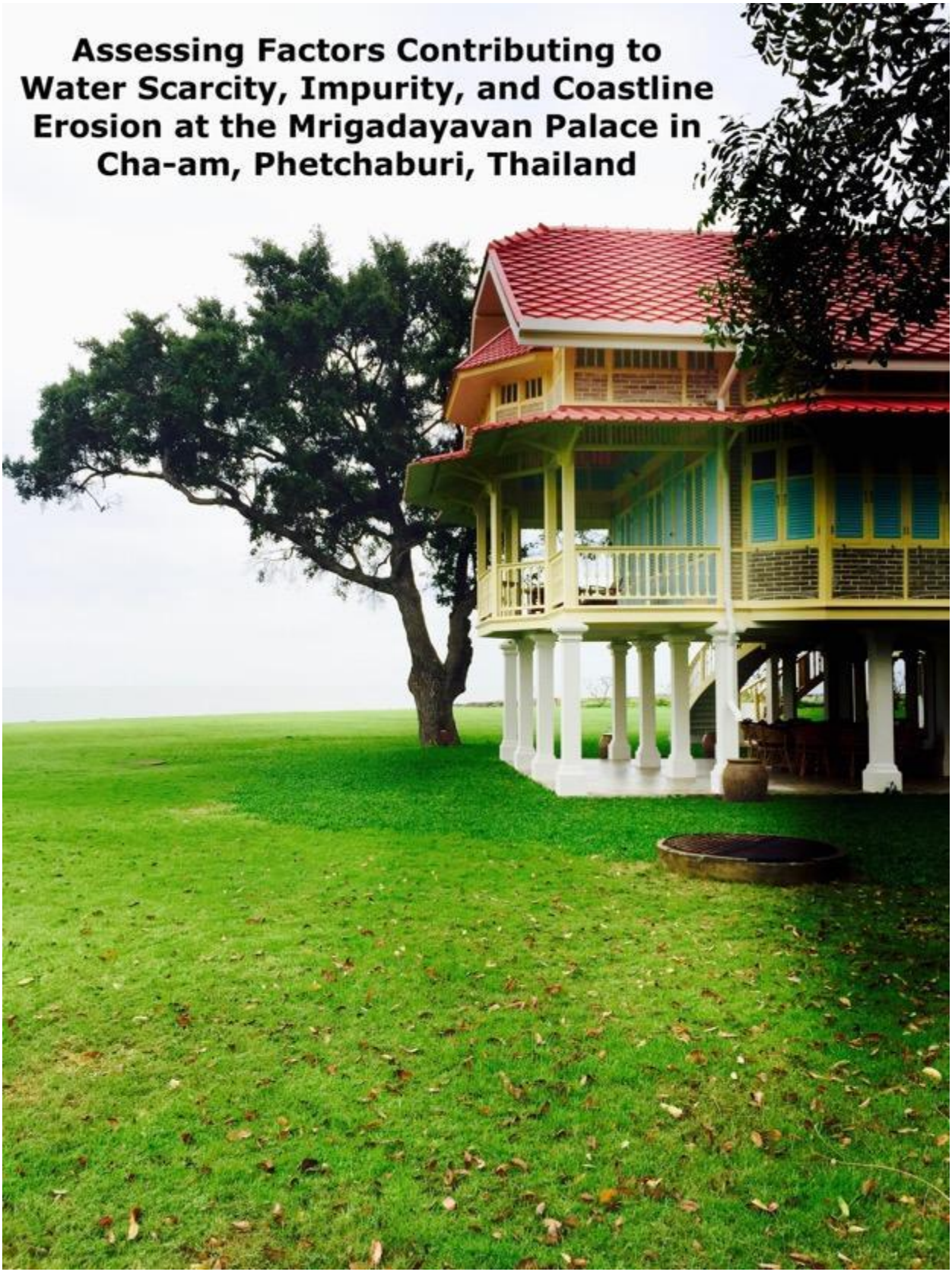
Assessing Factors Contributing to Water Scarcity, Impurity, and Coastline Erosion at the Mrigadayavan Palace in Cha-am, Phetchaburi, Thailand



Assessing Factors Contributing to Water Scarcity, Impurity, and Coastline Erosion at the Mrigadayavan Palace in Cha-am, Phetchaburi, Thailand

An Interactive Qualifying Project submitted to the faculties of Worcester Polytechnic Institute and Chulalongkorn University in partial fulfillment of the requirements for the Degree of Bachelor of Science in cooperation with The Foundation of the Mrigadayavan Palace.

Submitted on: March 2, 2017

Submitted by:
Monnaya Chalermnon, CU
Vorakit Chudatemiya, CU
Stephanie Gulezian, WPI
Evan Hasenfeld, WPI
Alison Hebert, WPI
Spun Kamarattana, CU
Katherine Nugai, WPI

Submitted to:
Prof. Melissa Belz, WPI
Dr. Daniel DiMassa, WPI
Dr. Parichatr Vanalabhpatana, CU

Project Website:
https://sites.google.com/site/bkk17palace/home

Acknowledgements

Project Advisors

Prof. Melissa Belz, Worcester Polytechnic Institute
Dr. Daniel DiMassa, Worcester Polytechnic Institute
Dr. Parichatr Vanalabhpatana, Chulalongkorn University

The Foundation of Mrigadayavan Palace Foundation

Khun Klaomard Yipintsoi, Director of the Office of Mrigadayavan Palace

Foundation Staff

Mrs. Nichapa Tikachok
Mr. Worameth Sriwanalak

Department of Landscape Architecture, Faculty of Architecture, Chulalongkorn University

Dr. Danai Thaitakoo

Border Patrol Police

Pol. Sub. Lt. Somjade Iamsopon

Interviewees

Mr. Somjai Noisaard, Huai Sai Nuer Community Chief
Mr. Charoen Chaisri, Chief Engineer of Novotel Hua Hin Resort and Spa
Ms. Metha Yenjit, Resident in Sam-Phraya area of Cha-am district
Mr. Sittipong Pratheung, Buffy's Belly Bar and Bistro Supervisor
Mrs. Aumporn Chanpetch, Villager
Ms. Gumrai Yodtanan, Palace Gardener
Ms. Saman Boonsong, Resident in Sam-Phraya area of Cha-am district
Mr. Nopporn, Springfield Golf Course

Abstract

Freshwater sources were abundant in the Mrigadayavan Palace area until industrial and coastal developments influenced the quality of water in the Palace. In order to investigate the factors affecting water quality and quantity, we analyzed the availability of water and impurities and the factors impacting the water sources, and we sought out public opinion on man-made structures. Our team produced an informational video and sign about the effects of the man-made structures. We concluded that the area's water became brackish due to two jetties allowing seawater to flow further inland through the canals to nourish artificial mangrove forests.

Executive Summary

Background

King Rama VI lived in the historical Mrigadayavan Palace, located on the coastline of the Cha-am district, during the summer seasons of 1924 and 1925. After the King passed away in 1925, the Palace was in disrepair until 1965. The Mrigadayavan Palace, Border Patrol Police, and the Sirindhorn International Environmental Park now reside in the King Rama VI Military Camp. Founded in 1992, the Foundation of Mrigadayavan Palace works toward restoring the Palace to its original landscape and horticulture and serves as an example of environmental sustainability for the Camp and district. The Foundation continuously struggles in this endeavor due to natural disasters such as monsoons and storms, as well as the construction of coastal protection structures.

To protect the shoreline and the Palace, the Marine Department helped the Foundation of Mrigadayavan Palace construct man-made coastal structures such as jetties, groynes, breakwaters, and a seawall. Groynes are located perpendicular to the shoreline and trap sand on their sides. Breakwaters are structures parallel to the shoreline and reduce the impact of large waves on the shoreline, and the seawall protects the Palace by keeping the land closest to the beach from eroding. Jetties allow seawater to flow inland to water the mangrove forests that the Sirindhorn International Environmental Park implemented within the Camp in 1994. This caused seawater to mix with freshwater sources, causing water in the canals to become brackish. Therefore, the Palace currently uses water from Ta Sa-ded reservoir, which is a freshwater reservoir located inside the Camp, for their plants.

Figure 1: Map of coastline of the Mrigadayavan Palace and the surrounding area

Our Goal & Objectives

The goal of our project was to maintain the environmental and historical legacy of the Mrigadayavan Palace by investigating the factors affecting the water quality and quantity.

Our objectives for this project were as follows:

1. Analyze the water quality and quantity within the Palace area.
2. Collect and analyze data on the factors that impact the region's water sources.
3. Investigate the current public opinion and perception of coastal man-made structures (jetties, groynes, seawall, and breakwaters) as well as the current state of the water in their area.
4. Develop an informative video and sign about water impurity and coastline erosion to present at the Palace.

Methodology

In order to accomplish the stated goal, we completed the four objectives by collecting data from interviews with local residents, a gardener, and specialists who work for the Palace. We used these objectives to gain knowledge about water quality and quantity in the Palace area. In order to understand the factors that impact the region's water sources, we also conducted interviews with the Palace's staff, nearby communities, and experts. In addition, we visited many locations affected by water quality and quantity problems, such as small fishing villages and the Mrigadayavan Palace. We toured the Palace to observe man-made structures, such as jetties, a seawall, groynes, and breakwaters. At the Sirindhorn International Environmental Park, we followed a guided tour through the artificial mangrove forest. The Huai Sai Royal Development Center taught us about water conservation, preservation, and water sources from the mountains that may have an impact on groundwater levels in the Rama VI Camp. The sites also allowed us to gain an understanding of local residents' perceptions of the man-made structures and the current state of water quality in the area. From data collection and analysis, we created an informational video and sign to be implemented at the Palace. They provided information on the causes of water scarcity, water salinity, and coastline erosion. The video and sign would be a first step toward helping the community understand all aspects, positive and negative, of the structures within the area so they can make informed decisions in the future.

Results and Findings

From the data we gathered, we found that groundwater in the area is scarce, and the water that is present has become brackish and is difficult to utilize in the Palace area. We continued researching to find the causes of this problem, which we found can be mainly attributed to urbanization and the addition of the artificial mangrove forests. Urbanization has led to the overexploitation of local water sources such as underground water that supplies personal wells due to the high demand of water from the increasing population. The mangrove forests near the Palace need seawater, which is brought in through a permanent opening in the jetties. Because of this, the water in the canals has a very high salinity level. The brackish water permeates the soil, affecting the soil to become salty. Our team learned that the very jetties that bring the seawater into the Palace grounds are a feature of a set of man-made coastal structures that the Marine

Department introduced eleven years ago to protect the coastline. In actuality, the jetties, along with a network of groynes, breakwaters, and a seawall, are causing Camp changes to the coastline.

Most local residents found the jetties and offshore breakwaters more beneficial than detrimental. Most fishermen found the offshore breakwaters beneficial to them in order to anchor their boats and prevent damage from harsh waves and storms. The majority of the local residents we interviewed stated that the negative effects of the structures impacted them very minimally, while the benefits have influenced them greatly. Farmers living inland, far from the sea shoreline, do not find the salinity of the water a problem since they are farther away from the sea and the seawater has not seeped far enough inland to impact them. People living in those areas are more concerned with the insufficient water supply of the tap water generated by fresh water in the Kaeng Krachan Dam in Phetchaburi. They believe climate change causes insufficient rainfall, thus contributing to the low water supply in Kaeng Krachan Dam. We also found that using groundwater as a water source is becoming obsolete in residential areas by the shoreline since it is more convenient for people to get water from the tap. The Palace also uses tap water for their household needs, but for gardening, groundwater is the main source used.

Deliverables & Recommendations

From this project, we created two deliverables which are a video and informative sign. This will help inform the Palace staff, as well as visitors to the Palace about the effects of the man-made structures in the area. From the video, the local residents will understand how the existence of the jetties leads to salt contamination of fresh underground water. They will also be informed about how groynes, jetties, and breakwaters contribute shoreline erosion.

We recommend the Foundation of the Mrigadayavan Palace implements our informational video into the Palace museum area and sign on the Palace grounds for visitors and Palace staff members to view. We also suggested that the Palace organize an event that hosts both local residents and large tour groups at the Mrigadayavan Palace to make sure the local residents are aware of all of the effects the structures may have on the environment. By informing the public, the Foundation can gage how the public may react to the change or removal of the structures. We believe the Palace should test water and soil for salinity in the Palace area regularly to monitor changes over time and ensure that salinity levels do not rise as well as research the overuse of underground water in nearby communities that may lower water table levels on the Palace grounds. Lastly, we suggest that the Palace propose to regulate the opening of jetties into the canals that were once freshwater sources.

Conclusion

With our recommendations, the Foundation of Mrigadayavan Palace could provide useful information to different groups and audiences as well as provide a baseline to continue researching the effects of man-made structures, in order to make changes in the future.

