

Multidisciplinary Project Vietnam

Project Hué

*Report and field study on the water related problems and solutions in and around
the Cau Hai lagoon and the Tu Hien inlet, Vietnam
for the*

**Faculty of Civil Engineering
Delft University of Technology**

Authors:

Jochem Franken
Yoeri Jongerius
Tessa Peters
Luc Ponsioen
Orson Tieleman

Under the guidance of
Ir. Henk-Jan Verhagen, TU Delft
Dr.ir. Maurits Ertsen, TU Delft
Prof.dr.ir. Quang Tuan, Water Resource University



Department of Hydraulic Engineering
DELFT UNIVERSITY OF TECHNOLOGY

Abstract

The Tam Giang-Cau Hai lagoon system, lying in the Thua Thien-Hue province in central Vietnam, is affected by a tropical monsoon climate. This among others is the reason the Cau Hai Lagoon area has a long history of floods and other water related problems. Inhabitants are very dependent on the lagoon, as the main sources of income of people living in the region are fishing, agri- and aquaculture. The project goal has been formulated as follows:

Finding an economic as well as technical feasible solution to reduce the water related problems, specifically navigability, salt intrusion and floods, in and around the Cau Hai Lagoon and the Tu Hien inlet and thereby improving the economic development of the region.

Concerning flood risk, navigability and salt intrusion the inlet stability and size are important aspects. Using an echo sounder the bathymetry of the inlet has been measured. The measured size of the inlet was one of the input parameters for the hydraulic model that has been set up. This basic model of the Cau Hai basin system was made to test some alternative solutions for the Tu Hien inlet. The different solutions were simulated for five different scenarios. These scenarios include average dry season conditions, average wet season conditions and multiple extreme events. The output of the model for the different alternatives was used to rate the alternatives for a couple of criteria in a Multi Criteria Analysis. Other criteria of the MCA are qualitatively rated.

The most promising alternative proved to be the one including a jetty at the northern side of the Tu Hien inlet in combination with a bank protection at the other side. In this way a large part of the littoral drift is blocked, enlarging the equilibrium cross-section of the inlet. This in turn results in a better flood evacuation capacity, navigability and water quality in the lagoon. For both mentioned elements a preliminary technical design is made, resulting in the stone class needed for the armour layers, dimensions of the toe and characteristics of the filter.

Preface

This report is the result of an exploratory study towards a solution for the water related problems at the Cau Hai lagoon near Hué, Vietnam. During two exciting months we have been working at the Water Resource University which we would like to thank for having us.

Our project started with a warm welcome from the university and students. In the next two weeks we would conduct our literature study and make all the arrangements for the third, rather important week: the fieldtrip. Accompanied by mr. Trung we went to Hué to observe the situation with our own eyes. We interviewed local inhabitants, measured the water depth with an echosounder and explored the area on our motorbikes. Also our stay in the local hotel, very different from what we're used to, was an experience. All in all, the fieldtrip was very informative and resulted in a exciting week.

When we came back with the results, the real work could start: processing the data, building the model and making sure we covered everything we thought was necessary to come to a sound recommendation.

We would like to thank our supervisors at the TU Delft and the WRU: Henk-Jan Verhagen, Maurits Ertsen and Thieu Quang Tuan. Special thanks to Le Hai Trung who has helped us a lot by joining us during the fieldwork. Without him, we would have been hopelessly lost and couldn't have done so much work. Mr. Minh from the local dike department in Hue deserves special thanks for helping us on his free Sunday by translating the interviews with the locals for us. And of course, the data and football lessons we got from mr. Tung appeared to be very helpful as well. Finally Hai, Linh and Zang were great office-mates that helped us with translating interview forms, but most of all, they were really nice company and great friends during the project.

Enjoy reading!

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Chapter 1

Introduction

The introduction consists of three parts. First some information about the project itself and the course multidisciplinary project, followed by the background on Vietnam and finally the study area in Hué is presented.

1.1 The Multidisciplinary Project

This report is written for the course "CIE4061 - Multidisciplinary Project" at the TU Delft. For this course groups of 4 to 6 students with different study-backgrounds perform a research project at a foreign university. Our assignment was to perform an exploratory study to solve the water related problems near the Cau Hai lagoon, focusing on the Tu Hien inlet. This assignment was discussed by another group of Dutch students who preceded us last year, finding possible study cases in and around Hué.

1.2 Understanding Vietnam

To put this project in context, some historical background information on Vietnam is presented here.

1.2.1 Ancient Vietnam

It is believed that the first people in Vietnam originated from migrants coming from the islands of Indonesia. They settled on the banks of the Red River in the Tonkin delta, located in north Vietnam. The first organised societies developed in South-east Asia in the Neolithic period (8000-800BC). During this era the inhabitants of Vietnam lived in large family-based communities and spread from the mountains in the west to the coast in the east. Between 800-200BC the sophisticated Bronze Age Dong Son culture emerged which is famous for its large ritualistic drums, decorated with portrayals of the life in that time. The Muong people, living in the mountains in the west still use these drums.

1.2.2 The Chinese Period

From 200BC - 100AD, many Chinese immigrants were forced to leave their country due to the expansion of the Han Dynasty. They settled in Northern Vietnam, bringing modern technology, culture and language with them. The expansion of the Han Dynasty in Southern China continued, until in 111BC Northern Vietnam was officially colonized. At first, only trading routes were established and everyday life didn't change drastically for the Vietnamese people.

Initially the rulers of the Au Lac kingdom, as the Vietnamese state was called then, accepted the Chinese and cooperated. They thought cooperating with their invaders was a way they could maintain their power. The Chinese however expanded their influence by replacing officials and building dikes, roads, schools and temples, further increasing the Chinese population in Vietnam.

After this initially peaceful period, the rebellion among the Vietnamese people grew as the Chinese raised taxes and confiscated land as soon as peasants could no longer pay their taxes. In the period 200-950AD many eruptions of rebellion marked the era, some more effective than others. In the 6th century, Ly Bon revolted against the Chinese and established his own kingdom but after four years already, the Chinese retook the area. From the beginning of the 7th until the 10th century, the Tang Dynasty ruled China and Northern Vietnam, changing the name to Annam (Pacified South). This further interfering with the country raised the anger of the Vietnamese people and another period of many uprisings started. In 939, Ngo Quyen led the most successful rebellion. He defeated the Chinese army at the battle of Bach

Dang River and declared himself king of the new independent state (Dai Viet). After his death five years later, anarchy and civil war broke out in the country. The Chinese army was not strong enough to retake the country and Vietnam enjoyed a long period of political independence. The Chinese had ruled the country so long however that their thought and culture were (and still is) part of everyday life in Vietnam.

1.2.3 An Independent Vietnam

After twenty years of unrest in the country, a man with a peasant background called Dinh Bo Linh, declared himself King of Northern Vietnam. He tried to reunite the country with measures that would appeal to all people. He attempted to bring together Chinese and Vietnamese culture as well as their beliefs. His dynasty would not survive long however and in 980 it was overthrown by Le Dai Hanh, inaugurating the also short-lived Early Le Dynasty (980-1009).

The Ly Dynasty (11th-13th century) consolidated the Vietnamese independence. The first university, The Temple of Literature, was founded, agriculture was promoted and the administrative system was reorganized. Attacks from the Chams, Khmers and the Chinese were fended off. The emerging Vietnamese state fought the weakened Champa state and eventually seized their country, greatly increasing the territory for the Vietnamese. Now Dai Viet stretched from the Chinese border to the Gulf of Thailand. After the Ly Dynasty the Tran Dynasty took over for hundred years, after which the Ho Dynasty began. During this change in leaders the Chinese saw opportunity to take over Dai Viet and destroy all libraries and books. The Chinese reign was ended by Le Loi with the Lam Son uprising after which he declared himself emperor of the Later Le Dynasty (1428-1788), the longest dynasty in Vietnamese history.

At the end of the Later Le Dynasty, the country was divided between the Trinh Lords in the North and the Nguyen Lords in the South. Both of the families only cared about becoming wealthier and by 1739 there was no land left for the peasants, causing them to leave their farms to search for food. Many of them died at the time. Three brothers started the Tay Son Rebellion, liberating and reuniting the country and starting the Tay Son Dynasty. The bureaucratic system was changed and education was improved. Also rights for woman were improved, even some generals in the army were women.

Dissension in the dynasty made the French getting an easy way to interfere in

the battle, with their help, Nguyen Anh proclaimed himself Emperor. The old tax-system was revived and bureaucracy reached new heights as there were now 18 levels of officials. While for decades the Vietnamese people struggled to survive, the French saw an easy chance to colonize the country, beginning in the South.

1.2.4 The French Period

This period (1874-1954) is characterised by many uprisings and deaths. The goal of the colonization was economic profit, but Catholic missionaries tried to convert people to their belief as well. As a result, much of the French culture is still noticeable in Vietnam. The French improved the country by building infrastructure, this with the goal of increasing economic profit and not to improve life of Vietnamese peasants, which only had the choice of collaborating with the French or become a poorly paid labourer.

Nationalism and ideas of overthrowing the French grew among the Vietnamese, especially under students. At the time it was allowed for them to travel. The young Vietnamese intellectuals were attracted to Lenin's ideas of communism, in which he opposed to colonization and unfair landowning. The most famous of these young Vietnamese was Ho Chi Minh, who travelled to France, China and Russia.

During World War II, the Japanese overthrew the French. They surrendered quickly however, when two of their cities were hit by atomic bombs. The communist party Viet Minh, started by Ho Chi Minh, saw a good opportunity for them to gain power by making a deal with the Japanese: they were able to leave peacefully when they gave their weapons to the party in return. With these weapons the party could launch a successful revolution. Ho Chi Minh proclaimed Vietnam to be independent and created the Democratic Republic of Vietnam. Not everyone was happy with the ideas of communism however and the country was divided into a communist northern part and a non-communist south, led by Ngo Dinh Diem.

1.2.5 Civil War (1945-1975)

The division of the country led to a civil war. Ho Chi Minh had the support of the USSR and initially the Chinese, while Ngo Dinh Diem had the support of the U.S. wanting to control the spread of communism. The government of Diem was unpopular and was known to be corrupt. The communist ideas

gained support from the people in the south, leading to an uprising in which Diem was killed. The U.S. did not like this spreading of communist thought and went from advisors to participants in the war. In 1964 there were 200.000 American soldiers in Vietnam, that number would rise to 500.000 in 1968. The major turning point in the war was the Tet offensive, a large attack on nearly every city in the south, leaving the Americans shocked. The support of the American people dropped after promises of retreating were not met. In 1975 the U.S. finally withdrew. Quickly after their retreat the North took over Saigon, ending the civil war.

1.2.6 Since 1975

After the war the large differences between the North and South became clear. Especially for the South the new situation meant an enormous economic step backwards. Since the 90's the situation is improving, with foreign investments in many economic sectors. Currently, everyday life is changing for Vietnamese people, as the country tries to maintain a balance between Communist ideology and economic elasticity. [Michigan State University, 2014] [Lambert, 2012]

1.3 Hué: A troublesome area

1.3.1 History of Hué

At the times of the Nguyen Emperors (1802 - 1945), the city of Hué used to be the feudal and imperial capital of Vietnam. The city is located in the middle of Vietnam on the banks of the Huong river (also called 'Perfume River'). In 1945, the city played an important role during the 'August Revolution', when Communist forces overthrew the last Nguyen King and Sài Gon became the capital.

During the Vietnam War, Hué acted as an important battleground due to its central location. In the war many buildings were destroyed and more than five thousand people died.

At present, Hué is the capital of of the Thua Thien province, consisting of 9 districts. The old capital in Hué has been recognized as a World Cultural Heritage Site by UNESCO.

1.3.2 Severe Flooding

An event that clearly illustrates the problems that could arise in the area is the flood of 1995. In the morning of 7 October a flood entered the upper lagoon by the pump station at Phuoc Ly village. A dam under construction was ruined with the flood as well as houses, total costs were estimated at 3 million USD. [Bil, 1995][Thanh, 2011]

Four years later, the flood of 1999 changed the coastal morphology to an even larger extent. In early November, cyclone Eve caused extreme rainfall with a maximum of 120 mm/hour, causing floods in central Vietnam. The maximum storm surge level was 2.5 m and the peak flood river water level was 5.94 m, which is an historical record for the Huong river. In total, 600 people died, 255.300 houses were destroyed and 6.500 ha of crops were lost. The total damage was estimated at 100 million USD.

The flooding had a large impact on the coastal morphology, especially the tidal inlets. The cross-sectional areas of the three inlets were doubled or even tripled in size. Also a new inlet was opened when the dune barrier breached, destroying houses and isolating people. [Lam, 2007][Tuan, 2007]

When interviewing people around the lagoon, most of them remember the flood of 1999 and use it as an example of severe flooding, see picture 1.1. Furthermore, on the way to Tu Hien there was a marking on a pole standing next to the road showing the water level at that time, about 2 meters above ground level.



Figure 1.1: A fisherman showing the flood level of '99.

Chapter 2

Analysis

2.1 Location Analysis

2.1.1 Water system

The Tu Hien inlet connects the Cau Hai Lagoon to the South Chinese sea. The Cau Hai Lagoon is part of the Tam Giang-Ca Hai Lagoon system which spans over 70 km at the central coast of Vietnam. The largest city in the area is Hue with a population of about 330,000.

Not far landwards of the lagoon system a mountain range is present. Multiple, generally steep, rivers originate from these mountains and flow into the lagoon system, of which the Huong River flowing through Hue is the largest.

An overview of the total water system is given in figure 2.1. The O Lau and Bo River flow into the Tam Giang Lagoon. At the Thuan An inlet the Tam Giang Lagoon is connected to the sea. At this point the Huong River also flows into the South Chinese Sea. The Thuy Tu connects the Cau Hai Lagoon to the rest of the system. The Cau Hai Lagoon is connected to the sea by the Tu Hien inlet.

There are multiple dammed reservoirs in the mountain range, meant for hydro power generation, flood control and/or irrigation. The Truoi reservoir from which the Truoi River flows into the Cau Hai Lagoon is built for irrigation purposes.

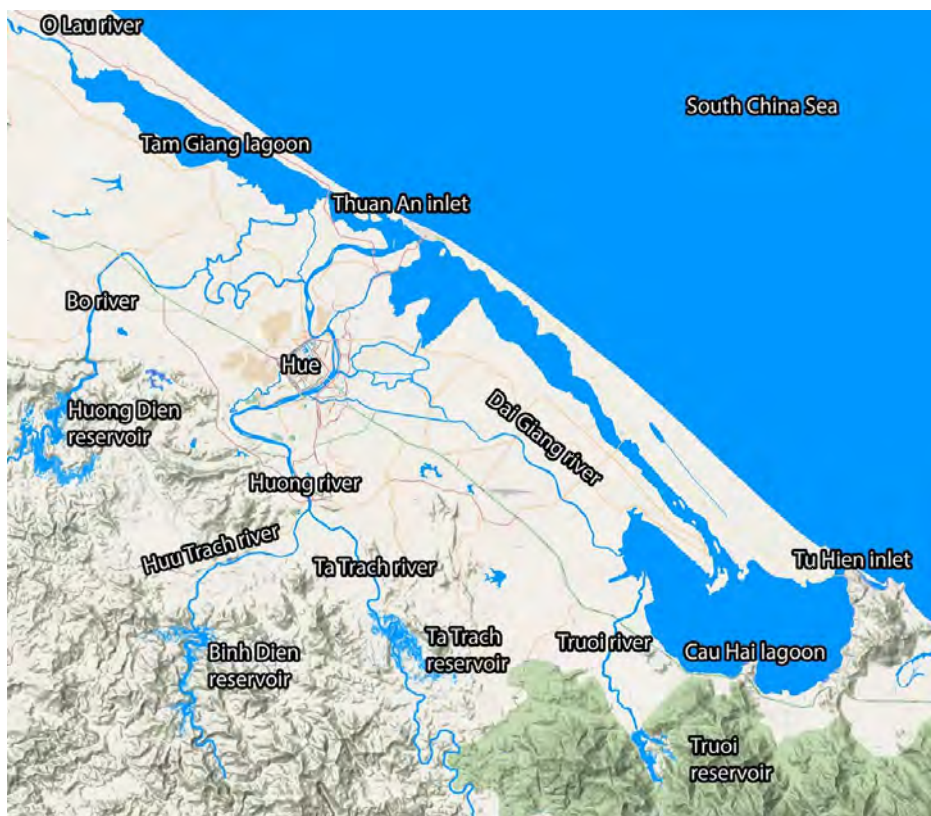


Figure 2.1: Tam Giang-Cau Hai Lagoon system

2.1.2 Land use

Based on satellite images and observations and interviews during the field visit, an estimation of the land use near the water system is made. An overview of the total area can be seen in figure 2.2. The whole water system is used intensively. Almost all available space at the waterfront is taken up by shrimp farms and other kinds of aquaculture. Large areas of the Cau Hai Lagoon are used for fishing and are occupied by fishnets. Both inlets are used by local fisherman to navigate to sea. At this moment the Thuan An harbour is more developed. An overview of the aquaculture usage of the Cau Hai lagoon is given in 2.3. This figure is drawn by a local fish farmer whom we interviewed in the context of the research.

A large part of the lagoon area is used by fish- and shrimp farmers. The area closer to the inlet contains mostly fish farmers, the area closer to the river mouths contains more shrimp farmers. This is due to the difference in salinity between these areas. The area closer to the inlet is more salty as it contains more sea water and is therefore better for the fish farmers. The shrimps prefer less salty water and will therefore grow better in the area close to the rivers. In the center of the lake one would notice a lot of fishing nets denoting also fish farming in this area. The connecting area between the northern lagoon and the Cau Hai Lagoon is almost completely covered by shrimp farmers. The combination of fresh water supply from the mountains and salt water supply from the tidal movement makes this area ideal for shrimp farming.

Most of the fishermen have two houses, one in the higher region and a very basic temporary one close to the inlet. They live the majority of the time in their houses near the inlet, only in the flood season they move to their other houses to stay safe from the rising water. During the floods fishing is not possible, in the dry season the fishermen fish 40 km offshore to catch among others tuna. In the wet season they fish near and in the inlet with smaller boats.

The fish and shrimp farmers and the fishermen live in the area close to the water. Further inland one finds local farmers who mainly cultivate rice, watermelon and cassava. The farmers live in the entire region around the lagoon, there is no specific area with predominantly farmers. The farmers still live in the area that is regularly flooded, despite the nuisances the floods are a great source of fresh water.

Along the Truoi River many agriculture is located, using the river for irri-



Figure 2.2: Overview of situation and activities near the water system

gation. It is therefore of importance that the Truoi River has enough water supply and low salt intrusion.

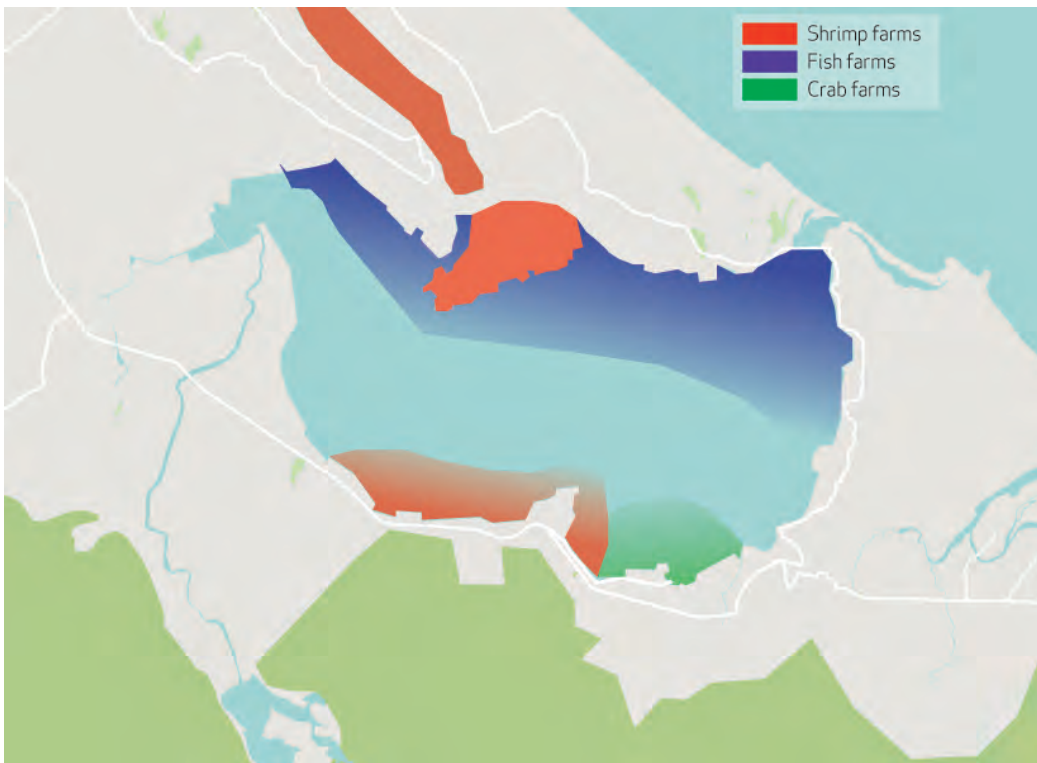


Figure 2.3: Overview of situation and aquacultural activities around the Cau Hai lagoon

2.2 Stakeholder Analysis

The Tu Hien inlet is situated in an area of multi-purpose use. To get an insight in the different processes and activities in the environment, the different stakeholders in the area should be indicated. There are a lot of people involved in the water related problems in the Cai Hai lagoon region. To reveal the conflicted interests and like-mindedness between the stakeholders, the most important ones are described.

Department of Dike Management and Flood Control

The Department of Dike Management and Flood Control is part of the Ministry of Agriculture and Rural Development (MARD). The department is responsible for managing the 128 km dike system. The central office of MARD is responsible for the policy and evaluation of the targets, while the provincial department allocates the funds based on proposals from the districts. The district level officers monitor the conditions of the dikes and evaluate the feasibility of new project proposals. Field engineers are responsible to organize participation on commune level. Dike management brigades maintain the dikes and construct the new ones planned. [Food and Organisation, 2003]

Besides the Department of dike management and flood control the ministry of agriculture and rural development supports the Integrated Management Of Lagoon Activities (IMOLA) project in the area, this project promotes the fishery livelihood by sustainable management of natural resources. Next to this project the government started in 2004 with different projects to develop the use of resources in the lagoon. This top down policy had several drawbacks starting with a lack of participation by the stakeholders, who use the resources in the lagoon. In the process implementing this new policy no influence of the stakeholders was taken into account. Two other problems occurred: the first is malfunctioning communication between the provincial planning office and the local resources users and the second is the poor sense of ownership by the users. Therefore poor compliance and cooperation were the result of this new policy. [Takahashi and van Duijn, 2012] The Vietnamese government is willing to improve the shore protection and develop the area but they lack financial resources, to execute the plans made [Pilarczyk and Nuoi, 2005].

Center for Social Research and Development

The Center for Social Research and Development (CSRD) is an NGO founded

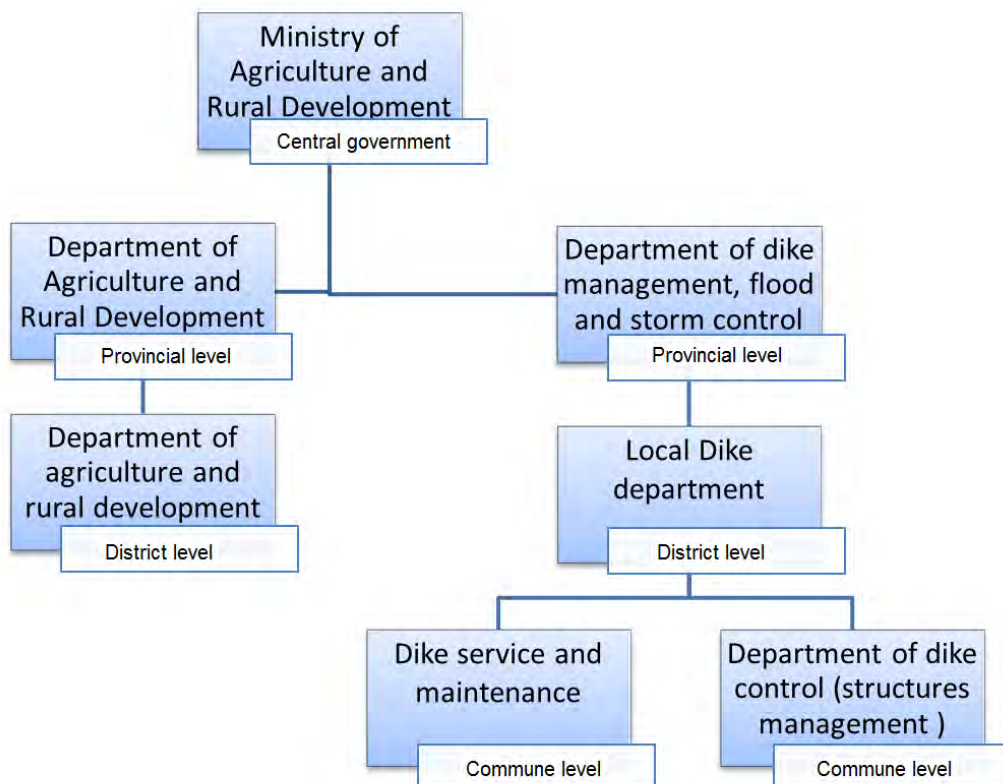


Figure 2.4: Hierarchical structure dike department

in 2008. Their main objective is to support the development of rural communities. The CSRD is aware of the communication problems between government and the minorities, therefore they try to create the opportunity for the communities of fishermen and farmers to cooperate and raise their voice in governmental projects.

Besides the governmental changes the construction of the three hydro dams in the province is threatening the farmers. Water scarcity for irrigation during the dry season occurs often and despite the promise of the stock company to empty the reservoirs before the wet season, unexpected floods occur regularly.

Hydropower Joint Stock Company

Three hydrodams owned by the Joint Stock Company are situated in the Thua Thien Hue province. Two of them are part of the two upstream rivers of the perfume (Huong) river. The Binh Dien reservoir in the Huu Trach river and the Ta Trach reservoir in the Ta Trach river. Besides these two dams the third Huong Dien reservoir is located in the Bo River, the most north river in the province. On yearly basis this plant delivers 700GWh to the Vietnamese national grid[Kable, 2014]. The small Truoi reservoir in the south near the Cau hai lagoon is owned by the ministry of agriculture and rural development.

Inhabitants

The city of Hue and its surroundings count over 330.000 inhabitants. The density in this area is quite high with 4,763 people per km^2 . 4.3% Of the population lives under poverty line. The population grows every year with 0.98 % and the GDP is 1,500 USD/person/year. Most of the people live in the low lands on a strip of 25 km between the sand dunes and the mountains in the west [Sang et al., 2012].

The Cau Hai lagoon lies within the Phu Loc district, the district covers $720.9km^2$ with population density of 187 people/ km^2 (see appendix A.2.2). It has sixteen communes and two towns. Phu Loc covers 34,000ha of forest, 12,000ha of Cau Hai lagoon and about 20 km coast line. The roads are improved over the last decade and highway 9 has a direct international connection with Laos. The main train route of Vietnam crosses the district, giving good conditions for economic growth. Phu Loc is one of the biggest rain centers of Vietnam with an average annual rainfall more than 3500 mm.

This area is subject to climate change and one of the most affected areas by cyclones according to IPCC, causing a serious threat to the inhabitants of this area and even a bigger challenge to give these residents a safe environment to live [Parry et al., 2007].

Agriculture - Farmers

Paddy rice is the main cultivated crop in the flat lowlands: 91% of the food output and 44% of the gross agriculture output in the area. Only 6-7 % is irrigated, mostly by water from the rivers and the 6 dams in the region [Tran and Shaw, 2007]. For agricultural purposes 57,000 ha is used in the area of which 25,900 ha is irrigated using the Ta Trach dam. As most people in the province live within 25 km from the sea, this area is densely populated and cultivated.

The quality of the water in the region is important for the agricultural sector, pollution and salt intrusion threaten the water supply. The rice farmers often suffer from droughts in the area, The second harvest often loses 30% because of the droughts. It is necessary for the farmers to have sufficient access to fresh water for irrigation in the dry season. Next to the droughts, the storms and typhoons threaten this area causing inundation of the lowlands behind the dunes every year. Saline water makes the fields unusable for agriculture for several months, causing a big problem for the farmers.

