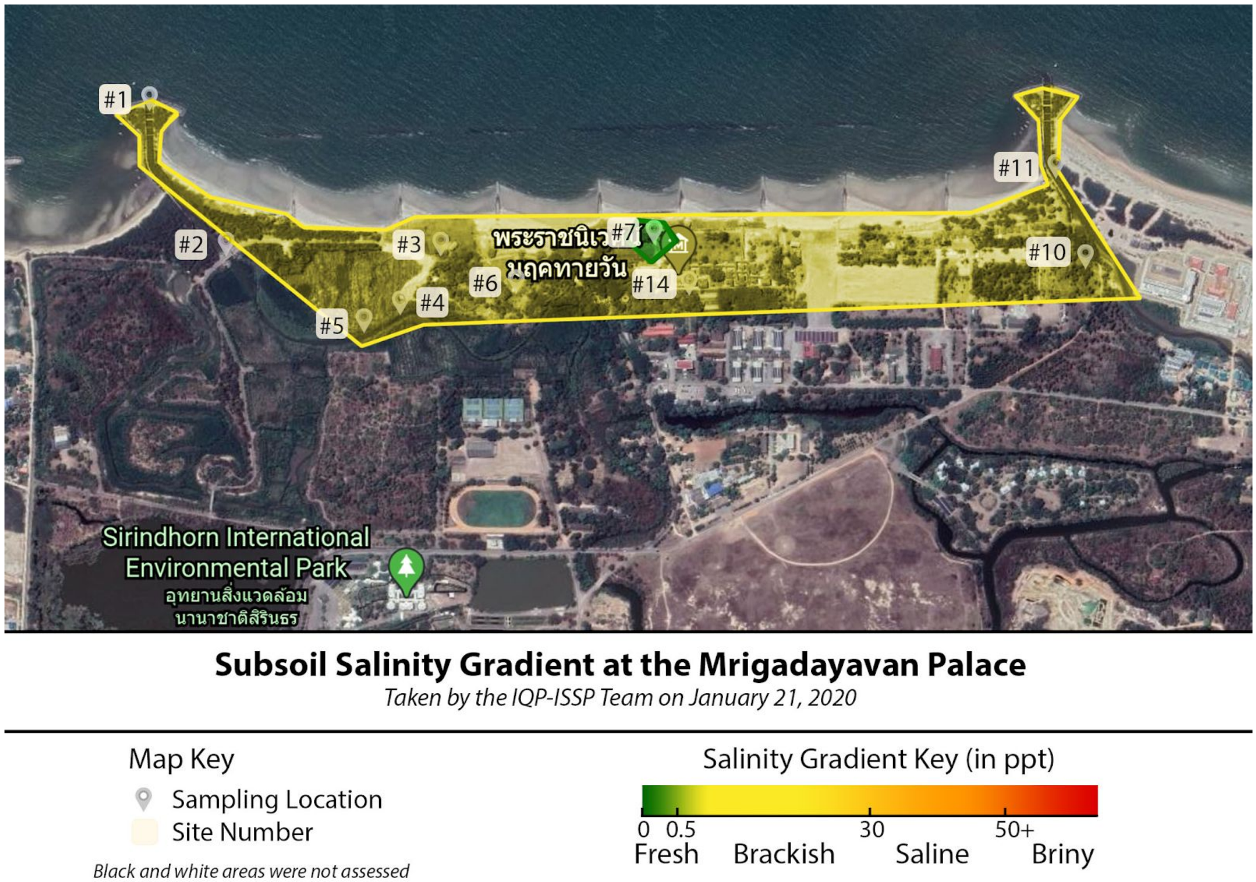


Figure 14: Gradient Map of Subsoil Salinity

4.4 - The Surrounding Community Appears to be Unaware of the High Groundwater Salinity

The team visited communities around the Mrigadayavan Palace such as Bang Khwai, including Sai Yoi temple and Sai Yoi School, the Border Police training camp, and shops and residences near the Palace. When asking questions related to our project, the full list is available in Appendix B, we found out that 53.8 percent of community members interviewed know what salinity is, but 69.2 percent do not know what the jetties are. Three people thought the jetties were implemented for different reasons than it was, such as protecting the environment or separating the beaches. When on the site we noticed that the jetties were being used by fishermen docking their boats (we counted over 50 boats being sheltered by the northern jetty). This is a positive aspect one of the fishermen interviewed mentioned. This showed us that when working on increasing awareness for the community we need to focus more on the issues related to the jetties than issues on salinity.

This lack of awareness can likely be attributed to the fact that all of the people we interviewed got their daily use water from the local reservoir supply and not from the groundwater. Even though nine people noticed a change in the vegetation and four people noticed a change in the beaches, they assumed these were caused by other issues.

From the interviews done at the Sirindhorn International Environmental Park, they mentioned mangroves are able to be self-sufficient so long as they have a brackish water source. The seawater supply for the mangroves comes from the jetties and is dependent on the natural tide. The mangrove forest should be able to thrive naturally from here. They aren't given any additional nutrients to survive as they can get them naturally from the dead leaves falling. Since the mangroves have a consistent source of water, the Environmental Park believes that the salinity of the water does not have an impact on the health of the mangroves. The only time the Environmental Park interacts or maintains the mangroves is when they remove mangroves from overcrowded areas.

4.5 - Jetties are Likely Causing On and Off Shore Pollution

Although the primary function of jetties is to allow seawater to flow inland, water exits into the ocean due to the tides, as well. As outlined in Figure 15, there is a stream of discolored water where sediment from land, likely the mangrove forest, has mixed with outflowing water.

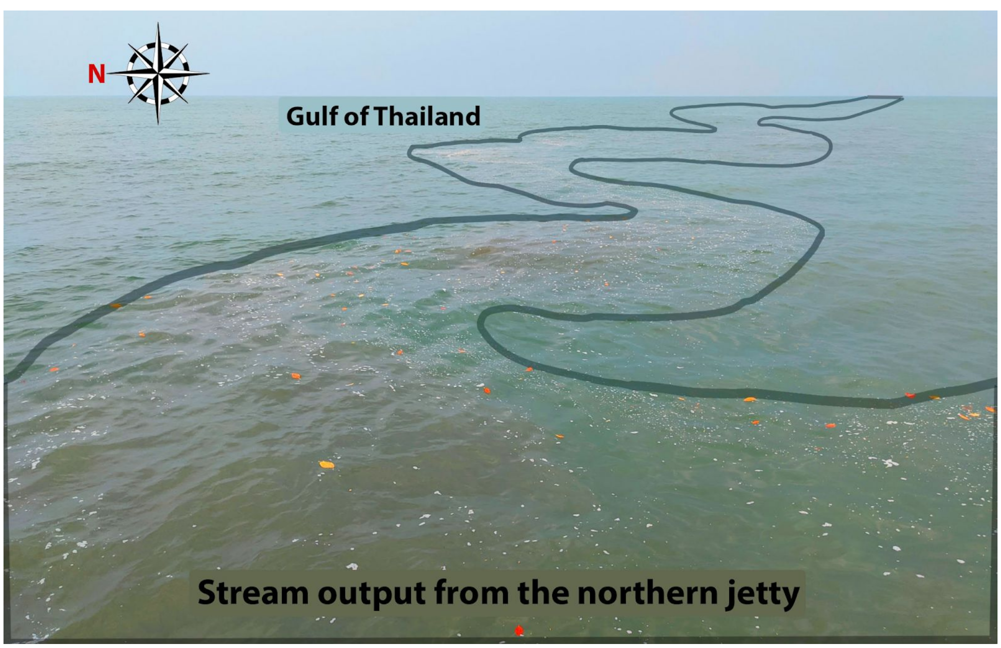


Figure 15: Photo of Sediment in Gulf
Source: Photo by Natalie Cohn

As the jetties leave the mouth of both channels open all year, it increases the amount of foreign sediment entering the ocean, and is likely polluting the gulf. This can cause disruption to the ecosystems within the Gulf of Thailand, as it may smother habitats on the seafloor.

4.6 - Jetties are Likely Negatively Impacting Beaches

There are notable changes in the shape of the shoreline between 1954 and 2019, especially after the construction of the jetties in 2005, and groynes in the years following. The shoreline remained relatively constant between 1954 and 2005, the year the jetties were constructed. Even when it would misform, there is a visible tendency to even back out. However, the updrift, indicated by the red arrows in Figure 16, and the downdrift, indicated by the green arrows, appear to be caused by the groynes and jetties, as they are not visible before 2005.

Although groynes are meant to protect beaches, these appear to be disturbing a shoreline that was not previously showing signs of erosion.