Table of Contents

List of Figures

List of Tables

Authorship:

Chapter	Section	Contributor(s)	Editor(s)
Executive Summary	Writing	Vorakit	All
Abstract	Writing	Katherine & Vorakit	Alison & Stephanie
Introduction	Writing	Stephanie, Alison, & Katherine	All
Background	Introduction	Stephanie	All
	Water Impurity	Katherine & Stephanie	All
	Freshwater Conservation	Evan & Vorakit	All
	Man-made Structures	Spun & Monnaya	All
	Mrigadayavan Palace	Stephanie	All
Methodology	Objective 1	Katherine	All
	Objective 2	Vorakit & Alison	All
	Objective 3	Stephanie	All
	Objective 4	Stephanie & Katherine	All
Results	Introduction	Alison	All
	High Salinity Levels	Vorakit & Alison	All
	Urbanization	Evan	All
	Mangrove Forest	Katherine	All
	Coastline Change	Monnaya & Spun	All
	Public Belief	Stephanie	All

Recommendation	Introduction	Spun	All
	Recommendation 1	Katherine & Evan	All
	Recommendation 2	Stephanie & Spun	All
	Recommendation 3	Alison, Spun & Monnaya	All
	Recommendation 4	Katherine & Stephanie	All
	Recommendation 5	Monnaya & Evan	All
Conclusion	Writing	Vorakit & Spun	All
Deliverables 1: Sign	Sign Layout	Stephanie & Katherine	All
	Sign Content	Stephanie	All
	Translating	Spun & Monnaya	Vorakit
Deliverables 2: Video	Video Script (English)	Stephanie	All
	Translating	Vorakit & Spun	Monnaya
	Video Images/Transition	Vorakit	All
	Video Editing	Vorakit	All

Chapter 1. Introduction

With the population estimated to grow by about two billion before the year 2030, approximately one third of the world's population will lack water resources (United Nations, 1998; Krchnak, 2016). Exacerbating the problem of scarcity is water impurity, which affects the ability of many countries to provide clean water for drinking, agriculture, and sanitation.

Industrialization and climate change have forced nations, including Thailand, to confront these hardships. Due to climate change, Thailand's dry season has increased in length, contributing to the lack of usable water. One third of Thailand's surface water is virtually unusable, and with 70% of Thailand's water supply used for agriculture, farmers and landowners experience the effects of the polluted water the most ("Thailand environment monitor," 2011).

The abundance of freshwater sources in the Cha-am district of Phetchaburi province influenced King Rama VI to build the Mrigadayavan Palace there in 1923. Since the year 1992, the Foundation of Mrigadayavan Palace aimed to restore the buildings, grounds, and surrounding areas to their original landscape and horticulture. This continues the effort of Thai royalty to make the Palace an example for sustainability in Cha-am. Since recent urban expansion caused depletion of water in the area, neighboring seawater seeped into the soil and mixed with groundwater, creating brackish water. Excess salt then accumulated in the soil, making the ground unsuitable for plant life.

Man-made coastal structures, especially jetties, also cause saltwater to seep into the Palace's groundwater. When built, the structures' main purpose was to protect the Palace's shoreline from erosion. Unfortunately, the jetties' structure caused the Rama VI Military Camp and neighboring areas to undergo even more severe erosion and aggravate water scarcity and salinity problems. The addition of the jetties, groynes, seawalls, and offshore breakwaters to the Palace's shoreline in 2006 influenced the landscape in unforeseen ways.

The Foundation asked us to look at the effects of the seawall, jetties, groynes, and breakwaters on water quantity and quality, as well as the shoreline of the Palace, and to present this information to the Foundation as well as local visitors. Our team accomplished the assigned task by completing four objectives; we analyzed water quantity and quality in the area, researched the factors that impact the region's water sources to further understand the sources of water impurity, investigated public opinion and perception of jetties, groynes, breakwaters, and a seawall and the current state of the groundwater in the local area. Our team also made an informational video and sign to inform visitors about the effects of man-made structures on the community. We hope that with these objectives, our final project will allow the Palace to begin raising public awareness on the issues it faces.

In this report, the background topics relating to water quality and quantity, and man-made coastal structures will be covered. Information and data gathered during our fieldwork visits will then be comprehensively analyzed into the methodology section, and the findings will be explained in our results section. Last, the recommendations for the Foundation will be included.

Chapter 2. Background

The Mrigadayavan Palace is establishing itself as a hub for sustainability and conservation initiatives as well as Thai history and culture. After being neglected for 40 years, the Palace is undergoing renovations to return this center to its natural glory. The area around the Palace has changed drastically, resulting in challenges that the Palace's restoration project now faces. In this chapter, we introduce the obstacle of water impurity and proceed to discuss the importance and effects of freshwater conservation. Furthermore, the recent installation of man-made coastal structures near the Palace leads us to outline the advantages and disadvantages of man-made structures on erosion and water quality. We conclude by charting the history and culture of the Mrigadayavan Palace in order to set the scope of our project. These topics are crucial for understanding the significance of this project — not only in the context of the Palace, but in areas facing similar challenges.

2.1 Water Impurity

Water impurity has become an increasing problem in Thailand, where standards for sanitation and drinking water are not fully established ("Thailand Overview," 2016). A report from the Pollution Control Department showed that in 2013, 13% of marine water in coastal areas had drastically deteriorated in quality in comparison to only 5% in 2009 (Pollution Control Department, 2013). Highly deteriorated qualifications were based on the Marine Water Quality Index. In addition, the preceding report from 2002 showed that water collected on the coast of Phetchaburi provinces was very good, on the other hand, in 2013 the water collected in the same area showed that the quality drastically deteriorated (Pollution Control Department, 2002; Pollution Control Department, 2013). Some of the causes of water impurity include declining water tables, proximity to pollution, urbanization, and climate change.

2.1.1 Urbanization

Urbanization exists as one of the leading causes of water impurity in Thailand ("State of water: Thailand," n.d.). In the 20th century, the population began to shift from rural towns to large, bustling cities. By 1967, cities that began with about 20,000 people had grown more than five percent (Srikam, n.d.). The district of Cha-am, where the Palace resides, currently grows in population by about 1.3% every year ("City Population," 2015). For Cha-am, this means that more people are using the same source of water, the reservoir at Huai Ta Paed, located west of Palace, and exhausting the amount of usable freshwater resources. This is a problem because the depletion of water tables can lead to impurities, such as saltwater leaching into the remaining freshwater reserves. Urbanization can also affect climate change by accelerating the rise in temperature, through growing populations, buildings, cars, and other urban activities that create pollutants that seep into water sources (Loo et al., 2015).

2.1.2 Climate Change

Water shortage has been more prevalent as climate change worsens. Through the extension and instability of rainy and dry seasons, tropical climates prominently highlight

climate change (Corlett, 2014). Thailand experiences three distinct seasons; the rainy season from May to October, winter from October to February, and summer from February to May. Although these seasons seem well defined, Thailand's weather patterns have been becoming more erratic over the past 15 years, alternating between severe floods and droughts. This exists due to climate change elongating the seasons, causing each period to become more drastic. Flooding has destroyed over 60,000 acres of land used for agriculture in 55 out of 76 provinces (Kisner, 2008). In 2005, 11 million people from 71 out of 76 provinces in Thailand were affected by water shortages due to climate change. In 2008, just over 10 million people faced a water deficit (Kisner, 2008).

2.1.3 Salt Water Intrusion and Brackish Water

Droughts can deplete water tables, allowing impurities like salt water to infiltrate fresh water. Saltwater from the sea can easily seep into underground sources when freshwater supplies dry up. "When river water meets sea water, the lighter fresh water rises up and over the denser salt water. Sea water noses into the estuary beneath the outflowing river water, pushing its way upstream along the bottom" (Geyer, 2005, p. 23). This shows that salt water intrusion is very difficult to prevent, as capillary action forces occur. Capillary action is the act of water molecules going against gravity due to molecular properties (Perlman, 2016). This allows seawater to reach higher elevations and seep further into inland freshwater sources. Brackish water can be detrimental to a society, ruining a community's source of water for showering, drinking, and agriculture.

Plants also struggle to adapt when a freshwater source becomes brackish from saltwater intrusion. With a higher salt content, most plants need to be watered much more frequently and with a higher quantity of water to receive the hydration they need, perpetuating overuse of water sources. If the plants do not receive the proper amount of water, they can suffer decreased growth, decreased water retention, wilting, and inefficiency of molecular processes (Parida & Das, 2005). Fortunately, for areas with brackish water, some plants are able to maintain growth and development even in high salinity water areas. For example, certain species of mangrove trees are able to "reach an optimum growth at salinities of 5–25% of standard seawater" (Parida & Jha, 2010, p. 201). This shows that mangroves are able to grow in a range of different salinity levels. With proper horticulture and landscape techniques, a brackish area can still thrive with the appropriate selection of plants.

2.2 Freshwater Conservation

Communities use underground fresh water to complete various domestic and agricultural tasks. Many communities whose residents' livelihoods depend on fresh water have devised strategies of water conservation. Because of exploitation, more and more groundwater faces critical conditions because people do not put community interest before environmental viability (Darwis et al., 2015). Some exploitation may be due to lack of regulations from the government. Cooperation and understanding of the people on the importance of groundwater conservation is therefore important. Two key issues in combating the impact of groundwater depletion on a society are the level of reliance upon groundwater and the cost of using water from another source. If groundwater is not widely used, then the loss of the resource is unlikely to have a significant impact on society if another water source is available. However, in many areas

worldwide, groundwater is the only source of water, giving it significant value (Morris et al., 2003).

The ongoing decline in water tables demands the development of new conservation policies and new water supplies. Over the past 30 years in Thailand, the quality of water resource management significantly increased (Sethaputra et al., 2001). The government worked to provide millions of Thai residents with "potable drinking water, water to produce cheap and abundant food, and to generate hydroelectricity" (Sethaputra et al., 2001). Building dams and reservoirs is one of the ways to conserve fresh water from rain, as shown by King Bhumibol Adulyadej's royal initiatives implemented in Thailand.

2.2.1 King's Projects

One of King Bhumibol Adulyadej's, or King Rama IX's, royal initiatives undertaken during his reign concerned itself with water and irrigation systems. The King always had a topographic map of Thailand and a camera to record what he had seen while he explored different parts of Thailand. By studying the map, he found topographical flows of water and how to conserve fresh water in different areas. For instance, in Cha-am, drought and insufficient water for usage became problematic due to deforestation by citizens for natural resources. Deforestation causes the loosening of soil due to the removal of underground roots, allowing water to run off mountains. This especially affected the Huai Sai area, west of the Mrigadayavan Palace.

Huai Sai Royal Development Study Center

After the reign of King Rama VI in 1925, with an increase in industrialization, people deforested the mountainous Huai Sai area in order to obtain natural resources. King Rama IX stated that "if this land is left [unattended], it would eventually be a desert," which initiated the Huai Sai Royal Development Study Center in 1983 ("Huai Sai Royal Development Study Center," n.d.). The Study Center has its goal to conserve forests and environment, as well as to provide a place for research and skills development for a better quality of life of the local citizens ("Huai Sai Royal Development Study Center," n.d.).

The Huai Sai Royal Development Study Center began restoring the forest by building check dams to keep water from running off the Savoey Kapi and Sam Phraya mountains, leading to the natural regrowth of the forests. The Study Center displays exhibits for visitors. Parts of the Center serve as a living exhibit with agricultural and farming areas. King Rama IX asked the Royal Irrigation Department to construct a network of reservoirs, in order to provide more fresh water for citizens living in Huai Sai area.

Reservoir Network Project

The Reservoir Network Project, under the Royal Development Initiative, is a system of reservoirs to divert the natural path of water and distribute water to other reservoirs within a network for agriculture ("Network of Reservoir...," n.d.). King Rama IX initiated this project and began construction in 1993 in Huai Sai ("Network of Reservoir...," n.d.). The Royal Irrigation Department conducted a feasibility study to aid in transporting water from the larger and higher elevated Huai Ta Paed reservoir to the lower elevated Huai Sai reservoir. All of the water reservoirs use gravity to drive water from one reservoir to another without additional energy or

power required (“Network of Reservoir...," n.d.). This is significant because it provided an affordable way to conserve and transport water to areas farther away from the mountains.

The Reservoir Network Project serves many purposes. One of the primary purposes is to preserve water in the canals and other water sources in order to get a sufficient supply of water delivered to nearby neighborhoods for consumption and agricultural use during the dry season. In addition, the project distributes water to the network system, which leads to the ability to assist agricultural areas and farmers evenly and thoroughly. Also, the project aims to provide a more efficient water management system and to have water for various research projects in the areas by the reservoirs (“Office of the Royal...," n.d.). Resources are delivered from reservoirs that have more water to aid the ones with less water retention (“Office of the Royal...," n.d.).