Aquaculture - Shrimp farmers

Shrimp farming is the largest percentage of the aquaculture in Vietnam. In the Thua Thien Hue region mostly tiger shrimps are grown. Between 1995 and 2004 the shrimp farming in the lagoon increased fast. After that, it declined due to water pollution linked to the intensification of shrimp farming in the lagoon [Truong et al., 2014]. As aquaculture is a big part of the economy and lives of people, the quality of the water for cultivation of the shrimps need to have the right salinity and diffused oxygen. A lower diffused oxygen rate indicates an increased amount of organic pollution (BOD) this occurs close to the large shrimp farms, which can harm the production.

Fishery - inland and on sea

Fishery provides 4 % of Vietnam's GNP. Estimated is that 100.000 people rely on aquaculture and captive fishery as their main livelihood in the Cau Hai Lagoon [Tuyen et al., 2010]. In the Cau Hai Lagoon fishing is done by stake traps. These traps influence the quality of the water in the

lagoon[Marconi et al., 2010]. Next to fishery in the lagoon the Tu Hien inlet is used for navigation to sea by fishermen. During the dry season fishermen fish up to 40 km offshore for tuna. The inlet is very shallow during the dry season, the navigational depth is sometimes limited to 1 m [Marconi et al., 2010]. During the wet season fishermen catch fish in the inlet during upcoming tide.

Tourism

Tourism is a significant part of the modern economy of Vietnam. Hue is one of the popular destinations of central Vietnam. Most of the tourist activity is concentrated in the city centre of Hue. Around the Cau Hai Lagoon little tourist activity is yet present, except for a single luxury resort at the south side. Phu Loc and the lagoon are on the route between the centre of Hue and the popular city of Hoi An. Although the tourist sector is not large at the moment around the lagoon, there is potential for future development.

Chapter 3

Problem definition and project scope

The coastal plains in the Thua Thien-Hue province in central Vietnam suffer from water related problems. The majority of these problems occur around the Tam Giang-Cau Hai Lagoon system which connects to the South China Sea through two inlets named Tu Hien inlet (in the south) and Thuan An inlet (in the north).

Some of the water related problems around the lagoon are caused or influenced by the inlets, who have proven in the past to be unstable. In order to guarantee decent navigational depth in the Thuan An inlet some structural measures have been taken in the form of jetties. [Lam, 2002]

The other inlet, the Tu Hien, seems to behave differently compared to the past. After the 1999 flood a new inlet opened and the connection to the old inlet closed. No closure has been noticed in the new inlet since then but there is still some spit growth and the inlet becomes narrower. The inlet does not seem to migrate large distances any more. [Biezen, 2014]

Although the structural measures, which were taken at Thuan An, and the new behaviour of Tu Hien inlet, the lagoon system still suffers from water related problems.

3.1 Water related problems

The most important water related problems around the lagoon are [Lam, 2002]:

Blocking navigation

Narrowing and migration of the inlet may cause problems for vessels passing the inlet. For example for ships seeking shelter against typhoons these problems may have severe consequences. In the Cau-Hai lagoon this is mainly a problem for fishermen since they use this inlet to reach the sea during the dry season.

Flooding

Due to shallowness of the lagoon and narrowing of the Tu Hien inlet the flood evacuation capacity of the lagoon is reduced. This results in an increased possibility of flooding due to high river discharges and a higher inundation depth during floods. The sand mining by local inhabitants can also increase the flood risk in the region because it weakens the dunes. Flooding of the lagoon area has large consequences such as fatalities, economic damage and environmental pollution.

Negative effects on the ecosystem

Changing the cross-sections of inlets also changes the characteristics of the lagoon. The narrowing of the inlet influences the quality of the ecosystem in the lagoon. When the inlet is becoming smaller the flushing capacity of the tidal prism, which reduces pollution in the lagoon, decreases. This has adverse effects on the water quality and can threaten the water supply in the region.

Negative effects on aquaculture

Changes in salinity and water quality have large influence on the cultivation of prawns and clams in the lagoon. Large changes in salinity may cause loss in revenues of aquaculture because of mortality of the species in the aqua farms. Reversely high production rates of shrimps in the lagoon can influence the water quality, which can possibly back fire on the shrimp production and the yield of the fish farms.

Negative effects on agriculture

Salt intrusion and pollution have adverse effects on agriculture in the lowland areas of the Thua Thien-Hue province when salty or dirty water overflows the cultivated fields. Because of this the farmers might compensate the effect by using more fertilizer, which is in turn not desirable as the excessive use of fertilizer damages the quality of the water supply even more.

Erosion

The opening of the new inlet in 1999 caused quite large changes in the current around the inlet resulting in large beach erosion at some location. At some spots the erosion is structural and the stability of the roads and houses are in danger. For example the erosion line at the down-drift side of the inlet is only 25 meters from the main road.

3.2 Social problems

Besides the technical problems, there are a lot of social problems from which the population suffers, mainly: bad sewerage, lack of fresh water and electricity systems. For many local people these problems have more priority. According to [Pham, 2014] important social problems in the region are:

- The knowledge of some people about health is limited;
- Poor households lack facilities to keep them warm in winter;
- There is no collective waste collection system;
- Some households still lack sanitation;
- Lack of hygiene knowledge and food preservation safety.

It should be mentioned that human influence on the system can also pose problems for the area. For example the sand mining by locals can disturb and erode the dunes. Although currently this is a minor issue [Tung, 2001], it can pose a larger problem in the future. Also the land area used for aquaculture has increased in recent years [Trung Tiên, 2013], if this trend continues it might have negative effects on the water quality in the lagoon.

3.3 Climate change related problems

Sea level rise is a phenomenon with a high uncertainty, but with a large effect on the coastal system. According to [Smyle and Cooke, 2014], Vietnam is expected to be very vulnerable to a rising sea. This is caused by extensive deltas in combination with the large amount of people living there. An increase of one meter in mean sea level could result in a loss of 7% of agricultural land.

Another aspect of climate change is the changing frequency of typhoons and heavy rain. It is expected that the wet and dry seasons both become more extreme, each bringing its problems: higher and more irregular river discharge, an increased storm damage and decreased food production [Smyle and Cooke, 2014].

3.4 Project focus

The Thua Thien-Hue province is influenced by population growth, climate change and sea level rise. The original high precipitation rates and quick run off in combination with the predicted climate changes will have a large impact on this particular area [IPCC, 2001]. In this crowded delta, floods and typhoons occur regularly causing large damages and thus setting back economic development. The project will focus on the natural process while taking into account human actions to interfere these processes. In this area the two inlets, Tu Hien and Thuan An, are known for their instability, caused by the low tidal prism combined with a large littoral drift. Most recent studies [Neut and et al., 2013b] [Berchum, 2014] have focused on the Thuan An inlet because of its location near the Huong River and its higher navigational meaning to fishery and tourism. This inlet is already intervened with by human actions. As in fact this is a combined system consisting of a lagoon with two inlets and multiple rivers discharging to this lagoon, the flood risk is not solely based on the two inlets.

No structural solutions have been applied yet to the most southern inlet of the system, the Tu Hien inlet. The scope of this project is therefore set on that inlet, which is connected to the Cau Hai lagoon. The lagoon is mainly used for aquaculture and fishery, the inlet is used by fishermen for navigation. In the west two smaller rivers, the Truoi river and the Dai Giang river, debouch in the lagoon. Upstream the Truoi river a reservoir stores fresh water for irrigation. During the wet season water is stored here, which will be released during the dry season for the agricultural sector.

3.5 Project goal

The main goal of the project is:

Finding an economic as well as technical feasible solution to reduce the water related problems, specifically navigability, salt intrusion and floodings, in and around the Cau Hai Lagoon and the Tu Hien inlet and thereby improving the economic development of the region.

Chapter 4

Theoretical background

4.1 Introduction

In this chapter some theoretical background will be given to clarify the calculations and to introduce the relevant processes in the lagoon. First, the processes of a basin with a single inlet system are explained and later some principles of a double inlet system will be described. Third, the salinity intrusion processes in deltas will be described followed by some background on chemical and biochemical water quality parameters.

4.2 Single inlet basin

The description of the single inlet system is mainly based on [Stive and Bosboom, 2013].

4.2.1 Escoffier

The surface area of the basin in combination with the tidal range form the *tidal prism*: the volume of water that flows in or out of the system in one tidal cycle. The tidal prism is an essential element in the determination of the stability of a tidal inlet. The second important element is the *littoral drift*. The littoral drift brings a certain amount of sediment into the inlet, which has to be flushed out by the tide.

Escoffier was the first to study the inlet stability in detail. He related u_e (the entrance flow velocity) to the hydraulic radius of the channel R , the cross-sectional area A and the tidal range Δ . All other variables become more or less constant. The variables are combined in one single variable x , of which u_e then varies as a function.

Escoffier introduced a method to determine the stability of the inlet, the so called *Escoffier curve*, which is illustrated in figure 4.1. Herein 'x' marks the variable as defined by Escoffier and u_{eq} marks the equilibrium velocity in the entrance.

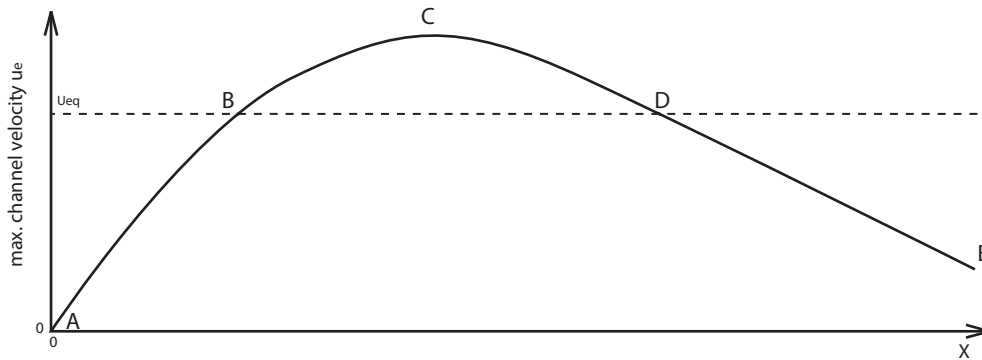


Figure 4.1: Escoffier curve, channel velocity geometry relationship

The intersections between the curve and the dashed line indicate equilibrium points. When the channel dimensions relate to a point that is placed on section A-B, the inlet will close. The channel is in that case too small and the friction too high to maintain itself. The channel will close by a natural process, therefore section A-B is unstable. If the channel dimensions place it on section D-E the channel will also become smaller since the low flow velocity causes accretion in the channel and therefore a smaller channel cross section. While the channel becomes smaller the flow velocity in the inlet increases, moving towards D until this point is reached. Finally, when the point is placed on section B-C-D, erosion in the channel takes place until point D is reached. Thus point D represents a stable equilibrium situation in the inlet channel. While point B represent an unstable equilibrium situation.

The velocity in the cross-section is approximated by a sinusoidal motion of which \hat{u}_e is the velocity amplitude. Then we can relate the maximum cross-sectionally averaged entrance velocity $u_e = \hat{u}_e$ to the tidal prism P . The tidal

prism is equal to the time integral of the inflow during flood or to the outflow during ebb, and is therefore equal to:

$$P = \int_0^{\frac{1}{2}T} A_e u dt = \int_0^{\frac{1}{2}T} A_e \hat{u}_e \sin\left(\frac{2\pi}{T}t\right) dt = \frac{TA_e}{\pi} \hat{u}_e \quad (4.1)$$

Leading to:

$$\hat{u}_e = \frac{\pi P}{A_e T} \quad (4.2)$$

To determine the location of the stable equilibrium point on the Escoffier curve, and thus the equilibrium cross-section, research has been done for more than 70 years. Starting with LeConte (1905) followed by O'Brien (1931), O'Brien (1969) and Jarrett (1976). This has led to the general form of the empirical relationship for the equilibrium cross-section based on the tidal prism as follows [Stive and Bosboom, 2013]:

$$A_{eq} = CP^q \quad (4.3)$$

In this equation A_{eq} is the minimum equilibrium cross-section of the entrance channel (throat) measured below mean sea level in m^2 ; P the tidal prism, often the spring tidal prism, in m^3 ; and C and q are empirical parameters obtained from observation data.

The coefficient C is not dimensionless, it's dimension is [1/L]. There are several researches done on the value of C and q that vary with the type of inlet. For instance the Dutch Waddensea inlet gives other values than the Hue inlet in Vietnam. The coefficient q is order of magnitude 1. In metric units, C is in the range 10^{-4} to 10^{-5} [Stive and Bosboom, 2013]. [O'Brien, 1969] showed that for 28 US entrances $C = 4.69 * 10^{-4}$ and $q = 0.85$ are best-fit values applicable to all entrances when P is measured in m^3 and A in m^2 . However, when limited to 8 non-jettied entrances he derived $C = 1.08 * 10^{-4}$ and $q = 1$ as best-fit values.

By comparing the littoral transport into the inlet to the flushing capacity of the tidal motion, Van de Kreeke [Stive and Bosboom, 2013] found an expression for coefficient C as follows:

$$C = \frac{MT^n}{k\alpha^m \pi^n} \quad (4.4)$$

With M the littoral drift, T the tidal period and k, α coefficients. According to [Stive and Bosboom, 2013] the values for m and n are in the order of 1 and 3.

4.2.2 The (S, φ) -curve

Bulk longshore transport is proportional to [Stive and Bosboom, 2013]:

$$S \propto H_{s,b}^{2.5} \sin 2\varphi_b \quad (4.5)$$

The power 2.5 is explained as a sediment load proportional to $H_{s,b}^2$ transported by a wave-induced longshore current velocity proportional to $\sqrt{H_{s,b}}$. Both $H_{s,b}$ and φ_b depend on the offshore wave height, wave period and angle of incidence φ_0 .

The relationship between angle of incidence φ_0 and longshore transport S is a central concept in shoreline modelling. It gives the transport as a function of the wave angle for a given set of wave conditions. As figure 4.2 demonstrates, the maximum longshore transport occurs for an angle somewhat smaller than 45° . Although the term $\sin 2\varphi_0$ in equation 4.5 would suggest the maximum would be at 45° , this is not the case since for larger values of φ_0 the waves break at smaller water depths, reducing c_b [Stive and Bosboom, 2013](section 5.2.3). This slightly affects the angle at which maximum occurs. The longshore transport reduces to zero for 0° and 90° . A φ_b of 0° implies normally incidence waves and hence only wave stirring and no longshore current.

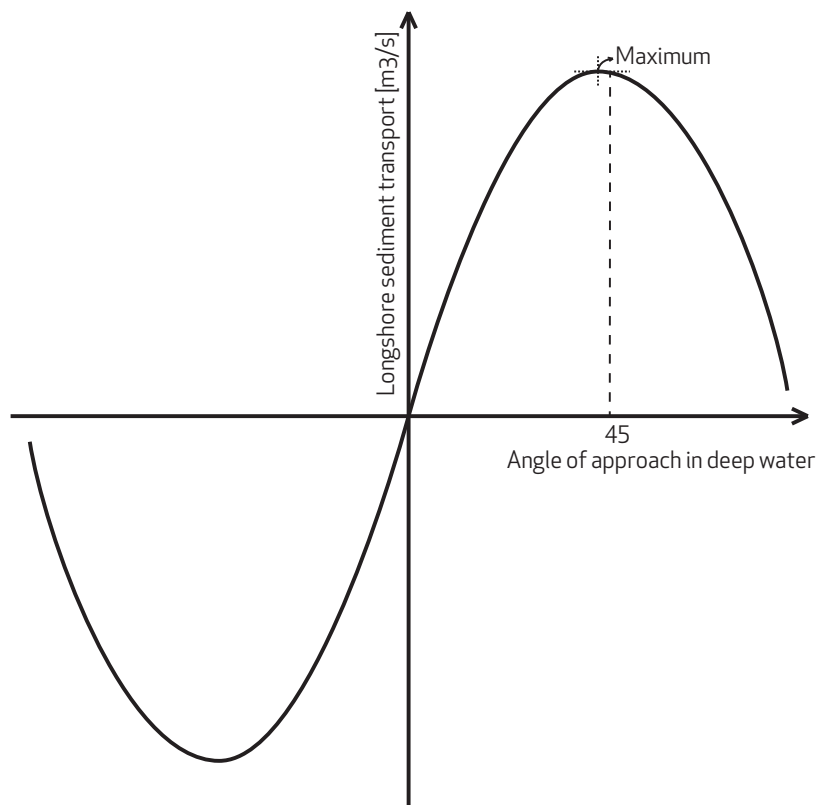


Figure 4.2: Longshore transport of sediment explained in an $S-\varphi$ curve.

4.3 Double inlet basin system

The stability of a two inlet bay system is more complicated. Borsje has schematized such a system to investigate this stability based on the known escoffier curves [Borsje, 2003].

Roughly distinction is made between two types of double inlet systems: Those with partition in between and those without partition. The difference is illustrated in figure 4.3 and 4.4.

The equation of motion of a single-inlet system is as follows [Borsje, 2003]

$$M \frac{dQ}{dt} = h_0 - h_b + \chi \frac{|Q|Q}{gA^2} \quad (4.6)$$

In which M is a local acceleration term; χ represents the losses in the in- and outlet. Q is the channel discharge; A the cross section of the channel; g the gravitational acceleration term; and h_0 and h_b the initial depth and the depth in the bay.

For a double-inlet system the following holds:

$$Q_1(t) + Q_2(t) = A_b \frac{dh_b}{dt} \quad (4.7)$$

Here Q_1 and Q_2 represent the discharge in both inlets; A_b the surface area of the basin and h_b the surface elevation of the basin.

Both equations of motion of the inlets are:

$$M_1 \frac{\delta Q_1}{\delta t} + W_1 Q_1 = h_{o1} + h_b \quad (4.8)$$

$$M_2 \frac{\delta Q_2}{\delta t} + W_2 Q_2 = h_{o2} + h_b \quad (4.9)$$

Here W_i is a friction factor, defined as:

$$W_i = -\frac{8}{3\pi} \chi_i \frac{\hat{Q}_i}{gA_i^2} \quad (4.10)$$

And M_i is an inertia factor, defined as:

$$M_i = \frac{Mass_i}{gA_i} \quad (4.11)$$

Unfortunately the amplitude of Q is yet unknown and needs to be iteratively determined.

We now have a system of 3 equations with 3 unknown parameters Q_1 , Q_2 and h_b . By iteration the parameters may be solved. To start the calculations the start values for Q_1 and Q_2 should be positive.

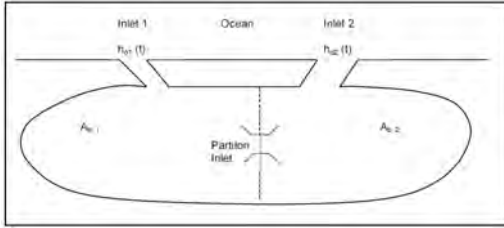


Figure 4.3: Double inlet system with partition

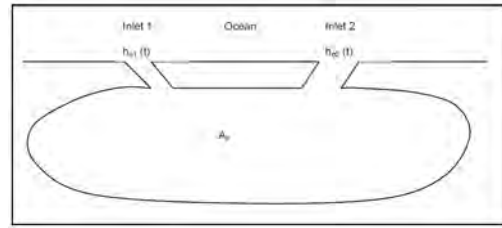


Figure 4.4: Double inlet system without partition

4.4 Salinity intrusion

For prediction of the salt water intrusion length in the lagoon several predictive models are derived from experiments and field studies. The models need to be directly implementable on measurements like geometry, fresh water and tide [Savenije, 1993].

Rigter (1973) based his model on experiments with constant cross-sections. He derived the following empirical relation for the salinity intrusion length in an estuary:

$$L^{LWS} = 1.5\pi \frac{h_0}{f} (F_d^{-1} N^{-1} - 1.7) \approx 4.7 \frac{h_0}{f} F_d^{-1} N^{-1} \quad (4.12)$$

Where h_0 is the tidal average depth at the estuary mouth, f is Darcy-Weisbach's roughness, N is Canter Cremers' estuary number defined as the

ratio of fresh water entering the estuary during a tidal cycle to the flood volume of salt water entering the estuary over a tidal cycle, P_t . Hence:

$$N = \frac{Q_f T}{P_t} = \frac{-Q_f T}{A_0 E_0} = \frac{\pi}{1.08} \frac{-Q_f}{A_0 v_0} = \frac{\pi}{1.08} \frac{-\mu_0}{v_0} \quad (4.13)$$

Where Q_f is the fresh water discharge and $\mu_0 = \frac{Q_f}{A_0}$ is the fresh water velocity at the estuary mouth, both of which are negative since the positive x direction is taken upstream; A_0 is the cross-sectional area at the estuary mouth and T is the tidal period. The flood volume can be approximated by the product of A_0 and the tidal excursion E_0 at the estuary mouth: $E_0 = 1.08 v_0 \frac{T}{\pi}$. where v_0 is the tidal velocity amplitude at the estuary mouth [Savenije, 1993].

$$F_d = \frac{\rho v_0^2}{\Delta \rho g h_0} = \frac{\rho}{\Delta \rho} F \quad (4.14)$$

Where F_d is the densimetric Froude number with $F = \frac{v_0^2}{g h_0}$ is the Froude number, ρ the density of the water and $\Delta \rho$ is the density difference over the intrusion length. Fischer (1974) in a discussion on Righers results proposed the following formula based on the same data, because it is observed that N and F_d are much smaller than unity, the number 1.7 in Righers equation can be disregarded and that Righers intrusion length is inversely proportional to N and F_d . Fischer:

$$L^{LWS} = 17.7 \frac{h_0}{f^{0.625}} F_d^{-0.75} N^{-0.25} \quad (4.15)$$

The degree of mixing largely depends on the flood number N , also called the Canter-Cremers number. roughly it can be assumed that if:

- $N \geq 1.0$: the estuary is stratified
- $0.1 < N < 1.0$: estuary is partly mixed
- $0 < N < 0.1$: the estuary is well mixed

Figure 4.4 shows the three types of mixing in an estuary with limited gradient. The Cau Hai has a limited gradient and during the wet season the Canter-Cremers number is between 0.2 – 0.3 therefore the lagoon is partly mixed while in the dry season the Canter-Cremers number is much smaller and the lagoon can be assumed as completely mixed [Savenije, 2005].

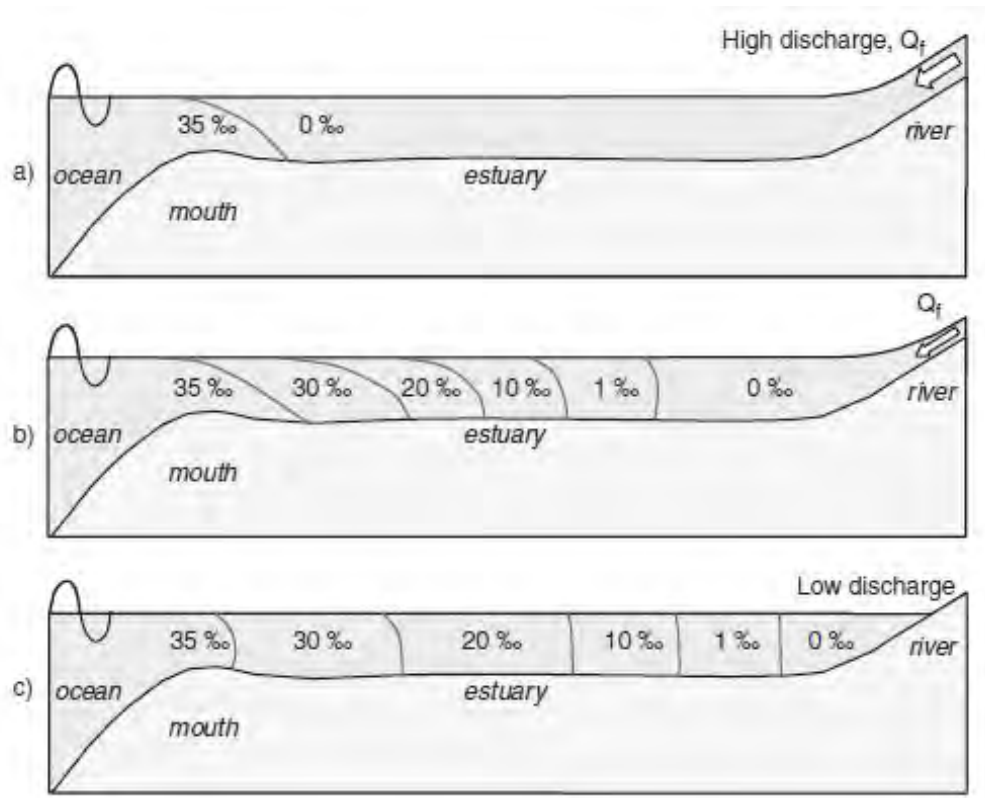


Figure 4.5: Longitudinal distribution of the salinity for a stratified estuary (a), a partially mixed estuary (b), and a well-mixed estuary(c)

4.5 Water quality

Water quality influences the vitality and health of the environment. The influence of the different parameters are described in this section.

4.5.1 Eutrophication and dissolved oxygen depletion

Eutrophication and depletion of dissolved oxygen are the main focus of concern in the Cau Hai region [Pham et al., 2010]. Eutrophication is caused by high levels of Nitrogen and Phosphorus. One of the consequences of Eutrophication is large daily variations in dissolved oxygen. This can lead to low levels during the night with mortality of fish as a result. Another result is the dead of plankton and weeds that settle at the bottom creating high sediment oxygen demand, which again results in low values of dissolved oxygen.

4.5.2 Nitrogen

Nitrogen is an important element for organisms. It is used to build proteins and genetic material. Nitrogen is mostly the limiting growth factor in moderate to highly saline environments such as coastal areas. The shortage is caused by the shortage of dissolved iron, which normally reacts with the high sulfate content in sea salt. The main sources of nitrogen to surface water are wasteloads of organic nitrogen, ammonia and nitrite and nitrate, or by run-off and seepage of groundwater[Baptist, 2006]. The maximum allowed Nitrogen concentration in surface water for the Netherlands is 50mg/l [van State, 2009].

Nitrogen is formed in different forms:

- Nitrogen gas N_2 dissolved in water equilibrium with the atmosphere
- Ammonium nitrogen NH^+ product of the decay of organic material
- Nitrite NO_2^- formed by nitrifying bacteria, often transformed to nitrate NO_3^- .
- Organic N, either dissolved or particulate.

4.5.3 Phosphorus

Phosphorus can absorb easily to sediment particles. Settling of the sediment particles diminishes the available phosphorus concentration for growth. There are two main sources of phosphorus to surface water, one is erosion of phosphate rock and igneous rocks [Baptist, 2006]. The second source is municipal waste waters. The guideline for phosphorus in surface water is 0.3mg/l [van State, 2009].

- Inorganic particulate phosphorus, or in a complex with carbonate, iron or aluminium.
- Organic phosphorus, in living organisms.
- Dissolved phosphate $PO_4^{3-} - P$.
- Dissolved organic phosphorus, originating from death organic matter.

4.5.4 Chemical oxygen demand and biochemical oxygen demand

BOD and COD stand for organic carbon and other organic substances that demand oxygen if decomposed to their inorganic form. Organic material is digested by heterotrophic bacteria. These create new bacterial biomass using the energy that is available in organic matter and consume oxygen. It was found that the decomposition goes in two steps, the two phases of oxygen consumption. The first starts immediately and the second phase after 6 to 8 days [Baptist, 2006]. The first phase is the oxidation of the organic carbon, the carbonaceous BOD. The oxygen consumed after 5 days is called the 5 day BOD or BOD_5 . The total phase takes about 20 days to complete. The second phase is oxidation of oxidizable nitrogen, the nitrogenous BOD. To avoid long periods of laboratory studies COD was introduced including the carbonaceous and nitrogenous BOD and some other oxygen demands.

If a load of BOD or COD is released in water, over time it will be broken down and oxygen in the water will be consumed in the process. The normal surface water concentration for oxygen is between $8 - 10\text{ mg/l}$. If 1 mg of BOD or COD is released to the water, 1 mg of oxygen will be consumed for decay [Baptist, 2006]. Dutch limitation for surface water on COD and BOD are set respectively at 40 mg/l and 6 mg/l [van State, 2009].