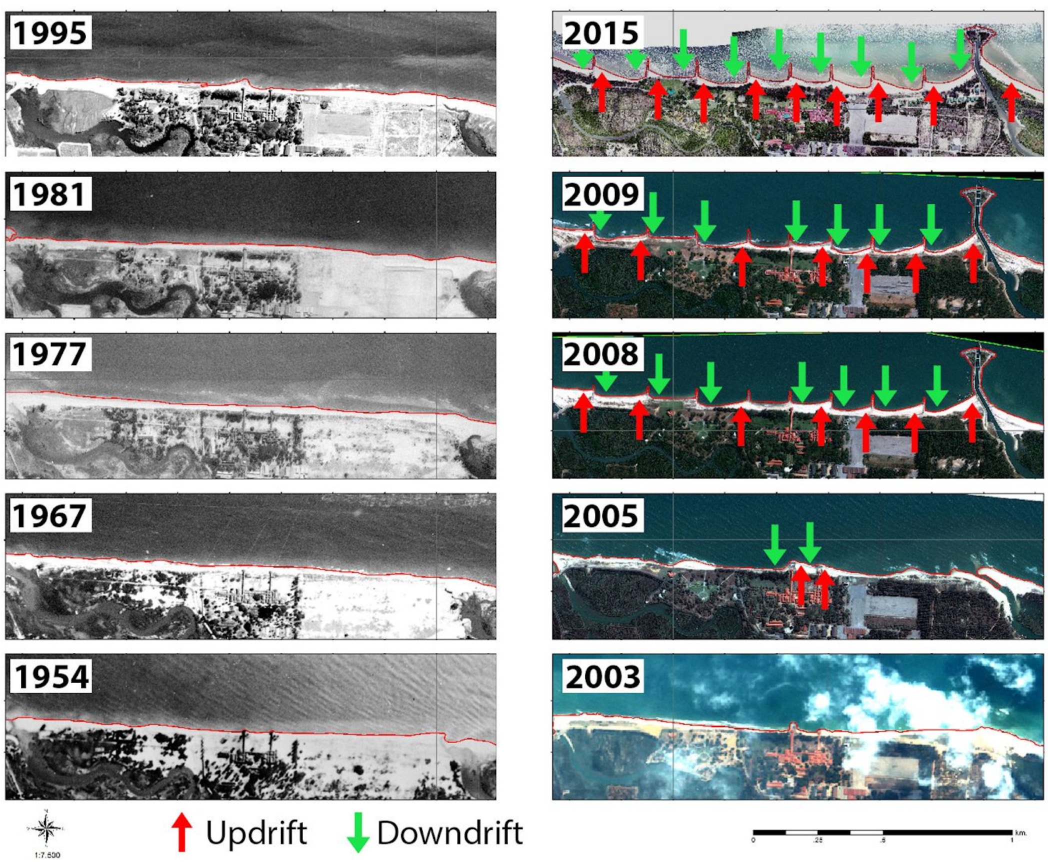


Figure 16: Flow of Updrift and Downdrift of the Mrigadayavan Palace's Shoreline
Source: Images from the Mrigadayavan Palace Foundation, diagrammed by Natalie Cohn

Another observation that can be made from Figure 16 is the longshore flow seems to change direction between 2009 and 2015. The updrift and downdrift along the groynes change sides, suggesting the reversal of current. The change in current flow can cause an unequal distribution of sand along coastlines.

5- Recommendations

The Mrigadayavan Palace Foundation presented us with the opportunity to investigate the issue of groundwater salinity and how it is impacting the local environment. We set out to discover the source of the issue and identify solutions to remedy the problem. We also wanted to create ways of raising awareness of the salinity problem within the local community.

5.1 - Recommendations Regarding the Jetties

Our results indicate it is likely that the jetties are the main cause of this problem. We researched how to fill in the jetties, remove the jetties, and the installation of a dock and pump to compensate for the current benefits of the jetties.

5.1.1 - Fill in the Jetties

Filling in the jetties with rocks, native soil, and sand will prevent seawater from entering past the coastline. It is the quickest way to stop the what is likely the main cause of the increasing groundwater salinity levels around the Palace grounds: seawater being absorbed into the soil in comparison to other techniques.

This process would be cheaper and faster than removing the jetties entirely. Furthermore, the potential to restore the mouths of the streams to their original condition—open for part of the year, and naturally closed for the rest—could be faster. However, it is possible that the mouths of the streams will be unable to naturally open and close unless the concrete opening them up to the sea is completely removed. The inland concrete barriers are slightly lower than the ground level and would be contained within the subsoil. It may prevent movement of subsurface groundwater. While nature may eventually remedy any obstacles, removal or breaking up of the concrete could be a more efficient method of restoring the aquifer.

The Palace Foundation wants to remove the groynes on their shoreline, but has no where to put the significant amount of rocks. To prevent high costs for long transportation after removal, the rocks that comprise the groynes can be used to fill in the jetty before smaller sediment is put on top.

5.1.2 - Jetty Removal

Removing the jetties would require removing the entire concrete structure framing the jetties, and then filling in where the jetties once were. This would cost significantly more than filling in the jetties as demolition as well as filling needs to be done. Jetty removal is not a common occurrence, nor is it a commonly offered service. This means that a company offering this service will likely cost a significant amount of money.

Seawater Pump Installation. One of the main benefits found from the jetty is that it brings in saline water to the mangroves. If the jetty is removed, it could cause damage to the mangroves if the steam is unable to regain the ability to open its mouth to the gulf for certain months of the year.

We believe that the salinity of the water in the mangrove forest should be monitored for a few years, along with the amount of water that they have access to. We feel it is best to wait to see if further action, installing a seawater pump for the mangroves, is the best solution before taking action, as it is possible nature could remedy the situation on its own.

If a seawater pump is necessary, the materials are very important. The Palace will decide what materials they feel would be preferred for their situation based on time, cost, and amount. Based on an article by Francis & Phillips (2003), materials used for this range from cast iron/steel, to nickel, to duplex stainless steel, to titanium. These materials vary in both cost and life expectancy. We were not able to find an exact cost on these materials, but they fall into an area of low, medium, and high cost. As cast iron would be the cheapest of the materials it is recommended for projects that last under a year for cost-efficiency. While a duplex stainless steel costs more, it can also last a couple of years. As there are more factors to be considered such as temperature, corrosion and so on there is no definite answer, but the team recommends a material in the medium cost area. These materials, such as nickel, bronze, and duplex stainless steel, are not the most expensive and will last the longest. From this the Foundation and Environmental Park can have the mangrove thrive without the need of the jetty.

5.1.3- Advocating for and Installation of a Dock

Since the northern jetty creates an artificial harbor and shallow to dock boats for fishermen, the community would likely be against removal. By installing a dock they can still experience the benefit with infrastructure suited to fit their needs.

The community would be more supportive of removing the jetty if the Foundation supported and advocated for the installation of a boat dock. This would be useful to the fishermen in the area as they currently use the jetty as a dock. Building a dock for a large community is not something done often.

5.1.4 - Installation of a Water Barrier

Even though the evidence gathered from the salinity meter and the Palace data indicated that the water sources around the jetties have become over-salinated because of the incoming ocean water, there could be too many problems involved with the removal of the two jetties. The construction of the jetties originally cost tens of millions of baht, therefore it may be very difficult to dismantle them due to complications and additional costs associated with demolition. While the jetties have increased the amount of ocean water flowing inland, one way this can be managed is the installation of water barriers at the entrance of each jetty. One third of the Netherlands is below sea level and in order to combat floods and water from coming into their lands, they have constructed water barriers called the 'Maeslantkering' which have been hugely successful. The total construction of the Maeslantkering cost 660 million euros but because the scale is much smaller for this situation and construction costs are cheaper on average in Thailand compared to the Netherlands, the cost should be manageable for the port authority.

5.2 - Desalination Methods for Seawater Intrusion

Below are various desalination methods that could be suitable for the current situation at the Mrigadayavan Summer Palace. Factors that will influence the selection of the most useful desalination method for the Palace Foundation include: water characteristics and consumption, constraints of the geography of the Palace's grounds and surroundings, weather patterns, waste disposal methods, operation and maintenance abilities, financial constraints, and energy requirements. Diagrams of each method of desalination is available in Appendix I, and a comparison of energy consumption of some methods is available in Appendix J.

5.2.1- Multistage Flash Distillation (MSF)

Multistage Flash Distillation dominates the market for seawater and brackish water desalination. The average desalination cost is 31.73 baht/m^3, and capital cost is around 50.50 baht per installed liter per day which is more expensive than membrane desalination due to the need for both thermal and mechanical energy. MSF is not only expensive, it is also a thermodynamically efficient process (Banat, 2007). However, this desalination is simple to construct, easy to operate, and the quality of the effluent water will be fresh enough to use for the Palace's purposes (Thimmaraju et al., 2018).

5.2.2 - Multi Effect Distillation (MED)

MED is a more thermodynamically efficient process than MSF according to Panat (2007), as it is adopted from desalination techniques used in the chemical industry. Its desalination cost is 22 to 32 baht/m^3, but its capital cost per installed liter per day is 33.67 baht, on average.

5.2.3 - Vapor Compression (VC)

VC desalination systems have the lowest operating costs of all the thermal desalination methods assessed in this paper, and have the smallest sized equipment, as it does not need to have multiple stages. However, maintenance of these systems, namely the heat exchangers and compressors, are more costly than other methods. As seen in Appendix I, there are two types of VC systems, mechanical and thermal.

5.2.5- Reverse osmosis (RO)

In this desalination, osmotic pressure pushes water across a semipermeable membrane that is impermeable to salt, producing two zones of different concentrations to produce fresh water. Saline water is required to be pretreated first before going through the process to prolong membrane life. This process can be used for a range of flow rates, and tends to have a high water recovery rate. The cost for reverse osmosis is approximately 16.80 baht per cubic meter (baht/m^3) to 50.08 baht/m^3 for seawater and 3.49 baht/m^3 to 34.86 baht/m^3 for brackish water (Advisian, 2012). Construction is typically quick and inexpensive, and operation is simple.