2.3 Man-made Coastal Structures

Other than urbanization and overexploitation of water sources, another factor that speeds up saltwater intrusion and causes erosion to the shoreline is man-made coastal structures. Thailand in particular is well known for its beautiful beaches, but shorelines erode quickly due to strong winds and menacing waves from storms such as typhoons. Thai coastlines are estimated to decrease by 2 square kilometers per year, with damages costing approximately 17 million US dollars as stated by World Bank in 2007 (Siripong, 2010). In an attempt to protect shorelines from erosion, engineered structures, including seawalls, jetties, groynes, and breakwaters, are often constructed. Two causes accounting for beach erosion include natural forces and man-made structures. Naturally, sand and sediments move in diagonal direction to the shoreline with a saw-toothed pattern that ensures the constant movement of sand with changing tides and seasons. Hence, accumulation and disappearance of sand is expectable due to this dynamic (Jack, n.d.).

2.3.1 Jetties, Groynes, Seawalls, and Offshore Breakwaters

Man-made structures implemented into the area in the recent decade include jetties, groynes, seawalls and offshore breakwaters. Groynes and jetties are structures built perpendicular to the shoreline while seawalls and offshore breakwaters are structure parallel to shoreline. Appendix A shows images of each of the man-made coastal structures.

A jetty is a long and narrow structure that reaches 100 to 1,000 meters into the sea. Jetties prevent seasonal sand dunes that accumulate and block the opening of canals during the rainy season, between the months of May and October. They also permanently open a navigation channel for boats and ships (“Shoreline Engineering," n.d.; Deguchi & Sawaragi, 1988). Groynes are usually found in a series that line up on a straight stretch of the beach. With this pattern, groynes trap sand that moves with longshore currents (Jack, n.d.). The direction of wind and water currents determine sand movement, so that if the wind blows in one direction, sand will accumulate on the updrift side of the groyne, resulting in accretion of sand onto the beach. In contrast, the other side of the groyne will lose sand (“Shoreline engineering," n.d.). Groynes are therefore used to control the location of sand accumulation, as seen in diagrams in Appendix B.

A seawall is often used for chronic shoreline erosion prevention. There are many types of seawalls, including vertical, concave, and mound; the most common type are vertical seawalls. These look very similar to retaining walls, and are often mistaken as one, however, they have different purposes. Seawalls “prevent landward retreat of shoreline” and they prevent seawater from flooding the land behind it (Krauas, 1988, p. 5). Offshore breakwaters reduce the effects of

waves, preventing them from crashing into the coastlines and taking away sands and sediments in addition to providing a space of calm marina, suitable for rehabilitation of beach area and a place for boats to dock (Sriariyawat, n.d.). There are a seawall, five offshore breakwaters, and six submerged offshore breakwaters in front of the Palace. Both types of breakwaters slow down strong waves, protecting beach behind them from erosion.

2.3.2 Effect of Man-Made Coastal Structures on the Environment

Man-made coastal structures can significantly harm communities. The construction of seawalls requires a large amount of land, which can potentially lead to government expropriation of properties. If there is not enough sediment supply, the amount of beach area in front of the seawall may reduce or disappear entirely (Krauas, 1988). In the long term, seawalls may deteriorate at the bottom due to scouring, the process in which repetitive wave breaking leads to strong wave forces at the bottom of the wall (Sumer & Fredsøe, 2002).

There are many concerns about offshore breakwaters because they have high construction cost and they are built on sand leading to inevitable erosion at the sand base (Panya Consultants Co., Ltd., 2013). Similarly, groynes and jetties interfere with the natural movement of sand by accelerating erosion and starving nearby beaches (Deguchi & Sawaragi, 1988). In addition, jetties allow for the mixing of fresh water with the ocean's seawater, resulting in brackish water.

2.4 Mrigadayavan Palace

The Mrigadayavan Palace was built for King Rama VI in 1923 as a place of relaxation during the summer months. The Palace, located on Bang Kra Beach, had long, secluded, white beaches and access to plentiful freshwater sources; these were important qualities to the King (Sirikulchayanont, 2003). The meaning behind names has high importance in Thailand, so King Rama VI wanted a fitting name for his summer house. King Rama VI named the Palace "Mrigadayavan" after the Isipatana Mrigadayavan forest of Buddha's first sermon (Mrigadayavan Palace, n.d). The King also chose the name because hog deer, Mrig, are abundant there (Sirikulchayanont, 2003).

The Mrigadayavan Palace is one of three main institutions in the Rama VI Camp. There is a Border Patrol Police Camp located in close proximity to the Palace. The Border Patrol Police are responsible for military training programs such as paratroop training and mental training Camp. Additionally, the Palace shares the area with Sirindhorn International Environmental Park, established by Her Royal Highness (HRH) Princess Maha Chakri Sirindhorn's royal initiative ("The Sirindhorn International Environmental Park," n.d.).

2.4.1 Foundation of the Mrigadayavan Palace

While the Mrigadayavan Palace originally was intended for King Rama VI's summer house, he unfortunately only spent two summers in its residence before passing away. The Palace was without maintenance for forty years before King Rama IX decided to devote members of the Border Patrol Police to the restoration and protection of the Palace. To serve this purpose, they formed the Foundation of Mrigadayavan Palace. The Foundation now devotes itself to the restoration of the Palace in order to return it to its original landscape and horticulture. They hope that by doing so, the "Palace would serve as a learning center for the people and a means to

express gratitude towards His Majesty King Bhumibol Adulyadej and King Rama VI" ("A Palace to Remember," 2016). This was said by Klaomard Yipintsoi, the director of the Office of the Foundation of Mrigadayavan Palace. She and many others see the Palace as a place of Thai culture and history and are devoted to renovating it. As Yipintsoi said in an interview, "the Palace's vision is to Preserve, Reserve and Restore" (Jan. 17, 2017). The Foundation hopes that with reverting to older methods of water conservation and landscaping, the coastline and indigenous plant life will return and thrive.

Chapter 3. Methodology

The goal of our project was to maintain the environmental and historical legacy of the Mrigadayavan Palace by investigating the factors affecting the water quality and quantity.

Our objectives for this project were as follows:

1. Analyze the water quality and quantity within the Palace area.
2. Collect and analyze data on the factors that impact the region's water sources.
3. Investigate the current public opinion and perception of coastal man-made structures (jetties, groynes, seawall, and breakwaters) as well as the current state of the water in their area.
4. Develop an informative video and sign about water impurity and coastline erosion to present at the Palace.

All of these objectives contributed to our final conclusions and deliverables.

3.1 Objective 1: Analyze the water quality and quantity within the Palace area.

The purpose of this objective was to gain sufficient knowledge about the water problem faced by the Palace in the Rama VI military Camp, located in the Cha-am district of Phetchaburi province. By analyzing data, we were able to clarify the potential effects of brackish water on the Palace and the surrounding area as well as the gardens' sustainability to the current salinity level.

First, we toured the Palace grounds to observe the landscape and structures. This tour was guided by two of the Palace's representatives, Mrs. Nichapa Tikachok and Mr. Worameth Sriwanalak, who gave us an overview of the Palace history and described what they know about problems of water quality and quantity, and man-made structures that are on the Palace's beach. During this time, we collected data and information on topics for further research.

Next, we interviewed a gardener at the Mrigadayavan Palace. As most interviews were conducted in Thai, one Chulalongkorn University student served as a translator during the interview to keep all members of the team informed regularly. When interviewing, we first asked permission to record the conversation, then we read to them a description of the purpose of our interview and asked for their permission to use their information and answers in our project. In this interview, we asked the gardener a set of semi-structured, open-ended, questions. The list of questions is included in Appendix C. The questions include changes in the salinity and scarcity of the area's available water, and opinions on multiple man-made structures in the area.

Next, our team conducted two interviews with two specialists; Dr. Danai Thaitakoo from Chulalongkorn University, a landscape architect who works closely with the Palace to restore the beach forest, and Dr. Sasin Chalermlarp from Seub Nakhasathien Foundation, a geologist who is currently working on forestry and wildlife conservation. These interviews were completed in order to supplement our literature review with experts' opinions who worked in the area. We learned about impacts of man-made structures, mangrove trees, and brackish water on the local area. We also learned about the history of the landscape of the area and how it has changed over the years. The list of questions presented during these two interviews is included in Appendix D.

Moreover, we acquired water quality test results from December 2016, which were completed by a third party organization, the 8th Regional Environment Office. This data showed the quality of water of the whole Camp. We also acquired from Foundation staff copy of high

resolution aerial pictures showing the landscape behind coastline taken between 1954 and 2015 by Geo-Informatics and Space Technology Development Agency (GISTDA). This was used to locate reservoirs, dams, and canals that associate with the Palace grounds. This data allowed us to understand the exact situation about the quality of the water in the area that Palace are using to hydrate the gardens.

3.2 Objective 2: Collect and analyze data on the factors that impact the region's water sources.

For this objective, we researched the different factors polluting the water reservoirs in the Mrigadayavan Palace, the Sirindhorn International Environmental Park, and nearby communities. During our tour around the Palace grounds, we conducted interviews with staff of the Foundation of the Mrigadayavan Palace to gather information on what they think could be potential causes of the water pollution. From this interview, we acquired information on the two canals surrounding the Palace, Klong Bang Tra Yai (South) and Klong Bang Tra Noi (North), groundwater, rainfall, and the impact of seawater to freshwater sources. At the Sirindhorn International Environmental Park, we toured their first artificial mangrove forest and observed the environment in the area. We gathered information regarding whether or not a mangrove forest would grow there naturally. This piece of information was very useful because it enabled us to make a decision on the effect of mangroves on area's water quality. We also conducted a phone interview with a local golf course located close to the Huai Ta Paed reservoir, from which the community draws its water, to better understand how development affects water. The interview, as seen in Appendix E, was conducted to learn about their source of water and to determine how the golf course affects the community's water supply.

Lastly we focused our research on King Rama IX's projects in Phetchaburi by going to the Huai Sai Development Study Center to learn about the reservoir network. We also learned what the King had done for the Cha-am area in terms of water conservation and preservation. Additionally, interviewing Dr. Danai Thaitakoo at Chulalongkorn University who works with the Palace allowed us to receive evidence on the factors affecting the Palace. We also studied the effect of the man-made structures on the erosion of the coastline by comparing aerial photographs of the shoreline throughout the past 63 years. We also gained information from interviews with experts and local residents.

3.3 Objective 3: Investigate the current public opinion and perception of coastal man-made structures (jetties, groynes, seawalls and breakwaters) as well as the current state of the water in their area.

By investigating the public opinions about the man-made structures and their impact on water quality and coastline, we were able to learn how accepting the community would be to changing the structures. By interviewing local business and homeowners, our team learned what local residents believe causes water impurity and their opinions of the local man-made structures.

When planning whom to interview, the first step was to evaluate what businesses would be influenced by the water impurity in the area. We chose locations based on their relative

proximity to the Palace and structures, as well as considered recommendations from our sponsor. Using these criteria, we contacted Mr. Charoen Chaisri, a chief engineer at Novotel Hua Hin Cha-Am Beach Resort And Spa, Pol. Sub. Lt. Somjade Iamsopon, a representative from the Border Patrol Police, Mr. Somjai Noisaard, a resident who has lived in Cha-am his entire life, Khan Bandai (also known as Khan Kradai) villagers, and local residents living behind the breakwaters at Sai Yoi temple. We had the intention of finding an array of different views on the same topics, since people living in different areas experience different impacts. The interview process followed the same procedure as mentioned in Objective 1. We conducted the interview using questions from Appendices F, G, and H.

When finding local residents to interview, we looked into communities located close to the Palace. We began in a well populated fishing neighborhood where we approached fishermen and shop owners in the area and asked if they would like to participate in an interview after we gave a description of our project. Groups of two to three team members approached the interviewee in order to cover more area in the time we had. We used questions from Appendix H. Once we were done with interviews, all recordings of conversations were translated and transcribed as precisely as possible to allow for exact uses of quotes. Opinions were then sorted into general categories.

For this objective, we decided that we needed data from two types of locations: communities right along the beach and agricultural communities further inland. Beach communities provided us with the opinions of fishermen, beach vendors, and local residents who reside along the shoreline. We approached them by introducing ourselves as students working on a project. In total for this group, we interviewed 28 people from Sai Yoi, Bor Ta Loong and Cha-am beachfront. Agricultural communities were our second target group. From them we learned about water usage, including use of underground water for agricultural and livestock farming. For this purpose, we interviewed 12 people from the Bong Wai and Sam Phraya communities.

3.4 Objective 4: Develop an informative video and sign about water impurity and coastline erosion to present at the Palace.

Through this objective, we hoped to provide information to Palace visitors and staff about the effects of the jetties, groynes, breakwaters, and seawalls on the surrounding area and water sources; we also intended to raise awareness and instill in them a sense of responsibility to protect their land. This objective will serve as an initial step toward helping the local community understand all aspects, positive and negative, of these structures so they can make informed decisions regarding them in the future. To achieve this goal, we completed a video that will be presented within the museum area of the Palace for people to watch while they tour the Palace.

We accomplished this goal by first analyzing all of our previous research from our interviews and literature review in order to compile data on the misconceptions that the public has on the man-made structures. Analysis was done by sorting through the interviews and creating a cross-check sheet with the list of interviewees down the left and the structures across the top. An empty version is below in Table 1. The main intention of the video was to state misconceptions and supply the public with factual information.