Chapter 5

System Description

There has been done quite some research into the Tam Giang-Cau Hai double inlet lagoon system in the past. However due to the highly dynamic behaviour the exact layout changes quickly. As described earlier, the flood of December 1999 has had a significant impact on the system. The Hoa Duan inlet was created during that flood, and was closed again in 2002.

As shown before, the tidal inlets have a cyclic behaviour over the year as well as over a longer period of about 9 years. The yearly variant is clearly characterized by a dry season, from January to August, and a wet season, from September to December. Although the short period of the wet season 70 percent of the yearly precipitation occurs in those months [Tung, 2001].

During the wet season high discharges occur, resulting in strong currents with high velocities in the inlets that scour the channels and flatten the sand bar in the ebb deltas and move sediment further offshore [Lam, 2008]. The inlet channel is re-orientated by the dominant direction of the river floods.

In case the floods are very extreme a breach can occur in the barrier islands, creating a new inlet like in 1999. As this cuts off local communities and increases the siltation of the existing inlets, this is considered an undesirable event. On the other hand the new breach might lower the water levels in the lagoon during the extreme event itself, possibly decreasing damages and mortalities.

The natural sediment bypassing is interrupted by the river floods as well. After the river flood, due to the increased inlet area the tidal currents are too weak to flush out the sediment transported to the inlet. After the wet season, this causes erosion on the adjacent coasts from about January to

March, when strong waves attack the coast. Due to waves the bars in the ebb tidal delta are built up and move landwards again [Lam, 2008].

When the rate of sediment transport from the coast to the inlet channel and ebb deltas decreases, the beaches are restored by longshore and onshore sediment transports. After the ebb delta has been built up, the sand bypassing continues until the wet season when the cycle repeats.

5.1 History of the Tu Hien inlet

First, the development of the Tu Hien inlet in the past will be described based on: [Lam, 2009], [Lam, 2008] and [Tung, 2011]. The more recent behaviour (the last fifteen years) is described in more detail. For this description also [Biezen, 2014], satellite images [Goslee, 2011] and the findings of the field-work are used.

5.1.1 Historical description

Before the year 1404 the Tam Giang - Cau Hai lagoon system had only one inlet, namely the Tu Hien inlet. At that time the Tu Hien inlet was part of the navigation route to the city of Hue. The inlet at that time was much larger because more water flushed the inlet. Around 1404 a new inlet was formed named the Thuan An inlet. As a consequence of the new opening the cross section of the Tu Hien inlet started to decline because less water was flushing the inlet. Because of this behaviour the Thuan An inlet grew in size and became the most important inlet for navigation. Since then the inlet is migrating between the places Vinh Hien and Loc Thuy in a morphological cycle, see figure 5.2. The migration towards Loc Thuy is caused by sand spit forming in the northern border of the inlet. The migration back to Vinh Hien is caused by a breach of the sand spit during an extreme event. The known phases of the two locations and their state in history are displayed in a time line, see figure 5.1.

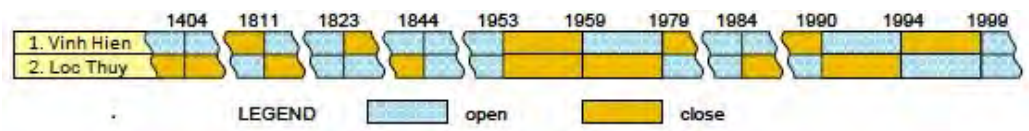


Figure 5.1: States of the different locations of the Tu Hien inlet[Lam, 2008]

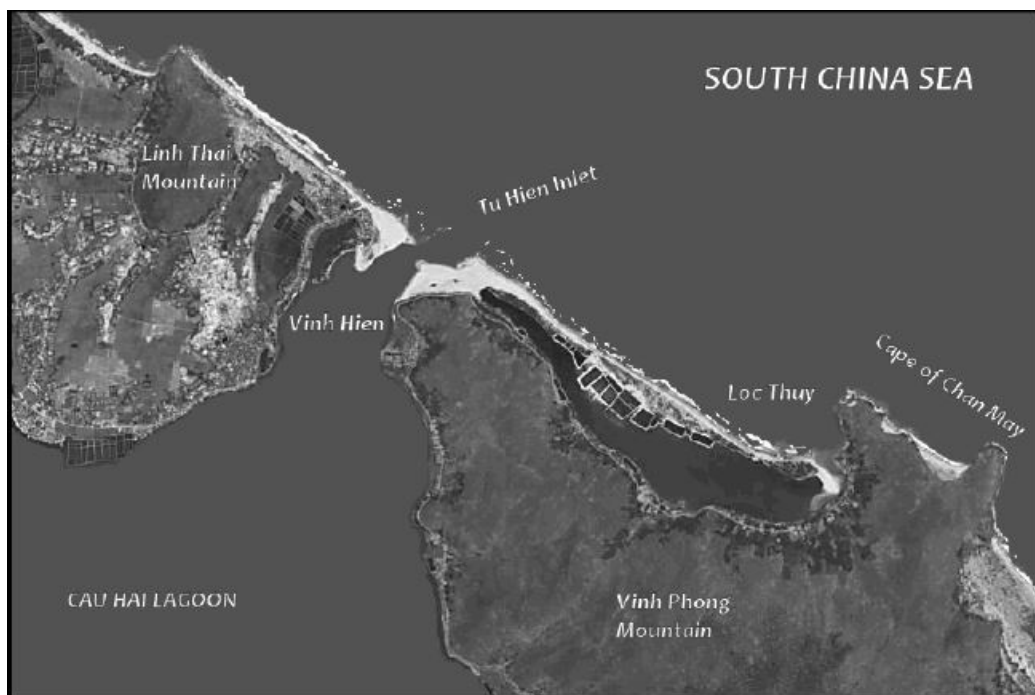


Figure 5.2: Tu Hien inlet area[Lam, 2009]

5.1.2 A more recent description

The last two morphological cycles of the Tu Hien inlet occurred between 1990 and 1994, and after that between 1994 and 1999. See satellite images in figure 5.3. The breach in the last morphological cycle was caused by the severe flood of November 1999. From 1999 on the behaviour of the inlet started to differ from the previous periods. In the last fifteen years, no closure of the inlet nor large inlet migration has taken place. The inlet of Tu Hien is thus already situated at the Vinh Hien location for fifteen years, see figure 5.4. There are signs of spit growing at the up-drift side, erosion on the down-drift side and narrowing of the inlet during the dry season, but no closure has taken place. It seems that at the moment the narrowing during the dry season is in some kind of balance with the flushing during the wet season. This doesn't directly implicate that closure or migration could not happen in the near future. From the satellite images, figure 5.3, it seems that the small lagoon which used to connect Cau Hai lagoon with the opening near Loc Thuy is closed off, and has become a lake. During the fieldwork it was found that this opening was actually still open, see figure 5.5. The narrowest part of the opening has a width of approximately 10 m.

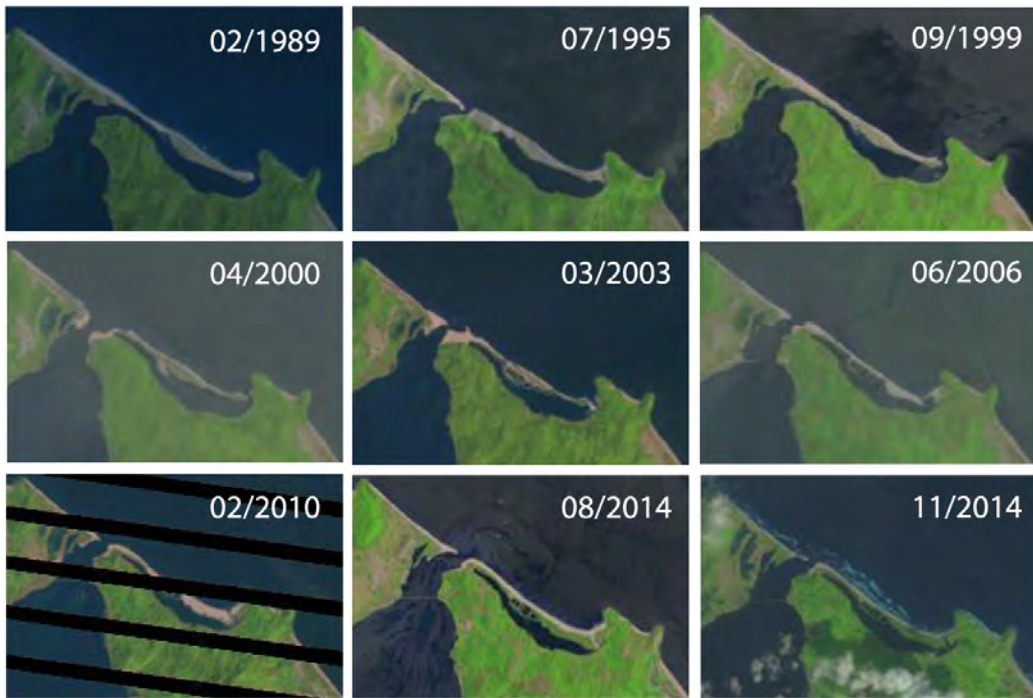


Figure 5.3: Selection of satellite images of past 25 years [Goslee, 2011]



Figure 5.4: Tu Hien inlet near Vinh Hien, current inlet of the Cau Hai lagoon



Figure 5.5: Inlet of the small lagoon near Loc Thuy

5.2 Lagoon and inlet dimensions

According to [Lam, 2009] the lagoon dimensions are as follows:

Table 5.1: Dimensions Cau Hai lagoon

Area [km^2]	Length [km]	Average width [km]	Average depth [m]
110,7	15	7	1 - 1,5

From the measurements described in appendix B the inlet dimensions are as follows:

Table 5.2: Table showing the values of the inlet cross section closest to the sea.

Width	Hydraulic radius	Average depth	Total area
126	128	4,87	614

For dimensions of more cross sections, their locations and information about the measurements, please see appendix B.

5.3 Meteorological climate

In this section the most important meteorological characteristics will be described.

5.3.1 Monsoons

The climate in the Thua Thien Hue-province is characterized as a tropical monsoon climate. The climate in Vietnam is affected by the Asia monsoon. During the hot summer months, the continent of Asia heats up more than its surrounding oceans. This results in a large low pressure area above the Asia continent. This creates a humid onshore wind from the Pacific ocean onto Central Vietnam. This causes the so called north-east monsoon or winter monsoon. In the colder months the process is reversed. The land cools faster resulting in a high pressure area above the continent, and dry offshore winds. This results in the south-west or summer monsoon [Broersen, 2010]. In central Vietnam the north-east monsoon is dominant from September till January while the south-west monsoon is dominant from May till August. [Tung, 2011].

5.3.2 Wind

The characteristics of the local wind regime are important in defining the local wave climate, which influences among others the littoral sediment drift along shore. The wind roses per month of the measurement station of Con Co island are included in appendix C.2. This measurement station is located forty kilometres offshore north of the Tam Giang - Cau Hai lagoon. The seasonal variation of the wind directions of the north-east and the south-west monsoon can be observed easily. Furthermore from January until July there is also a large wind contribution from south-east direction. The highest wind speeds are measured during the months October, November and December. This corresponds to the typhoon season. The wind direction at the shore will be somewhat different because of dispersion due to the many mountains in the area [IMHEN, 2008].

5.3.3 Rainfall

In central Vietnam there is a clear wet and dry season. The wet season is approximately from September to December. Table 5.3 gives annual and monthly rainfall data for three locations in the region. Hue is the main city in the province, Phu Loc is next to the Cau Hai lagoon on a low elevation level, while Loc Tri lies in the mountains behind the lagoon. The characteristics of a climate influenced by a rainy season are easily observed, as well as higher rain amounts in the mountainous area compared with the coastal plains. From the table it can be derived that approximately 75% of the rain falls in the rain season. The daily rainfall can reach very high intensities, for instance during the historical flood of 1999 the maximum daily rainfall at Hue was 978 *mm/day* [Thanh, 2011].

Table 5.3: Annual and monthly rainfall in *mm*[IMHEN, 2008]

Location	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hue	2555	95	48	34	47	104	125	71	120	335	762	562	252
Phu Loc	2689	93	60	35	85	135	100	102	153	314	841	509	271
Loc Tri	3436	187	53	20	63	189	225	75	95	531	924	779	295

5.3.4 Typhoons

The Thua Thien Hue province is located in one of the severest storm areas in the world, the north-west of the pacific ocean. The depressions in this area are cyclonic wind gusts formed in tropical oceans with diameters up to hundreds of kilometres. On the northern hemisphere wind flows counter clockwise into the centre of the storm.

From 1980 till 2011, 62 (super)typhoons and tropical storms have hit or passed closely to the Thua Thien Hue province[Biezen, 2014]. See appendix C.1 for an overview of the typhoons. The typhoon season for central Vietnam is mainly from October to November [et al., 2007]. The tropical storms can cause high storm surge levels due to low atmospheric pressures and high wind set-up because of the high wind speeds. Furthermore high rainfall intensities are common during tropical storms and typhoons. For example the flood of 1999 was caused by the tropical storm Eve. While the wind speed of the storm was not extremely high the accompanied rain lead to severe inundation of the area. Once in a blue moon typhoons may also close an inlet. The extreme waves caused by the typhoon greatly intensify the longshore sediment transport. The approach direction of the typhoon can weaken the tidal currents in the inlet, and if the river flood wave needs a

longer time to reach the inlet, the flushing capacity of the inlet may be too low to keep it open [Lam, 2009].

5.4 Hydrodynamical aspects

According to [Tung, 2011] the tidal prism of the Tu Hien inlet is $12 * 10^6 m^3$. With a total littoral drift $M_{tot} = 0,71 * 10^6 m^3/y$.

Presently the Tu Hien inlet is again the main inlet for the Cau Hai lagoon. In flood periods, flood dominated flows are the main reason for the opening of new inlets or widening and deepening of the current inlets.

In the classification of Hayes (1979), the Tu Hien inlet is a micro-tidal inlet in the wave-dominated regime. Such a situation is characterised by long straight barriers, few inlets, well developed flood tidal deltas and poorly developed ebb-tidal deltas. An aerial photo taken in May 2004, see figure 5.6, shows that the flood tidal delta of the Tu Hien inlet is well developed. Flood shoals and marginal ebb channels are clearly distinguished. However the ebb shoals are not easily recognised. Instead of ebb shoals, a system of bypassing sand bars is clearly visible in the bathymetrical map. [Tung, 2011]



Figure 5.6: Aerial photo of the Tu Hien inlet and flood tidal delta in the Cau Hai lagoon (photo taken in May 2004 by M.B. de Vries)

5.4.1 Tides

Based on the Admiralty Tide Table (Hydrographer of the Navy, 1983) and SHOM (1982) [Lam, 2009] the tidal range at the Tu Hien inlet is 0,61 m. The form factor $F = 1,25$ indicates the tide is mixed, mainly semi-diurnal.

At the Thuan An inlet the tidal range is 0,41 m with a form factor $F = 0,23$. The Thuan An inlet is the only location along the Vietnamese coast with a fully semi-diurnal character.

The tidal amplitudes of the different tidal aspects M2, S2, K2 and O2 are demonstrated in 5.4.

Table 5.4: Tidal amplitudes Thuan An and Tu Hien inlets

	M2 [m]	S2 [m]	K2 [m]	O2 [m]
Thuan An	0,18	0,04	0,03	0,02
Tu Hien	0,17	0,03	0,16	0,09

5.4.2 Wave-climate

Table 5.5 shows the wave height versus direction, as has been observed at a point offshore, but only some 30 km from the coast, and roughly 70 km west-northwest of the Thuan An inlet. Figure 5.7 gives a visual representation of the wave data. [Biezen, 2014]

Figure C.2 in C.3 represents the variation in wave- height and direction during the year. Noticeable are the high waves from the north-east and east in the October-November-December period. This is the winter monsoon period in which usually high waves occur. The South-West waves in the summer months seem strange on first sight, it would mean the waves are coming from land. However this is possible due to the offshore directed winds in the summer months which dominate over the weak North-East waves and the fact that the measuring station is located offshore. The conclusion from the wave climate is that the dominant wind direction is between North and East.

From the data in 5.5 a significant wave height of $H_s = 2,24 m$ is calculated.

Table 5.5: Wave climate near Tu Hien inlet

Wave height [m]	Directions								Total
	N	NE	E	SE	S	SW	W	NW	
0.25-0.5	19	31	79	50	20	64	9	8	280
0.50-0.75	53	140	377	289	63	249	26	79	1276
0.75-1.0	49	116	285	178	33	170	20	60	911
1.0-1.5	102	245	460	276	33	201	13	126	1456
1.5-2.0	98	188	217	86	2	72	3	102	768
2.0-2.5	121	207	118	30	4	54	1	80	615
2.5-3.0	105	103	36	5	0	15	4	66	334
3.0-4.0	98	163	34	4	1	4	4	35	343
4.0-5.0	29	74	14	0	1	0	1	9	128
5.0-6.0	6	1	1	0	0	0	1	2	11
6.0-7.0	6	3	1	0	0	0	0	1	11
7.0-8.0	0	0	0	0	0	0	0	1	1
8.0-9.0	0	0	0	0	0	1	2	1	4
9.0-10.0	0	0	0	0	0	1	1	1	3
Total	686	1271	1622	918	157	831	85	571	6141
	11%	21%	26%	15%	3%	14%	1%	9%	100%

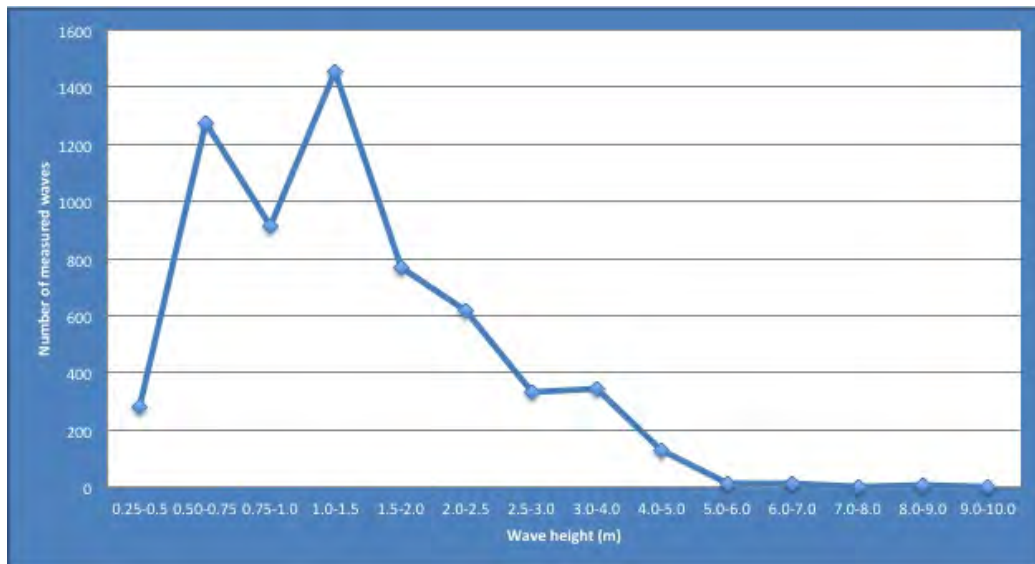


Figure 5.7: Visual representation of the wave height versus the number of measured waves

5.5 River influences

The Tam Giang-Cau Hai lagoon system receives water from a catchment area of about 4400 km^2 . In figure 5.8 the system is shown with averaged annual flow based on computations of [Lam, 2009]. This figure shows that the Tu Hien inlet is responsible for 13% of the total volume discharge of the system to the sea. The other 87% is discharged through the Thuan An inlet. From the same calculation [Lam, 2009] more detailed information of the inflow in the Cau Hai lagoon is shown in table 5.6. The river flow characteristics follow the wet season regime, as can also be seen in table 5.6. Because the region is characterized by short and steep river beds, water levels in the rivers can rise very quickly during a intense rainfall event. According to [Lam, 2009] average water level rising speeds in the larger rivers are in the range of $0.2\text{--}0.5 \text{ m/hour}$ and 1.0 m/hour in the smaller rivers more uphill. Because of the topography of the region the duration of high discharge events is not so long and lasts for a few days. A peak flow for the Huong river at the location of the Thao Long dam is given in [Lam, 2008] & [Lam, 2009], which amounts $12500 \text{ m}^3/\text{s}$. The catchment area that belongs to this location of the river is 2619 km^2 . This gives a relationship for the peak flow and catchment area of:

$$\frac{12500}{2619} = 4.8 \frac{\text{m}^3/\text{s}}{\text{km}^2} \quad (5.1)$$

This is a rather large value for such a kind of a relationship. This is explained by the occurrence of very high rainfall intensities and the steep topography in the region.

The peak flow of the Truoi River is known as well. Peak flows of other rivers into the Cau Hai Lagoon will be estimated by using a similar peak flow over annual flow ratio, rather than using the same peak flow over catchment area relationship.

[Lam, 2009] has found peak flows for multiple rivers in the region. Ratios between peak flow and annual flow vary from 30 to 100. For the Truoi River [Lam, 2009] found a ratio of 70. As this ratio is close to the mean of the mentioned range and the Truoi River is in the same region as the other rivers that run into the Cau Hai Lagoon, this value is used to find the peak flows of those rivers.

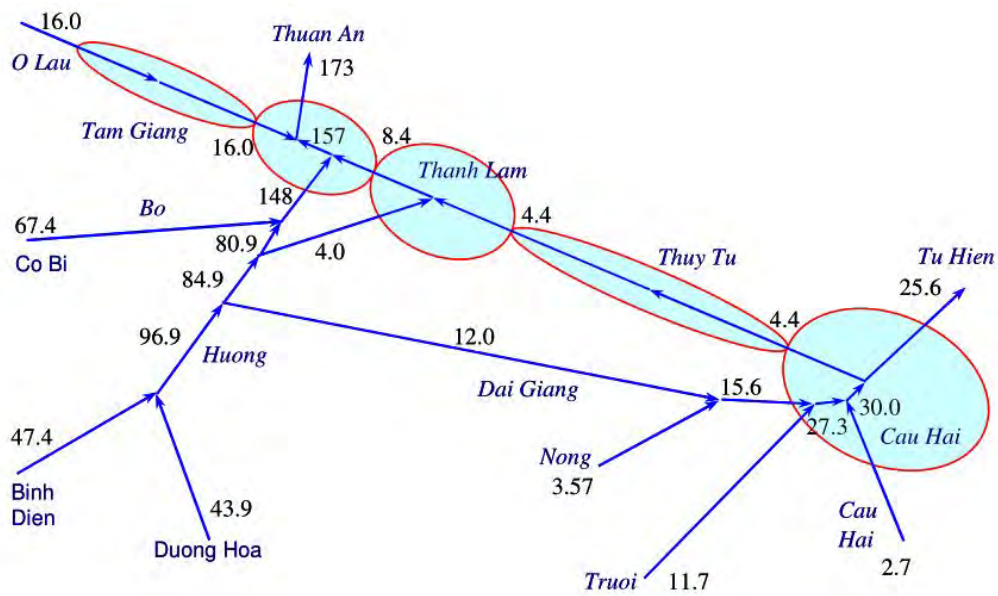


Figure 5.8: Overview of the watersystem of the Tam Giang - Cau Hai lagoon system with annual average discharges [Lam, 2009]

Table 5.6: Characteristics of rivers that flow in Cau Hai lagoon[Lam, 2009], peak flows added

	Catchment area (km^2)	Annual discharge (m^3/s)	Flood season (%)	Dry month (m^3/s)	Wet month (m^3/s)	Peak flow (m^3/s)
Dai Giang River	286	12	70	5.40	25.20	840
Truoi River	115	11.7	81.7	3.21	28.68	819
Nong River	66	3.57	80	1.07	8.57	249.9
Cau Hai River	40	2.7	80.1	0.81	6.49	189

5.6 Combination of high river discharge and storm surge levels

A special case concerning flood risk is the mutual occurrence of high river discharges and storm surge levels. This event is realistic for this region because of typhoons. Typhoons are often accompanied by large amounts of rainfall, which cause high discharge in the rivers. Besides that, typhoons also cause a low pressure area and high wind speeds. The low atmospheric pressure raises the water level because surrounding waters are pushed more down due the higher atmospheric pressure in the surrounding environment. The high wind speeds also raise the water level because the wind induces a gradient of the water surface, this process is called wind set-up. The wind set-up together with the low pressure effect is the storm surge. The water level at sea near the coastline can further increase because of the wave set-up during typhoons. This effect is caused by the energy dissipation when waves are breaking due to a reduced depth. When typhoons cause high water levels at the ocean side of the inlet and at the same time a lot of rainfall pours down on the river basin, the water level gradient over the inlet is reduced. This means that the run off discharge through the inlets reduce. This will increase the inundation depths and flood consequences in the region.

5.7 Salinity

The Cau Hai lagoon and river system is subject to salt intrusion, causing problems for irrigation in the agricultural sector. The lagoon itself is brackish, therefore in good conditions for aquaculture and fishery. Nevertheless, when floods occur or the inlet silts up the salt conditions in the lagoon change, destroying the aquaculture and fish farms in the lagoon. The ideal salt concentration for shrimp farmers is in the order 15-25 ‰. The brackish lagoon is entrapped behind coastal barriers and connected with the ocean by two inlets. Multiple rivers flow in the lagoon, supplying fresh water. The salinity in the basin has a variation in the dry and wet season. During the dry season sea water will dominate the lagoon compensating the diminished river flows and high evaporation rates of fresh water. During the wet season the evaporation rates are very low and the lagoon is flushed with fresh water, decreasing the salinity concentration in the lagoon. According to Bird (2008) the lagoon can be divided in three areas: a freshwater zone close to the river mouths, a salt water tidal zone close to the entrance and a transitional zone

of brackish limited tidal influence, see figure 5.7 [Bird, 2008].

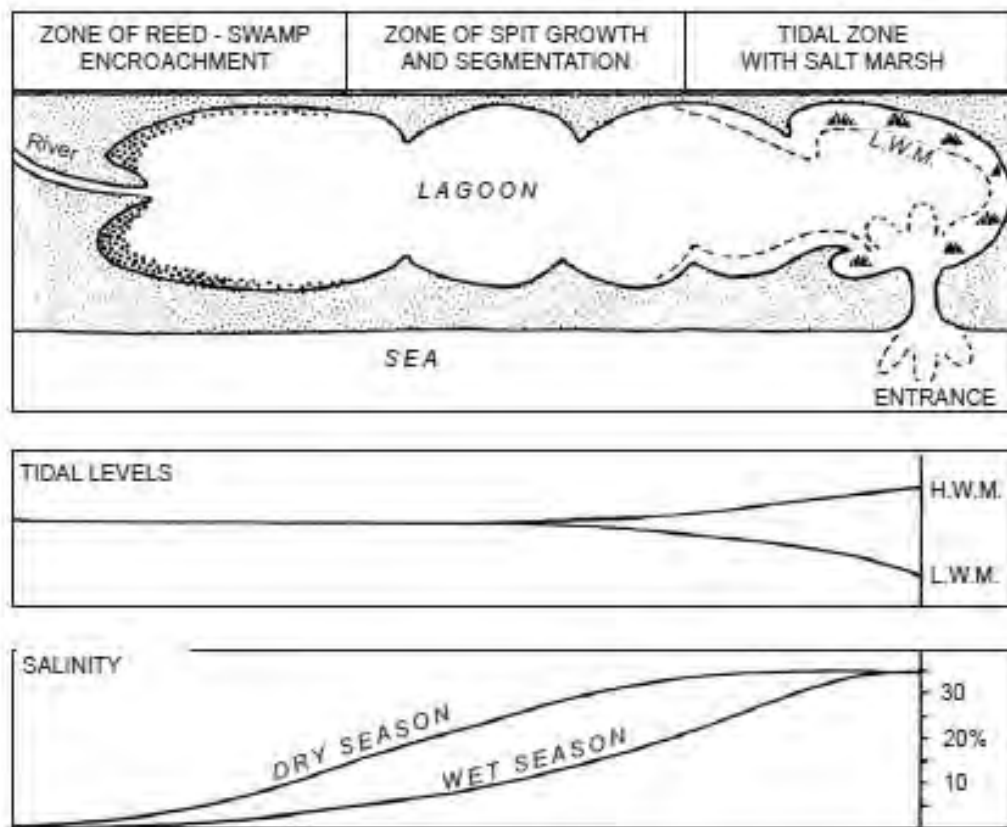


Figure 5.9: Lagoon zonation related to tidal levels and seasonal salinity variations[Bird, 2008]

Figure 2.1 shows the location of the rivers and reservoir in the South-West of the Cau Hai lagoon. The Truoi river and Dai Giang river are the two biggest rivers entering the system covering a catchment area of 470km^2 [Biezen, 2014] with an annual flow of $872 * 10^6\text{m}^3$ [Lam, 2002]. Multiple human influences affect the salinity in the lagoon and the rivers. One of these is the installation of the salinity screen in the Dai Giang river. This screen is closed during high tide and the dry season. Due to this measure the salinity in the Dai Giang river is limited. Another clear example is the Truoi reservoir, it prevents fresh water from entering the basin causing higher salinity concentrations in the lagoon and salt intrusion in the Truoi river.