In addition, RO does not consume as much energy as thermal desalination. RO is recommended for a moderate scale desalination plants as it does not require a large area for installation when compared to multistage flash distillation (Al-Mutaz, 1996).

5.2.4 - Electrodialysis (ED)

Electrodialysis is mainly used for desalination of brackish water in small to medium scale processes. Unlike the reverse osmosis method, ED is a much lower pressure system and the water quality is not affected by reducing energy (Westerling, 2015). The average desalination cost is 19 baht/m^3. However, the cost increases as the feed water concentration increases due to higher energy input and a more powerful membrane. Therefore, ED is recommended for deslaination of brackish water over saline water (Zhou, 2005).

5.2.6 - Solar Desalination

According to Alnaimat, Klausner, and Mathew (2018), solar desalination was invented centuries ago, and combination with technology has created an especially important system for rural or remote areas that are not connected to a grid or have limited infrastructure. Solar desalination systems can be used for small scale applications and function reliably as a source of potable water. Solar desalination can be combined with both thermal and membrane desalination to increase the efficiency of the desalination process. Costs of solar desalination are dependent on how much water is to be salinated by one square meter of the solar collector each day. Typically the solar collector accounts for anywhere between 20 and 40 percent of the capital cost of the system.

5.2.7 - Seawater Barrier

While a seawater barrier is not a method of direct desalination, it is a way to restore the aquifer. There are many instances of successful use of seawater barriers.

Groundwater Replenishment System. Using a Groundwater Replenishment System (GRW), like the one used in the 2008 Talbert Seawater Barrier expansion, would cost around 29 baht/m^3, converting from United States dollars and adjusting for inflation. The cost would include operation and maintenance and operation but excludes all other subsidies. To the project, the cost was equivalent to importing water, which gave it economic viability.

While effective, seawater barriers involve importing water from external sources in order to be injected into the aquifer. This may not be a viable solution in terms of sustainable development, as it is not a self-sufficient process. However, local water could be used if it was recycled and cleaned for use.

5.3 - Raise Awareness of Increased Groundwater Salinity in the Community

We determined that the community lacks awareness of the environmental changes around them from the interview responses. The World Education Blog discusses the impact of community education regarding environmental issues. When community members are educated on prevalent environmental issues in their area, as well as ways to mitigate their environmental impact, citizens are more likely to engage in sustainable practices in their everyday life.

We created a slideshow presentation and a brochure to inform the community on the environmental problems. The interviews we conducted lead us to believe that having a community meeting at the Palace or in another publicly accessible location would be an efficient way to spread information across many members of the community. The brochure was designed to cover similar material as the slideshow presentation. The full brochure can be seen in Appendix H in both English and Thai. The Mrigadayavan Palace Foundation will be able to distribute the brochures to whomever they believe will benefit from it. They could be used as supplemental material for meeting attendees to take home, or they could be given to the visitors and workers of the Palace. This will be helpful for anyone who was not able to attend the meeting. This increased awareness of the issue should encourage more citizens to engage in environmentally sustainable practices in an attempt to lower their individual environmental impacts.

5.4- Conclusion

In conclusion, we believe that the jetties bringing in seawater for the mangroves are causing the groundwater salinity to increase through seawater intrusion. We believe that either filling in or removing the jetties would be the quickest way for the Mrigadayavan Palace Foundation to stop the problem. Moreover, we believe that the installation of a boat dock and saline water pump would compensate for the benefits that the jetties currently provide. These may not be immediately necessary, and would likely only be needed in specific situations. However, if removing the jetties is not feasible, we suggest the implementation of a water barrier in order to manually simulate the area's past topography and control the inflow of water into the jetties. Finally, we recommend implementing a method of desalination for the water on the Palace grounds to expedite the environmental restoration process.

Annotated Bibliography

Advisian. (2012) “The Cost of Desalination - Advisian.” *Advisian.Com*. www.advisian.com/en/global-perspectives/the-cost-of-desalination#.

The website provides approximate cost for the desalination technology for both thermal and membrane desalination methods. This will assist us when suggesting recommendations to the palace as it can be used to support our points.

Alnaimat, F., Klausner, J., & Mathew, B. (2018). Solar Desalination, Desalination and Water Treatment, Murat Eyvaz and Ebubekir Yüksel, IntechOpen, DOI: 10.5772/intechopen.76981. Received from: https://www.intechopen.com/books/desalination-and-water-treatment/solar-desalination

This chapter provides information about solar desalination, as well as visual diagrams. The information is helpful to us when providing recommendations on desalination methods the Palace Foundation could employ. The information is from researchers and is a published paper.

Al-Mutaz, I. (1996) A Comparative Study of RO and MSF Desalination Plants, 99-106.

The report compares the two desalination technologies on capacity, economic and general advantages for each of them. This provides a better understanding of how one can be suitable for a specific occasion than others.

Banat, F. (2007). *Economic and Technical Assessment of Desalination Technologies*. Jordan University of Science and Technology, Jordan. Retrieved from https://desline.com/Geneva/Banat.pdf

This source offers descriptions and various statistics about different desalination methods. It provides both generalized and specific information about desalination technology that can be used in our recommendations of which desalination methods could be applicable to the Palace grounds. This source is a lecture from a professor. The professor has done work regarding the assessment and has significant education in the field.

Carreira, P. M., Marques, J. M., & Nunes, D. (2014). Source of groundwater salinity in coastline aquifers based on environmental isotopes (Portugal): Natural vs. human interference. A review and reinterpretation. *Applied Geochemistry* , 41, 163-175.

This paper gives insight into causes of increased levels of groundwater salinity. We can use this to determine potential causes of increased salinity at the Palace.

Classification and kinds of soil. (2014). Retrieved from http://www.ldd.go.th/ldd_en/en-US/classification-and-kinds-of-soil/

This is the website of the Land Development Department of Thailand. It lists every province/region of Thailand and describes the type of soil in the area. In addition, it lists the drainage, acidity, salt content, and fertility of the soil. This is helpful when comparing our soil samples to the greater area for analysis. It provides a base to compare our data to, allowing us to determine abnormalities.

Cotruvo, J. (2016). Desalination basics. Retrieved from https://www.watertechonline.com/process-water/article/15550278/desalination-basics

This website explains in depth about the two different methods used in desalination plants which are thermal processes and membrane processes. Thermal processes have three types; multiple flash distillation, multi-effect

distillation and vapour compression distillation. Thermal processes are much more energy intensive than membrane processes and their end product is less clean. By knowing the disadvantages and advantages of each method we will be able to give better recommendations.

Department of Water. (n.d.). Understanding Salinity. Retrieved from http://www.water.wa.gov.au/water-topics/water-quality/managing-water-quality/ understanding-salinity

This source has helpful background information regarding salinization of water. It begins by mentioning the three ways in which water becomes salinated, and later goes into further detail of how each type occurs. One part of the article that was particularly helpful was the table that defined the different salinity statuses, the range of salt, in milligrams per liter, and the impact that the salinity has on the surrounding environment. This article also defines the term "brackish" a word that had been previously assumed to just mean salinated, but now it is known that brackish water has between 1000 and 2000 milligrams of salt per liter.

Division of Groundwater Resources. (2015). Thailand groundwater situation report. (DGR Publication, no No.). Bangkok, Thailand: Ministry of Natural Resources and Environment. http://www.agriinfo.doae.go.th/year58/diaster/dgr_report.pdf (accessed Dec 22, 2019).

The report, written in Thai, discusses the conditions of the groundwater environment on what aquifers are covering them which are related to the amount of groundwater that can be produced. The information on tracking the groundwater level is also reported in this source. The number of the observation ponds stations and their locations are also stated clearly. This would benefit us to gain more information on the quality of the groundwater whether by beginning our sampling method over there or by asking for the existing information from these observation sites.

Ebeling, P., Händel, F., & Walther, M. (2019). Potential of mixed hydraulic barriers to remediate seawater intrusion. *Science of The Total Environment*, 693, 133478. doi: 10.1016/j.scitotenv.2019.07.284

This article looks at the feasibility of using a mixed hydraulic barrier for the remediation and prevention of salinated groundwater as compared to single positive or negative hydraulic barriers. This article explores and compares the effectiveness of each proposed barrier and determines that a mixed hydraulic barrier can be effective if implemented properly. This article will be very useful for us as a possible solution type to explore, and also as a starting point to further learn about hydraulic barriers and their classifications and functions. This article was recently published and from a peer reviewed journal making it a credible source.

[Electrodialysis desalination process]. (n.d.). Retrieved from https://www.researchgate.net/figure/Schematic-diagram-of-electrodialysis-Desalination-process-14_fig3_31807389

This paper provides a visual description of the desalination method called electrodialysis. It comes from a scholarly paper and is used in the Appendix to describe the process of electrodialysis desalination, a type of membrane desalination.

Francis, R., & Phillips, L. (2003). Cost effective materials selection for pumps

This article discusses what to consider when installing a pump. It goes into details over the materials types, cost, and time expectancy of them. This is quite important to the paper as we are recommending a seawater pump to our sponsor for the mangrove forest.