After determining the contents of the video, we then analyzed the most applicable method of delivery of information at the Palace. We found through speaking with our sponsor and touring the Palace that a video and sign would be the best deliverable. While touring the Palace

we also noticed that informative signs can be found throughout the Palace and could be easily implemented, as the Palace already have necessary materials for it. We created a script for the video based on content that we found necessary to inform the public. Once completed, we edited a video to contain pictures of the Palace and surrounding area to be the visual aid for the content in the script.

	Mangroves	Jetty	Seawall	Groins	Breakwater	Coastline/Erosion	Water Quality
Border Patrol Police: Pol.Sub.Lt. Somjate Iamsopon							
Mr. Somjai Noisaard							
Buffy's Belly Bar and Bistro: Mr. Sittipong Prathoong, Supervisor							
A group of 3 fishermen in Khao Sai Yoi area							
Villager inside, slightly away from shoreline							
Villager							
Privilege Condo, Staff							

Table 1: Empty Cross-Check Sheet

Chapter 4. Results

In this chapter, our team synthesizes the information we gathered from interviews, tours, and background research into a set of findings. We show how the water quality and quantity of the Mrigadayavan Palace has decreased over time, due to urbanization, the introduction of mangroves to the Sirindhorn International Environmental Park, and man-made coastal structures. We also discuss how the man-made structures have changed the coastline, along with how the local community interprets the costs and benefits of these structures.

4.1 Quality and Quantity of Water at the Rama VI Military Camp

4.1.1 Finding 1. Water in the Palace is scarce and has high salinity levels.

There are two canals in the Rama VI Military Camp where the Mrigadayavan Palace is located, Bang Tra Yai Canal and Bang Tra Noi Canal, both of which originally served as freshwater sources for the Camp. In addition, eight underground water wells supplied fresh water for the Palace, but some of them were shut down by bombings during the Pacific War (1941-1945) according to Mr. Somjai Noisaard, a 78-year-old Cha-am resident. Pol. Sub. Lt. Somjade Iamsopon, retired Division 1 Border Patrol Police, stated that the Patrol Police were not aware of existing wells, and accidentally covered them when they began to restore the Palace. A severe decrease in the availability of fresh water in the Camp occurred once the wells closed. As a result of this diminished availability, the Camp built reservoirs to retain water, as seen in Figure 2. Nowadays the Palace uses water from the Ta Sa-ded Reservoir, the biggest reservoir in the Camp built between 1995 and 2003, also shown in Figure 2. This reservoir is the main source of water for all organizations inside the Camp.

Figure 2: Aerial maps of Palace and the grounds with circles indicating reservoirs
Source: GISTDA

The 8th Regional Environment Office, a third party organization, sampled and tested water in Mrigadayavan Palace area in December 2016. The results show that all but two locations of the water in the Camp are in the range of brackish water, which is 0.5 to 34 parts per thousand (ppt). The average salinity of an ocean is 34.9 ppt, indicating that the salinity levels near the canals by the Palace are dangerously close to seawater levels (Pawlowicz, n.d.). In point of fact, Table 2 shows a trend in salinity levels where water salinity increases in closer proximity to the jetties which shows the connection between the jetties and the brackish water infiltration. The sample locations are indicated with yellow stars in Figure 3. Table 2 shows that the salinity levels of the two canals (numbers 1 through 6 in Table 2 and Figure 3) are about 24 ppt, which is an extremely high value, since the standard groundwater value is very close to 0 ppt. There is an almost-zero ppt concentration of salinity within the rainwater collection pond (Sample 2.1 in Table 1 and Figure 3) which, when it rises to a certain level, overflows into the canal. The overflow has a salinity concentration of 21 ppt (Sample 2.2 in Table 1 and Figure 3), which is a significant increase from the previous 0 ppt. To avoid using the brackish water from the canals, the Palace must use water directly from the collection pond to water the Palace grounds.

Testing area	pH	Temperature (°C)	Salinity (ppt)
1.1. Bridge crossing over canal of Department of Public Works and Town & Country Planning (in front of water gate)	7.94	-	24.5
1.2. Bridge crossing over canal of Department of Public Works and Town & Country Planning (back of water gate)	7.78	26.5	24.3
2.1. Ta Sa-ded pond (pond's side)	8.4	26.4	0.1
2.2. Ta Sa-ded pond (canal's side)	7.44	26.6	21.3
3. Water reservoir opposite of soccer field	8.42	26	1.8
4. Sapan Sung (bridge)	7.62	25.9	20.1
5. Water gate, Superintendent's house	8.08	26.5	24.4
6. Sapan Waen (bridge)	8.07	26.4	24.5
7. Old freshwater well	8.09	27.5	0.3
8. Benjanareetum Garden well	7.35	28	3.4
9. Sakuntala Garden well	8.06	26.4	1.3
10. Phraya Ramrakop Resident well	8.17	26.9	2.6
11. Pond opposite of the Park	8.39	26	2.45
Standards of surface water			~0
Typical Ocean Salinity			35
Brackish water			0.5-34

Table 2: Salinity Testing Areas at Rama VI Camp (8th Regional, 2016)

The water in the canals has a salinity level that exceeds 1 ppt, which is not suitable for drinking or watering some types of plants (Salinity and drinking water, n.d.). On the other hand, the groundwater wells and rainfall collection reservoirs (Table 2: samples 3, 7-11) that are isolated from canals and seawater have fairly low salinity levels, staying between 0.1 and 3.4 ppt. However, the test was performed in December 2016, which recorded a higher amount of rainfall than usual as compared to previous years. This may cause data to report with lower salinity values. In addition, there is a possibility of seawater intrusion to the underground water wells. The wells are between the sea and surrounding canals, and contain brackish water, especially when water from the wells is taken out, or in dry season when there is less rainfall. This means that less fresh water causes less pressure to push against seawater, thus allowing seawater to seep into freshwater sources easier (D. Thaitakoo, personal communication, Feb. 3, 2017). The Palace has to be selective about which wells and reservoirs they use water from. The issue of water scarcity faced by the Palace is not only due to closure of wells or overuse, but external factors such as community expansion and land development.

Figure 3: Map showing starred and numbered locations of water sampling around the Palace provided by the Foundation of Mrigadayavan Palace [Names of each location in Appendix I]

4.2 The Causes of Scarcity and Salinity

4.2.1 Finding 2. Development has diminished water quality, quantity, and transportation efficiency.

In our interviews with the local community as well as literature reviews, we found that urbanization has impacted the water quality, quantity, and transportation of water in the Cha-am district.

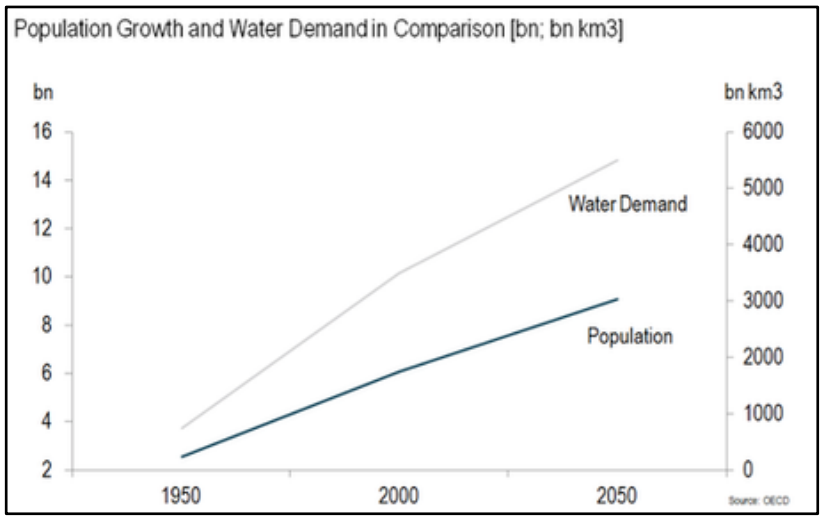


Figure 4: Size of population versus its impact on water usage in society (Water Demand and Management Issues, n.d.)

With an increasing population, there is an increase in water use per person, as evident in Figure 4. In an interview, Pol. Sub. Lt. Iamsopon informed us that an increase in roadways prevents water from running from the mountains to the ocean, creating floods in higher elevated

areas, and droughts in lower elevations. These issues can be attributed to the development of major roadways that would affect both the quality and quantity of the surface water (D. Thaitakoo, personal communication, Feb. 3, 2017). With the introduction of these roadways, underground water pathways are becoming blocked by pavement and construction, resulting in the inability to move from the mountains down to the coast.

Name	Native	Population Census 2000-04-01	Population Census 2010-09-01
Cha-am	อำเภอชะอำ	64,501	73,894
Area: 661 km² – Density: 111.8 inh./km² [2010] – Change: +1.31%/year [2000 → 2010]			

Figure 5: Size and population density of Cha-am along with its growth in the past decade (National Statistical Office, 2015)

This increase in infrastructure is a result of the growing population. The population of Cha-am currently increases at a rate of 1.31% per year, as shown in Figure 5. The increase in population results in the local underground water supply, used mostly for agriculture and watering personal gardens, being depleted at a faster rate than previously seen. In the past, underground water was the sole water source for the people in the Cha-am region. From our interviews, we found that tap water sourced from Kaeng Krachan Dam, individual home rainwater collection, and reserve 20 liter containers of drinking water, are now the main water sources for most families. These sources have led to the decreased use of groundwater. Saman Boonsong, a resident in Sam-Phraya area of the Cha-am district for over forty years, described how occasionally the mountains water resource becomes so scarce that the tap only runs once out of seven days (Feb. 7, 2017). When inquiring why the natural resource of water has begun to deplete, most of our interviewees replied that it is due to climate changes, specifically, less rainfall and an increase in temperature. Metha Yenjit, a resident of Cha-am for over forty years, said that she believes that in addition to climate change, an increase in cattle farming has impacted water scarcity (Feb. 7, 2017). She said that cattle farming requires much more water than agricultural farming, which is how the land was used in the past (M. Yenjit, personal communication, Feb. 7, 2017).

With an increase in development and water scarcity, water management becomes more important. Ms. Boonsong described overuse of the underground water source stating that there is no regulation on digging for underground water (S. Boonsong, personal communication, Feb.7, 2017). Many local residents, when they start running low on water, dig a freshwater well to provide water to their farmland. With ineffective regulations, there is significant overexploitation of the source, causing scarcity problems for people at lower elevations. The Underground Water Act of 1977 states that for Phetchaburi province permission from the government is only needed when digging a well deeper than 30 meters (Manual for Drilling Underground Water Well, n.d.). In addition, we visited several livestock and agricultural farms located inland, including Sam-Phraya, Bong-Wai, and Mrigadayavan temple, where we learned about the quality of water coming from local reservoirs on the mountains. The farmers did not seem concerned about the levels of salinity in the area. This was supported by the data we collected in Finding 1, which confirmed that areas closer to jetties have a higher salinity level, not areas inland.

The Huai Sai Royal Development Study Center explained that with the increase in

urbanization, the amount of water they have would be insufficient in comparison, leading to the need to find new freshwater sources. One of the sources is Sai Ngarm in Prachuap Khiri Khan province, adjacent to Phetchaburi province to the south. It can hold almost ten million cubic meters of water to be the main storage for reservoirs network to serve communities in Cha-am district of Phetchaburi province. The reservoirs connect with pipelines as part of the Reservoir Network Project under the Royal Development Initiative.

Lastly, we looked into the claim that there is an abundant overuse of local water resources associated with businesses such as local hotels and golf courses. In an interview with the chief engineer of the Novotel Resort and Spa, one of the largest hotels in Cha-am, the representative mentioned that the hotel and gardens used tap water from Cha-am pipelines. The hotel uses an average of 200 cubic meters of water per day, and their water stores can hold up to 400 cubic meters of water at any time (C. Chaisri, personal communication, Jan. 18, 2017). Storing water is helpful because the level of water in the dam is dependent on rainfall. When this supply is not sufficient, like during the dry season, they can manage to only obtain 100 cubic meters of water per day, which forces them to buy water from external resources and have trucks deliver groundwater or water from the canals to the hotel (C. Chaisri, personal communication, Jan. 18, 2017). However, when discussing the golf courses, we encountered some inconsistencies from those we interviewed. During an interview with a staff member of the Huai Sai Royal Development Study Center, the interviewee stated that there was less water in the area due to the two nearby golf courses, Springfield and Lakeview (Jan. 19, 2017). From an interview with local villagers, we were told that the water used by the golf courses comes from a different reservoir than the town's water supply. Many local citizens thought that the construction of these new buildings and golf courses posed no burden on their water supply.

Overall, our discussion has highlighted how increased development, such as the construction of several large-scale hotels and golf courses, has contributed to the lack of water in areas downstream. Despite the insufficiency, we see it is necessary to implore local villagers and local business owners to be more understanding of the environmental issues that occur within this area.