5.7.1 Salinity intrusion length

For the salinity intrusion length in the Cau Hai lagoon the equation derived by Fischer and Rigter can be used. In combination with the measured cross-sections in the inlet, the discharge of the rivers for the dry and wet season and the annual average, a prediction for the salinity intrusion length can be made. The results for both Rigter and Fisher show large differences between the different cross sections and the water depth in the inlet, as can be seen in D.2. Knowing that the salinity intrusion in the dry season reaches the river mouths implicates that the intrusion length needs to exceed fifteen kilometres. Table 5.7 shows the large variation in calculated salinity intrusion lengths.

Table 5.7: Rigter's salinity intrusion length in km

with	A0=615 m, h0=4.9 m	A0=1015 m, h0=2.5 m	A0=742 m h0=2.3 m
Wet season discharge	4.14 km	1.62 km	0.70 km
Dry season discharge	38.16 km	16.23 km	9.74 km
Annual discharge	12.08 km	5.03 km	2.81 km

The large variation can have different causes. The first is the river discharge: normally this equation is used for one river/estuary entering the ocean but in this situation four rivers are combined to one discharge, the lagoon discharge. Second is the tidal velocity amplitude v_0 which normally varies with the season but is now taken as a set value derived by [Lam, 2009]. The continuous model gives the output for the velocity amplitude with the different alternatives. Another aspect worth mentioning here is the influence of the water level and the cross-section on the calculations. The three cross-sections used here are measured at different locations. Knowing that Rigter based his empirical equation on measurements with set cross-sections explains why the results in practice are highly differentiated [Savenije, 1993].

5.7.2 Completely mixed system

The lagoon system, rivers and the tidal inlet are described as a large completely mixed system to see the influence of the tide and discharge on salt concentration and water level in the lagoon. Overall the lagoon is brackish. When the system is compared to the three zonation scheme of Bird, see figure 5.7, it is situated in the tidal zone with salt marshes. Because the Thuy Tu entering from the Tuan An inlet is also brackish, the salt in

the lagoon is spread throughout the basin, supporting the completely mixed assumption.

5.8 Longshore sediment transport

Looking at the coastline orientation around the Tu Hien inlet and comparing this to the wave impact as described in 5.4.2, one would see that the impact of the dominant waves (north-east and east) is roughly between 0° and -45° . Which means, according to the S, φ -curve, the sediment transport is north-westward like demonstrated in figure 5.11.

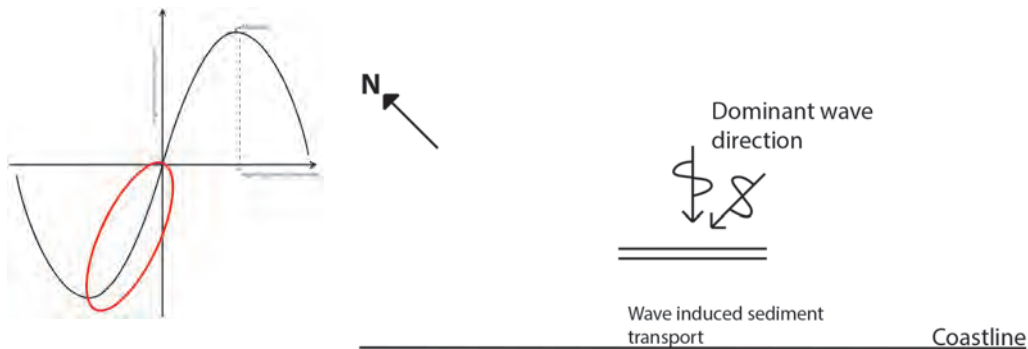


Figure 5.10: Area of the dominant waves on the S, φ -curve

Figure 5.11: Transport direction caused by the dominant waves

Longshore transport is a highly uncertain parameter. In the past several researches published results with an order 100% difference. Lam (2009) looked at all researches and found a decent estimation for the long-shore sediment transport [Lam, 2009]. He estimated the longshore transport near the Tu Hien inlet to be $0,72 * 10^6 \text{ m}^3/\text{year}$ south-eastward, $0,5 * 10^6 \text{ m}^3/\text{year}$ north-westward based on surveys in 1993 and 1995. The net sediment transport is therefore $0,22 * 10^6 \text{ m}^3/\text{year}$ south-eastward and the gross transport is $1,21 * 10^6 \text{ m}^3/\text{year}$.

The difference in the findings of Lam and the results of the transport direction of the S, φ -curve is caused by the rock formation at Chan May which blocks the sediment. Another cause could be that wave induced sediment transport is not the main transport system along the coast but tidal movement is.

5.9 Inlet stability

5.9.1 Escoffier

The stability of inlet is estimated with the Escoffier curve. In order to use the Escoffier curve the tidal prism is required, defined as the amount of water flowing in and out of the system in one tidal movement. It is determined by the surface of the bay times the tidal range, $P = A_b * \Delta$.

In the case of the Tu Hien inlet the bay water level amplitude is 0,09 m [Lam, 2009] and the surface of the bay is $110,7 * 10^6 m^3$ leading to a tidal prism of:

$$P = A_b * \Delta = 110,7 * 10^6 * 2 * 0,09 = 19,93 * 10^6 m^3 \quad (5.2)$$

As described in section 4.2.1 the maximum cross sectionally averaged entrance velocity $u_e = \hat{u}_e$ can be related to the tidal prism:

$$\hat{u}_e = \frac{\pi * P}{A_e T} \quad (5.3)$$

Measurements during the fieldwork have shown that the inlet cross section is $615 m^2$. T is the tidal period, being $T = 44.700 s$ (semi-diurnal tide). Resulting in:

$$\hat{u}_e = \frac{\pi * 67,53 * 10^6}{582 * 44700} = 2,41 m/s \quad (5.4)$$

When using the Escoffier curve, an equilibrium velocity in the inlet $u_{eq} = 1$ is assumed. Since $2,41 > 1$ this means the cross section of the inlet will become larger until a stable situation is reached.

The equilibrium cross section of the inlet is determined by:

$$A_{eq} = CP^q \quad (5.5)$$

It is assumed the inlet has about the same C-coefficient as determined by Lam (2009), $C = 1,44 * 10^{-4}$ and the q-coefficient is $q = 0,97$. Using these values

in combination with the tidal prism and inlet cross section as determined earlier, leads to:

$$A_{eq} = 1,44 * 10^{-4} * (19,926 * 10^6)^{0,97} = 1733,0 m^2 \quad (5.6)$$

5.9.2 Seasonal variation

Tung and Stive developed a conceptual method based on the Escoffier curve to explain seasonal variation in a tidal inlet. The method explains development of a tidal inlet caused by shoaling, narrowing or entirely closing during the dry season. In the model both littoral drift and tidal current are integrated which represent respectively filling and flushing of the tidal inlet.

The conceptual model shows two stable equilibrium points *B1 and B2* in between the inlet fluctuates during the seasons. Also two unstable equilibrium points *A1 and A2* are present. The model is demonstrated in figure 5.12, where Points A1 and A2 are the unstable equilibrium points and B1 and B2 are the stable equilibrium points corresponding to seasonal variation of the closure curve in the flood and the dry season. [Tung, 2011].

In the flood season the equilibrium cross section of the inlet enlarges significantly compared to the dry season. The flood water flushes the inlet and therefore creating a new equilibrium cross section point B2. The new equilibrium point quickly shifts back however, as the flow velocity in the inlet decreases and accretion takes place.

Seasonal variation in wave climate also causes large fluctuations in littoral drift, resulting in different equilibrium points or an unstable equilibrium of the inlet channel.

Due to seasonal variation in the lagoon the inlet stability varies during the year. According to Bruun et al. (1978) the stability of the inlet is determined by the ratio between tidal prism and total littoral drift:

$$\frac{P}{M_{tot}} \quad (5.7)$$

The ratio indicates the stability of the inlet. As demonstrated in table 5.8 the stability is rated in five categories.

The total littoral drift is estimated by [Biezen, 2014] to be $0,2 * 10^6 m^3/s$. According to [Lam, 2009] the tidal prism varies between $0,9 * 10^6$ and $15 * 10^6$.

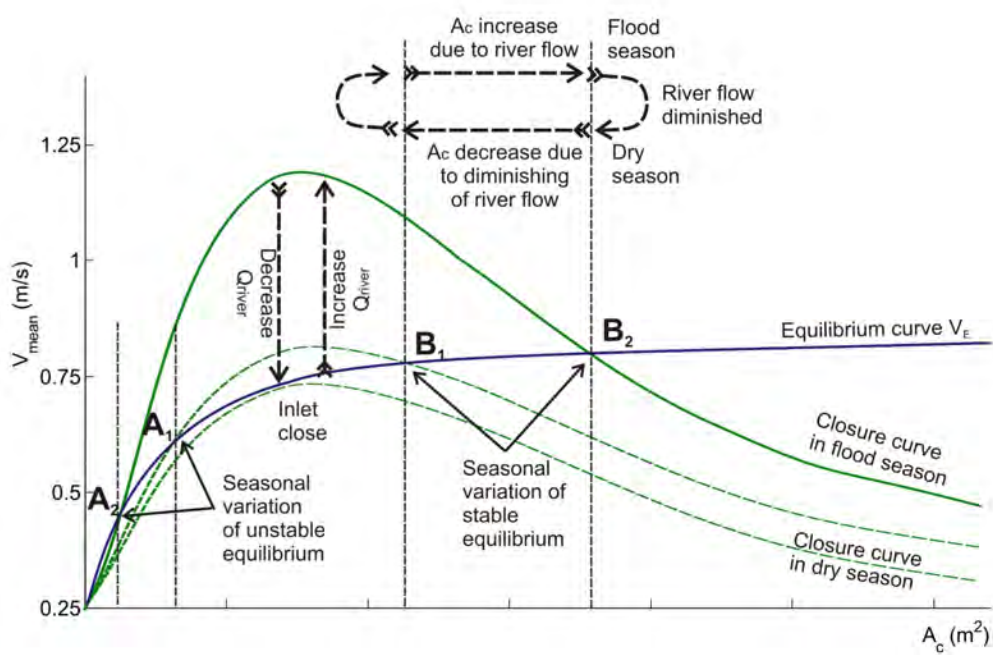


Figure 5.12: Escoffier diagram extended for seasonal variation of the closure curve.

Table 5.8: Inlet stability according to Bruun et al. (1978), after Tung (2011)

T/M_{tot}	M2 [m]
>150	Good, little bar formation and good flushing
100-150	Fair, offshore bar formation more pronounced
50-100	Fair to poor, entrance bar rather large
20-50	Poor, typical bar-bypassing
<20	Poor, entrance unstable and may close

This leads to a P/M_{tot} ratio varying between 4,5 and 75. According to table 5.8 this means the stability of the inlet is poor, and even unstable for small tidal prisms. Although there is quite a significant difference in the P/M_{tot} ratio, the stability of the inlet is generally not stable.

5.10 Water quality

The water quality in the Cau Hain lagoon is seen as one of the main problems, and is endorsed as point of concern by the local dike department and the Center for Social Research and Development. A

5.10.1 Shrimp farms

When arriving to the Cau Hai lagoon one can see that many shrimp farmers are located here. Mostly large black tiger shrimps are cultivated in this area, the farms can be found near the Thuy Tu connection with the Tuan An inlet and in the south of the lagoon. Shrimp farming and other aquaculture is a main source of income in the Phu Loc district, besides the main livelihood fishing. The Phu Loc district had an area of 1387.7 Ha of aquaculture in 2013 and 3001 Ha in the Phu Vang district [Trung Ti n, 2013]. Compared to other countries Vietnam has a relatively small density in the shrimp ponds: 20-40 post larvae (PL)/ m^2 , compared to 50 – 100 PL/m^2 in Thailand or Mexico [Pham et al., 2010]. To prevent yield loss Vietnamese farmers add a lot of pesticides, antibiotics and nutrients to the water. Together with the waste water of the ponds the pesticides are flushed out into the Cau Hai lagoon. Between 1994 and 2004 the area of shrimp farming expanded in the Cau Hai lagoon. This increase due to contracts between shrimp farmers and wholesaler led to widespread outbreaks of diseases [Truong et al., 2014]. After 2004 the number of shrimp farms decreased. Now, the farmers indicate

that the water quality is worsening and the number of farms increasing. Truong (2014) stated that regulation of the pollution by shrimp farmers can be done by transferable feed quotas as most efficient policy measure.

5.10.1.1 Shrimp pond cycle

To prepare a pond for the cultivation of shrimps the pond needs to be dredged. In case of a sulphate soil it needs to be flushed 3 – 4 times and treated with lime (CaO) to increase the pH in the pond. After that the ponds are aerated for 3 – 4 days to kill all the infectious diseases carriers. Different sterilizers and fertilizers are added before the feed and the shrimp larvae can grow in the pond. The shrimps are grown for typically 100 – 120 days. Depending on the season the water needs to be exchanged every 10 days with a 10 – 15% exchange in the dry season. After this period shrimps reach the harvesting size of 40 – 50 *shrimps/kg*. After this period the pond is flushed again and prepared for the new harvest.

5.10.1.2 Pollution parameters

The waste water of a shrimp farm contains different pollution parameters: Biochemical oxygen demand (BOD), Chemical oxygen demand (COD), nitrogen (N) and phosphorus (P) are causing oxygen depletion and eutrophication of the lagoon. Presented in Table 5.10.1.2 are the characteristics of the waste water.

Table 5.9: Waste water of shrimp ponds per month during growth period [Pham et al., 2010]

Parameter	Unit	<1 month	2-3 months	3-4 months	Standard
BOD_5	mg/l	21	39	41	<6
COD	mg/l	68	100	132	<40
N	mg/l	2.2	3.2	5.7	<50
P	mg/l	0.25	0.4	0.7	<0.3

The amount of waste water flushed for the first month is estimated 1125 m^3 . The second and the third month 6750 m^3 and the fourth month 9750 m^3 per shrimp farm (0.5ha) [Pham et al., 2010]. 42% of the area used for aquaculture in the Phu Loc district is for shrimp farming [Trung Tiên, 2013]. Using some simplified calculations it can be concluded that yearly an amount of

20133 ton COD, 7047 ton BOD, 106 kg nitrogen and 13 kg phosphorus is flushed into the Cau Hai Lagoon.

5.10.2 River pollution

The Dai Giang river and the Nong river are both passing Hue city, which discharges a lot of waste into both rivers. The main source of pollution is the direct discharge of untreated domestic and industrial waste in the rivers. The organic compounds in the waste water increase the COD and BOD concentration in the river water, these are higher in the dry season. In the wet season the Phosphorus concentration is increased due to run-off from the mountains, possibly causing eutrophication in the river. The eutrophication in the rivers is confirmed in this period as high algae concentrations were measured. Table 5.10.2 shows the river parameters measured between 1998 and 2002. The water quality of the river was worsening in this period. It can be seen that the average dissolved oxygen concentration is below the normal concentration for surface water levels, which is 8 – 10 *mg/l*.

Table 5.10: River parameters Perfume river 1998-2002 [Nguyen et al., 2004]

Parameter	Concentration	Unit
COD	1	mg/l
BOD	8	mg/l
N	0.02	mg/l
P	0.015	mg/l
DO	7	mg/l

Chapter 6

Hydraulic model

6.1 Introduction

To get a better understanding of the water system a simple model will be set up to estimate flow velocities and water levels. In addition, also the concentration of salt and multiple pollution types in the lake will be determined. Simultaneously, this model could be used to calculate effects of the different solutions.

[Borsje, 2003] has made a model of the Tam Giang - Cau Hai Lagoon system including friction and inertia. The model used here will be a larger simplification, not including those terms. However, Borsje does not include river discharges and extreme events, which is essential to take into account for the purpose of this report.

From [Borsje, 2003] it becomes clear that during normal dry season conditions due to the large length of the Thuy Tu Lagoon the Tam Giang and Cau Hai Lagoon act mainly independent of each other. Therefore the model will only include the Cau Hai Lagoon, neglecting the connection. Instead a fixed discharge will be given to the connection. It must be noted that during the wet season or an extreme event, when water levels are higher, friction probably has a smaller effect.

6.2 Assumptions and equations

A discrete model is used, assuming uniformly varying water levels in the Cau Hai Lagoon. Most equations are from [Battjes and Labeur, 2014]. This thus neglects the wave-like character of the in- and outflowing water. This simplification is justified when the length of the basin is much shorter than the wave length of the propagating wave.

The ‘forcing’ of the varying water level in the basin is by the tide, which is mainly semidiurnal and thus has a period of $T = 44700s$. The water depth in the lagoon is about 1.5 m on average. This results in a wave propagation speed of $c = \sqrt{g * d} = \sqrt{9.81 * 2} = 3.84m/s$ and thus a wave length of $L = c * T = 4.43 * 44700 = 171.4km$. This leads to a ratio L/λ of 1/12.3. As this ratio is larger than 1/20, the simplification is not fully justified and there will in reality be some water level differences. However, as the ratio is still acceptably small and the simplification very useful to get a quick insight in the behaviour of the system, this approach will be used any way.

As the length of the basin is relatively short in comparison to the wave length and considered closed off, flow velocities are small. This means friction and inertia play a small role and can thus be neglected in the bay. This only applies when the Cau Hai Lagoon is considered independent from the rest of the lagoon system. The length of the whole water system is much larger, which means wave like motion certainly plays a role.

The model assumes the inlet has only a transporting function and does not store any water. The lagoon in turn does the opposite and only stores water. This is valid when the surface area of the inlet is very small in comparison to the bay, which is the case.

When the surface area of the lagoon is considered not to vary with the water level, the continuity equation reduces to:

$$\sum Q(t) = A_k * \frac{dh(t)}{dt} \quad (6.1)$$

In reality the surface area is a function of the water level. With increasing water levels the surface area of the lagoon increases as well, reducing the relative increase in water level.

$$\sum Q(t) = A_k(h) * \frac{dh(t)}{dt} \quad (6.2)$$

In the case of the Cau Hai Lagoon the inflow is from the rivers and potentially the Thuy Tu connection in combination with in- and outflow through the inlet, see equation 6.3.

$$\sum Q(t) = Q_{inlet}(t) + \sum Q_{rivers}(t) + Q_{Thuy Tu}(t) \quad (6.3)$$

For flow through the inlet, inertia will be neglected as well. Some hydraulic loss will be included. The hydraulic head between sea and basin will in that case overcome only the total hydraulic loss, consisting of outflow loss and resistance.

$$h_{basin} - h_{sea} = \frac{|U|U}{2g} + c_f * l/R * \frac{|U|U}{g} \quad (6.4)$$

Using the dimensionless loss coefficient $\chi = \frac{1}{2} + c_f * l/R$ the equation can be written as in equation 6.5.

$$h_{basin} - h_{sea} = \chi * \frac{|U|U}{g} \quad (6.5)$$

The flow velocity, and therewith the discharge, can now be calculated in each time step of the discrete model, see equation 6.6. In this equation m is the contraction coefficient, which shows the part of the inlet area (A_s) that's effective as flow area.

$$Q_{inlet} = m * A_s * \sqrt{\frac{h_{sea} - h_{basin}}{\chi} * g} \quad (6.6)$$

Neglecting hydraulic loss in the inlet would result in $\chi = \frac{1}{2}$, which leads to the well-known equation $Q = m * A_s * \sqrt{2 * g * \Delta H}$. Equation 6.2 and 6.6 form a system of coupled equations, which can be used to calculate the discharge and water levels in each time step.

With the discharges known, a mass balance can be added to calculate the salt and pollution concentration in the lake. For this purpose, the water in the lake is assumed fully mixed. In reality a gradient will be present. In the

case of salt, the lake will obviously be saltier at the inlet than at the point of the river inflows. In the case of salt the mass balance becomes:

$$\frac{M_{salt}(t + \Delta t) - M_{salt}(t)}{\Delta t} = \begin{cases} -Q_{inlet}(t) * C_{basin,salt}(t) & \text{if } Q_{inlet}(t) \geq 0 \\ -Q_{inlet}(t) * C_{sea,salt} & \text{if } Q_{inlet}(t) < 0 \end{cases} \quad (6.7)$$

In this case a positive inlet discharge is defined when the flow is from the Cau Hai Lagoon to the sea. The concentration of salt in the basin can be calculated by $C_{basin,salt}(t + \Delta t) = M_{salt}(t + \Delta t)/V_{basin}(t + \Delta t)$.

A similar balance is used to calculate the pollution in the lake. For different types of pollution like phosphorus and nitrate, and measures of pollution like COD and BOD. In comparison to the mass balance of salt, the pollution now has as source the production in and around the lagoon and the inflow of the rivers. It is assumed that no pollution enters the lake from the sea. The equation is shown below, in which $P_{basin,p}(t)$ represents the production of the pollution in kg/s at each moment in time. The new concentration is calculated in the same way as with salt.

$$\frac{M_p(t + \Delta t) - M_p(t)}{\Delta t} = \begin{cases} -Q_{inlet}(t) * C_{basin,p}(t) + \\ \sum(Q_{riv}(t) * C_{riv,p}) + P_{basin,p}(t) & \text{if } Q_{inlet}(t) \geq 0 \\ \sum(Q_{riv}(t) * C_{riv,p}) + P_{basin,p}(t) & \text{if } Q_{inlet}(t) < 0 \end{cases} \quad (6.8)$$

6.3 Model input

The input of the model can be divided into two categories: the input variables and the parameters. Some of the important parameters are the basin surface area as a function of the water level and the flow surface of the inlet. The input variables consist of the tide and discharges for different scenarios.

6.3.1 Parameters

Cau Hai Lagoon surface area

The Cau Hai Lagoon surface area at MSL is known to be 112 km^2 [Tung, 2011].

During the field visit it was concluded that some areas are regularly flooded. Especially around the Thuy Tu connection, which is not yet included in the model, were large flood areas. Due to existing infrastructure these flooded areas did not contribute significantly to the flow area however.

Beneath +0.5 m MSL the surface area of the Cau Hai is considered constant at the mentioned 112 km^2 . Based on the elevation data (see table C.4 at page 190) the surface area as a function of the water level is determined for above +0.5 m MSL. This results in equation 6.9 below:

$$A_k(h) = \begin{cases} 112 \text{ km}^2 & \text{if } h < +0.5 \text{ m MSL} \\ 112 + 66 * (h - 0.5) \text{ km}^2 & \text{if } +0.5 \text{ m MSL} < h < +1.0 \text{ m MSL} \\ 145 + 36 * (h - 1) \text{ km}^2 & \text{if } +1.0 \text{ m MSL} < h < +1.5 \text{ m MSL} \\ 163 + 16 * (h - 1.5) \text{ km}^2 & \text{if } +1.0 \text{ m MSL} < h < +1.5 \text{ m MSL} \\ 171 + 11.5 * (h - 2) \text{ km}^2 & \text{if } +2.0 \text{ m MSL} < h \end{cases} \quad (6.9)$$

Inlet flow area

As a result of depth measurements during the field visit, three cross-sections has been set up. To calculate the discharge through the inlet, the smallest cross-section will be taken as the governing, which is located at the inlet mouth. The cross-sectional profile at this point was set-up and has a flow area of 615 m^2 (see table B.1 on page B.1).

Hydraulic losses

As mentioned in section 6.2, the flow in the inlet results in both outflow and friction loss. These are both included in the loss coefficient χ . To determine the friction in the inlet, its length, hydraulic radius and friction coefficient must be known.

Although the smallest cross-section will be taken to calculate the flow velocity and discharge, the friction will be calculated over the inlet length from the inlet mouth till the bridge. After this point, the inlet widens significantly decreasing flow velocities and friction influences (as mentioned before these terms are neglected in the basin).

Cross-sections are available until halfway the inlet, it is assumed that after the last measured cross-section, the same flow area and hydraulic radius are maintained. The cross-sections and hydraulic radii at the different locations

are shown below.

l=0: $A = 615 \text{ m}^2$, $R = 128 \text{ m}$

l=420: $A = 743 \text{ m}^2$, $R = 320 \text{ m}$

l=500: $A = 1015 \text{ m}^2$, $R = 400 \text{ m}$

l=1130: $A = 1015 \text{ m}^2$, $R = 400 \text{ m}$

Based on these cross-sections the c_f/R value of each cross-section will be determined. The c_f value is a characteristic of the inlet material. A value of 0.004 is used according to [Battjes and Labeur, 2014]. The weighted average over the length of these values will be taken to determine the friction loss of the characteristic inlet, see equation 6.10. In this equation n runs from 1 to 3, representing the intervals between the four inlet cross-sections.

$$\chi = \frac{1}{2} + \sum (l(n+1) - l(n)) * \frac{\frac{c_f}{R(n+1)} + \frac{c_f}{R(n)}}{2} \quad (6.10)$$

This results in a loss coefficient of $\chi = 0.516$. Although the significant length of the inlet, due to the large hydraulic radius the outflow loss is by far the governing factor.

Based on the weighted average of the cross-sections and the friction value, an effective hydraulic radius can be determined. The characteristic inlet then has the following values:

Characteristic inlet: $L = 1130 \text{ m}$, $A = 880 \text{ m}^2$, $R_{eff} = 276 \text{ m}$

Salinity concentration

The salinity concentration of the sea water and the river water are input for the salinity modeling part. The south China sea has a concentration of $33.5g/kg$ and the river water has a concentration of less than $0.01g/kg$ and is therefore assumed $0g/kg$. The volume of the lagoon changes by inflow of the river discharges. This continuous model gives outputs for the water level in the lagoon h , the tidal prism, velocity amplitude and tidal excursion, which are used to predict the intrusion length with Rigter, see equation 9.3.

Water quality parameters

Shrimp farms produce a lot of waste which is discharged in the lagoon, the

characteristics of this waste water are presented in table 6.1:

Table 6.1: Input parameters shrimp farm pollution

	unit	First month	second-third month	fourth month
COD	kg/s	0.07	0.64	1.23
BOD	kg/s	0.02	0.25	0.38
Nitrogen	mg/s	2.10	3.05	5.44
Phosphorus	mg/s	0.24	0.38	0.67

Besides the shrimp farms there is a lot of pollution coming in the Cau Hai lagoon by the rivers passing the city Hue. The pollution parameters in this river are presented in section 5.10.2.

6.3.2 Input variables

6.3.2.1 Scenarios

For the input variables multiple scenarios will be created, representing the dry season, wet season and extreme storm events. During the dry and wet season scenarios average water levels at sea and mean wet and dry season river discharges will be used.

The extreme events will be represented in three different scenarios, including river discharge, storm surge and a combination. This results in the following scenarios:

Scenario 1: Dry season

Scenario 1 represents the dry season and combines the measured water levels with the average dry season discharges. The dry season has a duration of eight months.

Scenario 2: Wet season

Scenario 2 represents the wet season and combines the measured water levels with the average wet season discharges. The wet season has a duration of four months.

Scenario 3: Extreme river discharges

Scenario 3 combines the average wet boundary conditions of scenario 2 with an extreme river discharge event. There are three types of extreme discharge events used, all based on known peak flows. The same factors between the peak flows are used as for the calculated storm surge levels of 1/5, 1/20 and 1/50 frequency (see next section 6.3.2.2). This does not mean the discharge events are linked to those frequencies however. These discharges represent a smaller, medium and larger extreme event. In this scenario only the smaller and larger extreme event are included in the model.

Scenario 4: Extreme storm surge levels

Scenario 4 combines the average wet boundary conditions of scenario 2 with an extreme storm surge event of a 1/5 and 1/50 frequency.