Hebert, A., Hasenfeld, E., Nugai, K., & Gulezian, S. (2017). Assessing Factors Contributing to Water Scarcity, Impurity, and Coastline Erosion at the Mrigadayavan Palace. Retrieved from https://digitalcommons.wpi.edu/iqp-all/457

This Interactive Qualifying Project was completed two years ago with the same sponsor our team will be working with. This project will be a very good place for us to start as it can give us information pertaining to the area and the Palace specifically. This project also began looking at the general water quality and availability and will help us understand the current state of the Palace and the groundwater. It is also very helpful to see how this previous group took advantage of being able to get input opinions from the community on the project to see how the issue harmed or benefited them.

Herndon, R. & Markus, M. (2008). *Large‐Scale Aquifer Replenishment and Seawater Intrusion Control Using Recycled Water in Southern California* (California, United States of America, Orange County Water District). Retrieved from https://www.ocwd.com/media/1857/large-scale-aquifer-replenishment-and-Seawater-intrusion-control-using-recycled-water-in-southern-california.pdf

This paper describes certain technology used in seawater barriers that was found to be very successful in California. If the Palace decides to argue that a larger scale desalination method should be used, this could be helpful information in regard to the cost and effectiveness of this newer method. It is a documentation of technology used in Orange County, California. The paper was published by the Orange County Water Authorities.

Kress, N. (2019). Desalination Technologies. *Marine Impacts of Seawater Desalination*, 11–34. doi:10.1016/b978-0-12-811953-2.00002-5

This paper gives an overview of many different desalination technologies that are both used and emerging. It also offers thorough summaries and descriptions of desalination in general. This would be a good place for the entire group to start when it comes to brainstorming and identifying solutions and management plans.

[Mechanical and thermal vapor compression systems]. (n.d.). Retrieved from https://www.sciencedirect.com/science/article/pii/B9780128133064000136

This paper offers images of mechanical and thermal vapor compression systems. The images are used in the Appendix to offer a visual description of each process. The source is a scholarly paper.

Meltaylor. (2013). "Pros and Cons of Beach Jetties." *BrigantineNOW*. Retrieved from brigantinenow.com/pros-and-cons-of-beach-jetties

This website discusses the advantages and disadvantages of installing jetties near beaches. One of the biggest disadvantages to installing jetties near beaches is that beach erosion occurs much faster due to sand displacement.

Mrigadayavan Palace. (n.d.). Retrieved from http://www.mrigadayavan.or.th/landing/english/eng_home.html

This site holds a variety of important information for our project as it is the website of our sponsor. This site outlines the history of the palace as well as the restoration efforts. It has descriptions of the different aspects of the palace they are restoring and conserving. In addition, it contains information on visiting the palace, the foundation, the conservation and history of the Palace, and how to engage in and support the conservation efforts. The historical and conservation information includes topics in architecture, art and culture, archeology, and the environment. This is important information for our group to familiarize ourselves with so that we have a good understanding of the current state of the palace and surrounding area as well as the steps taken to get it to this state.

Podmore, C. (2009). Urban salinity-causes and impacts. Retrieved from https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/309316/Urban-salinity-causes-and-impacts.pdf

This study extensively talks about the damages that are done to local infrastructure by salty water. Surprisingly, salt water has the ability to destroy roads, bridges, sewage pipes and household appliances by forming cracks in them. We can use this knowledge when explaining about the effects that salty water has on the local community's infrastructure.

Primary Industries, (2000). Salinity Notes. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/168882/water-salinity.pdf

This publication gives information on how to test water salinity. It compares water test meters and gives step by step instructions on how to carry out sampling and testing the water. This could be useful if we are required to complete water salinity testing ourselves around the site. This would be useful information for our group to know so we are informed about how sampling is being done at the project site.

Sae-Ju, J., Chotpantarat, S. & Thitimakorn, T. (2018). Assessment of seawater intrusion using multivariate statistical, hydrochemical and geophysical techniques in coastal aquifer, Cha-am district, Thailand. Hydrology and Earth System Sciences Discussions. 1-50. 10.5194/hess-2018-137

This article discusses the possible impact of seawater intrusion on the groundwater aquifers in Cha am, Thailand. The article covers several specific aquifers and classifies the level of seawater intrusion for each one. This is relevant to our project because it could be a possible cause of the increased groundwater salinity. This article is recent, having been published in 2018, and is from a scientific journal which is a credible source.

Seawater Barrier (n.d.). *Public Works*, Los Angeles County Department of Public Works, https://dpw.lacounty.gov/wrd/barriers/

This site discusses the seawater barrier projects implemented in Los Angeles to combat seawater intrusion. It is a LA County government website.

Seawater Barriers (n.d.). *West Basin*, West Basin Municipal Water District, https://www.westbasin.org/water-supplies-groundwater/seawater-barriers

This site discusses the seawater barrier projects implemented in Los Angeles to combat seawater intrusion. It is an organization that works with the government to manage two of the barriers and purchase the imported water to inject into the barriers.

Shoreline Structures. (2015). Retrieved from http://www.beachapedia.org/Shoreline_Structures

This page defines shoeline structures, as well as describing their benefits and downfalls. This information is helpful when describing the structures on the Cha Am coast. In addition, the pros and cons of each structure can be evaluated in our analysis. The website is written by the Surfrider Foundation, an organization dedicated to the protection of beaches and coastal areas.

Sirikulchayanont, P. (2003). *The interpretation programme for the Mrigadayavan Summer Palace* (Master's thesis, Silpakorn University, Bangkok,Thailand). http://www.thapra.lib.su.ac.th/thesis/showthesis_th.asp?id=0000006117

This programme is meant to be a study to better educate visitors and the international community about the Mrigadayavan Summer Palace, our site. We have limited information beyond what is on our sponsor's website about the Palace. This provides interviews of visitors and data regarding tourism. It also includes more history about King Rama VI. The tourism information is vital to understanding how much upkeep on the palace is required due to wear and tear from tourism. It could also provide information about the original plants that populated the grounds of the Palace, as we assume restoring fresh groundwater is a step towards restoring the original environment around the palace.

Sirindhorn Park (2012). *Coastal erosion protection*[online] http://sirindhornpark.or.th/2019/learning.php?id=315

The website discusses the coastal structures that are currently in place to prevent coastal erosion along the Mrigadayavan Palace. There are numbers and roles of each structure stated clearly on the website. The information provided would allow the team to identify any possible impact if some coastal structures were to be removed in the future as a part of the project' solution.

Svasti, P. (2016). A Palace to Remember, *Bangkok Post*. https://www.bangkokpost.com/print/1120185/

This article gives more insight into the importance of the Palace to the Thai people. While most articles focus on the tourism surrounding the Palace, this one talks of the learning that takes place at the Palace. Along with this, the article talks about the setup of the Palace. This includes the sleeping quarters, where the learning centers are, and some of the reasoning behind the architecture.

Thimmaraju, M., Sreepada, D., Babu, G.S., Dasari, B.K., Velpula, S.K. and Vallepu, N. (2018). Desalination of Water. *Desalination and Water Treatment*. https://www.intechopen.com/books/desalination-and-water-treatment/desalination-of-water

The source discusses different types of desalination processes that have been used extensively worldwide. The advantages and disadvantages are state clearly for each method. The information helps us understand more about what desalination methods will be suitable for the palace situation.

Vineyard activities guide, measuring soil salinity. (2010). Retrieved from https://www.awri.com.au/wp-content/uploads/v_activity_soil_measure.pdf, page 1-2

This book is about determining soil salinity. It mainly talks about sampling methods and what we can expect from the results of our samples. We are going to use the sampling methods mentioned in this book to do our soil measurements.

Wang, B. (n.d.). [Solar desalination]. Retrieved from https://www.nextbigfuture.com/2018/08/nanoparticles-can-triple-the-rate-Of-evaporation-for-solar-desalination.html

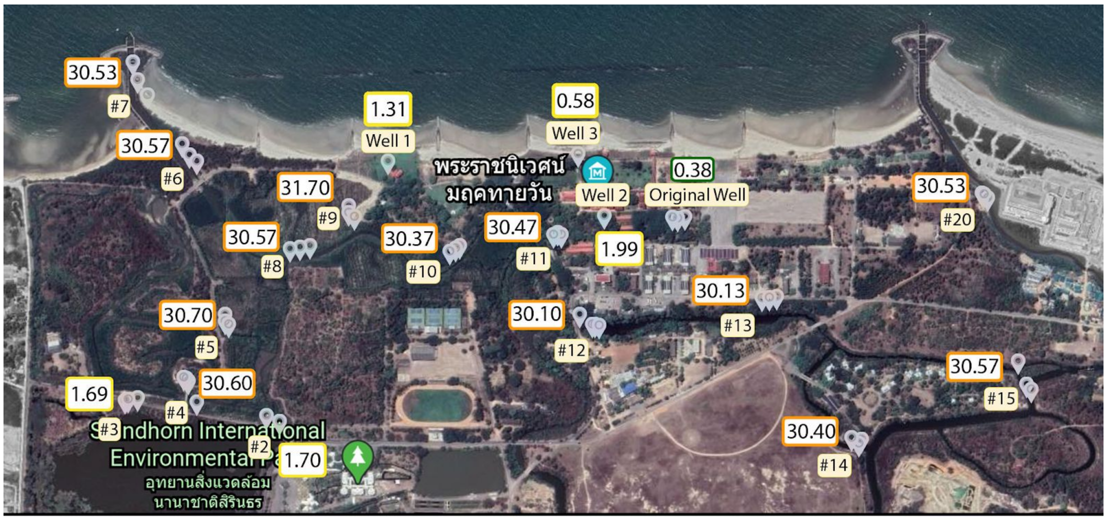
This image of the solar desalination process is helpful in depicting the process in the Appendix. It comes from a scholarly review of newer solar desalination technology, but is still a simple image that describes the general process.