4.2.2 Finding 3. Efforts to conserve the artificial mangrove forests in the Sirindhorn International Environmental Park led to saltwater intrusion on the grounds of the Mrigadayavan Palace.

Through the addition of an internal canal in the jetties, seawater enters upstream to nourish artificial mangrove forests in the neighboring Sirindhorn International Environmental Park seen in Figure 6. We learned from an interview with Pol. Sub. Lt. Iamsopon that this man-made forest was created under the direction of HRH Princess Sirindhorn in order to restore the ecosystem in the area, with the first mangrove tree planted in 1994 (S. Iamsopon, personal communication, Jan. 20, 2017; "The Sirindhorn International Environmental Park," n.d.). In 2003, The Sirindhorn International Environmental Park formally opened to the community in order to maintain the mangrove forest.

Pol. Sub. Lt. Iamsopon told us that the Border Patrol Police, who worked alongside the park at the time, believed, due to the discovery of mud in the local canals, that there must have been a natural mangrove forest in the past (Jan. 20, 2017). A professor at the Department of Landscape Architecture at Chulalongkorn University, Dr. Danai Thaitakoo, told us that the land

the mangrove forests occupy was once salt marshes, thus the area was already slightly salty. Although there was a salt marsh, the soil contained a high amount of sand (D. Thaitakoo, personal communication, Feb. 3, 2017). Sandy soil does not contain the nutrients needed to keep mangroves healthy (Kathiresan & Bingham, 2001). Therefore, the Park brought mud in to fill the mangrove forest so the trees would have a foothold to grow.

Figure 6: Man-made Mangrove forest at Sirindhorn International Environmental Park

After the introduction of the forest, the trees did not grow as well as hoped. Sand accumulation at the mouth of the canals led to an insufficient amount of seawater entering the canals to nourish mangroves. The park needed to give the trees the brackish water they craved, and a feature inside the jetties built in 2006, allowed seawater to flow into the canals and provide water to the forest (S. Iamsopon, personal communication, Jan. 20, 2017; D. Thaitakoo, personal communication, Feb 3, 2017). This feature, shown in Figure 7, is an inclined trough designed to bring water in with the waves, but to restrict it from moving out with the pull of the tide. Although the trough helped the mangroves grow, it also caused saltwater intrusion into the freshwater sources in the area. This can be damaging to gardens because most plants do not have a high salinity threshold and cannot filter out the salt (Parida & Das, 2005). Salt stress can slow growth because it creates a water deficit inside the plants, stunting their natural growth pattern (Parida & Das, 2005).

The jetty structure allows for opening of the canal mouth all year round. Naturally, the direction of wind and the season greatly impacts the dynamic of the sand. During the winter season, the north wind blows sand to the beach in the south. Then when summer comes, the wind changes direction, sending sand back to its original place (The Climate of Thailand, 2015). The addition of jetties has disrupted this pattern by blocking the sand from moving with the seasons. Natural disasters such as typhoons and monsoons can also temporarily alter this erosion pattern. Moreover, this natural pattern used to create a seasonal sand dune that covered the mouths of the canals, which protected the water from leaking and ultimately prevented the fresh water from becoming brackish.

Figure 7: Inside feature that allows seawater to enter the forest through the jetty

When touring the Sirindhorn International Environmental Park, we observed that employees of the Park focused on the preservation of the mangroves and explained the benefits of the mangrove forest. Mangroves can help protect underlying soil from erosion, as well as help foster a healthy environment for many types of fish, crabs, birds, and insects (Kathiresan & Bingham, 2001). However, the forest is one of the main causes of saltwater intrusion. Table 1 shows the 11 places around the Camp where the water is tested for salinity. Although all 11 spots are meant to be fresh water, with a level of about zero parts per thousand, areas 1.1, 1.2, 2.2, 4, 5, and 6, all have levels of 20 ppt or more, indicating brackish water. Overall, this shows that areas that were originally fresh water have been infiltrated with salty water.

4.3 The Cha-am District's Response to Water Impurity and Scarcity

4.3.1 Finding 4. Man-made structures are contributing to unnatural effects in the area.

Not only do the jetties bring in seawater, contaminating the freshwater resources, but they and other man-made coastal structures also create unnatural erosion patterns. Factors that lead to erosion include rising sea levels, natural disasters, and man-made structures. A study stating that sea levels rose 14 centimeters in the 20th century suggests that seaside countries worldwide experience rising sea levels (Kopp et al., 2016). Phetchaburi province is at risk of receding coastlines due to rapidly rising sea levels.

A record from the Meteorological Department shows that in the past 65 years, the southern part of Thailand had 53 tropical cyclones[1] (The Climate of Thailand, 2015). During this time, two devastating storms hit the southern part of Thailand: Typhoon Gay in 1989 and Tropical Storm Linda in 1997. They both resulted in reduction of the coastlines. From an interview at Kan Bandai community, fishermen in the area told us that the 1989 Typhoon Gay

[1] Cyclones are classified into three types according to wind speed. Tropical depression has a maximum wind speed of less than 63 kilometers per hour; tropical storms have wind speeds between 63 and 118 kilometers per hour; and a typhoon has a maximum wind speed of 118 kilometers per hour and beyond (The Climate of Thailand, 2015).

“caused a significant amount of erosion” and “created a lot of damage” (Jan. 18, 2017). Due to this crisis, many affected villagers asked the government to help them build man-made structures to protect their coastline.

In an attempt to prevent further erosion to the Palace grounds and the surrounding coastal areas, authorities from many organizations decided to build the man-made structures. However, the organizations observed an unexpected change to the coastline. While most residents agreed that man-made structures protect the coastline, we found that they protect only certain sections of the coastline, and damage other parts.

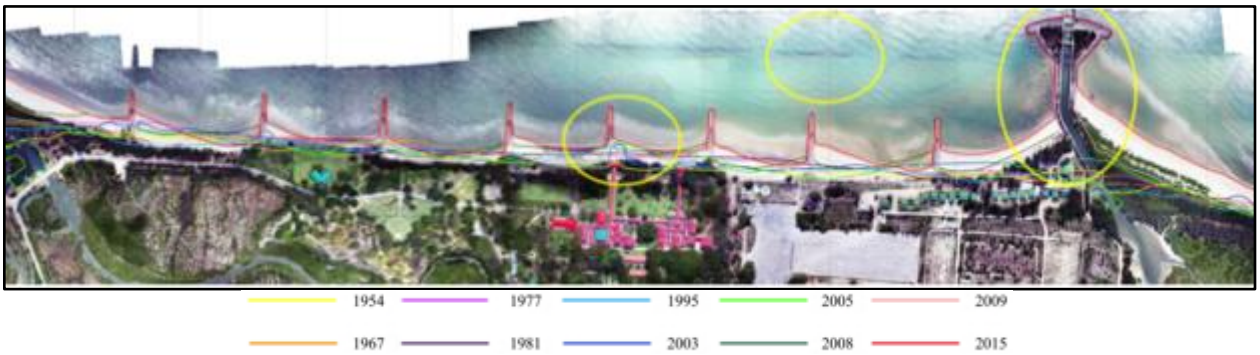


Figure 8: Map of coastline of the Mrigadayavan Palace and the surrounding area. From left to right: a groyne, a breakwater and a jetty. Source: GISTDA

Jetties and groynes stretch into the sea, obstructing the dynamic sand movement that travels parallel to the coastline, hence causing significant changes after their addition. They promote erosion as sand accumulates on the updrift side and erodes on the downdrift side. In the case of groynes, we found from fieldwork observations that sand gets trapped around groynes instead of moving to the beach. Both groynes and jetties cause the beach to lose its straight shoreline and to become concave, as illustrated in Figure 8, where various colored lines indicate the changes to the coastline; the progress started from 1954 to 2015. Even though the initial intention of these structures was to protect coastline from erosion, a Mrigadayavan Palace Foundation staff member, Mrs. Nichapa Tikachok, sees the negative consequences. From her interview, she informed us that the impact of man-made coastal structures perpetuates the problem of erosion indefinitely, thereby resulting in the need for more structures to be built (Jan. 17, 2017).

Breakwaters can also significantly affect the shape of the beach. The community behind the breakwaters has seen an increase in beach area, unlike other areas where erosion is more severe. Many shop owners and hotels behind the breakwaters have positive opinions of the structures, such as Mr. Sittipong Pratheung, supervisor of a local bar and bistro. He thought that they “bring back sand” and prevent sand from being taken into the ocean (Jan. 18, 2017). A staff member at Privilege Condo also told us that sand started to gather there more than before the breakwaters existed (Jan. 18, 2017). In contrast, the hotels located outside the protection range of the breakwaters suffered worse erosion. Mr. Chaisri said it is necessary to “buy sand to add to their beach” and “build a seawall” to help prevent further erosion into their land (Jan. 18, 2017).

The accounts from the Foundation staff’s Mrs. Tikachok and Novotel’s chief engineer Mr. Chaisri are some examples of opinions from people who see the negative effects of man-made structures. Their opinions, however, contradict with many other residents’. Though there

are widespread opinions, the most important thing to occur is the conversation about them. With more people discussing these coastal structures, there can be further understanding and a spread of knowledge through the community about the environmental value of these constructions.

4.4 Public Opinion on Cha-am's Response to Water Issues

4.4.1 Finding 5. Many local people believe that man-made structures are more beneficial than detrimental to the area.

We found that some local residents did not know some of the negative effects of the addition of the structures, such as unnatural erosion on the outskirts of the jetties. The man-made structures were put into place to help protect the land between the jetties, and local residents trust they are doing the job well. When conducting an interview with Pol. Sub. Lt. Iamsopon, we found that he believes the structures provide sufficient protection for the Palace and the temples in the nearby village (Jan. 20, 2017).

When speaking with retired Police Officer Utad Meechaitorn, he described how he views the influence of the King's water conservation projects to be beneficial. He said that the reservoirs and structures built from the King's projects were the reason that water scarcity does not impact the area as much as it could (February 6, 2017). He described how the King's projects on water conservation have greatly influenced the area and how well regarded the projects are by the local people (U. Meechaitorn, Personal Communication, February 6, 2017). Local fishermen also expressed the view that they benefit from the protective features of the structures.

Among all of our interviews with the local community, fishermen benefited most noticeably from the man-made structures, especially the breakwaters. The breakwaters provide protection from large waves that endanger the fishermen as they work on their boats. Furthermore, they provide a location for the fishermen to dock their boats, so there is less of a chance of their boats moving during a storm. Residents who live in the area behind breakwaters also believe that having the structures prevent sand from being washed into the sea. Prior to our interviews, we expected to find information regarding the decrease in fish population due to the structures as suggested by the literature review done during our research period. Research implied that the structures would cause unnatural water turbulence, negatively affecting the fishing community (Geyer, 2005). However, when interviewing local fishermen at the Sai Yoi and Bor Ta Loong communities, we found that they believe the introduction of the man-made structures positively influenced their fishing industry by both controlling the water currents and increasing the fish population.

In terms of the amount of beach area, several long-term residents believe that there was more beachfront in the past. For example, Mr. Somjai Noisaard, a 78-year-old local Cha-am resident described that when he was young, the beach in front of the Mrigadayavan Palace was "a long beach with natural white sand and trees along the coastline...it was beautiful" (S. Noisaard, personal communication, Jan. 19, 2017). Pol. Sub. Lt. Iamsopon, a Border Patrol Police officer, also perceived the beach the same way (Jan. 20, 2017). They both wish that the beach could be as it was in the past. Moreover, three villagers in the Bor Ta Loong area mentioned that the beach used to be double its current width before Typhoon Gay hit (Feb. 6, 2017). These interviews brought insights as to how the local residents view their surrounding

area. Within our interviews, although many people reminisced on older views of the landscape, no one described ways to help with the changing environment.

Figure 9: Interviewing a local villager in Sam-Phraya sub-district

Prior to our interviews, we predicted that we would see the villager's lives impacted by water impurities. What we found instead is that the majority of the population now uses water originating from the reservoir of the Kaeng Krachan Dam, instead of groundwater for daily use, while underground water is mostly used for agriculture and watering gardens. Therefore, the impurity of local groundwater does not directly impact the community, nor does brackish water negatively influence public opinion of the structures

The majority of the people we interviewed believe that the structures are more beneficial than detrimental, which may partly be because of a lack of communication. Ms. Aumporn Chanpetch, a local in the Sai Yoi area, and Mr. Chaisri, chief engineer of the Novotel hotel, informed us that a general meeting occurred one or two years before construction began to discuss the man-made structures in order to inform the public of their effects. However, many people were confused about who should attend this event and topics of discussion. In one interview, fishermen from the Aow Khan Kradai community stated that people did not know that there was a meeting held, implying that the officials who organize the events intentionally left the public in the dark. Meanwhile, a villager who lives near the coastline informed us that he did hear about the meeting, but could not attend, suggesting that some local people knew about man-made structures prior to construction.