Scenario 5: Extreme river and storm

Scenario 5 combines the average wet boundary conditions of scenario 2 with a storm event, that includes both extreme discharges and extreme storm surge. As it is less likely both a very extreme discharge and a very extreme storm surge will happen simultaneously, but as they are still highly correlated due to the same source, namely typhoons, a storm surge event with a frequency of 1/20 is combined with the medium scale discharge event. This scenario represents the most realistic design storm event on which flood levels could be based.

6.3.2.2 Values**Tide and storm surge**

The measured water levels at the Tu Hien marine are known for April and October. The measurements of April are taken representative for the whole dry season and those of October for the wet season. Continuous measurements or tide data during a whole or multiple years would of course give better results, this data is however not available.

For the calculation of the return frequency storm surge level is referred to appendix D.1 on page 191. The calculation is based on wind speeds with corresponding return frequencies as can be seen in figure 6.1. The calculation is performed with the available wind data of tropical storms and typhoons. The values of the total storm surge levels, which include wind set up and a

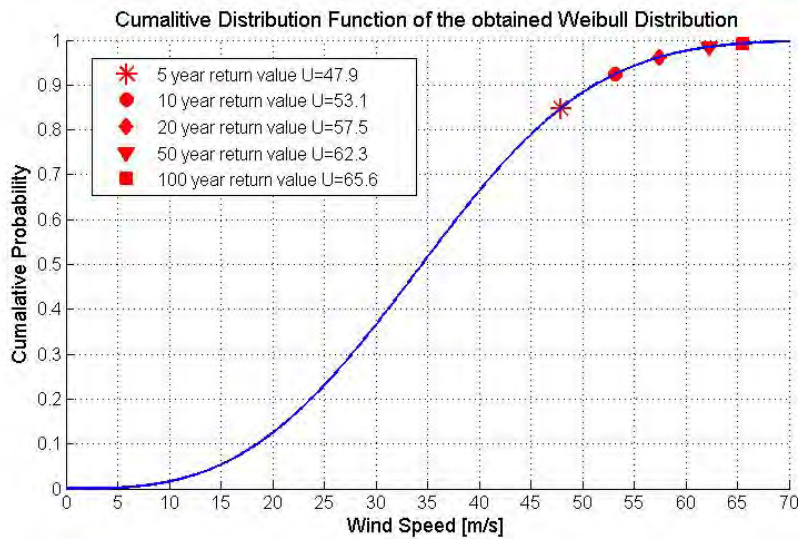


Figure 6.1: Results of probabilistic analysis of wind speeds

contribution for low atmospheric pressure, are shown in table 6.2.¹

Table 6.2: Storm surge levels

	Total set up [m]
5 yr return value	2.13
10 yr return value	2.60
20 yr return value	3.08
50 yr return value	3.59
100 yr return value	3.93

For the shape of the storm surge peak, a normal distribution is used with a 'flat' top at maximum storm surge level for the duration of two tides or about one day, see figure 6.2.

As mentioned, for the storm surge only scenario the frequencies of 1/5 and 1/50 years will be looked at. Scenario 5 will use the 1/20 year value of 3.08 meter.

¹No storm surge measurements seemed to be available. Therefore a probabilistic calculation was performed on basis of typhoon wind speeds to find storm surge levels. During the end presentation Prof. Tuan mentioned that storm surge levels on basis of water level measurements were available. The 100 year storm surge level appeared to be 2.5 m. In this report the values from appendix D.1 are used.

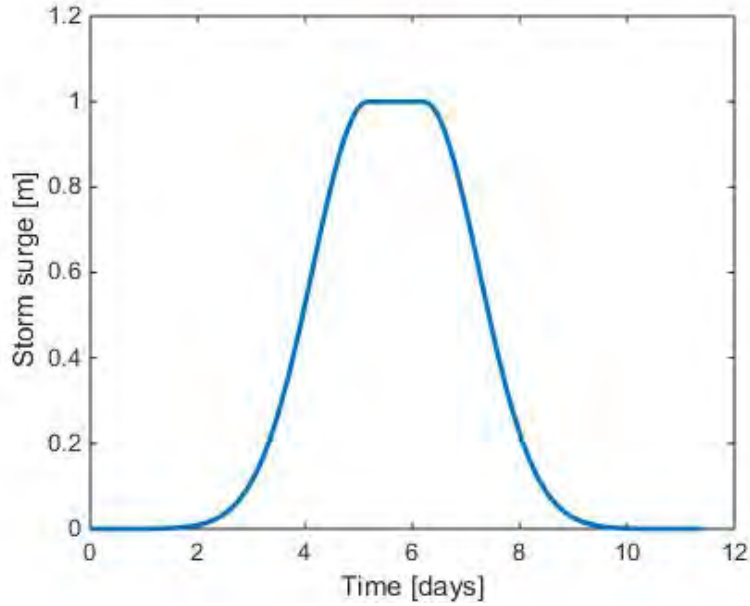


Figure 6.2: Characteristic storm surge peak

River discharge

Average river discharges into the Cau Hai Lagoon during the dry and wet season are known, see table 5.6 on page 46. Peak flows can also be found in this table.

A normal distribution is taken to model the extreme discharge event. The peak flow is the maximum values reached during this flood wave. The full rain event is taken to be about 18 tides or somewhat more than 9 days. The function is shown below.

$$Q(t) = Q_c + (Q_{peak} - Q_c) * C * \frac{1}{\sigma * \sqrt{2 * \pi}} * \exp \frac{-(t - \mu)^2}{2 * \sigma^2} \quad (6.11)$$

In which $Q(t)$ is the discharge during the storm event; Q_{peak} is the peak value of the discharge; C is a factor to make the top of the normal distribution equal to the peak value; μ is the mean value and thus the time of the peak and; σ is the standard deviation.

As standard deviation a value of two tides, or somewhat more than one day, is chosen. This means about 67% of the flood discharge will happen in a two day interval. The flood discharge is added to the mean wet season discharge.

In figure 6.3 an example of a river discharge curve with a peak flow of 1250 is shown.

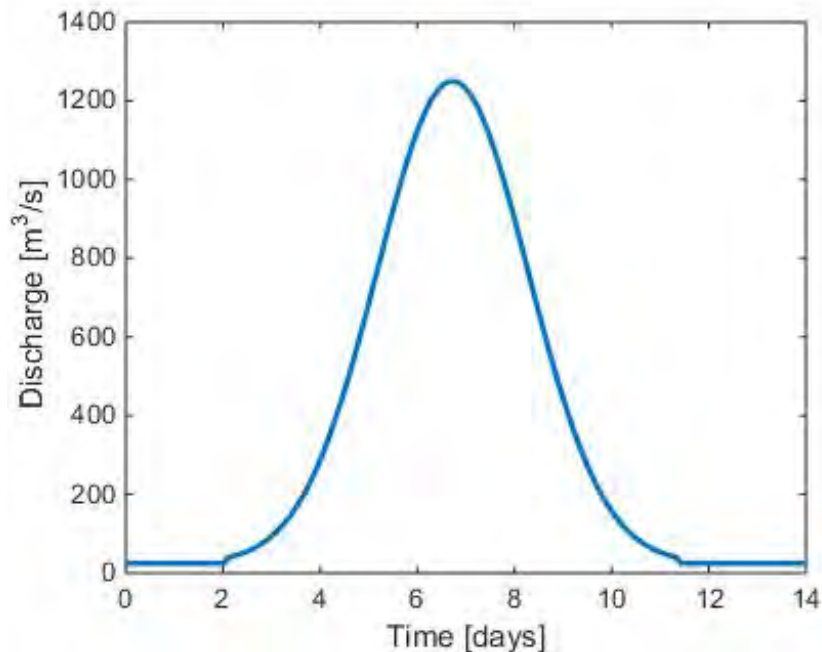


Figure 6.3: Characteristic river discharge distribution

The peak flows as known from table 5.6 will be taken as the 'medium' extreme peak discharge. As mentioned, to estimate the smaller and larger discharge event, the peak values will be multiplied with the same factor as between the storm surge values: $\frac{2.13}{3.08} = 0.69$ and $\frac{3.59}{3.08} = 1.17$.

6.4 Model results current situation

To compare effects of alternatives in a later stage, first the current situation will have to be analysed. The current situation is seen as the 'do-nothing-alternative'.

The results show that under normal circumstances, thus without storm surge and with average discharge, the water levels in the lagoon vary between -0.2 m and +0.35 m in the dry season and -0.2 m to 0.5 m in the wet season, see figure 6.4 and 6.5.

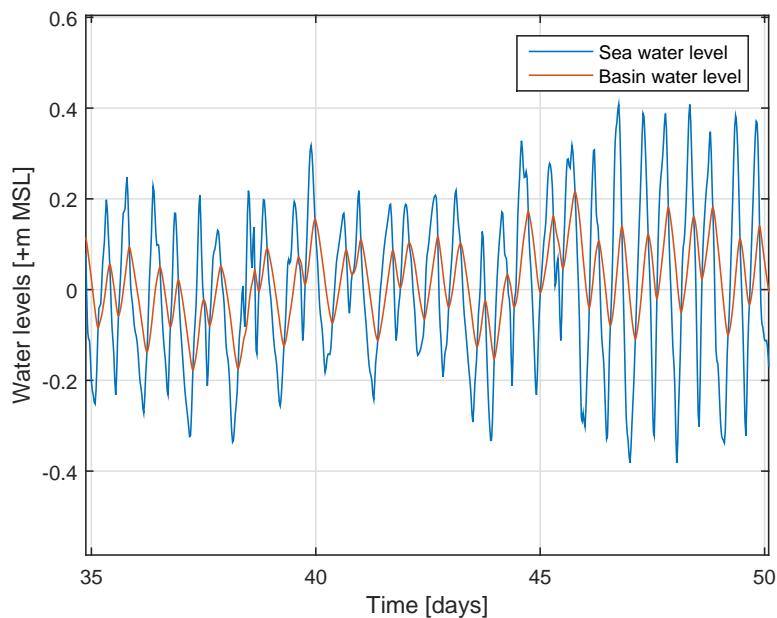


Figure 6.4: Water levels at sea and in the basin during dry season

During a relatively low extreme rainfall event, water levels rise to 0.91 m, which is just manageable but when the extreme rainfall increases in magnitude, levels of 1.67 m (figure 6.6) can be reached, which would be problematic.

Storm surge has an even greater effect on the water levels in the basin. During the 1/5 year storm surge event water levels rise to 2.4 m above MSL and during the 1/50 year storm to 3.87 m. The highest water level in the lagoon is reached during scenario 5 with extreme discharge as well as storm surge from a 1/20 year event (see figure 6.7), although not much less than the 1/50 storm surge only event.

From figures 6.8 and 6.5, showing the concentrations of COD & BOD during the dry and wet season, the different production levels of the shrimp farms can be clearly recognized; medium, high and low output months respectively. The influence on the pollution concentrations are according to the production, but lags behind the output of the farms. Minimum and maximum concentrations in the dry season do not differ much from the wet season situation. The adjustment time does, which is about 20 days for the dry season while only two weeks during the wet season. This can most clearly be seen at the change from high to low output.

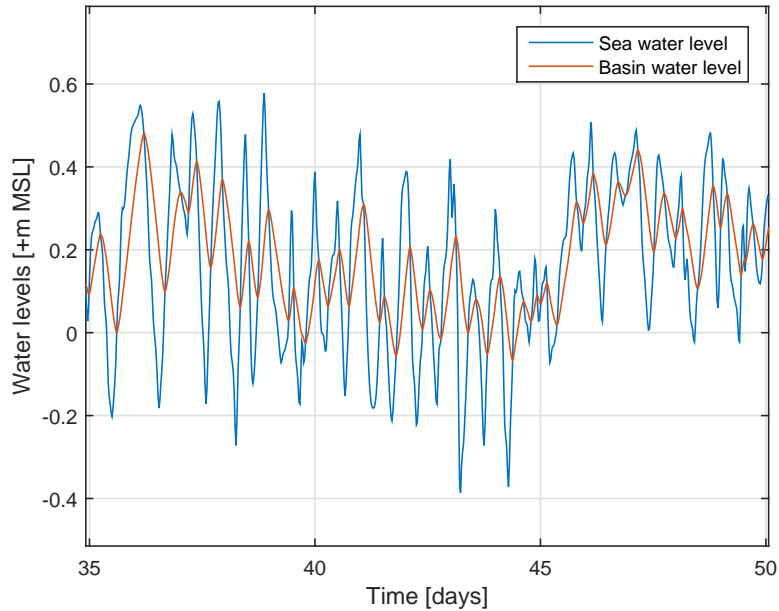


Figure 6.5: Water levels at sea and in the basin during wet season

Productions values of the shrimp farms and known average pollution levels of the rivers are included in the calculations. Although the shrimp farms are one of the contributors to the pollution in the lagoon system, alone they do not pollute enough to reach unacceptable pollution concentrations.

When more sources of pollution would be included, like polluted urban storm run-off and fish farms, pollution could exceed the acceptable levels, especially during dry season.

On the smaller scale the influence of the tide is visible, when the tide is high, the concentration of the pollutants decreases slightly. In scenario 35 (see figure 6.10), with the high river discharge, a sharp drop in pollution concentrations can be observed during the flood event. This is due to the higher water levels while no extra pollution input is assumed. The same happens in scenario 4 during the extreme storm surge event.

With the salt concentrations in the lagoon it is somewhat different. In the dry season the salt concentrations can get rather high, the equilibrium is as high as 32.5 ‰(see figure 6.11), in the wet season this equilibrium is lower and varies between 27.5 and 29 ‰(see figure 6.12).

During extreme river discharges the salt is continuously flushed out of the

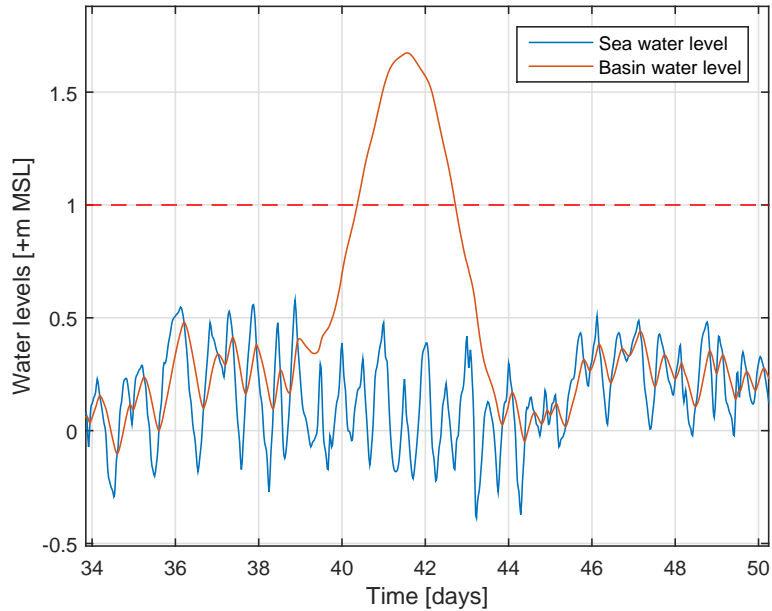


Figure 6.6: Water levels at sea and in the basin during the large discharge event

system, the concentration of salt has its minimum at 2.5 ‰, which is extremely low. It can take 25 days for the salt concentration to recover to its equilibrium level. During storm surge extra salt is imported in the lagoon, the difference is 2 to 4 ‰. During a combined storm and discharge event, the high river discharge dominates the process resulting in a drop of the salt concentration.

For the inlet stability it is interesting to look at the flow velocities in the mouth. During storm surges, large flow velocities occur, into the lagoon as well as outward directed. During high river discharges however, the flow velocities still show the tidal variations but the line is now shifted upwards, the water flows outwards only. As during extreme floods the inlet will erode in reality, the maximum hydraulic head and thus flow velocities will be reduced.

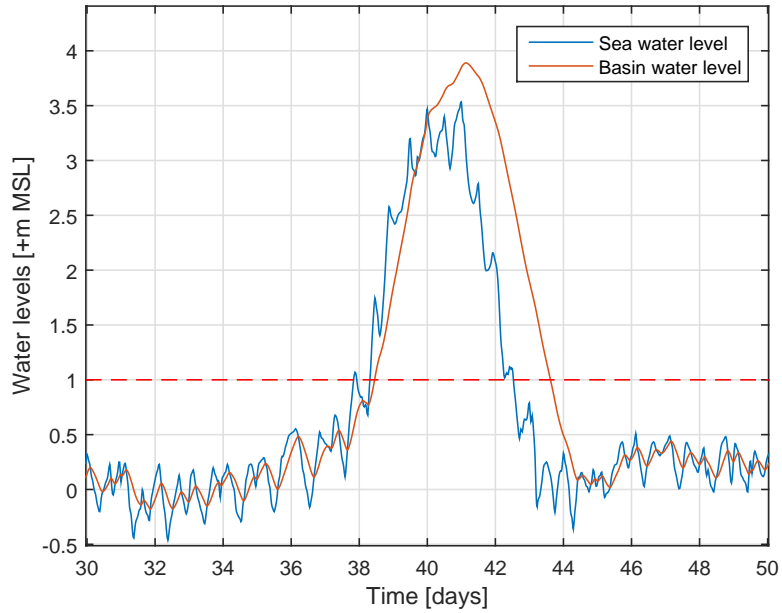


Figure 6.7: Water levels at sea and in the basin during scenario 5

Table 6.3: Maximum water levels per scenario for the current situation

Scenario	Maximum water level reached [m]
1	0.34
2	0.48
35	0.91
350	1.67
45	2.41
450	3.87
520	3.89

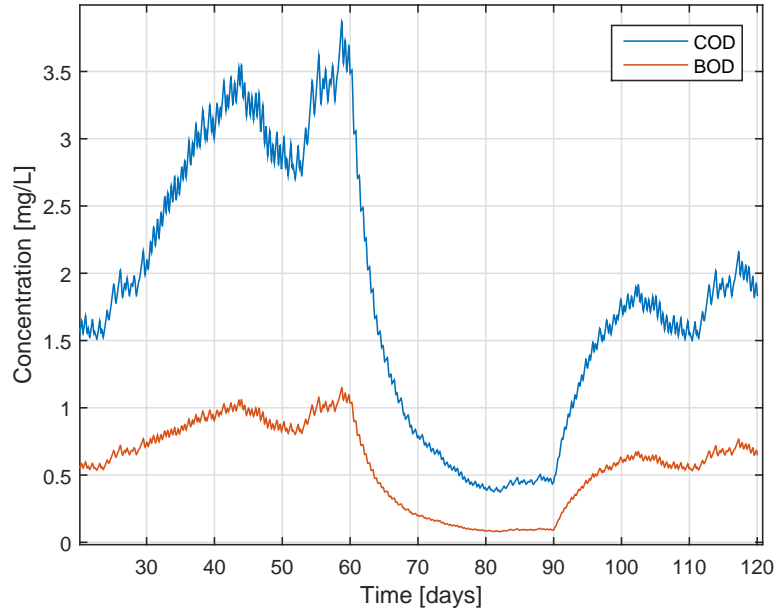


Figure 6.8: COD and BOD levels during the dry season

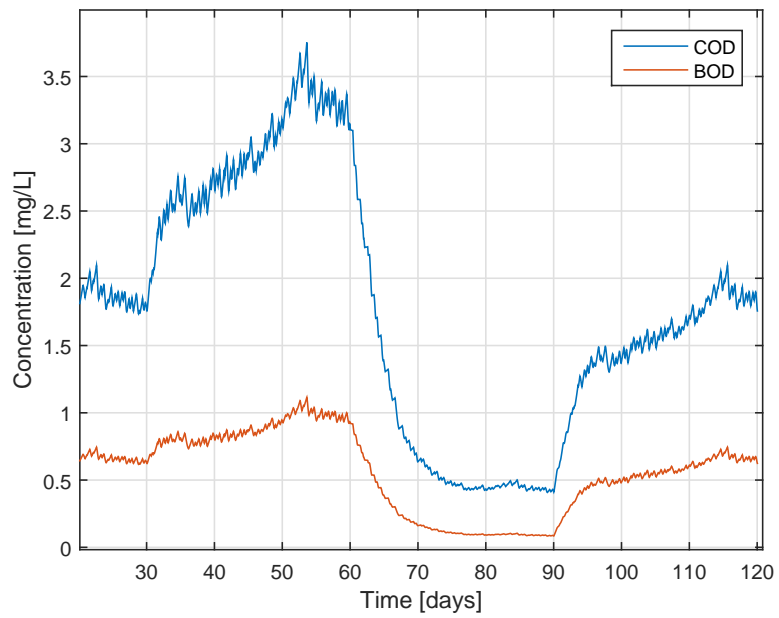


Figure 6.9: COD and BOD levels during the wet season

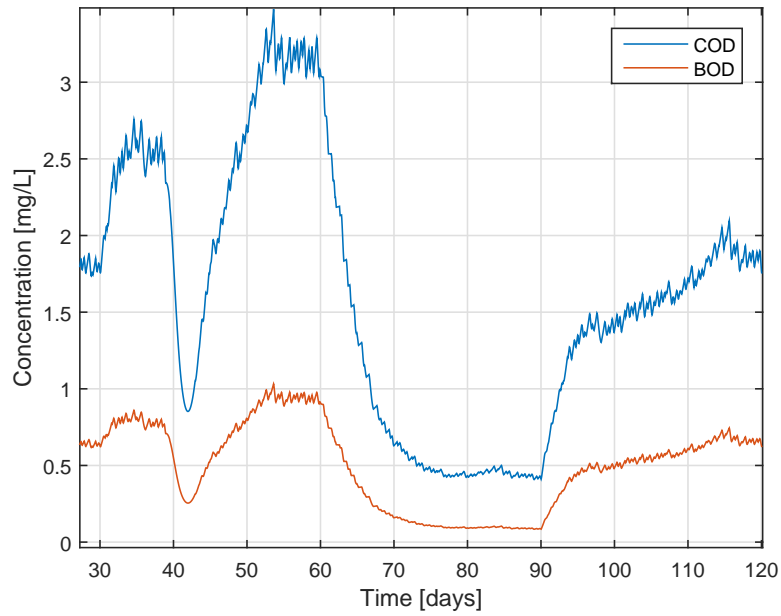


Figure 6.10: COD and BOD levels during the smaller extreme discharge event

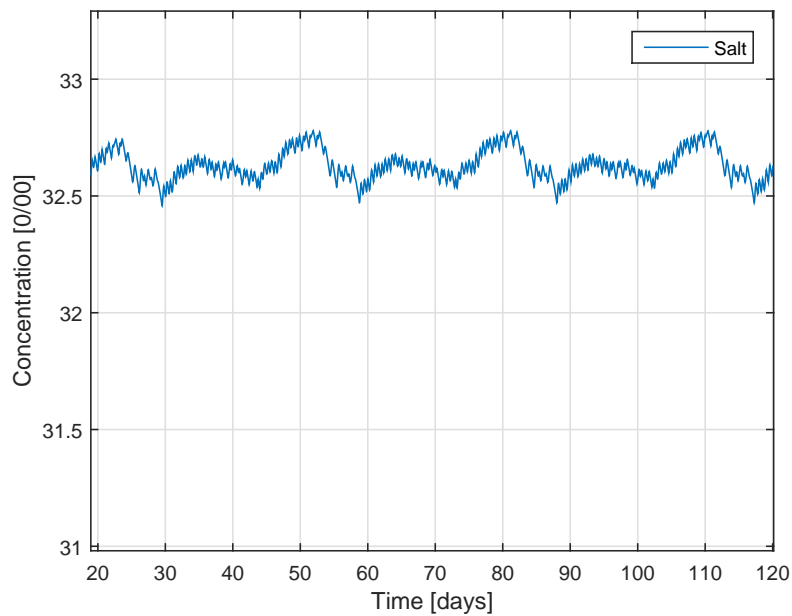


Figure 6.11: Salt concentrations during the dry season

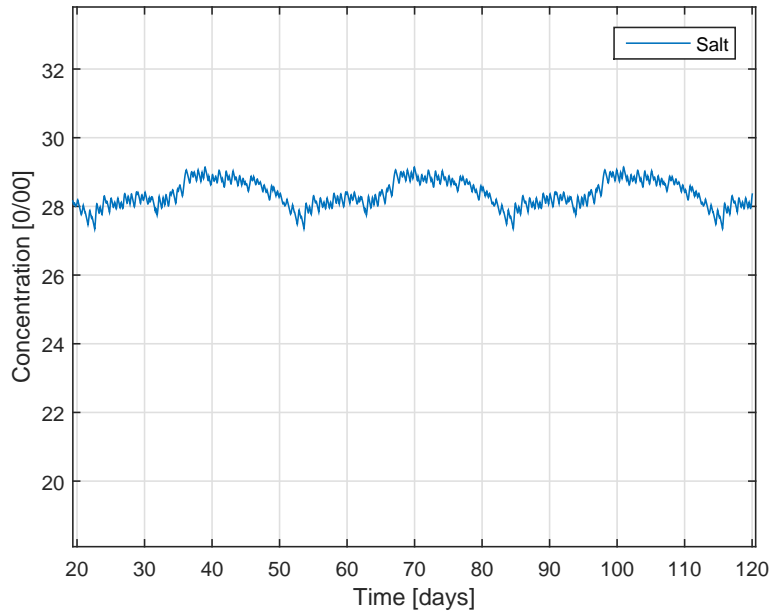


Figure 6.12: Salt concentrations during the wet season

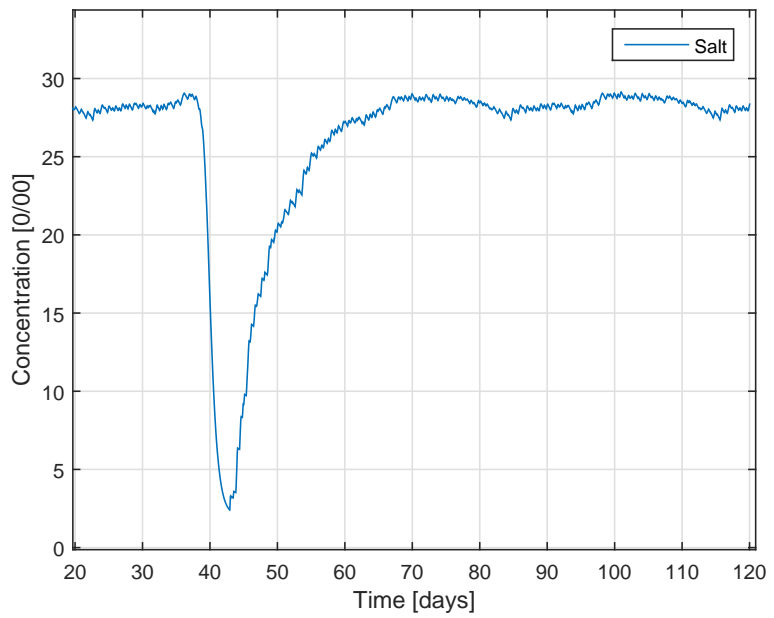


Figure 6.13: Salt concentrations during a smaller extreme discharge event

6.4.1 Conclusions

From analysing the model results of the current situation for the different scenarios, the following can be concluded:

- During the extreme events, water levels in the lagoon can become very high, well above +1 m MSL defined as the water level above which damage will occur.
- Storm surge has a greater absolute effect on the rise in water level, however a combined event is still governing.
- During high river discharges salt concentrations in the lagoon can drop significantly, potentially resulting in damage for the shrimp farms.
- Alone, shrimp production is not enough to reach unacceptable pollution levels in the lagoon. However, when more pollution sources would be included, pollution could exceed the acceptable levels, especially during dry season.

Chapter 7

Requirements

From the literature study, analysis and field visit many problems have become apparent. The solutions will aim to solve those problems. Some requirements are posed to ensure the solution fulfils the main demands. At this moment, only functional requirements and some additional desired effects will be stated.

7.1 Functional requirements

A solution or set of solutions should improve and support the economic development of the region, by:

- Stabilizing the Tu Hien inlet.
- Ensuring navigability for the future governing ship.
- Decrease flood levels around the Cau Hai Lagoon.
- Decreasing salt intrusion into fresh water and rivers.
- Improving water quality of the lagoon.
- Maintain or improve conditions for aquaculture.