Xiao, H. Y. (2018). "Water Issues in California." *Kleinman Center for Energy Policy*, University of Pennsylvania. https://kleinmanenergy.upenn.edu/policy-digests/Water-issues-california

This page discusses the water issues in California that help add context to why the state has issues with groundwater salinity and drought. It gives good information to use in the examples of solutions section of the background.

Appendix A: Initial Charts and Diagram

These charts show the data we received from our meeting with our sponsor.



Groundwater Salinity at the Mrigadayavan Palace

Taken by the Mrigadayavan Palace Foundation on December 28, 2019

Map Key
- Sampling Location
- Site Number
- Salinity Measurement

Salinity Gradient Key (in ppt)

0 0.5 Fresh — Brackish — 30 Saline — 50+ Briny

Goundwater Salinity Gradient at the Mrigadayavan Palace

Taken by the Mrigadayavan Palace Foundation on December 28, 2019

Map Key
- Sampling Location
- Site Number

Black and white areas were not assessed

Salinity Gradient Key (in ppt)

0 0.5 Fresh — Brackish — 30 Saline — 50+ Briny

Appendix B: Community Interview Questions

The answers from community members to the following questions will give the team a better understanding of how they have seen the community change, specifically their water. This data will narrow down the possible causes of brackish groundwater.

Interview Questions for Community:

1. Occupation?
2. How long have you lived in this region?
3. How has the population changed since you started living here?
4. How has the economy changed since you started living here?
5. Where do you get your drinking and tap water from?
6. Have you noticed any change in the groundwater that has affected you?
7. Have any changes occurred that have affected the groundwater?
8. Do you know what salinity is?
9. Do you know that there is an increase in groundwater salinity in this area?
10. What do you believe is causing the increase in the salinity of the groundwater?
11. How have the jetties impacted the community?
12. How have the jetties impacted the economy?
13. How has the mangrove forest impacted the community?
14. How has the mangrove forest impacted the economy?

15. How often do you go to the beach?

16. How have the beaches changed since you've lived here?

17. How has the vegetation changed since you've lived here?

18. What is the source of your local information?

19. What kind of community events does the community have/do you attend them?

20. Do you know of any upcoming changes to the local infrastructure?/What are your opinions on them?

Appendix C: Sirindhorn Environmental Park Questions

Interview questions for the Sirindhorn Environmental Park:

1. What is their water source?
2. What is your care schedule for them?
3. What type of root structure do they have?
    a. Do they help prevent erosion?
4. Do mangroves produce any food source?
5. Does the forest attract visitors?
6. What type of animals do mangroves attract?
    a. Are there any animals who use the mangroves as their habitat?
    b. Do mangroves have any relationships with any particular animals (like a symbiotic relationship)?
7. What type of soil condition do mangroves need?
    a. Do mangrove forests provide any environmental benefits (soil filtration, increased oxygen production, etc.)?
8. Do mangrove have any historical/spiritual significance?
    a. Does this forest have any local meaning?
9. What was the purpose of planting the mangrove forest?
10. How are mangrove forests planted?
    a. Did this follow the same procedure?
11. Why did you decide to plant a mangrove forest in this particular location?
    a. Is it an ideal location for the plants?
    b. How is the forest doing?
12. Has there been an impact as a result of the mangrove forest?
    a. Societal?
    b. Economic?
    c. Environmental?

Appendix D: Informed Consent Form

Informed Consent Form

Study title	Restoring Groundwater Salinity at the Mrigadayavan Summer Palace
Researchers	Natalie Cohn, Nicole Cotto, Megan Seely, and Margaret Raque Worcester Polytechnic Institute (WPI), Worcester, Massachusetts, USA Pichayapa Vjirsangpyroj, Penpicha Janprasert, Radmehr Mohammadali, and Chisanupong Kunmas Chulalongkorn University (CU), Bangkok, Thailand

We're inviting you to participate in a research study. Participation in interviews are completely voluntary. All answers will remain anonymous and no identifying information will appear in any reports or publications.

Overview

Purpose: Interviews are being conducted in order to gather information regarding human and environmental activity in the area. This information will be used to determine the human impacts on the salinity of groundwater in the area. We believe that this information will be crucial in creating long term treatment plans for the area.

Procedures: Participants will be asked questions by the researchers. Questions include, but are not limited to, occupation, observation of human activity in the area, vegetation in the area

Time Commitment: Interviews will take no more than 1 hour.

Primary risks: Breach of Confidentiality

Benefits: The results of the data may help the Palace increase tourism, boosting the local economy, and may improve local environment

What is the purpose of this study?

We want to understand how human activity affects the amount of salt in the groundwater in the Cha Am area. We also want to gain knowledge about community awareness of the groundwater's salinity levels and any significant weather events that have happened in the past decade.

What will I do?

In our interview you will be asked questions about your profession and your experience working/living in the area. In addition, you will be asked questions about the environment and any observations you have of water quality.

Risks

Possible risks	How we're minimizing these risks
Breach of confidentiality (your data being seen by someone who shouldn't have access to it)	● Data is anonymous. ● We'll remove all names before being published. ● We'll store all electronic data on a password-protected computer. ● We'll discard all paper data.

There may be risks we don't know about yet. Throughout the study, we'll tell you if we learn anything that might affect your decision to participate.

Other Study Information

Possible benefits	● Participants can be updated on study findings regarding the salinity level of the groundwater in their area and at the Mrigadayavan Summer Palace, if desired. ● The report given to the Palace may increase tourism in the area and add to the economy.
Estimated number of participants	20 Cha Am community members and 5 Sirindhorn Environmental Park.
How long will it take?	Each interview will take no more than 1 hour.
Costs	The participant will be subjected to no costs.
Compensation	There is no compensation provided for the interview.
Future research	Your data won't be used or shared for any future research studies.
Recordings / Photographs	We will record you. The recordings will be used to help researchers analyze and remember specific answers to interview questions. The recording is optional.

Confidentiality and Data Security

We will not collect any personal information. Responses will be kept anonymous and not identifying information will be published or publicized.

Where will data be stored?	Data will be kept on the researcher's computers and in WPI databases.
How long will it be kept?	Physical data will be discarded once digitized. Digital data will be kept in storage for a few years.

Who can see my data?	Why?	Type of data

The researchers	To conduct the study and analyze the data	Responses to interview questions.
The IRB (Institutional Review Board) at UWM The Office for Human Research Protections (OHRP) or other federal agencies	To ensure we're following laws and ethical guidelines	Responses to interview questions.
Anyone (public)	We are presenting our findings in publications or presentations to WPI and Chulalongkorn students and staff. Plus, publications will be accessible through university resources.	Findings of the study, possibly including answers to interview questions. No identifying information will be publicized.

Contact information:

For questions about the research	Natalie Cohn, Nicole Cotto, Megan Seely, Margret Raque, Pichayapa Vjirsangpyroj, Penpicha Janprasert, Radmehr Mohammadali, and Chisanupong Kunmas	gr-BKKC20-salinity@wpi.edu Or bsacchaam2020@gmail.com
For questions about your rights as a research participant	IRB (Institutional Review Board; provides ethics oversight)	414-229-3173 / irbinfo@uwm.edu
For complaints or problems	Natalie Cohn, Nicole Cotto, Megan Seely, Margret Raque, Pichayapa Vjirsangpyroj, Penpicha Janprasert, Radmehr Mohammadali, and Chisanupong Kunmas	gr-BKKC20-salinity@wpi.edu Or bsacchaam2020@gmail.com

Signatures

If you have had all your questions answered and would like to participate in this study, sign on the lines below. Remember, your participation is completely voluntary, and you're free to withdraw from the study at any time.

____.

Name of Participant (print)

____. __________.
Signature of Participant Date

If participant is a minor or requires a Legally Authorized Representative:

____.
Name of Parent, Guardian or Legally Authorized Representative (print)

____. __________.
Signature of Parent, Guardian or Legally Authorized Representative Date

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____.
Name of Researcher obtaining consent (print)

____. __________.
Signature of Researcher obtaining consent Date

Appendix E: The YSI Salinometer

Information regarding usage of YSI salinometer:

1. This device only measures between 0 to 50.0 parts per thousand
2. To turn on the device, press on the sunlight button for around 7 seconds
3. The cord should always be connected to the handheld device during measurement
4. During measurement, the whole head of the cord should be fully immersed in water otherwise measurements will not be accurate
5. While the head of the cord is fully immersed in water, it is recommended for the user to move the head of the chord a bit for more accurate results
6. Stabilization of salinity measurements require fifteen seconds
7. The temperature of the water (Celsius) and the salinity of the water (in parts per thousand) will come up on the device
8. After you're done using the device, wash the head of the chord with freshwater until the readings go back to 0.0

9. To turn off, press on the sunlight button for more than 7 seconds

Anatomy of YSI salinometer:

1. Handheld device
2. 10 metre Chord
3. Cylindrical head of the chord (most critical part of this device)

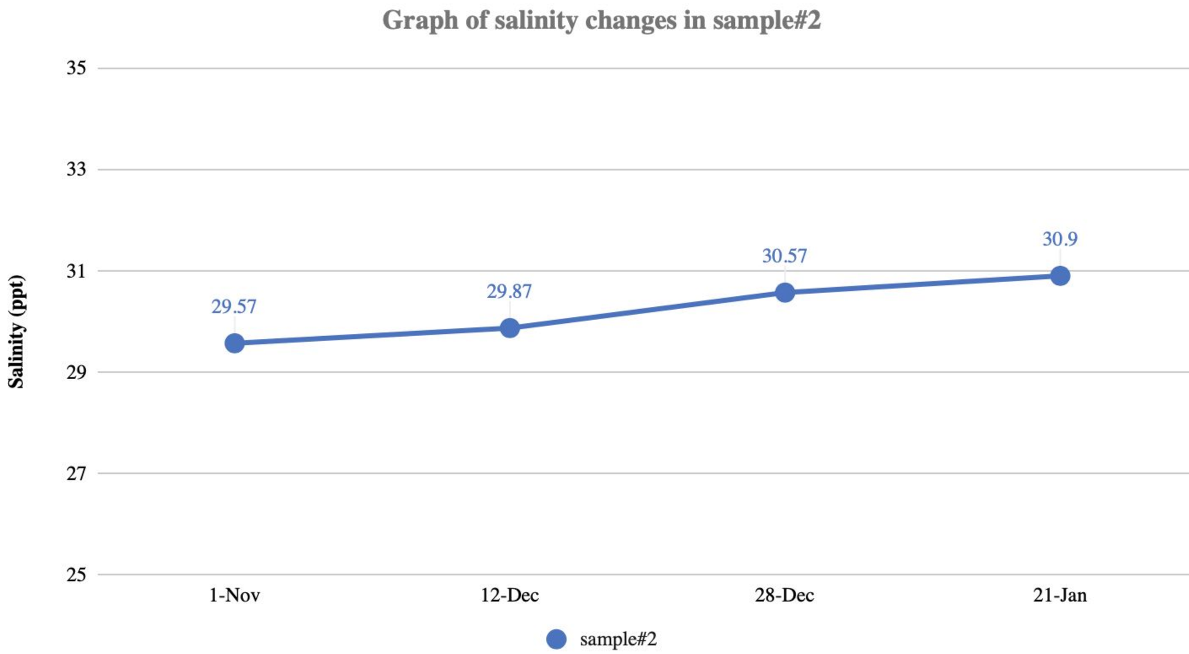
Safety information regarding YSI salinometer:

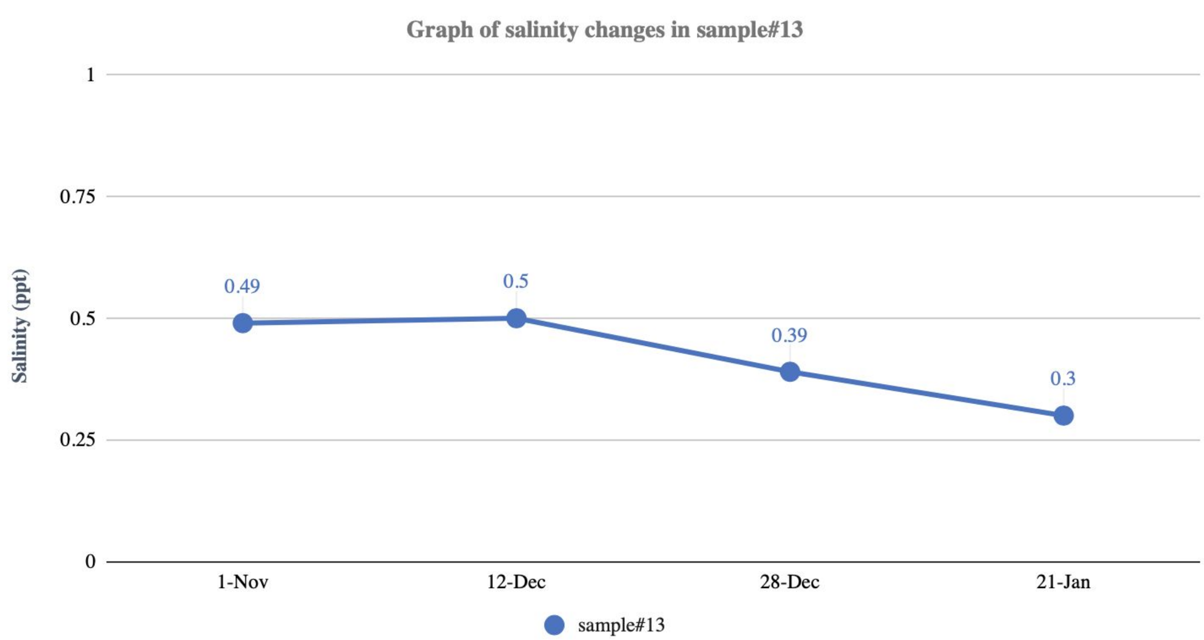
1. Do not expose this device to temperatures exceeding 50 degrees celsius
2. The handheld device on its own is not waterproof, the plastic covering it makes it waterproof, therefore it is recommended to not take off the plastic
3. Before using, remember to tightly fix the chord, handheld device and cylindrical head of the chord to each other
4. If you drop the handheld device in water, please retrieve it back with thick gloves on due to the probability of getting electrocuted

Appendix F: Timeline

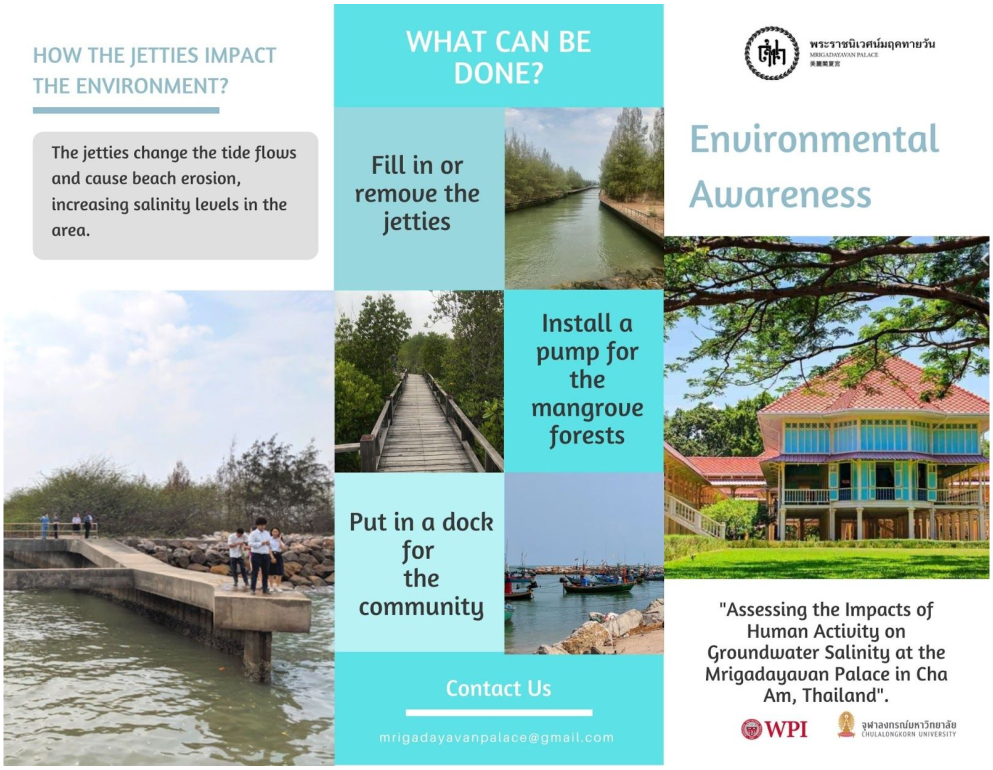
Week	Activities
Jan. 13-17	First meeting with Sponsor, finalize interview questions, complete methodology first draft, project timeline, and table of contents
Jan. 20-24	First visit to the Palace, complete literature review first draft
Jan. 27-31	Processing interview answers and salinity data, research literature on other infrastructure interference with salinity, complete methodology second draft and introduction first draft
Feb. 3-7	Research possible recommendations based off the results, complete results and analysis outline first draft
Feb. 10-14	Find ways to inform the community, complete final report first draft
Feb. 17-21	Work on final recommendations, presentation, and report
Feb. 24-28	Finalize and practice final presentation
March 2-4	Finalize final report