With these findings, we concluded that the local residents have an overall positive opinion towards the man-made structures on the coast. Although the jetties impact the quality of the local water sources through their canals, most villagers do not experience the effects of the water impurity due to the reduction of the use of underground water. Groundwater use became more obsolete because of the reservoir water supplying the area with convenient water from the tap. With the mangrove forest needing the inflow of saltwater for their nourishment, it is difficult to avoid the seeping of seawater into the freshwater sources. Although few villagers and businesses feel the impacts of the increasing brackishness near the Palace, it is difficult to say if these structures provide more benefits or detrimental effects to the area.

Chapter 5. Recommendations

In this chapter, our team compiled recommendations that we believe the Foundation of Mrigadayavan Palace should consider implementing. For each recommendation, we give details on its apparent necessity, and explain how it could be implemented. The topics of the recommendations cover all aspects of the project, including use of deliverables, regulation of man-made structures, and actions to initiate new studies.

5.1 Recommendation 1:

We recommend that the Foundation implements the video and sign we produced in the museum areas of the Mrigadayavan Palace. Our team compiled a video and sign to give visitors an overview of the history of the Mrigadayavan Palace, as well as information on the changes to the Palace grounds due to the recent addition of coastal man-made structures. Through our interviews, we found that the public perceived many benefits from the man-made structures, but either not many people were cognizant of the disadvantages, or they felt the benefits outweighed the drawbacks. Our video and sign would provide an educational experience to inform visitors and staff of the ecological and topographical effects of the man-made structures.

The video is approximately four minutes long and geared towards both the Mrigadayavan Palace staff and tourists, since both groups are important baseline audiences for the information presented. Our other deliverable, a sign, also covers similar information, which will appeal to the local perception of the importance of protecting and cherishing royal history. It contains specific details about the effects caused by each man-made structure as well as the Palace area's problems of water quality and scarcity.

We believe that both forms of media could be easily implemented into the Palace's group tour procedure and/or into the museum exhibits. We recommend that these forms of media be implemented as soon as possible and that they remain a part of the Palace as long as the Foundation sees necessary. The sign would best fit on the Palace grounds near the seawall, north of the King's royal bathing pavilion. This way, the information provided on the sign could connect to the exact areas discussed. We also suggest that this sign be implemented into the guided tour of the Palace, to ensure the most possible visibility for the tourists. We expect that the Foundation of Mrigadayavan Palace will find these deliverables useful aids to communicate with the public.

5.2 Recommendation 2:

We recommend that the Foundation organize an event for both local residents and large tour groups to visit the Mrigadayavan Palace and teach them about man-made structures. As briefly mentioned in Finding 5 of the Results chapter, there is a lack of thorough communication between authorities, researchers, and the community on both the current and potential effects of the structures. An event that brings local people to the Palace would help provide the needed exposure to make a stronger connection between the Palace and the community, and provide needed information to local residents about the role of man-made

structures and the process of shoreline erosion.

The Foundation of the Mrigadayavan Palace can implement this recommendation by hosting local events where the main focus is environmental education for the public, which allows an open dialog between the public and the Palace. This would ensure as many people as possible know about the area's environmental instability and changes to the land and water quality and quantity. It would also be wise to inform the public on all of the effects of the structures. This educational public event could also exhibit the sign and video we created. The Palace would host these events periodically, allowing public awareness of changes to the local environment and the areas surrounding the Palace.

Further emphasizing this, we observed during our fieldwork that many local residents have no connection to the Palace. We encountered several people who know the Palace simply as a part of the Rama VI Military Camp and a location where fishermen anchor their boats. This event could be an integration of the Palace into the local community, allowing local residents to begin to appreciate and celebrate the beauty and historical significance of the Palace.

Attendees of this event should include residents from beach side communities, such as the Sai Yoi, Bor Ta Loong, and Nern Sura, as well as representatives from local businesses such as hotels and restaurants along the beach. The attendees list should not limit itself to village representatives, as it is necessary to urge all community members to attend and become informed. The attendance of as many people as possible could bolster people to become more active within the community. This would ensure an effective spread of our goal of environmental sustainability knowledge.

We further recommend that the timeframe of this event be within the next few months because it will take time to plan, organize, and advertise the event. The sooner the conversation begins within the community about environmental sustainability, the sooner the Foundation of Mrigadayavan Palace can make strides toward improving the local environment.

In order for this event to be successful, we recommend that the Foundation provides incentives to draw in people to the event such as free admission or refreshments. By doing this, they provide an additional reason to attend besides the educational draw. The Foundation should advertise the events as not only informative, but essential for the well-being of the area.

5.3 Recommendation 3:

We recommend the Foundation test salinity levels of the water and soil on a regular basis to ensure that salinity levels do not rise any further. We would like to ensure that the Foundation of Mrigadayavan Palace avoids further decline in water or soil quality. Scientists from the 8th Regional Environment Office typically test the salinity levels of the water in the Rama VI Camp quarterly. This way they maintain an up-to-date understanding of the quality of water in the area. However, we found that there is a lack of data prior to the data set we obtained, so we suggest that the Foundation does more testing. Salinity level trends would allow for a bigger picture on the impact of man-made coastal structures on the salinity in the area. For water salinity, the areas we recommend the Palace test are reservoirs located at the north and south of the Palace grounds, in addition to locations seen in Appendix I. For soil salinity, we believe the most important areas to test are the Phisan Sakon section of the Palace (the ladies' quarter), near the Palace's north and south water reservoirs, near the old canals where the jetties reside, near the well in front of the Phraya Ramrakop Resident, and on the side of Ta Sa-ded reservoir. It is

beneficial to tell which areas get the most saltwater intrusion, so the Palace could then look into possibly implementing a preventative measure that would counteract the intrusion. The locations are marked in the map found in Appendix L.

From our fieldwork observation, we saw that the Palace has a water level marker close to the north reservoir. This equipment allows the Palace workers to know how much water is in the soil. The Palace could use the level marker as a water testing site as well. The Foundation would obtain data on the salinity of water with respect to soil, because if the water is salty, then the soil is likely to be salty as well. Therefore, we recommend that gardeners at the Palace install more water level markers, as pictured in Appendix J, throughout the Palace grounds, especially in the gardens, to test the quality of water and the soil. The Palace staff might be able to collect more samples and send them to the environmental agency for testing.

Due to the lack of data from the past, it is critical to analyze and determine the standard results. We highly recommend doing all tests regularly, ideally every month, because salinity could change quickly depending on environmental conditions (Department of Primary Industries, 2000). For example, during the rainy season, the salinity levels would most likely be lower due to the additional fresh water from the rain. Whereas in the dry season, the salinity level would be higher because of a lower water to salt ratio. If cost is a factor, the regular testing interval of once every three months is acceptable because Thailand has three seasons and studies suggest that change in seasons may affect water and soil salinity.

5.4 Recommendation 4:

We recommend that our sponsor research and document the unregulated use of groundwater by the nearby communities. In Finding 2 we explained that the digging of freshwater wells is only regulated for wells going over 30 meters into the ground. Ineffective development of the wells can lead to a further decline in water tables and exacerbate water scarcity. The Foundation should begin by inquiring with local government in Cha-am about doing a survey on use of groundwater by residents. They could also contact the Department of Groundwater Resources to investigate the number of communities that use freshwater wells and whether that use impacts the local water tables or salinity levels. It may also benefit the Palace to research the current local policies on water sources. This recommendation could serve as a starting point for future initiatives to regulate water quality and quantity.

Unfortunately, the Foundation will need to do more extensive research on this. The data that currently exists is very minimal. We only briefly investigated the underground water regulations of the area or how this will impact the water quantity of the Palace. The Foundation should collaborate with the Department of Groundwater Resources to gather information on groundwater usage. Regulating groundwater usage would take significant effort, time, and resources that our sponsor must take into consideration.

5.5 Recommendation 5:

We recommend that our sponsor propose to regulate the jetties' opening into the canals that were once freshwater sources. Based on information mentioned in the Background chapter and Finding 3 of the Results chapter, we believe that the openings of the jetties that allow seawater to flow inland influence the salinity level of the area. This feature of the jetties alters

the seasonal sand dunes that previously blocked the opening of the canals.

We recommend that the Foundation of Mrigadayavan Palace and authorities responsible for the jetties, such as the Marine Department, Border Patrol Police, and the Sirindhorn International Environmental Park, regulate the frequency and duration of opening the jetties to the ocean water. This action may control the amount of salt water that enters the area, making salinity levels more manageable.

Regulating the jetties would be more manageable than immediately closing them because the Palace will be able to determine the impacts that may follow if the canals were closed. This would also give time for the fishermen to adapt to the changing ecosystem. While researching how to control the water coming inland, it is necessary to research the minimum salinity level needed to sustain the species of mangroves in the Park. This would provide insight as to how often and at what volume seawater should be allowed in, so that the inflow of salty water does not heavily impact the environment. Complete removal of jetties will immediately impact the fishing industry and erosion of the beach, therefore, the Foundation and stakeholders should thoroughly research all possible relevant environmental impacts before attempting to do so. If the jetties are removed, it will take some time for the coastline to return to its previous state.

When considering how to regulate the canals, we recommend that the Foundation consider outside stakeholders who have interest in the jetties. As well as benefiting from the breakwaters, fishermen also benefit from jetties. The picture in Appendix N shows how fishermen rely greatly on the jetties because they protect the boats from direct encounter with waves and wind. Therefore, public opinion plays a significant role in the possible altering of the jetties. Additionally, the process to regulate the jetties would be time-consuming, so it is important for the Foundation to do sufficient research into how to complete the process, as well as the outcomes of the regulations. The Foundation should also know that the effects of closing the jetties on the soil and water will not occur immediately. This is because brackish water has already settled in the area for more than ten years, which may have turned soil in the canals salty. Copious amounts of fresh water may be necessary to dilute saltwater.

Chapter 6. Conclusion

The goal of our project was to maintain the environmental and historical legacy of the Mrigadayavan Palace by investigating the factors affecting the water quality and quantity. In this project, our team analyzed the area's water sources and the factors altering those sources' purity and availability. We investigated public opinion on man-made structures to provide the Foundation with the necessary information to continue their research efforts on the environmental legacy of the Palace grounds. We also produced an informational video to present to tourists and staff on the impact of the coastal structures on the area's coastline and water sources. We found that industrialization in the Cha-am district, including local villages, apartments, hotels, and golf courses, has created a significant impact on the local environment.

We believe that this project and the data collected will assist our sponsor in their long-term goal to conserve the historic nature of the Palace, restoring the buildings and environment to their original landscape and horticulture. Moreover, our project would be useful for the communities along the coast in Cha-am to sustain their ecosystem. Our findings would benefit the Palace and the Foundation, as well as the Cha-am district itself, and areas experiencing similar problems of water purity, water scarcity, and erosion in Thailand. Our fieldwork led us to conclude that many people in the Cha-am district use tap water instead of groundwater. A question raised by our research was to what extent climate change and other natural phenomena impact water quality and scarcity and erosion. From the interviews, many local residents believed that what the area is experiencing is natural, thus it would be very interesting to see the results of an environmental impact study.

This project and the recommendations suggested will help the Foundation. The initiative the Foundation has taken through this project will be a good baseline for future projects. The situation of freshwater resources in the Palace is complicated since many factors are involved, but if some party takes the initiative to address the problem for all stakeholders, then there will be a solution.

Works Cited

Boonsong, S. (2017, Feb. 7). Personal Interview.

Chaisri, C. (2017, Jan. 18). Personal Interview.

Chanpetch, A. (2017, Jan. 18). Personal Interview.

City Population: CHA-AM (District, Phetchaburi). (2015, April 22). Retrieved January 11, 2017, from https://www.citypopulation.de/php/thailand-admin.php?adm2id=7604

Corlett, R. T. (2014). The impacts of climate change in the Tropics. *STATE OF THE TROPICS*, 155-160. Retrieved January 24, 2017, from http://stateofthetropics.org/wp-content/uploads/Essay-2-Corlett.pdf

Darwis, Rakhim N, Muhammad A, Lahming, Muhammad A. (2015). Shallow Groundwater Conservation Based Empowerment and its Influence Factors by Groundwater User Farmers in Takalar Regency. Hydrol Current Res 6:187. doi: 10.4172/2157-7587.1000187

Deguchi, I., & Sawaragi, T. (1989). Effects of Structure on Deposition of Discharged Sediment around Rivermouth. *Coastal Engineering 1988*. doi:10.1061/9780872626874.118

Geyer, R. (2005). Where the rivers meet the sea: the transition from salt to fresh water is turbulent, vulnerable, and incredibly bountiful. *Oceanus, 43*(1). Retrieved January 13, 2017.

Huai Sai Development Center, (2017, Jan. 19). Personal Interview.

Huai Sai Royal Development Study Center. (n.d.). Retrieved January 16, 2017, from http://www.phetchaburi.go.th/data/kingproject/project_7.html

Iamsopon, S. (2017, Jan. 20). Personal Interview.