7.2 Desired effects

For the chosen solution to be successful, it needs to have certain positive effects on the considered area. The main desired effects are stated below:

- The area gets an economic boost due to better conditions for farming, fishing, trade and tourism.
- The flood levels in the rest of the lagoon system decrease to some extent.
- The maintenance frequency and its costs should be low.
- The solution functions as an example of solving water related problems in Vietnam.
- Local people are involved in constructing and maintaining the solution.
- Preferably the solution should be built with sustainability in mind.

Chapter 8

Alternatives

To determine the most promising solution, several alternatives have been composed out of a set of elements. In this chapter first these elements are shown and after that the alternatives will be presented below.

To create the alternatives initially not all elements have been used. Mainly the elements preventing floods and erosion, stabilizing the inlet and/or increasing its size have been incorporated into the alternatives.

After the evaluation and assessment of those alternatives, described in sections 8.2 to 8.6, a review of the possible adaptations with the remaining elements is made.

8.1 List of Elements

1. Jetty at spit side

A jetty at the spit side decreases the sediment transport along and into the inlet, thus increasing the size and stability of the inlet. Blocking the sediment transport at this side of the inlet, might increase the erosion at the other side however. Thus this solution might need to be combined with another measure.

- Increasing inlet size
- Partially stabilizing location
- Might cause erosion

2. **Jetty on each side**

By constructing a jetty on each side of the inlet, the sediment transport on both sides into the inlet is blocked. Due to the flushing of the tide and river discharge, the inlet is then expected to increase in size. The shifting of the inlet location will most likely be stopped.

- Increasing inlet size
- Stabilizing location

3. **Bank protection at erosion side**

A bank protection at the erosion side of the inlet could fix this end of the inlet and stop the erosion.

- Stop erosion at southern side of the inlet
- Partially stabilizing location

4. **Movable storm surge barrier**

To decrease flood levels during high water storm surge at sea, a movable barrier (in many possible forms) could be a solution. A large contributor to the flood levels however, is the discharge from the rivers. It should therefore be investigated whether such a solution could indeed decrease the flood levels. Additionally, the storm surge barrier could simultaneously function as a salt intrusion dam.

- Decreasing flood levels behind barrier
- Stop salt intrusion

5. **A barrage with deeper navigation channel and higher ‘flood-plains’**

This solution tries to create a small but deep inlet channel at a fixed location, most likely the current one. Next to the deep inlet channel, a spillway will be created at a certain level above MSL. During normal conditions this prevents large salt intrusion. During high river discharges and thus high water levels in the lagoon, the spillway increases the inlet flow area. This possibly decreases the water levels in the lagoon. However, as mentioned for the storm surge barrier, contributions to the high water levels at the lagoon are both from the river discharges as well as the storm surge levels at sea.

This solution possibly needs to be combined with a jetty at the northern side of the spillway to prevent accretion on top or in front of the created spillway. On the southern side of navigational channel a bank protection might be needed to fix the channel location.

- (Possibly) decreasing flood levels
- Ensuring a deep navigational channel
- (Possibly) decreasing salt intrusion

6. Dredging

Instead of a structure, a ‘soft’ solution is also possible. In this case the accretion in the inlet is not stopped. By dredging the inlet periodically, it can be kept deep enough to use for navigational purposes. This also increases the flow area of the inlet. By choosing the quantity and return period of the dredging, the inlet area increase can be determined.

7. Mangroves

Mangroves are very suitable as shoreline protection and storm protection, by dampening the incoming flood wave and stabilizing the sand in which the trees grow. There have been many mangrove restoration projects in Vietnam as many of the mangroves were destroyed during the war.

The survival rate of the mangroves during these projects was very low however, mostly because restoration was done by untrained people. Other reasons of the low survival rate were inadequate management, continued fuel wood collection and conversion to shrimp ponds. However, some relative successful mangrove restoration projects were done around the Cau Hai Lagoon.

Conditions are not optimal for mangroves: alluvium carried by the rivers in central Vietnam coast is too little to form seashore swamps and is swept away by tides and waves. Rainfall is high but unequally distributed. The coast is strongly influenced by storms and monsoons. Due to these reasons, there are no mangroves along the entire seashore, except in areas protected by sand banks. It should however be possible to grow mangroves along the central coast, according to [Marchand, 2008].

- Decreasing flood levels
- Decrease the erosion along the shoreline
- Natural solution, benefits for ecology

8. Alternating discharge regime reservoirs (Truoi & Ta Trach)

By changing the discharge regime of the dam salt intrusion as well as flood levels might be decreased. The main purpose of the Truoi reservoir is already to ensure irrigation. The Ta Trach dam however

is meant for hydro power generation. The CRSD mentioned that the regime does not yet contribute largely to flood prevention A.2.2. At some times during floods, water is still released. Making rules in collaboration with the dam owner can improve the conditions.

- Decreasing salt intrusion
- Decreasing flood levels

9. **Making adaptations to the connecting channel**

By altering the Thuy Tu connection between the Cau Hai Lagoon and the Thuan An inlet, the amount of water that is exchanged between the two lagoons during some events could be changed. The magnitude of this effect should be investigated further to know whether this solution could benefit the Cau Hai Lagoon, also without negatively affecting the Thuan An inlet.

- (Possibly) increasing inlet size

10. **Salt intrusion dam**

Salt intrusion in the rivers is a problem for agriculture around the lagoon. The salt water affects the harvest in a negative way. Salt intrusion may be prevented by a dam close to the river mouth which stops salt water, but is also able to discharge surplus water from the rivers in case of heavy rainfall. The best option is to construct a movable dam or a dam below the water level so navigation from the river to the lagoon and vice versa is still possible.

- Decrease salt intrusion
- Might cause hindrance for ships

11. **Regulating land use for farmers**

By adapting a policy aimed at sustainable land use for agri- and aquaculture, the water quality as well as safety can be improved. When the number of shrimp farms is limited, less pollution will enter the lagoon and when the farms are not allowed to be build in the flood plains the damage during a flood will be reduced.

- Improve water quality
- Decrease damage in case of flood

12. **Improving dike system around lake**

By improving the dike system around the lagoon a large part of the

problems regarding floods are tackled. Many people need to move since a lot of them live in the area where a potential dike is to be constructed.

- Improve safety against flooding
- Possible need to relocate houses

13. **Improving dunes on barrier islands**

Improvement of the dunes on the barrier islands will prevent flooding due to storm surges from the sea. Moreover, improvement of the dunes is a way of supplying sand to the eroded beaches. Improving the dunes will also decrease the chances of a new inlet forming during a flood, which would have large negative consequences for the existing ones.

- Decreasing flood levels
- Preventing opening of new inlet

14. **Sand bypass**

A sand bypass is used in a situation where the littoral drift is interrupted, for example in a harbour mouth or inlet. At one side of the entrance the sand is accreting while at the other side erosion can take place. A sand bypass transports the sand from the accreted side to the erosion side and thus restores the balance.

- Reduce accretion/erosion behind the jetties
- Requires maintenance and running costs during its lifetime

8.2 Alternative A: Jetty and bank protection

Alternative A consists of the construction of a jetty at the spit side together with a bank protection at the erosion side, as shown in figure 8.1. In this figure, the proposed jetty is drawn in black at the spit side of the inlet. The bank protection is drawn in blue at the erosion-side of the inlet. In brown the expected accretion is drawn, this is explained below.

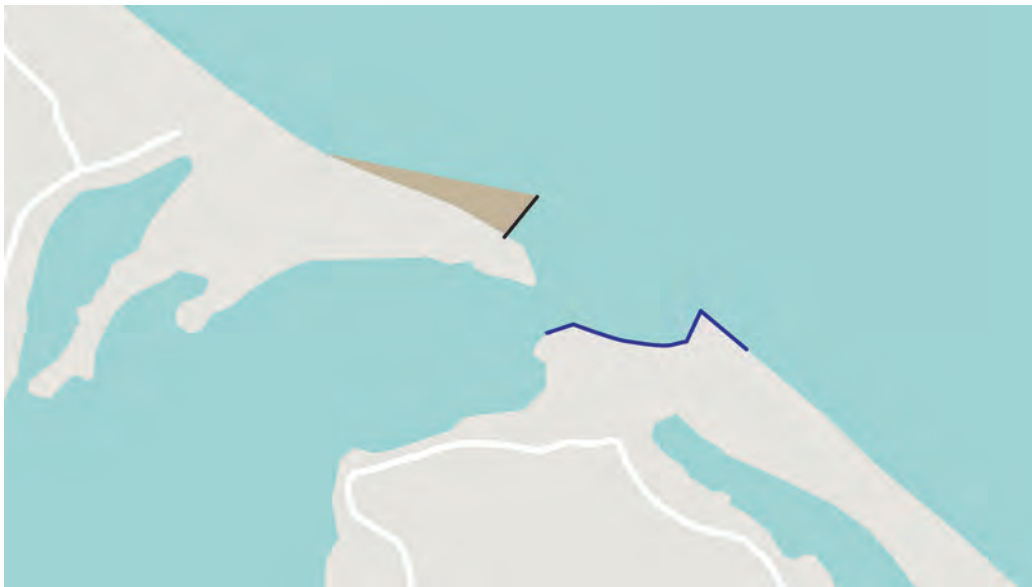


Figure 8.1: Schematic overview of alternative A

Constructing the jetty at the spit side of the inlet will block the littoral drift, causing accretion behind it and increasing stability of the inlet as it is no longer silting up. The downside of this blocked littoral drift however is the erosion that can be expected at the other side of the inlet. In this alternative, to protect the down drift side of the inlet from eroding, a bank protection is proposed. This protection should stop or at least limit the underlying sand from washing away due to wave action, even in storms.

An additional aspect to take in mind is that in time, it is possible that sand-bypassing of the jetty will occur. Also, to totally stop the area around the lagoon from flooding, the land should be raised or dikes should be constructed, which is not included in this alternative. An increased inlet size could reduce the flood levels caused by high river discharge however.

Advantages and disadvantages

Advantages

- Stabilization of the inlet.
- Increasing the cross sectional area of the inlet.

Disadvantages

- Maintenance dredging might still be necessary.
- Flooding of the area not completely solved.

8.3 Alternative B: Jetty on each side of the inlet and a sand bypass

In alternative B a jetty is constructed on each side of the inlet. The jetties will reach far into the sea, covering most of the surf zone to stop the littoral drift in both directions. Also a sand bypass is incorporated in this alternative. According to [Stive and Bosboom, 2013] it is wise to wait with deciding on the sand bypass until the actual accretion is initiated. When the sand bypass is constructed beforehand there is a large risk of over dimensioning it. The bypass requires maintenance. Alternative B is shown in figure 8.2.

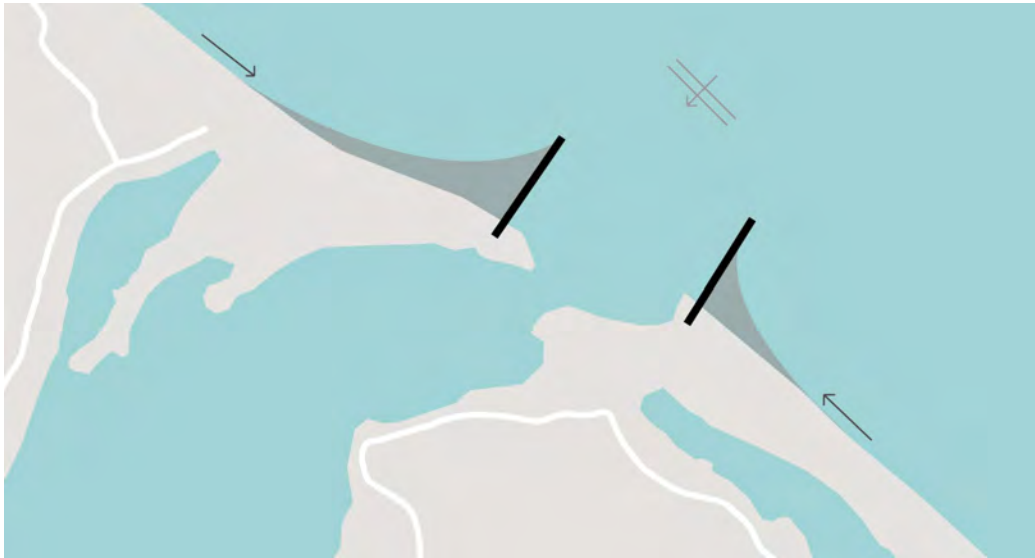


Figure 8.2: Schematic overview of alternative B

By constructing a jetty on each side of the inlet, the sediment transport into the inlet is blocked from both sides. Littoral drift will not affect the sediment transport in the inlet any more. Therefore the main reason for closing of the inlet is removed from the system.

Cross shore wave induced sediment transport forces and Stokes drift may cause some sediment to enter the inlet. Due to the flushing of the tide and river discharge however, the inlet is expected to increase in size and the mitigation of the inlet location will most likely be stopped.

Because littoral drift occurs in both directions along the coast, sedimentation is expected on both jetties. The sedimentation will be larger on the northern

jetty since the south-eastward directed sediment transport is greater than the north-westward directed transport. The sand bypass will thus have to direct the sand from before the northern jetty to after the southern jetty.

Advantages and disadvantages

Advantages

- The inlet will most likely increase in size
- Good possibilities for the development of a port since large ships have the possibility to enter the lagoon
- River flood evacuation capacity is enlarged

Disadvantages

- A larger inlet may cause more salt intrusion
- The solution doesn't solve floods due to storm surge

8.4 Alternative C: Jetty combined with a barrage

Alternative C has been composed out of a jetty at the updrift side in combination with a bank protection at the erosion side, similar to alternative A. The main difference is a kind of spillway that is incorporated in this alternative. This structure is explained below. An overview of the alternative and its elements is given in 8.3.



Figure 8.3: Schematic overview of alternative C

The spillway

The spillway incorporated in this alternative tries to limit salt intrusion in the lagoon as well as prevent flooding of the land. The spillway consists of a deep channel with spillways on either sides of it. The deeper part functions as a shipping channel, it needs to have sufficient depth for the largest ships. When the water level rises, the spillway height is reached and the cross section is increased considerably. This allows for the water to be transported to the sea in case of major river discharge. It should be noted that this solution alone is only stabilizing the inlet and blocking salt intrusion. To fully prevent flooding of the land around the lagoon in case of storm surge at sea more measures should be taken. For example the land could be raised or dikes could be constructed.

A front view of the spillway can be seen in figure 8.4. This is a conceptual drawing. In reality the deeper navigational channel could have slopes consisting of rock similar to a bank protection.

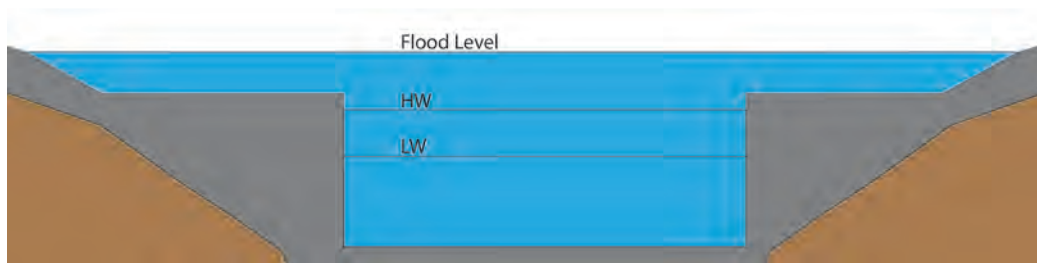


Figure 8.4: A drawing of the cross section of the spillway

Advantages and disadvantages

Advantages

- Stabilization of the inlet.
- Increasing navigability through the inlet.
- Decrease flood levels in case of high river discharge.

Disadvantages

- No solution for storm surge at sea.

8.5 Alternative D: Jetty on each side of the inlet in combination with a movable storm surge barrier

In alternative D a movable storm surge barrier is added with respect to alternative B. Although the jetties are a good solution for a stable and wide inlet, and therefore will let the inlet be able to discharge large amount of water from the lagoon, it will not prevent a storm surge from the sea. A flood wave from the sea won't be stopped and can cause damage around the lagoon. To prevent this, and still let the boats be able to navigate in and out of the lagoon, a movable storm surge barrier is suggested.

The barrier must be able to stop a flood wave from the sea and of course the water must not be able to flow along the barrier. Probably the best place to construct the barrier is under or alongside the Cau Tu Hien bridge, which is close to the inlet. Just constructing the barrier won't be enough. In order to prevent water from flowing along the barrier some dikes need to be constructed on the northern side of the inlet. The location of the storm surge barrier and potential locations of the dikes are demonstrated in figure 8.5, indicated by the red line. Of course further research is required to determine the best location for the dikes and barrier.

Since the storm surge barrier is movable, therefore it won't have a large effect on the water quality of the lagoon. If the barrier is also used to prevent salt intrusion on a more regular basis however, this could have an effect on the water quality.

The construction of a movable storm surge barrier is an expensive solution. The feasibility can thus be questionable and requires more research. Flood waves from the sea occur less often than flood waves due to high discharges of the river. This means the impact of a sea flood wave must be large to make it worth the cost of the barrier.

Advantages and disadvantages

Advantages

- The whole lagoon area is protected against flood waves from the sea
- Discharge of flood water from the lagoon is easier due to the larger inlet



Figure 8.5: Visual impression of Variant D, two jetties to prevent sedimentation in the inlet and a storm surge barrier to prevent flood waves from the sea.

- Good possibility for the construction of a port since the navigability for large ships is improved in the inlet

Disadvantages

- Expensive solution due to the construction of the storm surge barrier
- The construction of the dikes may force many people to move to another place

8.6 Alternative E: 'Soft measures'

This alternative tries to incorporate more 'soft measures' to successfully solve problems around the Cau Hai Lagoon.

Incorporated in this alternative are the following:

- Dredging the inlet.
- Regulate land use for farming.
- Mangrove planting.
- Improve dunes on barrier island.

The dredging is done in order to maintain the navigational capabilities of the inlet channel. It is assumed that the depth will be increased by one meter. The frequency needs to be defined in a later stage. To stabilize the inlet and increase the safety against flooding, the following measures described below are taken.

Mangroves

A mangrove forest would have many benefits for the area if it can be planted and can survive in the conditions present. These benefits include storm protection and shoreline protection. Besides that, the trees provide a good habitat for wildlife.

In this alternative, mangroves would be desired at the barrier island near the inlet to strengthen the coast there. [Marchand, 2008] states in his report that the success of a rehabilitation project depends mainly on the knowledge available, as the choice of species depends heavily on the hydrological- and building conditions. The seedlings can't survive if the waves are too high so a temporary protection would have to be constructed in order for the seedlings to settle. Furthermore, socio-economic considerations like land ownership and regulations should also be taken into account [Schiereck and Verhagen, 2012].

The conditions in central Vietnam are not optimal for a mangrove forest due to strong wave attack and little nutrient-rich alluvium that reaches the shore. There are however mangrove species that could survive here. Furthermore, in this alternative there is sand accretion expected behind the proposed jetty that could function as a nutrient-rich starting place for the reforestation.

Dune improvement

The dunes on the barrier island serve an important function, but are in a bad state. Erosion due to longshore transport and sand mining by local people have had its impact on the dunes.

The function of the dunes is to protect the land behind it from flooding during high water levels and to act as a sand buffer during strong storms, eroding the sand in cross-shore direction. In this alternative the sand barrier is restored by nourishing the beach. This should be done every couple of years.

Regulate land use for farming

The agri- and aquacultural land usage has a large impact on the area. With farming both aqua- and agriculture are meant. Especially shrimp farms leave their footprint on the area. Good regulation can prevent important dune areas to be used for farming and forests from being cleared. Also the water quality benefits from restrictions on aquaculture. Collaboration of the farmers is key here so a good participation-programme is needed where the benefits for the farmers are explained.

Advantages and disadvantages

Advantages

- Stabilizing the inlet in a more natural way.
- Higher safety against flooding due to nourishment of the barrier island.
- Better control on land use.

Disadvantages

- The cooperation of farmers is needed and might be difficult to obtain.
- Beach nourishment needs to be executed every couple of years.
- Mangrove planting is vulnerable for failure.

Chapter 9

Results and evaluation

In this chapter the results are discussed and the most feasible alternative will be chosen. To differentiate the alternatives in the model, the effect of the measures on the equilibrium flow area are calculated analytically. Additionally the closing of the storm surge barrier in alternative D is taken into account.

9.1 Inlet cross-sections of alternatives

9.1.1 Effect jetties

The jetties used in alternative A to D are meant to block the littoral drift into the inlet and thereby enlarging the inlet size. How much the inlet increases in size depends on the existing littoral drift and the amount blocked by the jetties.

[Lam, 2009] researched the littoral drift at the Thuan An and Tu Hien inlet. With the help of a model, he calculated the littoral drift and the sediment transport in the inlet. The model is presented in figure 9.1. H1 and H2 represent the sediment transport in the inlet and the cross-shore transport, H3 and H4 represent the littoral drift. The data as provided by Lam is presented in table 9.1.

The littoral transport data, column H3 and H4, can be used to determine the effect of the construction of a jetty on the cross-section of the inlet. The littoral drift is processed in the C coefficient in the empirical relationship

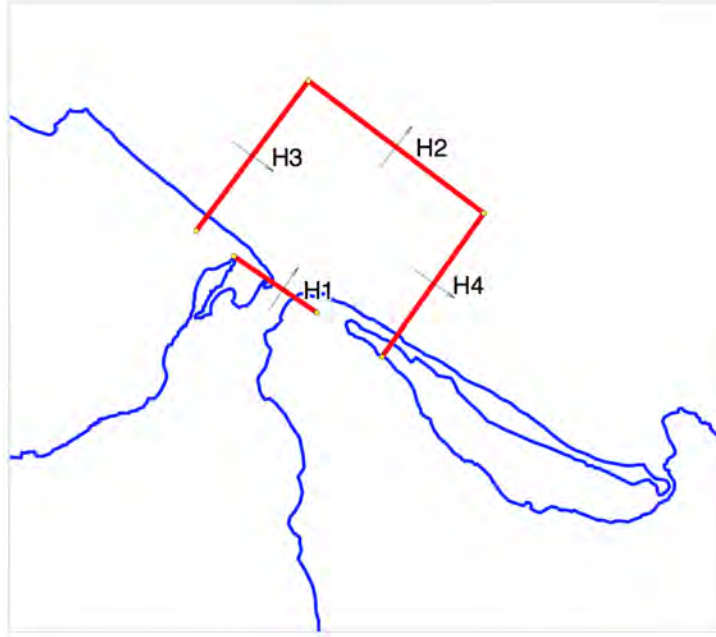


Figure 9.1: Model for sediment transport near the Tu Hien inlet as used by Lam (2009)

between inlet cross section A_{eq} and tidal prism P .

$$A_{eq} = CP^q \quad (9.1)$$

Van de Kreeke (2004) found an expression for the coefficient C as follows:

$$C = \frac{MT^n}{k\alpha^m\pi^n} \frac{2}{m-2n} \quad (9.2)$$

With M the littoral drift, T the tidal period and k, α coefficients.

According to [Stive and Bosboom, 2013] the values for m and n are respectively 1 and 3. Which means the coefficient C is related to littoral drift M to the power $-\frac{2}{5}$, or in formula:

$$C \propto M^{-\frac{2}{5}} \quad (9.3)$$

Table 9.1: Data provided by research of Lam (2009) [Lam, 2009]

	H1	H2	H3	H4
Jan-Mar	0,014	0,008	0,208	0,204
	-0,019	-0,004	-0,057	-0,115
Net	-0,005	0,004	0,151	0,089
Apr-May	0,013	0,006	0,036	0,035
	-0,017	-0,002	-0,043	-0,047
Net	-0,004	0,004	-0,007	-0,012
Jun-Aug	0,017	0,008	0,006	0,006
	-0,015	-0,002	-0,031	-0,034
Net	0,002	0,006	-0,025	-0,028
Sep	0,042	0,33	0,027	0,025
	-0,013	-0,001	-0,014	-0,032
Net	0,029	0,329	0,013	-0,007
oct-dec	0,078	0,064	0,447	0,429
	-0,036	-0,006	-0,179	-0,517
Net	0,042	0,058	0,268	-0,088
Yearly	0,164	0,119	0,724	0,699
	-0,1	-0,015	-0,324	-0,745
Net	0,064	0,104	0,4	-0,046

And directly following from that relation also follows:

$$A_{eq} \propto M^{-\frac{2}{5}} \quad (9.4)$$

With this relation between littoral drift and tidal inlet cross-section we can estimate the influence of a jetty on the Tu Hien inlet cross-section.

Passage H3 and H4 in figure 9.1 both represent littoral drift. H3 minus H4 represents the amount of sediment that lags behind in the defined area. To simplify the calculations, this is considered the amount of sediment that causes sedimentation in the inlet.

A jetty will block part of the littoral drift at either H3 or H4. The amount blocked is depended on the length of the jetty and whether its impermeable or not. It is assumed the jetties can be designed in such a way that it blocks 80 percent of the littoral drift at the specific location. By multiplying the

column H3 in table 9.1 by 0.2 the new littoral drift is then estimated.

The total net littoral drift after this reduction and the original net littoral drift are both used as input in the empirical inlet cross-sectional relation as shown in equations 9.1 and 9.2. The ratio $(M_{new}/M_{old})^{-2/5}$ tells how much bigger or smaller the inlet becomes as a result of littoral drift reduction at passage H3 or H4. For instance for a jetty at H3, $M_{new} = H3 * 0,2 - H4$ and $M_{old} = H3 - H4$;

The results of these calculations are presented in table 9.2. One can see that the impact of a jetty at the H3 passage causes the inlet cross-section to become 66% larger. The impact of a jetty at H4 is not significant with only 4% inlet increase. Although the impact of a jetty at the H4 passage on itself is not that large, the combination of the two jetties still causes a significant inlet increase of 90%.

The cross section as measured during the fieldwork was 615 m^2 , meaning the new cross sections of the inlet after constructing one or two jetties is as presented in the last column of table 9.2.

Table 9.2: Impact of jetties on the littoral drift and cross-sectional areas

	$M_{old} [Mm^3/y]$	$M_{new} [Mm^3/y]$	Inlet increase [%]	New cross-section surface [m ²]
Single jetty (H3)	0.446	0.126	66	1021
Single jetty (H4)	0.446	0.409	4	640
Two jetties (H3 and H4)	0.446	0.089	90	1169

9.1.2 Cross-sections alternatives

The new equilibrium cross-sections beneath MSL of alternatives A to D are now known. It is assumed that the storm surge barrier has no significant effect on the hydraulic resistance of the inlet. As the friction is so small compared to the outflow losses, also a change in χ due to the change in inlet cross-section is neglected.

The inlets are presumed to maintain their shape and thus the increase in cross-section area will both result in a larger average depth as well as a larger width. For example the 66 percent increase in cross-section of variant B will result in a new width of $126 * \sqrt{1.66} \approx 162$ and a depth of $4.88 * \sqrt{1.66} \approx 6.26$.

In chapter 8 it was stated that with alternative E the inlet will be dredged in such a way that on average the depth is increased by one meter. This results in a new inlet cross-section of $(4.88 + 1) * 126 = 741 \text{ m}^2$. In table 9.3 the inlet cross-sections are summarized.

Although in a different shape, it is assumed that beneath MSL the cross-section area of alternative C will increase with 66 percent due to the single jetty as well. A width of 116 meter beneath +0.5 m MSL is chosen. This fixed width would then result in a depth of $\frac{1021}{116} = 8.80 \text{ m}$. Above +0.5 m MSL a width of 320 m is chosen, which is the inlet width in the other measured cross-sections (see appendix B).

Table 9.3: Sizes inlet cross-section variants

Variant	Cross-section [m ²]	Binlet [m]	Dinlet [m]
0	615	126	4.88
A	1021	162	6.26
B	1169	174	6.72
C	1021 (<i>below +0 m</i>)	116 (<i>below +0.5 m</i>) 320 (<i>above +0.5 m</i>)	8.80 (<i>below +0 m</i>)
D	1169	174	6.26
E	741	126	5.88

9.2 Model results

9.2.1 Comparing alternatives

Water levels

Concerning water levels in the lagoon, the inlet size seems to be the most important factor. This becomes clear when alternative A, B and E are compared for the dry season, see 9.2. Alternative B has the largest inlet cross-section due to the two jetties at either side of the inlet, see section 9.1.1. Therefore the water level in alternative B is higher than in alternatives A and E. Compared to the current situation the levels increase slightly by around 0.04 m. This higher response causes more flushing of the basin, see section 9.2.1.