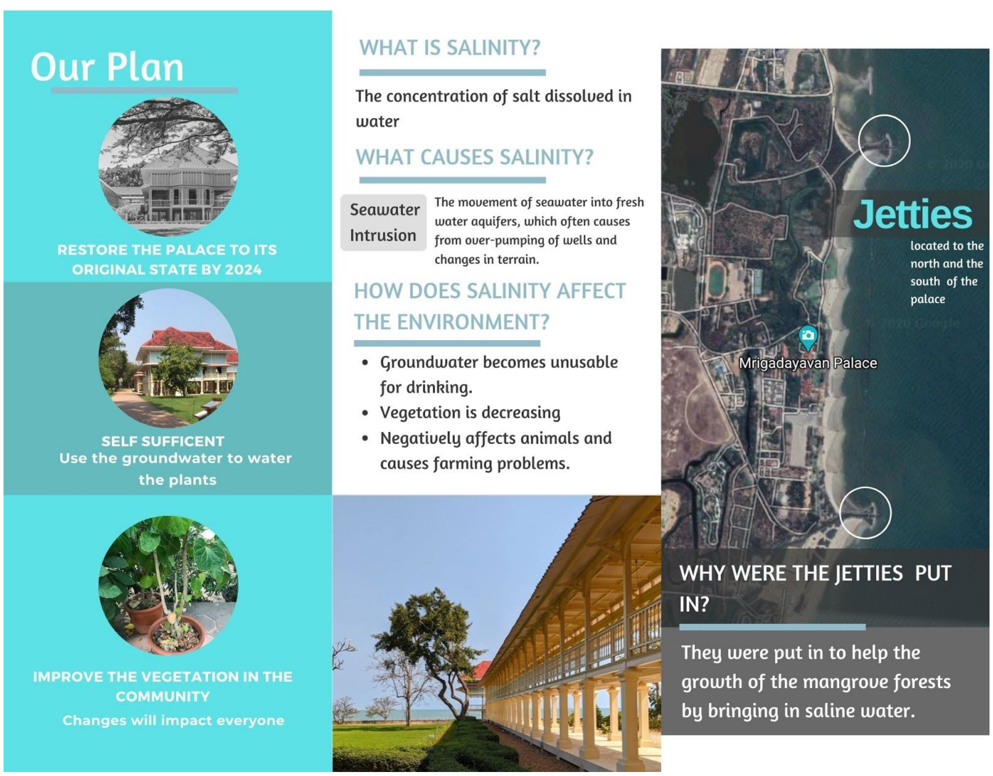
Appendix G: Graphs of salinity changes





Appendix H: Community Awareness Brochure





ผลกระทบจากการสร้างเขื่อนป้องกันทรายและคลื่นปากร่องน้ำต่อสิ่งแวดล้อม

- คลื่นทะเลแปรปรวน
- การพังทลายของชายหาดเพิ่มขึ้น
- ค่าความเค็มในพื้นที่ใกล้เคียงเพิ่มขึ้น

สิ่งที่เราสามารถทำได้?

นำเขื่อนป้องกันทรายและคลื่นปากร่องน้ำออกหรือถมปิดการใช้งาน

สร้างปั๊มเพื่อป่าชายเลน

สร้างที่จอดเรือในชุมชน

ติดต่อเรา

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พระราชนิเวศน์มฤคทายวัน
MRIGADAYAVAN PALACE

ความตระหนักด้านสิ่งแวดล้อม

"การประเมินผลกระทบจากกิจกรรมของมนุษย์ที่ส่งผลต่อการเพิ่มขึ้นของค่าความเค็มในน้ำบาดาล ณ พระราชนิเวศน์มฤคทายวัน"

WPI จุฬาลงกรณ์มหาวิทยาลัย CHULALONGKORN UNIVERSITY

แผนงาน

ดำเนินการทำให้วังกลับสู่สภาพเดิมภายในปี พ.ศ.2567

เศรษฐกิจพอเพียง นำน้ำบาดาลมาใช้ เพื่องานสวน

ปรับปรุงการทำการเกษตรในชุมชน การเปลี่ยนแปลงนี้จะส่งผลดีต่อทุกคนในชุมชน

ค่าความเค็มในน้ำคืออะไร?

ค่าปริมาณความเข้มข้นของเกลือที่ละลายในน้ำโดยเฉพาะ โซเดียมคลอไรด์

อะไรที่ส่งผลให้ค่าความเค็มในน้ำเพิ่มขึ้น?

การแทรกซึมของน้ำทะเล คือ การเคลื่อนที่ของน้ำทะเล ซึ่งส่วนมากเกิดจากการสูบน้ำจากบ่อน้ำมากเกินไปและการเปลี่ยนแปลงของพื้นดิน

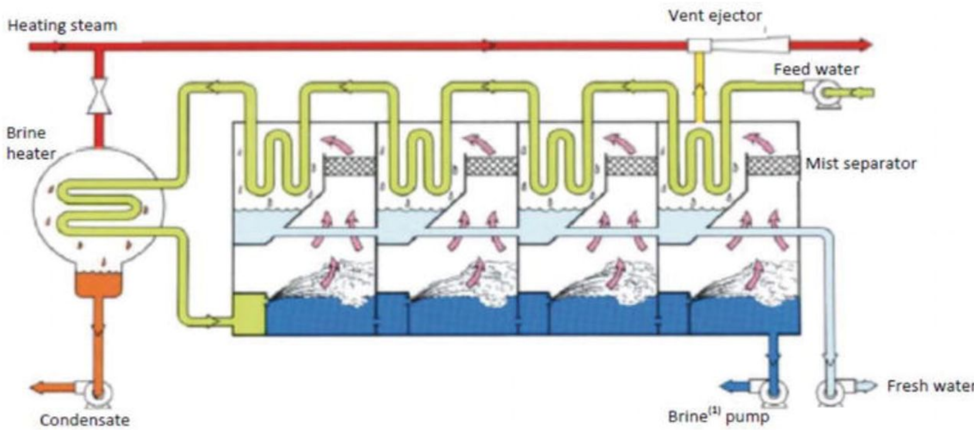
ความเค็มของเกลือในน้ำมีผลกระทบอย่างไรต่อสิ่งแวดล้อม?

- ไม่สามารถนำน้ำบาดาลมาใช้เพื่อการบริโภค
- การนำน้ำมาใช้เพื่องานสวนมีปริมาณลดลงอย่างเห็นได้ชัด มากไปกว่านั้นยังส่งผลต่อสัตว์และการทำการเกษตรในพื้นที่ใกล้เคียง

จุดประสงค์ของการสร้างเขื่อนกันทรายและคลื่นปากร่องน้ำ

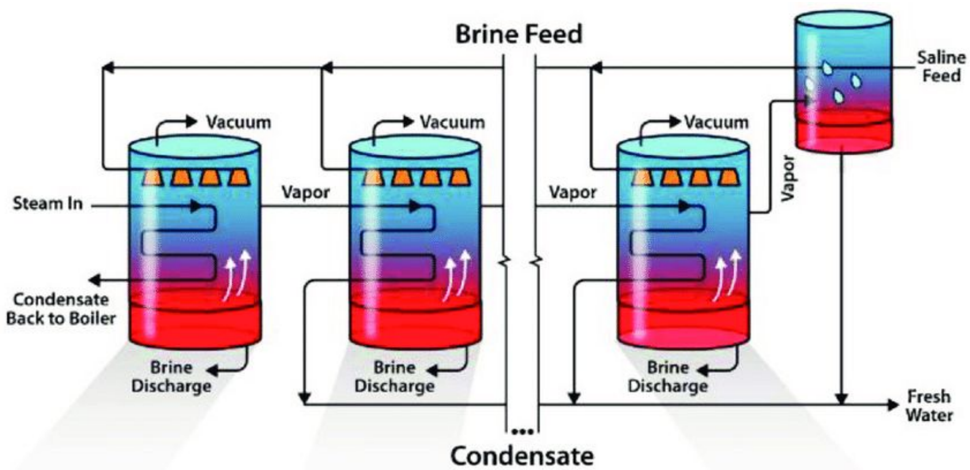
เพื่อนำน้ำเค็มจากทะเลมาช่วยในการเจริญเติบโตของป่าชายเลน