Jack, E. (n.d.). 4.3 Coastal erosion and the ban on hard structures. Retrieved January 24, 2017, from http://www.learnnc.org/lp/editions/nchist-recent/6374
Johnson, N., Revenga, C., & Echeverria, J. (11 May 2001). Policy forum on ecology: Managing water for people and nature. *Science (Washington), Vol. 292, no. 5519, pp. 1071-1072*

Kathiresan, K., & Bingham, B. (2001). Biology of mangroves and mangrove Ecosystems. *Advances in Marine Biology*, 81-251. doi:10.1016/s0065-2881(01)40003-4

Kisner, C. (2008, July). Climate Change in Thailand: Impacts and Adaptation Strategies. Retrieved January 11, 2017, from http://climate.org/archive/topics/international-action/thailand.htm

Kopp, R. E., Kemp, A. C., Bittermann, K., Horton, B. P., Donnelly, J. P., Gehrels, W. R., . . . And, E. D. (2016, January 4). Robert E. Kopp. Retrieved January 31, 2017, from http://www.pnas.org/content/113/11/E1434.full

Krauas, N.C. (1988). The effects of Seawalls on the Beach: An Extended Literature Review. Retrieved January 11, 2017, from http://www.jstor.org/stable/25735349?seq=1#page_scan_tab_contents

Loo, Y. Y., Billa, L., & Singh, A. (2015). Effect of climate change on seasonal monsoon in Asia and its impact on the variability of monsoon rainfall in Southeast Asia. *Geoscience Frontiers,6*(6), 817-823. doi:10.1016/j.gsf.2014.02.009

Manual for Drilling Underground Water Well, (n.d.). Retrieved February 21, 2017, from http://www.dgr.go.th/water/waterforlife1_1.htm

Map Showing Coastline around the Sirindhorn International Environmental Park [Photograph]. (n.d.). GISTDA, Bangkok.

Meechaitorn, U. (2017, Feb. 6). Personal Interview.

Morris, B. L., Lawrence, A. R. L., Chilton, P. J. C., Adams, B., Calow, R. C., & Klinick, B. A. (2003). Groundwater and its Susceptibility to Degradation: A Global Assessment of the Problem and Options for Management. Early Warning and Assessment Report Series, RS. 03-31.

Mrigadayavan Palace. (n.d.). Retrieved January 16, 2017, from http://www.mrigadayavan.or.th/history.php

National Statistics office. (2015). Retrieved February 03, 2017, from https://www.citypopulation.de/php/thailand-admin.php?adm2id=7604

Network of Reservoir Operation under Royal Initiative. (n.d.). Retrieved January 16, 2017, from http://www.phetchaburi.go.th/data/kingproject/project_14.html

Noisaard, S. (2017, Jan. 19). Personal Interview.

Office of The Royal Development Projects Board. (n.d.). Retrieved January 24, 2017, from http://km.rdpb.go.th/Knowledge/View/27

Panya Consultants Co., Ltd., Visuddhi Consultants Co. Ltd. .(July 2013). Retrieved February 2, 2017, from http://www.dmcr.go.th/bookRead.php?WP=nGI4ZUN0oGW3G0lDooya4UERnHy4Ljo7o3Qo7o3Q

Parida, A. K., & Das, A. B. (2005). Salt tolerance and salinity effects on plants: a review. *Ecotoxicology and Environmental Safety, 60*(3), 324-349. doi:10.1016/j.ecoenv.2004.06.010

Parida, A. K., & Jha, B. (2010). Salt tolerance mechanisms in mangroves: a review. *Trees*, *24*(2), 199-217.

Pawlowicz, R. (n.d.). Key Physical Variables in the Ocean: Temperature, Salinity, and Density. Retrieved February 05, 2017, from http://www.nature.com/scitable/knowledge/library/key-physical-variables-in-the-ocean-tmperature-102805293

A Palace to Remember. (2016, October 27). Bangkok Post article. Retrieved January 17, 2017, from http://www.bangkokpost.com/print/1120185/

Perlman, H. (2016, December 2). Capillary action. Retrieved February 01, 2017, from https://water.usgs.gov/edu/capillaryaction.html

Pratheung, S. (2017, Jan. 18). Personal Interview.

Primary Industries. Salinity Notes. (October 2000). Retrieved February 21, 2017 from http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/168882/water-salinity.pdf

Pollution Control Department. Summary of Thailand's Pollution Situation of 2013. (2013). Retrieved 20 February, 2017, from http://infofile.pcd.go.th/mgt/report2556.pdf?CFID=3279734&CFTOKEN=57043963

Pollution Control Department. Summary of Thailand's Pollution Situation of 2002. (2002). Retrieved 20 February, 2017, from http://infofile.pcd.go.th/mgt/report45.pdf?CFID=3279734&CFTOKEN=57043963

Salinity and drinking water. (n.d.). Retrieved February 20, 2017, from http://www.sahealth.sa.gov.au/wps/wcm/connect/public content/sa health internet/protecting public health/water quality/salinity and drinking water

Shoreline Engineering. (n.d.). Retrieved January 24, 2017, from http://coastalcare.org/educate/shoreline-engineering/#groins-jetties

Sirikulchayanont, P. (2003). The Interpretation Programme for the Mrigadayavan Summer Palace. 12-29. Retrieved January 16, 2017, from http://www.thapra.lib.su.ac.th/objects/thesis/fulltext/thapra/Paramaporn_Sirikulchayanon/fulltext.pdf

The Sirindhorn International Environmental Park: Background. (n.d.). Retrieved January 16, 2017, from http://sirindhornpark.or.th/2014/EN/about1.php

Siripong, A. (2010). Detect the Coastline Changes in Thailand by Remote Sensing. *International Archives of the Photogrammetry, Remote sensing and Spatial Information Science, XXXVIII*, 992-996.

Sriariyawat, A. (n.d.). (Slide Show). Retrieved February 2, 2017. http://www.eric.chula.ac.th/download/cep/procdoc/sem_doc03.pdf

Srikam, W. (n.d.). Urbanization and Urbanism in Thailand. Retrieved January 12, 2017, from http://www.cujucr.com/downloads/pdf_4_2006/Wichai%20Srikam.pdf

State of water : Thailand. (n.d.). Retrieved January 13, 2017, from http://www.wepa-db.net/policies/state/thailand/thailand.htm

Sumer, B. M., & Fredsøe, J. (2002). *The mechanics of scour in the marine environment*. River Edge, NJ: World Scientific. Page 399 and 402.

Thailand environment monitor: Integrated water resources management - a way forward. (2011, June). *World Bank*. Retrieved November 14, from http://documents.worldbank.org/curated/en/367151468303847751/pdf/633680ESW0P180RM00June020110Final0.pdf

Thailand Overview. (2016, September). Retrieved January 23, 2017, from http://beta.worldbank.org/en/country/thailand/overview

Thaitakoo, D. (2017, Feb. 3). Personal Interview.

Tikachok, N. (2017, Jan. 17). Personal Interview.

United Nations. (1998). World population prospects 1950–2050—the 1998 revision. New York, New York, USA.

Water Demand and Management Issues. (n.d.). Retrieved February 08, 2017, from http://igeogers.weebly.com/water-demand-and-management-issues.html

Yenjit, M. (2017, Feb. 7). Personal Interview.

Yipintsoi, K. (2017, January 17). Personal Interview.

8th Regional Environment Office. (2016). Water Field Test Result in Mrigadayavan Palace Area [PDF]. Ratchaburi: 8th Regional Environment Office.

Appendices

Appendix A: Images of all man-made coastal structures

Jetty

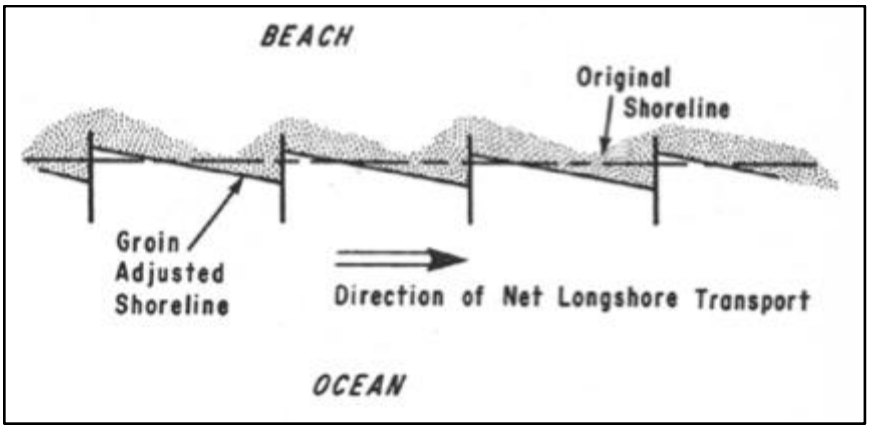
Groyne

Seawall (depicted by Yellow arrow)

Offshore Breakwater (depicted by yellow circle)

Appendix B: Diagram of updrift and downdrift beach

Source: Google Map



Source: Sriariyawat, A, n.d.

Appendix C: Interview questions for gardeners

We are a group of college students from Chulalongkorn University and Worcester Polytechnic Institute working with the Foundation of Mrigadayavan Palace to preserve the Palace Gardens. Currently, we are conducting an interview to understand the factors contributing to water impurity issues and effects of man-made structures at the Palace and the surrounding area.

Your participation in this interview is completely voluntary and you may withdraw at any time. Please remember that your answers will remain anonymous if you so choose. Your name or identifying information may appear in any of the project reports or publications, if you are comfortable with that.

If interested, a copy of our results can be provided through an internet link at the conclusion of the study.

1. How long have you been working for the palace?
2. What is your typical work routine?
3. Are there tests you have to do before watering plants?
4. Are there any areas of the garden that require more work or water?
5. Have you seen water scarcity and/or brackish water as a problem?
    a. For how long?
6. Are there any factors affecting the Palace water's well-being?
7. When you first came to the Palace, were there any mangroves?
8. After a breakwater was put in place, did you see more change in erosion?
9. When you first came, what kinds/species of plants were there?
10. Which trees are more susceptible to a salty environment (air, soil, water)?
11. Are you a local resident?
    a. How about the workers here in general?
12. Since you worked at Huai Sai before, do you think they face similar problems?
13. We saw gardeners watering plants at noon, doesn't the heat make the water evaporate?
14. Is it possible for sandy soil to subside?
15. Is there a way to clean water, like use alum?
16. Are there any water treatment systems like that of the Park?
17. Are the other Palace workers aware of the brackish water and erosion problems?

Appendix D: Interview questions for specialists working with the Palace

We are a group of college students from Chulalongkorn University and Worcester Polytechnic Institute working with the Foundation of Mrigadayavan Palace to preserve Palace Gardens. Currently, we are conducting an interview to understand the factors contributing to water impurity issues in Cha-am.

Your participation in this interview is completely voluntary and you may withdraw at any time. Please remember that your answers will remain anonymous if you so choose. Your name or identifying information may appear in any of the project reports or publications, if you are comfortable with that.

If interested, a copy of our results can be provided through an internet link at the conclusion of the study.

1. How does the jetty affect the land/coastline?
    a. Are there any ways to reverse the effects?
2. Does the sea wall affect the land/coastline?
    a. How?
    b. Are there any ways to reverse the effects?
3. Does the mangrove ditch affect the land/coastline?
    a. How?
    b. Are there any ways to reverse the effects?
4. Are there any plans in the works to make more jetties/man-made structures that could affect the land/coastline?
5. How are sea water levels changing the shoreline?
6. How are the seawater levels affecting rivers and water sources?
7. What kinds of water projects are being conducted in the area?
8. Did you notice any differences between the shoreline before and after the jetty was put into place?
9. Do mangroves have effect on the ecosystem and fresh water?

Appendix E: Interview questions for Springfield Golf Course

We are a group of college students from Chulalongkorn University and Worcester Polytechnic Institute working with the Foundation of Mrigadayavan Palace to preserve Palace Gardens. Currently, we are conducting an interview to understand the factors contributing to water impurity issues in Cha-am.

Your participation in this interview is completely voluntary and you may withdraw at any time. Please remember that your answers will remain anonymous if you so choose. Your name or identifying information may appear in any of the project reports or publications, if you are comfortable with that.

If interested, a copy of our results can be provided through an internet link at the conclusion of the study.

1. Where's your location in relation to the Huai-Ta-Paed?
2. Water source? What water?
3. Do you have a water impurity problem?
    a. Water scarcity?
4. What is your water capacity?
5. Since the course is higher than the Huai-Ta-Paed, doesn't it block or affect the water collection ability of the Huai-Ta-Paed?

Appendix F: Interview questions for Novotel Hua Hin Cha-Am Beach Resort and Spa

We are a group of college students from Chulalongkorn University and Worcester Polytechnic Institute working with the Foundation of Mrigadayavan Palace to preserve Palace Gardens. Currently, we are conducting an interview to understand the factors contributing to water impurity issues in Cha-am.

Your participation in this interview is completely voluntary and you may withdraw at any time. Please remember that your answers will remain anonymous if you so choose. Your name or identifying information may appear in any of the project reports or publications, if you are comfortable with that.