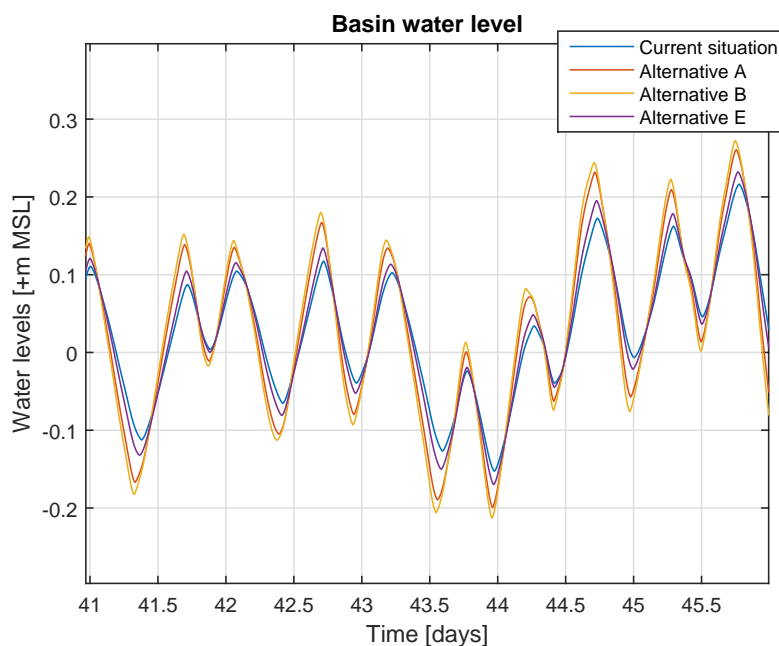


Figure 9.2: A plot showing the water levels in the lagoon during the dry season for the current situation and alternatives A, B & E

From figure 9.3 it can be seen that all alternatives are beneficial for the water level during a high river discharge. The flood level drops from 0.9 m to 0.6 m with all the 'structural' alternatives. Alternative E scores lower as it only reduces the peak water level to 0.8. Alternative D seems to lower the water levels slightly more than the others, this is due to the blocking of the

seawater during the event. This becomes more clear when the high discharge is increased in magnitude, see figure 9.4. Now the difference between the current situation and the alternatives A, B & C increases to 0.6 m. With alternative E it is only 0.2 m.

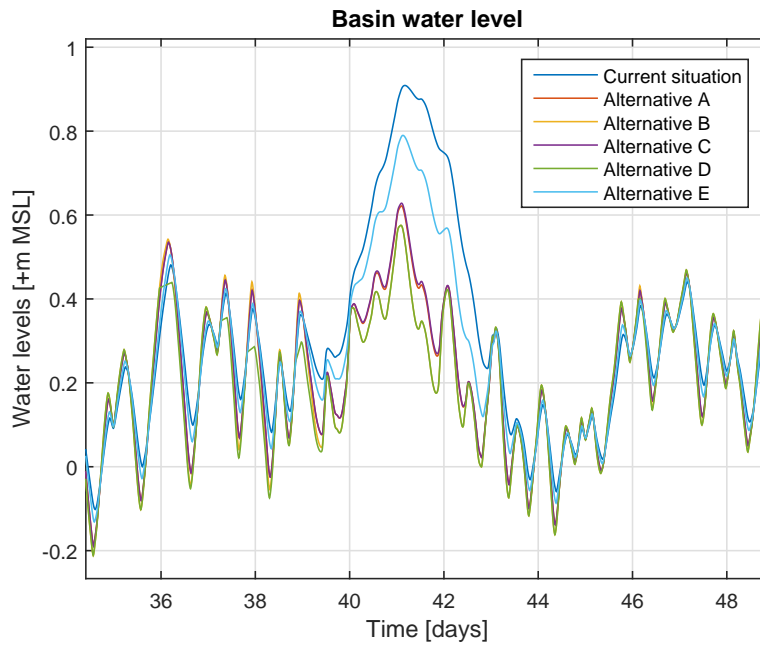


Figure 9.3: A plot showing the water levels in the lagoon during a high river discharge with all alternatives

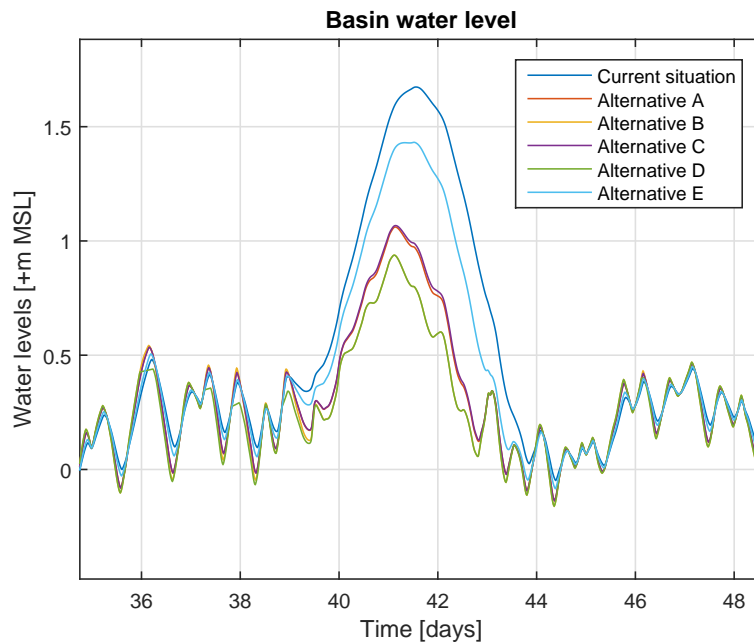


Figure 9.4: A plot showing the water levels in the lagoon during an extreme river discharge with all alternatives

During a 1/5 years storm surge the situation is different, see figure 9.5. The basin water levels in the lagoon with all but alternative D are able to directly follow the forcing water level at sea. The storm surge barrier in alternative D however is closed with this high storm surge, preventing water from entering the lagoon. The water level is not fixed however, the river input is still entering the lagoon but this amount is negligible compared to the effect the storm surge has.

When a storm of 1/50 years is modelled another effect becomes visible, see 9.6. Due to enlargement of the inlet with alternative A, B & C the water level in the lagoon follows the water level at sea more directly. This results in a faster rise of the levels compared to alternative E and the current situation, but a faster drop in water levels as well.

When looking at the combined event, all but alternative E score better than the current situation when looking at the water levels in the basin, see figure 9.7. Alternative D is the exception here. The water level rises slower and the peak is less high, the difference is approximately 0.2 m compared to the other 'structural' alternatives.

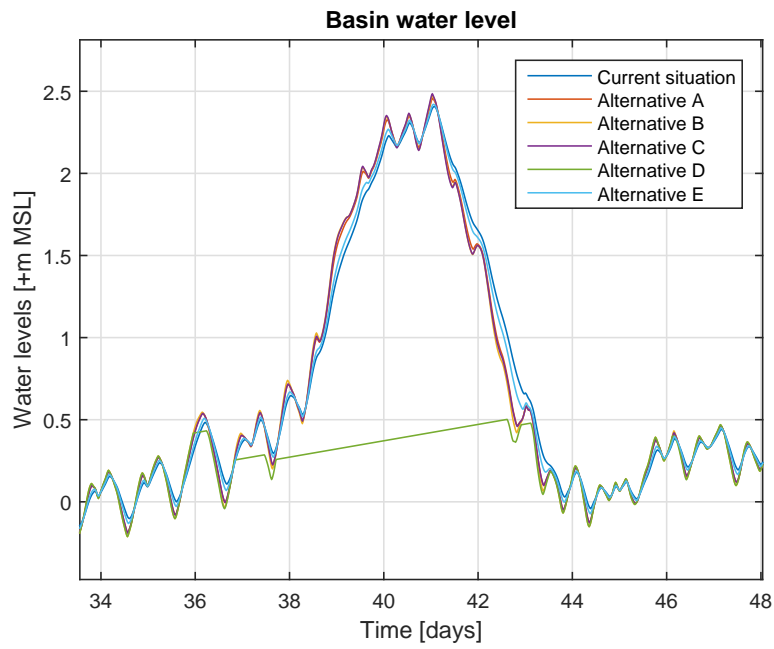


Figure 9.5: A plot showing the water levels in the lagoon during a storm event of 1/5 years with all alternatives

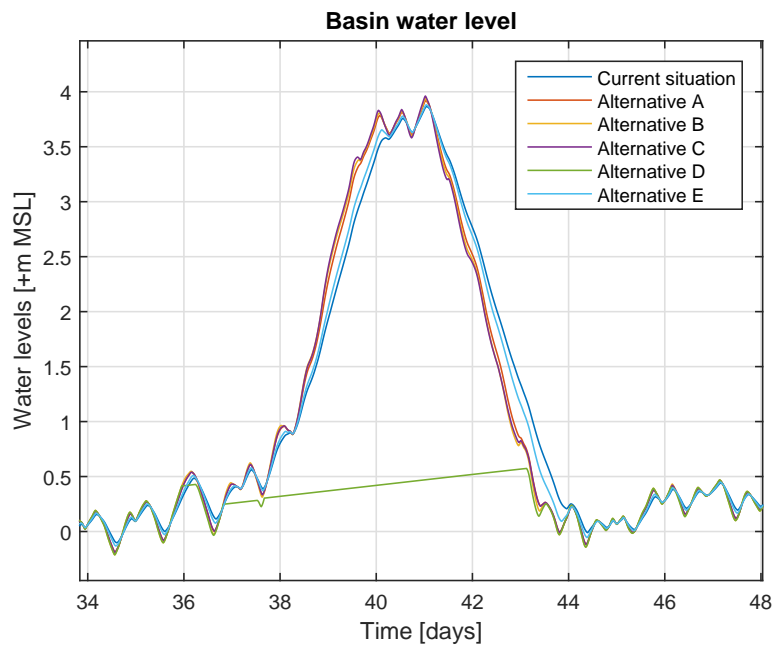


Figure 9.6: A plot showing the water levels in the lagoon during a storm event of 1/50 years with all alternatives

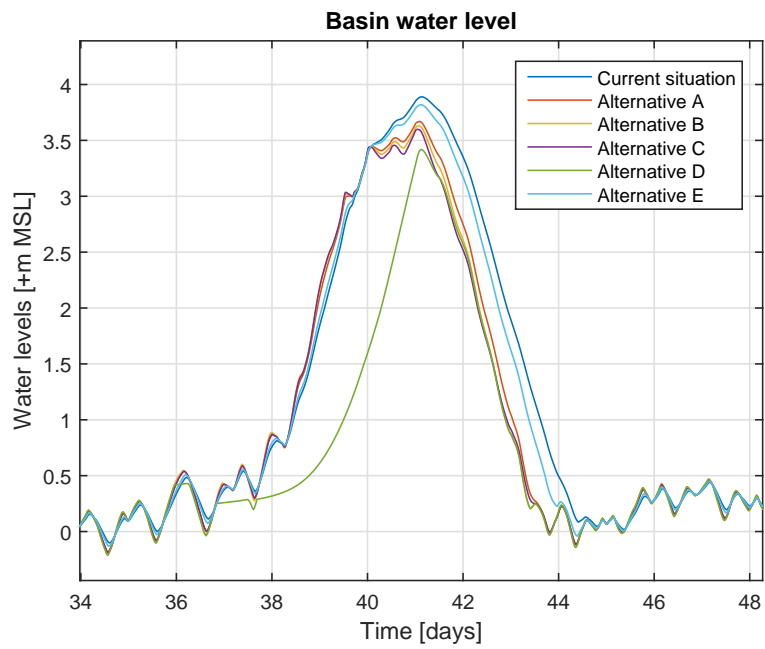


Figure 9.7: A plot showing the water levels in the lagoon during a combined high discharge event with a storm of 1/20 years

Pollution

Pollution in the lagoon is an important model parameter as it has a large influence on liveability in and around the lagoon. For the model two key pollution parameters have been chosen: COD and nitrogen concentrations, see 5.10.1.2. COD is the key parameter for waste from aquaculture and is formed mainly in the lagoon, while nitrogen resembles the output from agriculture coming primarily from the rivers.

In figures 9.8 & 9.9 it can be clearly seen that all three considered alternatives perform better than the current situation during the dry season. Alternative E performs worse than A and B, this is due to the smaller inlet size. The same results are found in the wet season.

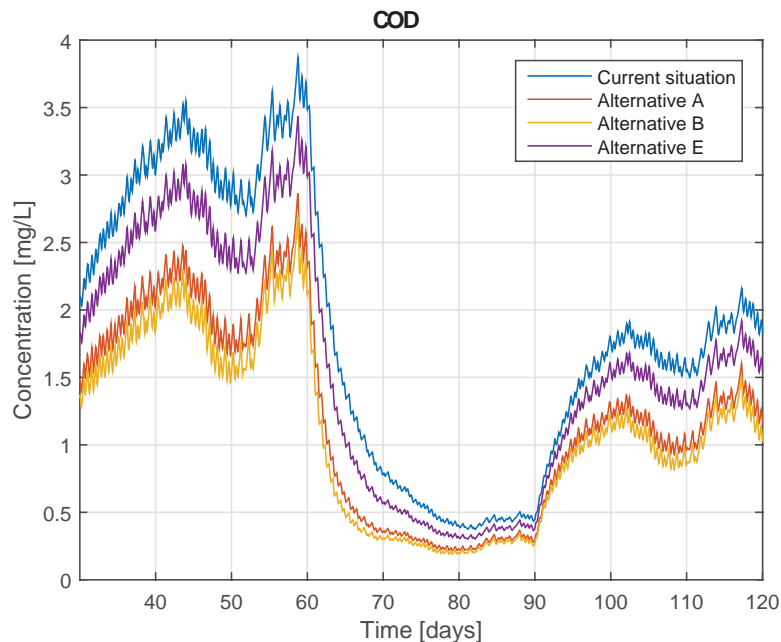


Figure 9.8: A plot showing the COD concentration in the lagoon for the current situation and with alternatives A, B & E during the dry season

When looking at a high discharge event, the results show a decrease in nitrate concentration for all alternatives compared to the current situation. Also the flushing effect of the river input at $T = 40$ can be easily recognized from figure 9.10. The same holds for the COD concentration, see figure 9.11. Between all 'structural' alternatives there are no notable differences, the only alternative that performs significantly worse is alternative E. This is due to its limited cross section at the inlet.

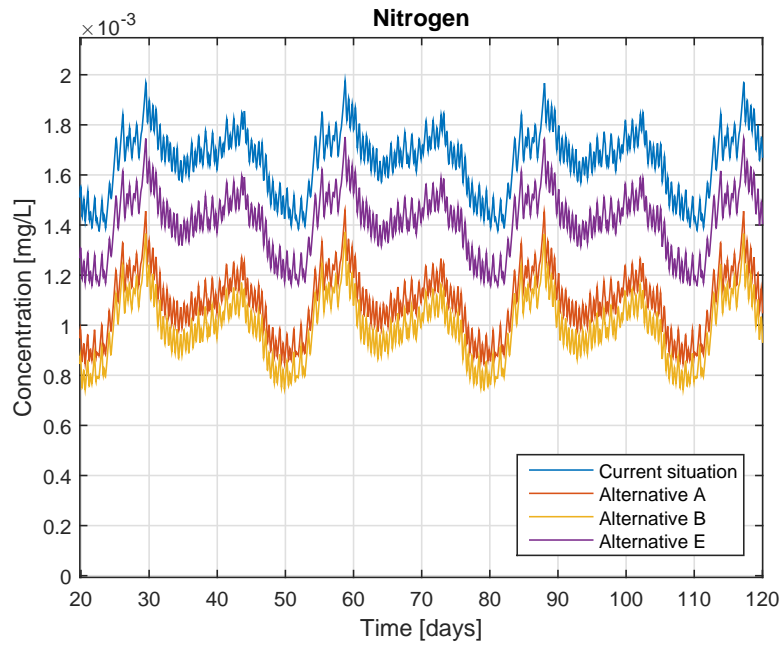


Figure 9.9: A plot showing the nitrogen concentration in the lagoon for the current situation and with alternatives A, B & E during the dry season

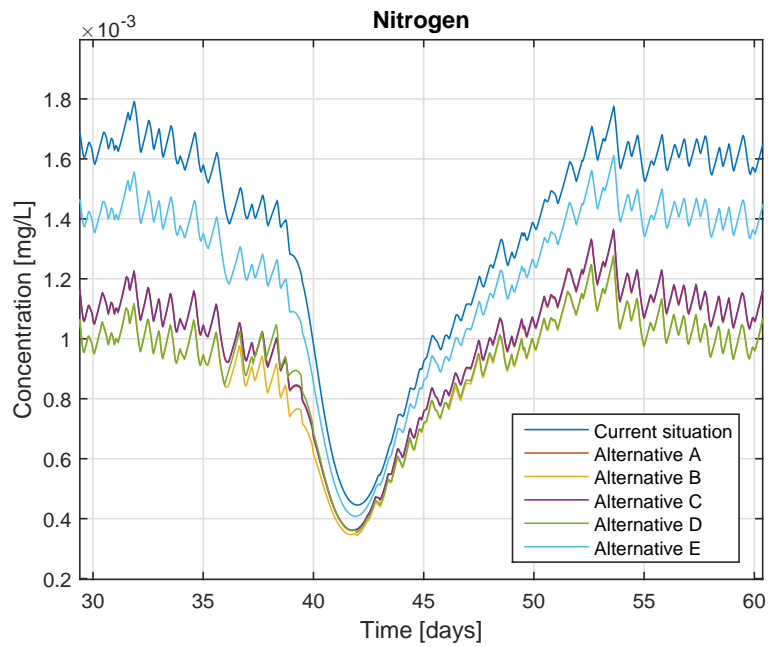


Figure 9.10: A plot showing the nitrogen concentration in the lagoon for a high river discharge with all alternatives

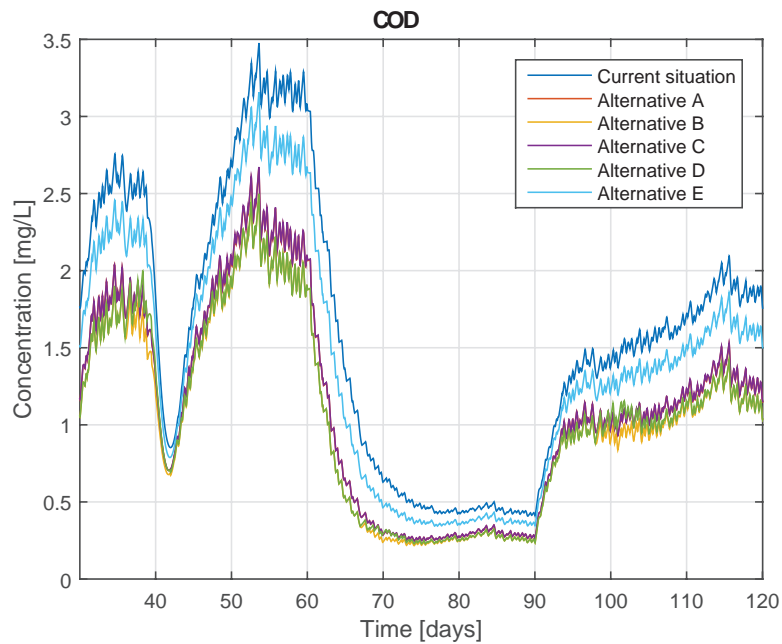


Figure 9.11: A plot showing the COD concentration in the lagoon for a high river discharge with all alternatives

The results for the pollution concentrations during a storm surge show large similarities to that of the high discharge. Also in this event the lagoon is flushed, see 9.12. All but one alternative improve the situation. The exception is alternative D however. During the storm the gates close, preventing the pollution from flowing out of the lagoon. Alternative E still improves the pollution concentrations over the current situation, but only marginally.

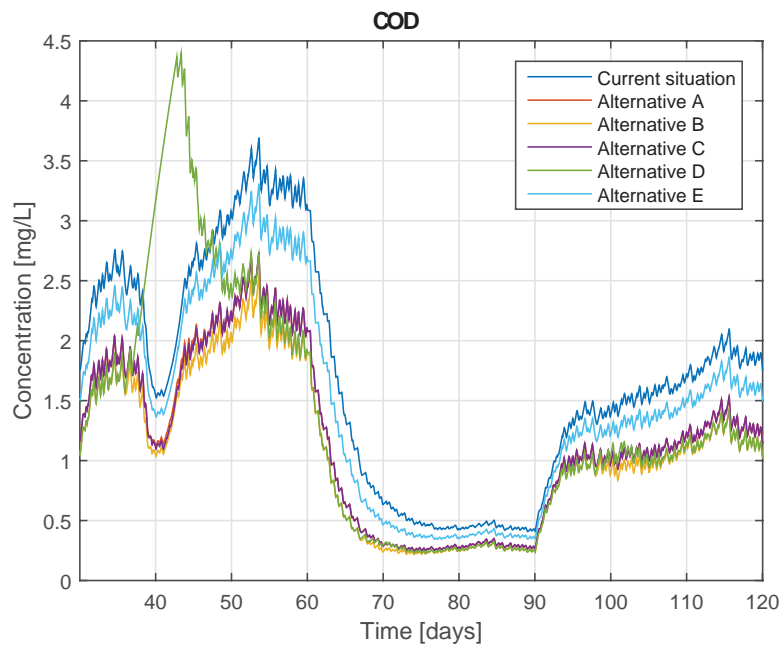


Figure 9.12: A plot showing the COD concentration in the lagoon during a storm surge of 1/50 years with all alternatives

Salt intrusion

Due to inlet changes, salt concentrations in the lagoon will change. With the many different stakeholders it is hard to say which salt concentrations are preferred. As in reality there is a gradient in salinity, different salt concentrations occur over the length of the lagoon, making different functions possible.

In general, as salt intrusion is a known problem in the current situation, increasing salt concentrations can be considered undesirable. Especially in the dry season, salt intrusion will play a role. The effect of the different variants on the salt concentrations in the lagoon can be seen in figure 9.13.

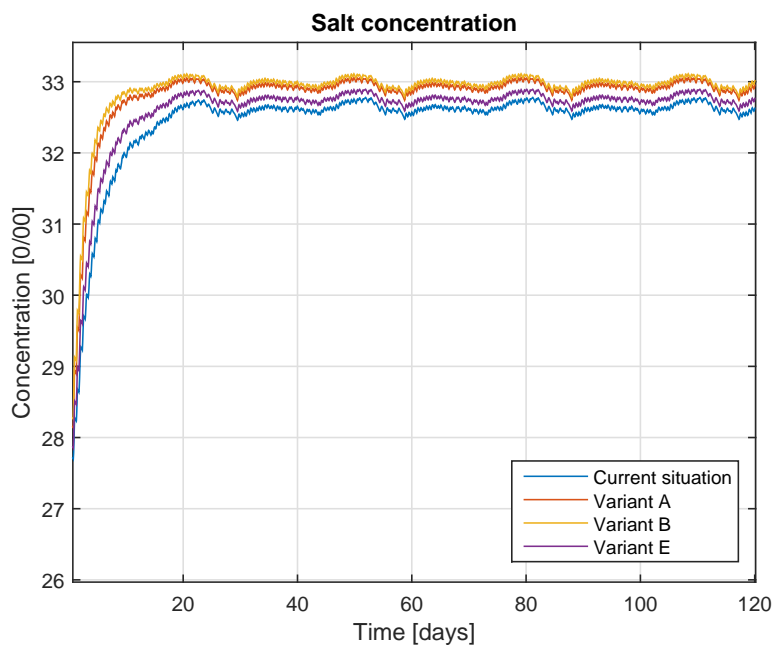


Figure 9.13: Salt concentrations during dry season for the current situation, variant A, B and E

Salt concentration will rise somewhat for variant A and B. Variant C and D respectively will have about the same rise in concentration. Since salt concentrations during the dry season are already high, the increase is not very significant in a fully mixed situation. As variant E has a smaller increase in salt concentrations due its smaller flow area. The increase in concentrations during the wet season is a bit larger, from 28 to 30 on average.

In case of a gradient the increase at the end of the of the basin might be

relatively more. At the mouth of the Dai Giang River measures have already been taken to prevent salt intrusion. At the other rivers this is not the case. Therefore to compare the alternatives the relative effect on the salt concentrations should be compared. An increase of a thousands in the fully mixed situation could mean an increase of multiple thousands at the river mouths in reality.

As can be seen in figure 9.14 a river discharge event can reduce the salt concentration very significantly, reducing the concentration to about 3 ‰. This is the case for the current situation as well as the variants. In the figure, concentrations of variant A can not be seen as in this case they are identical to variant C.

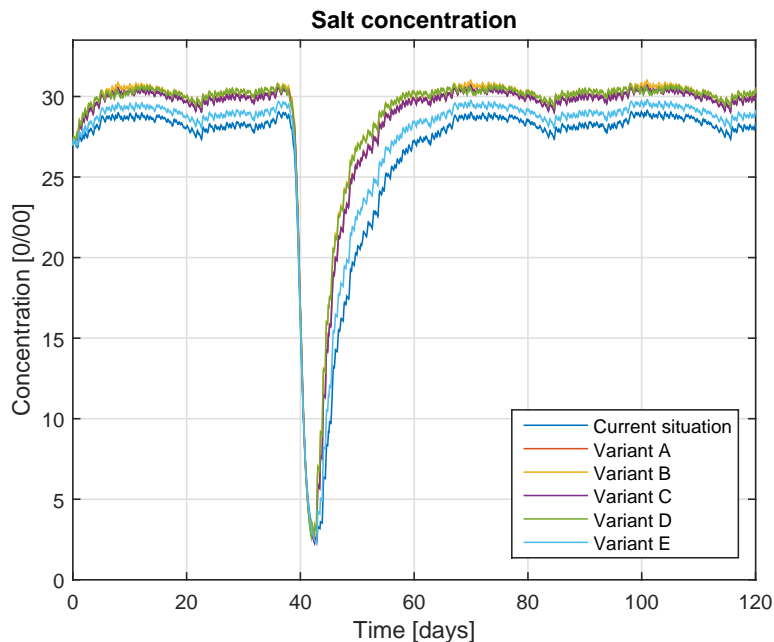


Figure 9.14: Salt concentrations during smaller flood event for all variants

The time to restore to equilibrium is smaller in the case of variants A to D. Instead of a restore time of about 25 days, it is now about 15 days. The restore time of Variant E is close to that of the current situation. A decrease in restore time is favourable for aquaculture, as the shrimp farms need brackish water. During a flood event salt intrusion into the rivers does not play a role, as the high discharges in the rivers result in very little salt intrusion.

One can imagine that during more frequent and smaller discharge events, the

restore time can also play an important role.

As can be expected, during an event with only storm surge the salt concentration in the lake becomes higher. For variant A, B and C this salt intrusion is higher than in the current situation. As the storm surge barrier will close for high sea levels, the salt intrusion is prevented in this variant. Due to the discharge that still flows into the lagoon, the salt concentration even drops a few thousands, see figure 9.15.

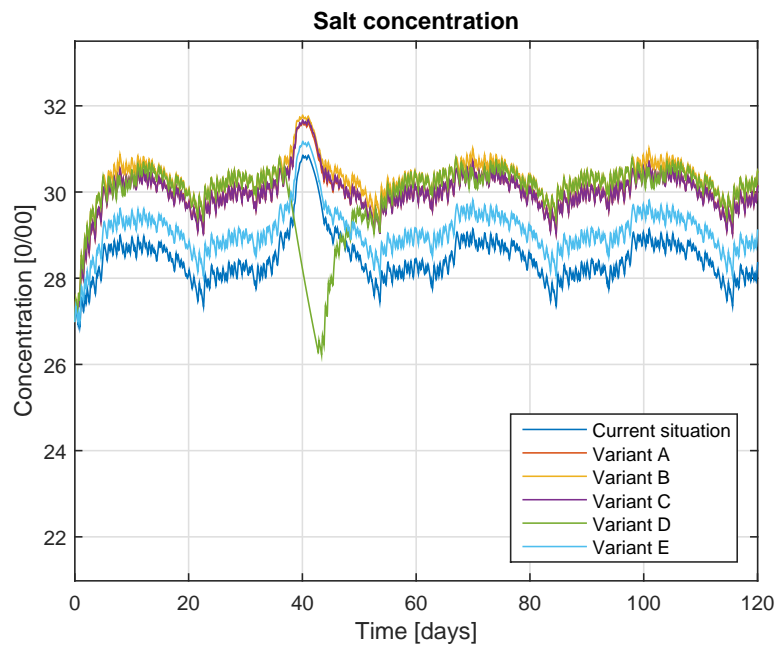


Figure 9.15: Salt concentrations during 1/5 frequency storm surge event for all variants

During an extreme event with both high discharges and high storm surge levels, the discharge has the largest effect on the salt concentration. Therefore, salt concentrations drop in the lagoon during this event. This can be seen in figure 9.16.