Appendix I: Desalination Methods

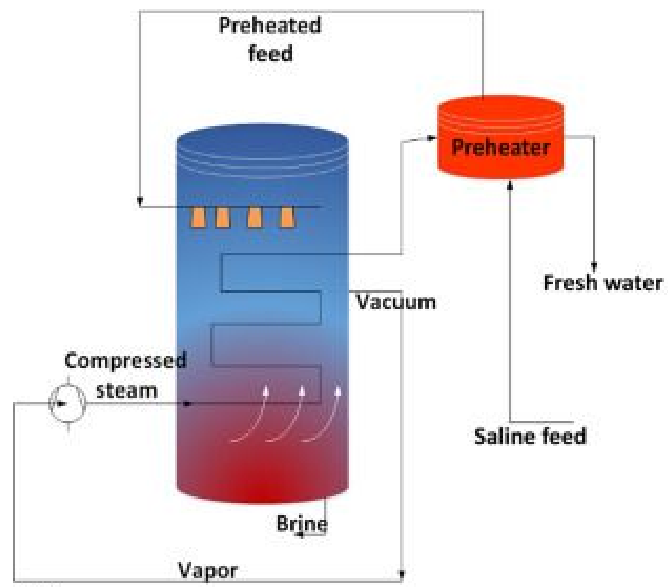


Multi-stage Flash Distillation

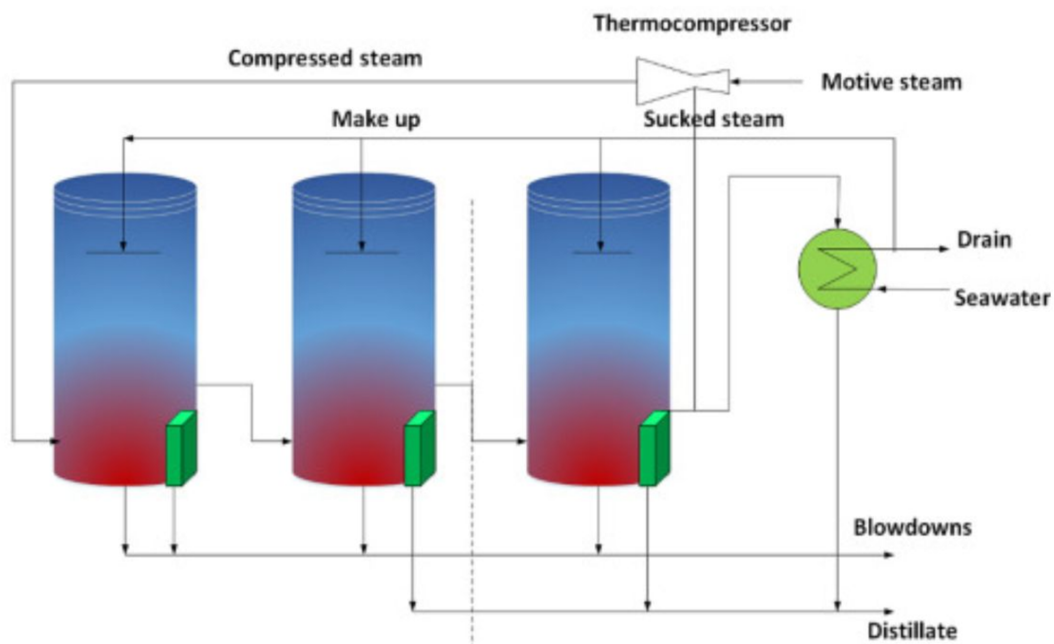
Source: Desalination of Water



Multi Effect Desalination
Source: Distillation-Innovative Applications and Modeling



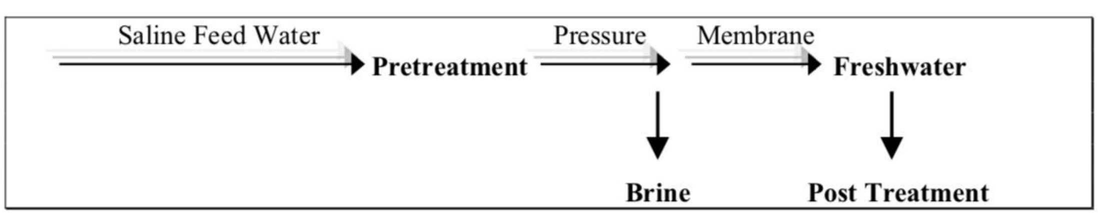
A



B

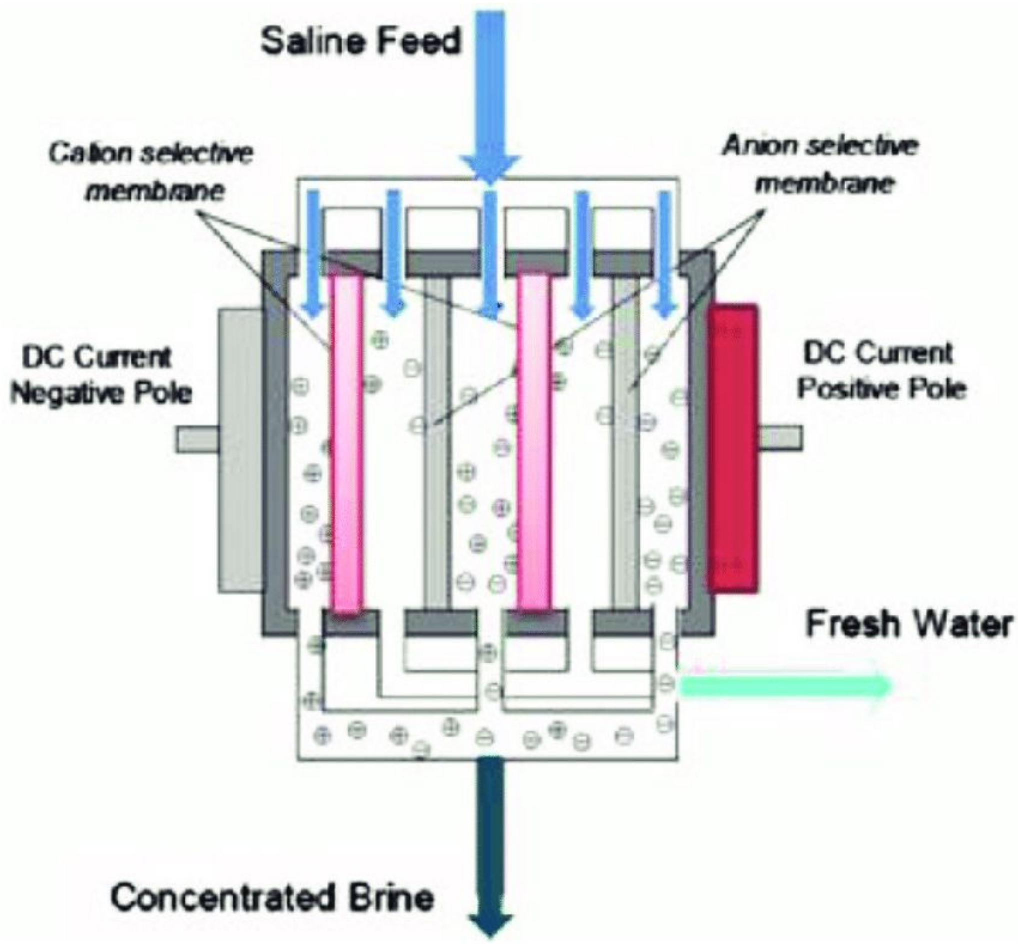
(A) Mechanical and (B) Thermal Vapor Compression System

Source: Polygeneration with Polystorage for Chemical and Energy Hubs



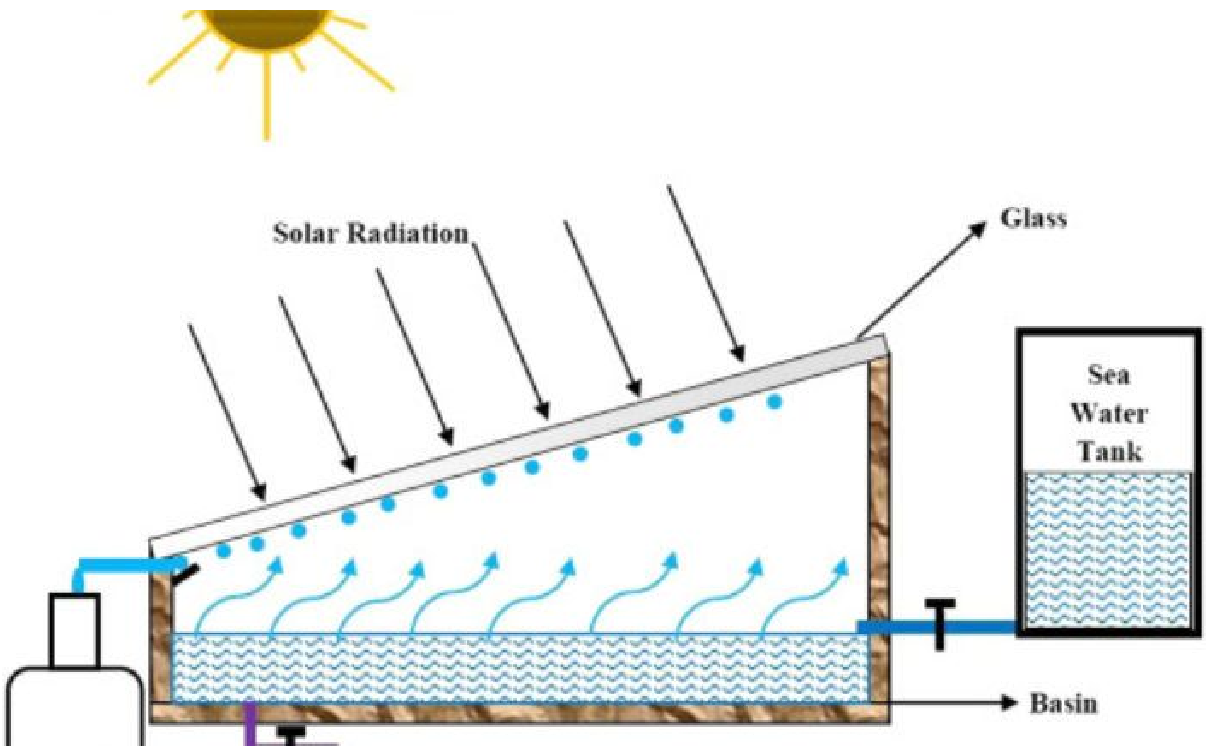
Reverse Osmosis System

Source: Desalination Guidelines Development for Drinking Water



Electrodialysis Desalination Process

Source: Electrodialysis desalination process



Solar Desalination

Source: B. Wang

Appendix J:Energy Consumption of Some Desalination Methods

Energy consumption of seawater desalination methods.[30]

Desalination Method >>	Multi-stage Flash MSF	Multi-Effect Distillation MED	Mechanical Vapor Compression MVC	Reverse Osmosis RO
Electrical energy (kWh/m^3)	4–6	1.5–2.5	7–12	3–5.5
Thermal energy (kWh/m^3)	50–110	60–110	None	None
Electrical equivalent of thermal energy (kWh/m^3)	9.5–19.5	5–8.5	None	None
Total equivalent electrical energy (kWh/m^3)	13.5–25.5	6.5–11	7–12	3–5.5

Image is rotated for optimal viewing.