If interested, a copy of our results can be provided through an internet link at the conclusion of the study.

1. How long have you been working here?
2. How long have you been living in the area?
3. Does the hotel have water impurity issues?
    a. Personally, what do you think is the cause?
4. Does the hotel have a water scarcity problem?
    a. What does the hotel have to do when there's not enough water?

5. What measures have the hotel taken/ does it plan to take to prevent erosion?
    a. Did the hotel have to build the seawall by themselves?
    b. When the hotel has to refill sand, where does the sand come from?
        i. Does that affect the feel of the beach?
            1. Is there coarser sand, is it more packed, etc.
6. Before the government built man-made structures, did they advertise it or hold a public hearing?
7. In front of the hotel, are there still beach areas for tourists to 'play'?
    a. Did tourists complain about the scenery?
8. Personally, who do you think benefits from man-made structure?

Appendix G: Interview questions for Military and Border Patrol Police

We are a group of college students from Chulalongkorn University and Worcester Polytechnic Institute working with the Foundation of Mrigadayavan Palace on a project about the effects of man-made structures and water issues in the area.

Currently, we are conducting an interview. Your participation in this interview is completely voluntary and you may withdraw at any time. Please remember that your answers will remain anonymous if you so choose. Your name or identifying information may appear in any of the project reports or publications, if you are comfortable with that.

If interested, a copy of our results can be provided through an internet link at the conclusion of the study.

1. How long have you been in the area?
2. Since you were here did you see changes in the terms of erosion?
3. Did the government organize a public hearing before building?
4. What about mangroves?
    a. Does bringing in seawater through jetty to water the mangrove not affect fresh water?
5. In the past, where did freshwater come from?
6. During the extreme dry season, is there freshwater scarcity?
7. What do you think of the man-made structures (seawalls, groynes, and jetties)?
    a. Advantages?

    b. Are there any downfalls?
    c. Do they affect erosion?
8. You said that eventually sand will cover groynes, how long will that take?
    a. Are there any examples of this from before?
    b. Doesn't it take sand from beach and therefore lessen the beachfront to cover the groyne with sand?

Appendix H: Interview questions for fishermen

We are a group of college students from Chulalongkorn University and Worcester Polytechnic Institute working with the Foundation of Mrigadayavan Palace to preserve Palace Gardens. Currently, we are conducting an interview to understand the factors contributing to water impurity issues in Cha-am.

Your participation in this interview is completely voluntary and you may withdraw at any time. Please remember that your answers will remain anonymous if you so choose. Your name or identifying information may appear in any of the project reports or publications, if you are comfortable with that.

If interested, a copy of our results can be provided through an internet link at the conclusion of the study.

1. How long have you lived in the area?
2. Where is your source of water?
3. Are there any problems with that water?
4. How long has there been a breakwater?
    a. What do you think of it?
    b. Any disadvantages?
5. Before its construction, were there any public opinion hearings or meetings?

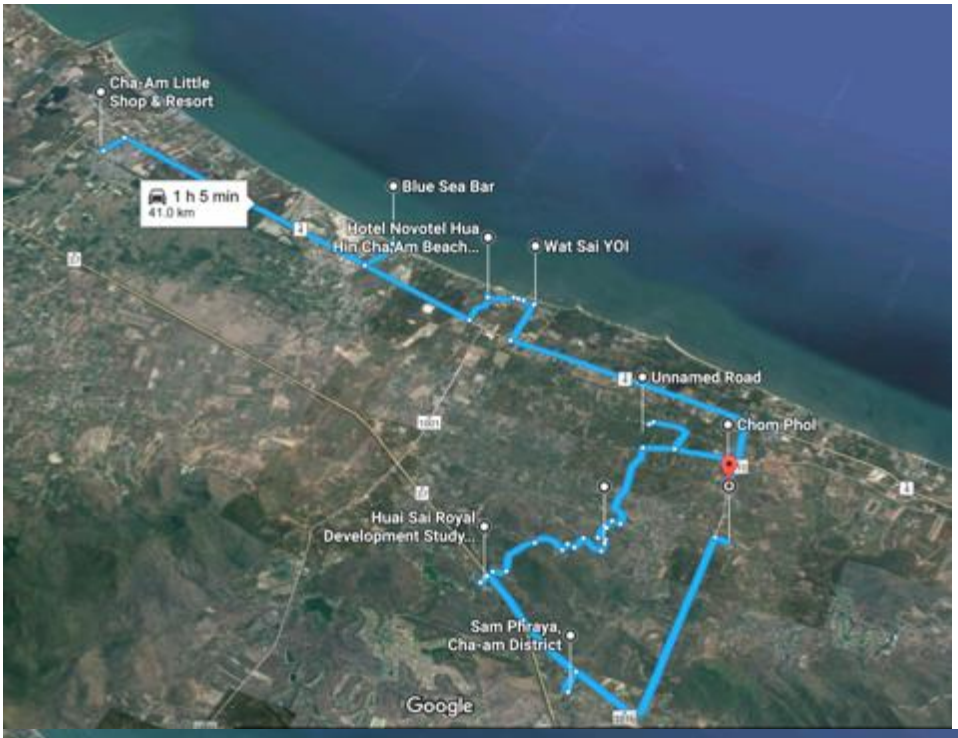
Appendix I: Starred and numbered locations of water sampling around the Palace

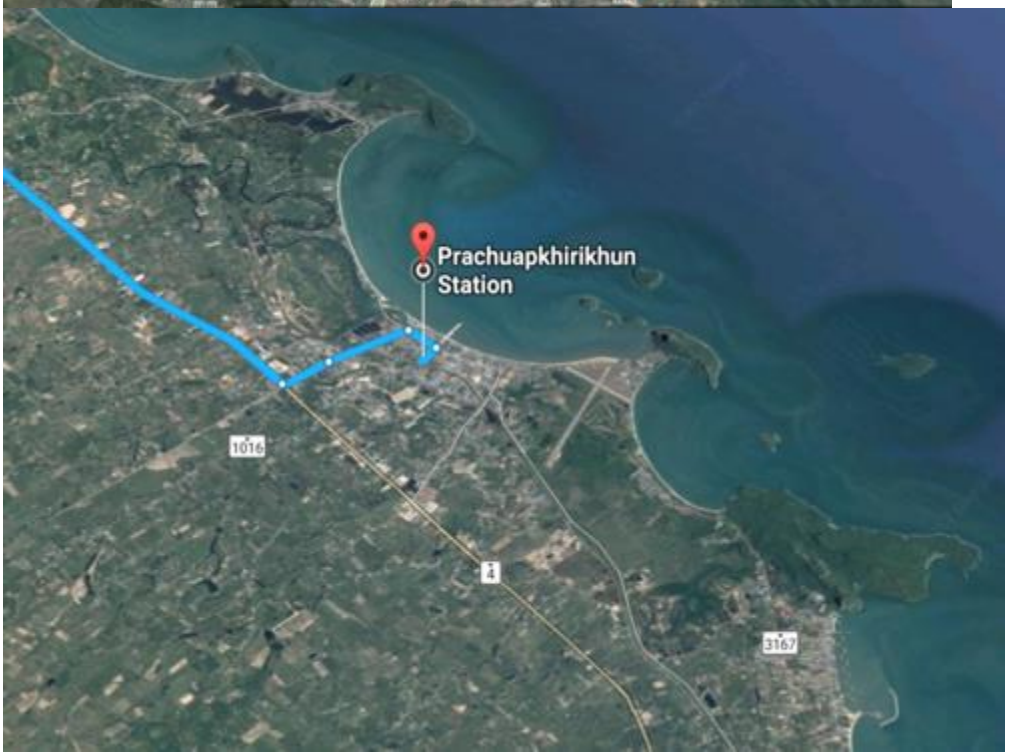
1.1. Bridge crossing over canal of Department of Public Works and Town & Country Planning (in front of water gate)
1.2. Bridge crossing over canal of Department of Public Works and Town & Country Planning (back of water gate)
2.1. Ta Sa-ded pond (pond's side)
2.2. Ta Sa-ded pond (canal's side)
3. Water reservoir opposite of soccer field
4. Sapan Sung (bridge)
5. Water gate, Superintendent's house
6. Sapan Waen (bridge)
7. Old freshwater well
8. Benjanareetum Garden well
9. Sakuntala Garden well
10. Phraya Ramrakop Resident well
11. Pond opposite of the Park

Appendix J: Water level marker

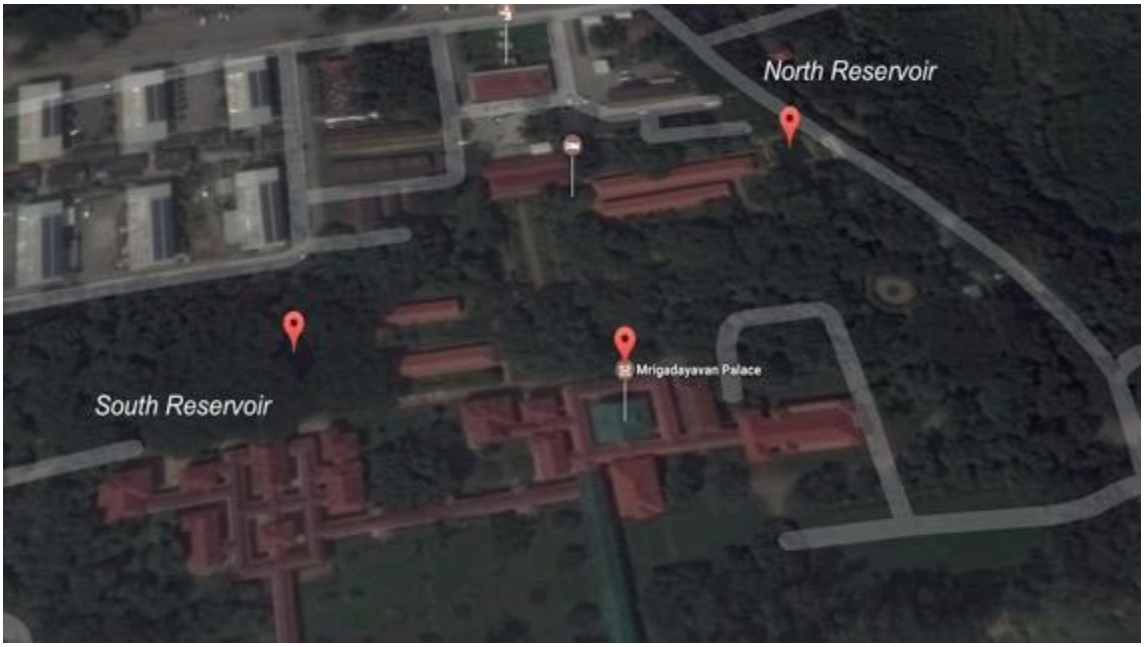
Top View Front View

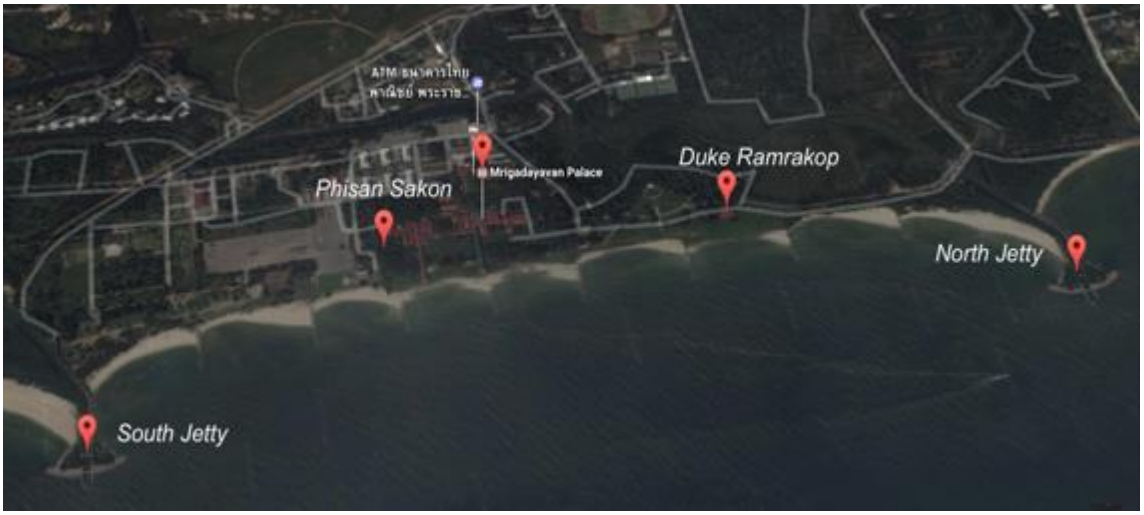
Appendix K: Maps of interview locations around the Cha-am district





Appendix L: Location of recommended sites for soil salinity testing





Appendix M: Locations of salinity testing done by the 8th Regional Environment Office

Appendix N: Image showing how fishermen anchor their boats near the jetty

Source: GISTDA