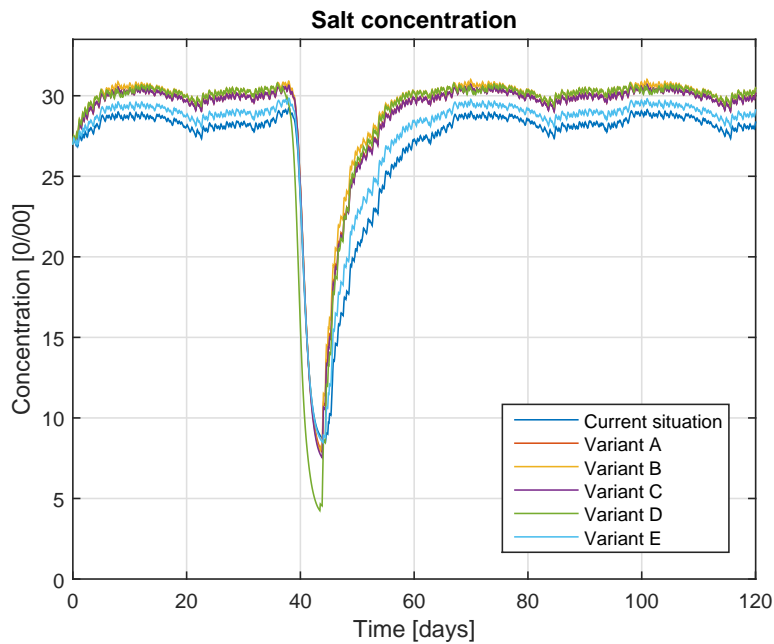


Figure 9.16: Salt concentrations during an extreme storm and discharge event for all variants

It is also possible to decrease salt levels with variant D on a more regular basis, by closing the gates during upcoming high tide. This however also decreases the flushing of the lagoon, and thus worsens the water quality.

Inlet flow velocities

The inlet flow velocities during the design event with high storm surge as well as high discharge can become very high, see figures 9.17 and 9.18.

As the inlet has increased in size, the flow velocities reduce for all the variants. The inlet flow area in the model is taken as fixed. In reality flow velocities of 4-5 m/s will most likely not be reached, as the large flow velocities scour the inlet. During the 1999 storm the Tu Hien inlet increased with about a factor 2.5. This will reduce flow water head differences and thus flow velocities significantly. Flow velocities of variant E are still close to the original situation.

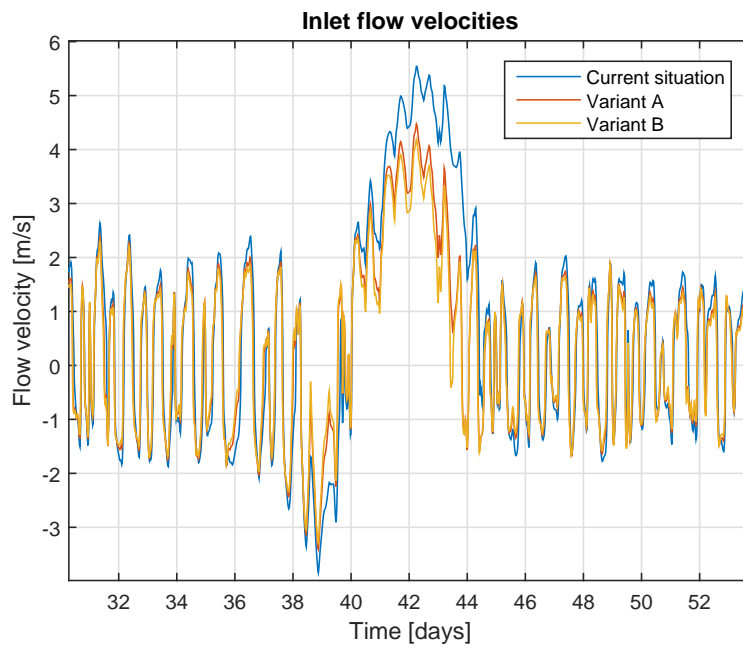


Figure 9.17: Salt concentrations during an extreme storm and discharge event for all variants

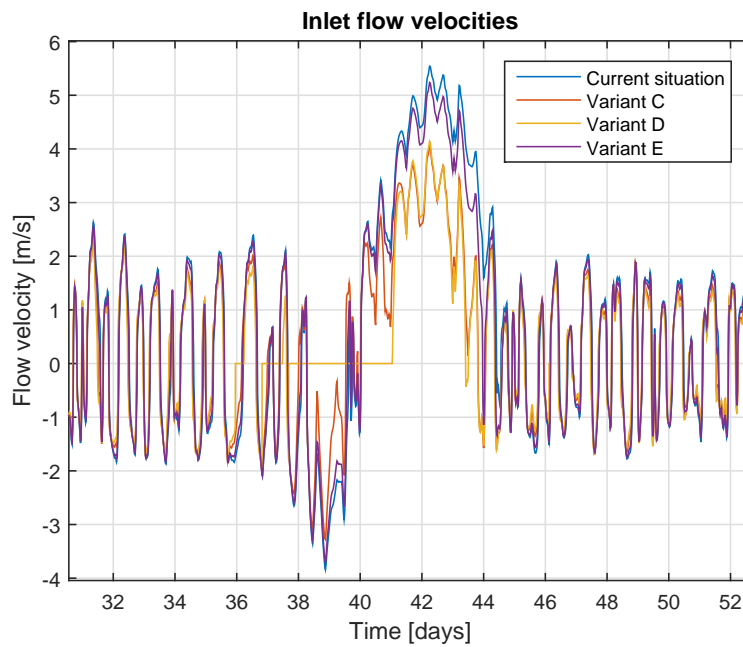


Figure 9.18: Salt concentrations during an extreme storm and discharge event for all variants

9.2.2 Conclusions

- Concerning flood levels in the lagoon, the storm surge has the largest absolute contribution during the design event. However, an increased inlet size still reduces the maximum occurring water level during the design event as water levels in the lagoon eventually rise above sea level.
- In case of a high discharge event, which is known to occur often in the region, an increased inlet size reduces flood levels significantly.
- The storm surge barrier in Alternative D is effective in the surge only situation. As soon as high peak discharges occur, its effect is limited however. Although there is an improvement in water levels during the combined extreme event, the basin seems not large enough to make the rise in water level due to the discharge small.
- Alternatives A to D significantly improve the water quality in the lagoon. The increase in inlet size of alternative E has a much smaller effect.
- An increase in inlet size does not only affect maximum salt concentration or minimum pollution levels, but also reduces the adaptation time to equilibrium after an extreme event. This can be considered favourable.
- Average salt concentrations are already high and therefore do not increase much in the fully mixed situation. In reality the salt intrusion can differ more however due to the gradient and effect of inlet depth. The latter will also result in a larger difference between the alternatives.

9.3 Salinity intrusion into the lagoon and rivers

The output of the continuous model for tidal excursion, tidal velocity and tidal prism is used to calculate the salinity intrusion in the total lagoon system. In D.7 the used input parameters and the intrusion length per alternative for the dry season are presented.

The Truoi river has a much steeper gradient than the Cau Hai lagoon therefore the intrusion length calculated by Rigter will not be exactly correct, but it is known that in the dry season farmers suffer from saline water intrusion in the river, which is used for irrigation. What can be seen is that widening

Table 9.4: Salinity intrusion length for the different alternatives

	Parameter	Alternatives					
		0	A	B	C	D	E
Cross section area	A_0	615	1021	1169	1021	1169	741
Water level	h_0	4.8	6.18	6.65	8.8	6.65	5.8
Intrusion length(km)	L^{LWS}	14.77	34.83	50.81	71.30	50.81	27.08

and deepening of the inlet has large influence on the salinity intrusion length. When such measure is desired one must think about extra salinity intrusion screens in the river to protect the fresh water supply.

9.4 Multi Criteria Analysis

A Multi Criteria Analysis is performed in order to compare the alternatives and the current situations. The 5 alternatives are scored, normalized and weighted for 10 predefined criteria. In the appendix Multi Criteria analysis E this process is described and a more elaborated version of the criteria are represented.

9.4.1 Criteria

The most important criteria to score the alternatives are presented below. A more elaborate explanation including all other criteria is given in the appendix.

Construction costs

To take an educated decision on which alternative is most suitable for the situation, one should take into account that investments in Vietnam are often financed by the government or foreign parties, this makes it more difficult to implement an expensive alternative. Construction costs is therefore the most important criterion to score the alternatives on.

Flood risk

The project focuses on the improvement of flood safety in the area, the alternatives are scored for whether they lower the water levels of the lagoon during design storm surges and events.

Salinity concentration

It is known that in the area the salinity concentration in the lagoon water is important to the farmers and as well to the shrimp farmers, so the alternatives should improve or at least not worsen the salinity concentration in the Cau Hai lagoon.

Navigability

To prevent problems with a closed inlet the alternative should improve navigability over the entire year. The inlet depth is a measure to score this criterion on navigability.

9.4.2 Results

The results of the Multi Criteria Analysis are presented in table 9.5. Alternative A: Jetty and bank protection (see figure 8.1) scores the highest on the weighted score card, therefore it is the most desirable alternative to implement at the Tu Hien inlet.

Table 9.5: Multi Criteria Analysis: Alternatives scored and weighted for the criteria

	Weight	Alternatives					
		0	A	B	C	D	E
C1: Construction costs	9	9.00	8.32	8.21	5.15	0.00	8.80
C2: Flood risk	5	0.00	3.32	3.88	3.65	5.00	1.27
C3: Salinity concentration lagoon	2	1.50	1.00	0.50	0.00	2.00	1.50
C4: Salinity intrusion in Truoi river	2	2.00	1.29	0.73	0.00	0.73	1.56
C5: Water quality	3	0.00	3.00	3.00	3.00	1.50	1.50
C6: Influence for ecology	1	0.67	0.33	0.33	0.00	0.33	1.00
C7: Maintenance	2	0.67	2.00	0.67	2.00	0.00	0.67
C8: Navigability of the inlet	4	0.00	1.38	1.82	4.00	1.82	1.00
C9: Durability	2	0.00	2.00	2.00	2.00	2.00	1.33
C10: Sustainability of the construction	2	0.67	0.67	0.67	0.00	0.00	2.00
Total scores alternatives		14.50	23.31	21.79	19.79	13.37	20.63

9.5 Most promising alternative

The alternative with one jetty and a bank protection has been shown the most promising, considering the criteria included in the MCA. With this solution the inlet has been enlarged for relatively low costs. By stabilizing

and deepening the inlet, the navigability is improved. The enlargement of the inlet also improves the water quality of the lagoon.

Some of the elements listed in section 8.1 were not yet integrated in the alternatives. In this section it is reviewed whether some of those measures could be integrated in the most promising alternative to improve it and mitigate some of its shortcomings.

The model results showed salinity intrusion into the lagoon will increase for this alternative as was expected when the inlet cross-section is enlarged. To prevent further salt intrusion into the Truoi River, a salt intrusion dam could be a solution. The mouth of the Dai Giang River already has a salt intrusion dam. Whether such a dam will be feasible for the Truoi River should be determined in a separate study.

Two scenarios were deemed the most important in terms of floods: the design storm with both storm surge and high discharges and floods mainly due to high river discharges only. Although from the model it can be concluded that in the design storm scenario the reduction in flood levels is quite small, during extreme river discharge events the reduction is higher for the most promising alternative.

The storm surge barrier was judged as non feasible at this moment in time. However, an integrated flood defence system can be a good future perspective. This will include the heightening of the sand dunes on the barrier islands and possibly movable storm surge barriers at Tu Hien and Thuan An.

One of the measures mentioned in section 8.1 that could further decrease flood levels during high discharges, is changing the discharge regime of the reservoirs. There is already some regulation to make sure there is some storage capacity available when a high rainfall event is predicted. However, the regulation could be stricter, making sure the part of the reservoir storage is always available during the wet season. This will reduce the efficiency of the dam for hydro power generation and it thus unfavourable for the private corporations owning the dams. A societal cost benefit analysis could determine whether stricter regulation of the hydro power dams is desirable.

In time, the performance of the jetty might decrease as sand by-passing will occur. This could be solved by a by-passing system. Another way is facilitating and regulating sand mining at the upstream part of the jetty. It is known that sand mining by local habitants already occurs at the moment, currently possibly at harmful places where erosion is already a threat. A regulated area of sand mining could solve both problems.

Chapter 10

Preliminary Design

The two structural measures from the most promising variant will be technically elaborated in this chapter. The goal of this elaboration is to get better insight into the measures of the most promising variant.

10.1 Jetty design

In this section the structural measure of a jetty will be further elaborated in a basic preliminary design. This basic design could give more insight in the possible future problems, which could be encountered when a jetty needs to be designed. By making this design the recommendations for a possible solution in the region can be improved. In this section specific parts of the jetty will be elaborated and designed.

10.1.1 Existing breakwaters in the region

At the Thuan An inlet a jetty is constructed in order to reduce sedimentation in the inlet. One jetty is constructed on the southern side of the inlet and two jetties are constructed at the northern side [Neut and et al., 2013b]. During the fieldwork the south-eastern jetty was visited. Because the jetty was poorly constructed, soon after its construction severe erosion between the armour units was noticed. This in combination with poor foundation, or at some spots no foundation at all, caused the jetty to not function as a jetty any more. Some sedimentation on the downstream side can be noticed but in general the jetty doesn't do much against sedimentation in the inlet

[Neut and et al., 2013b]. As shown in figure 10.1 the jetty is constructed with Haros which are unequally placed due to the poor foundation.

The two north-western were not visited during the fieldwork. According to [Neut and et al., 2013b] the two north-western jetties are designed much better than the south-eastern jetty. However, due to poor placing of the jetties already a sediment bypassing is noticed and especially the most western jetty is completely filled-up with sand. The western jetty is constructed out of modified Haros and Tetrapods. The northern jetty is constructed out of four layers of regularly placed Tetrapods.



Figure 10.1: Jetty at Thuan An inlet

10.1.2 Possible alternatives

A jetty can be constructed out of many materials. Different kinds of concrete elements are available such as Tetrapods, Accropodes, Haros, X-blocks, Ecopodes and Core-locs. Of course it is also possible to use natural rock for the armour layers. It is probably the cheapest solution to use natural rock. A stone quarry is located close to the Tu Hien inlet and therefore the transport cost of the rocks are low. In order to use concrete element a factory

needs to be built somewhere in the neighbourhood of Tu Hien, which is expensive.

10.1.3 Boundary conditions

The boundary conditions of the waves will be described in this section

Wave height and wave period

As determined in section 5.4.2, the significant wave height at the Tu Hien inlet is 2,24 m. However, this is not the significant wave height to be used in the design calculations of the Jetty. To calculate the diameter of the rocks in the armour layer the Van der Meer formula is used. The Van der Meer formula uses the $H_{s,2\%}$ in stead of H_s .

In order to get $H_{s,2\%}$ a wave climate from Argoss is used as found in [Biezen, 2014]. Using a Weibull distribution $H_{s,2\%}$ is determined from the data. The data and a plot of the Weibull distribution is shown in Appendix D.3 on page 197. A probability of exceedance of a once in a thousand year storm is used: $P = 10^{-4}$. The calculation leads to $H_{s,2\%} = 4,45 m$.

The wave period is determined by:

$$\frac{H_s}{1,56T_p^2} = s \quad (10.1)$$

With wave steepness $s = 0,05$ the wave period will become $T_p = 7,55 s$

The used wave climate is measured a bit offshore. Therefore the waves are not totally representative for the waves attacking the coastline. A shoaling factor is used to estimate the wave height closer to shore. This shoaling factor is [Stive and Bosboom, 2013]:

$$H_{sh} = \frac{H}{H_0} = 0,91 \quad (10.2)$$

This leads to a new design wave height $h_s = 4,94 m$. Bare in mind, this is still an estimation. Further calculation, and mostly more data is required to calculate a more accurate design wave height.

10.1.4 Design

In this section specific parts of the jetty will be elaborated and designed.

Surf zone and jetty length

It is not realistic to expect from a jetty to catch all sediment and therefore reducing littoral drift to 0. Such a jetty would be far too expensive. A more realistic option is to construct a jetty which reaches roughly until the breaker line into the sea so it basically covers the surf zone. This is suitable since most sediment transport takes place in the surf zone and by constructing the jetty in such a way that it covers this area it should reduce littoral drift with about 70-80%.

The surf zone is the coastal area from where the waves start to break until the shoreline. Waves start to break when the ratio significant wave height and water depth is about 0,8:

$$\frac{H_s}{h} \approx 0,8 \quad (10.3)$$

Since the significant wave height $H_s = 2,24m$, as determined in section 5.4.2, this means the breaker line is where the water depth is about $2,8 m$. Based on measurements at Tu Hien in 1996, see figure 10.2, the breaker line is about 200 meters from the shoreline. This means a jetty that reaches 200 meters into the sea is required to catch the sediment. The used significant wave height for the jetty length seems to be contradictory compared to the design wave height as determined in section 10.1.3. This wave height, however, is the storm wave height. The jetty length would be over-dimensioned when this wave height is used, in order to stop the normal daily longshore sediment transport the 'normal' significant wave height is sufficient.

The used data to determine the beach profile seems a bit out dated since the measurements were done at the old breakwater. However this is the best data available and the expectation is that the beach profile at the current inlet is not that different compared to the profile at the old inlet.

Layer rock diameter

As said before the rock diameter of the armour layer is determined by the Van der Meer formula. In this method distinction is made between surging

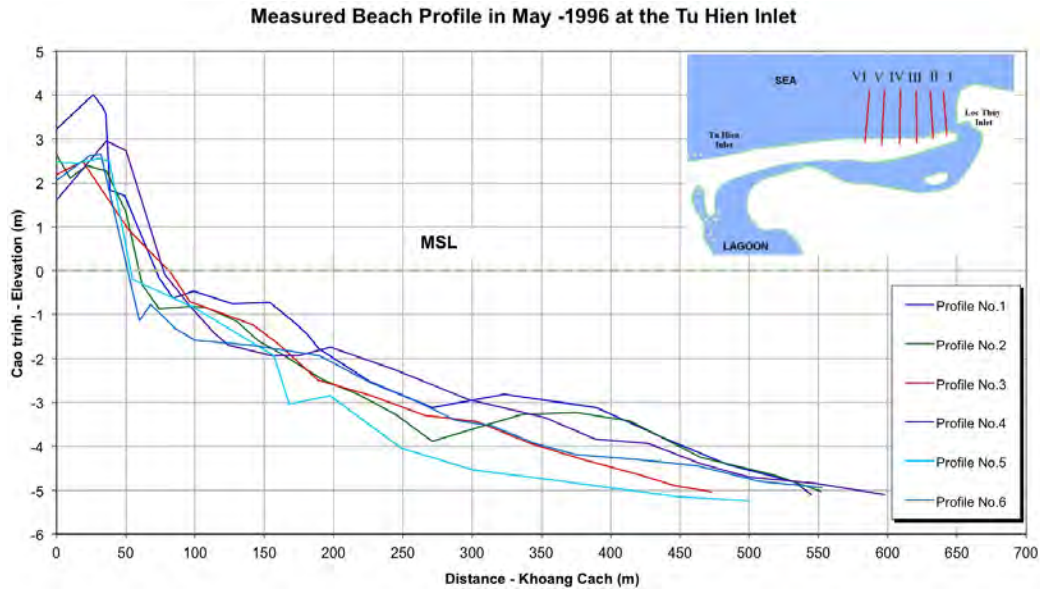


Figure 10.2: Beach profile according to measurements at Tu Hien in 1996

and plunging waves. The formulas below show the two different formulas, the first one is for plunging waves, the second one for surging waves:

$$\frac{H_{s,2\%}}{\Delta d_{n50}} = c_{pl} \cdot P^{0,18} \left(\frac{S}{\sqrt{N}} \right)^{0,2} (s_{m-1,0})^{0,25} \sqrt{cota} \quad (10.4)$$

$$\frac{H_{s,2\%}}{\Delta d_{n50}} = c_s \cdot P^{-0,13} \left(\frac{S}{\sqrt{N}} \right)^{0,2} (s_{m-1,0})^{-0,25} (\xi_{s-1,0})^{P-0,5} \quad (10.5)$$

Here

$T + m - 1,0$ = the wave period, calculated from the first negative moment of the spectrum

$T_{m-1,0} \approx 0,85T_p$. $s_{m-1,0}$ is the fictitious wave steepness

$$s_{m-1,0} = \frac{2\pi H_{s,2\%}}{gT_{m-1,0}^2}$$

D_{m50} = the nominal median block diameter

N = the number of waves

Δ = the relative density of the rocks

S = the damage level

α = the angle of seaward slope of the structure

P = the notional permeability coefficient.

Observations during the fieldwork, see figure 10.3, show that At the Tu Hien inlet clearly plunging waves occur. This can also be calculated with the beach

profile slope, see figure 10.2, leading to:

$$\cot\alpha = \frac{1}{\tan\alpha} \quad (10.6)$$

$$\tan\alpha = \frac{1}{88,8} \quad (10.7)$$

$$\cot\alpha = 88,8 \quad (10.8)$$

Since $\cot\alpha \geq 4$ the waves are plunging [Schierreck and Verhagen, 2012]

This means the first Van der Meer formula is to be used for calculation of the rock diameter. According to [d'Angremond and van Roode, 2001] c_{pl} is 6,2 for plunging waves, however for design purposes 5,5 is recommended as a better value.

For a permeable breakwater the permeability coefficient is about 0,6 so this value is used. For the damage level coefficient 2 is chosen and for the seaward slope angle $\cot\alpha = 2,8$ is chosen.



Figure 10.3: Observations during fieldwork show plunging waves at the inlet

The parameters to be used are shown in 10.1

This leads to a nominal median rock diameter $d_{m50} = 0,93 m$. According to [Schierreck and Verhagen, 2012] this is stone class 1000-3000 kg.

Table 10.1: Values taken for Van der meer formula

$H_{s2\%}$	4,94
$T_{m-1,0}$	6,42
$s_{m-1,0}$	0,10
Δ	1,61
c_{pl}	5,5
N	7631
S	2
$cot\alpha$	2,8
P	0.6

Head and core

The head of the Jetty usually suffers from heavier wave attack than the sides. To protect the head against erosion it is possible to use a higher stone class which is the class 3000-6000 kg. Another solution could be to construct the head under a milder slope, but this is usually a more expensive option.

The core of the jetty is made out of sand to let the jetty be permeable. When the 1000-3000 kg rock are dumped directly on the sand core the sand core will erode in no time. To prevent this two sub layers are required. The rock size of the under-layer must not pass through the gaps between blocks of the armour layer otherwise it will wash away. To determine the diameter of the rocks two different ratio's are taken into account. The recommended weight ratio of subsequent layers is between 1/10 and 1/25. The ratio between the diameter of the subsequent layer is between 1/2 and 1/3. For the first under-layer stone class 60-300 kg is chosen. For the second under-layer stone class 10-20 mm is chosen.

In stead of the second under-layer, it is also possible to use geotextile. This will hold all the core material together and will provide enough support for the rock layer on top. However, geotextile is very expensive in countries like Vietnam. And this fact, combined with the fact that a stone quarry is nearby decides not to use geotextile.

Height

The crest height of a breakwater is normally determined by the amount of overtopping. With the online programme *Cress*¹ the amount of overtopping for certain crest heights may be determined. The overtopping shouldn't be

¹Available at www.cress.nl

more than a certain benchmark in order for the breakwater to be safe. However, this is not completely true for the jetty at Tu Hien. Wave overtopping is not really a problem since there is nothing to protect 'behind' the jetty. The armour layer should be able to protect the jetty against the design storm waves. Therefore a crest height of 2 meters above still water level should be sufficient. The jetty will be under water during a design storm since this will cause up to 4 meters wind set-up. There will be some sediment transport over the jetty and the inlet might close a little, but the flushing capacity of the lagoon after the storm is so high that the inlet will widen soon after the storm.

An example of the cross section of the jetty design is given in figure 10.4. The dimensions of the jetty are not given since the cross section of the breakwater changes with the length of the jetty. More seawards the underwater section of the jetty is much larger since the depth is larger compared to more landward sections.

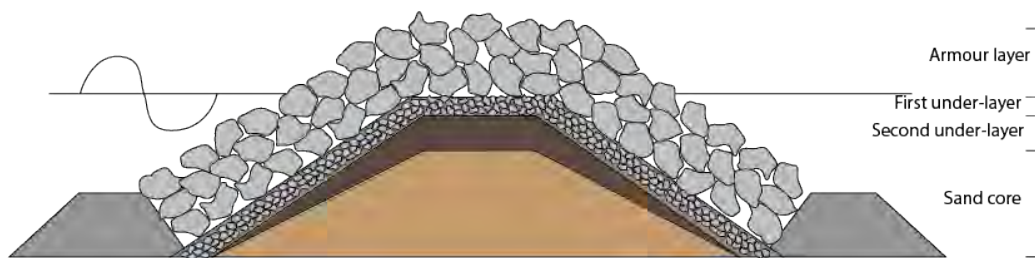


Figure 10.4: Jetty design, the jetty is build out of four layers, one armour layer, two supporting under-layers and one core layer.

Toe

The toe of the jetty is to support the armour layer at the bottom and to prevent the armour layer from sliding of the under-layer. The stones in the toe can be much smaller than those of the armour layer since they are not heavily attacked by waves. The stone size of the armour layer can be seen as the maximum stone size of the toe.

The diameter of the stone to be used for the toe can be determined by one of the following formulas:

$$\frac{H_s}{\Delta \cdot d_{n50}} = 8.7 \left(\frac{h_t}{h_m} \right)^{1.4} S \quad (10.9)$$

$$\frac{H_s}{\Delta \cdot d_{n50}} = 1.1 \left(0.24 \frac{h_t}{d_{n50}} + 1.6 \right) \quad (10.10)$$

In which:

- H_s = Significant wave height
- h_t = Water depth above toe
- h_m = Water depth at still water level
- Δ = Relative density
- d_{n50} = Stone diameter of the toe

Equation 10.9 is valid for relatively deep toes ($h_t/h_m > 0.4$), for other cases equation 10.10 is to be used. Equation 10.10 requires iteration to find the correct value for d_{n50} .

In order to determine the height of the toe the diameter of the armour layer is considered. The largest stones in stone class 1000-3000 kg are 1,04 m in diameter. This is used to determine the toe height. The toe height is set to 1,1 m to be sure it is capable of supporting the big stones in the armour layer.

Since h_m at the deepest point of the jetty is 3.0 meter the assumption of a relatively deep toe ($h_t/h_m = 1.9/3.0 = 0.63$) is valid. With a significant storm wave height of 4.94 meter close to shore this leads to a d_{n50} :

$$d_{n50} = \frac{H_s}{\Delta \cdot 8.7 \left(\frac{h_t}{h_m} \right)^{1.4}} = \frac{4.94}{1.95 \cdot 8.7 \cdot \frac{1.9^1}{3.0} \cdot 1.4} = 0.68 \text{ m} \quad (10.11)$$

Stone diameter 0.68 m lead to stone class 300-1000 kg.

It is expected that a filter layer as well as a scour protection layer is needed in the design of the jetty. This is however more detailed work and is not in the scope of this research.

10.1.5 Construction aspects

Constructing a breakwater or jetty in Vietnam is different than it would be in The Netherlands. Since labour is cheaper and equipment is not as advanced

probably a lot of work is done by hand. The movement of the smaller rocks and the sand can be done by wheelbarrow instead of using big cranes, which are very hard to get to the construction site over the bad roads.

The jetty is built in layers. First the sand core is placed on the bottom, afterwards the first and second under-layer are placed and finally the armour layer is placed over the under-layers. The idea is that the core layer is left unprotected as short as possible otherwise the risk of losing the sand due to the current is too big. Therefore the under-layers and armour layer will be placed while the core layer is not finished yet, as demonstrated in figure 10.5

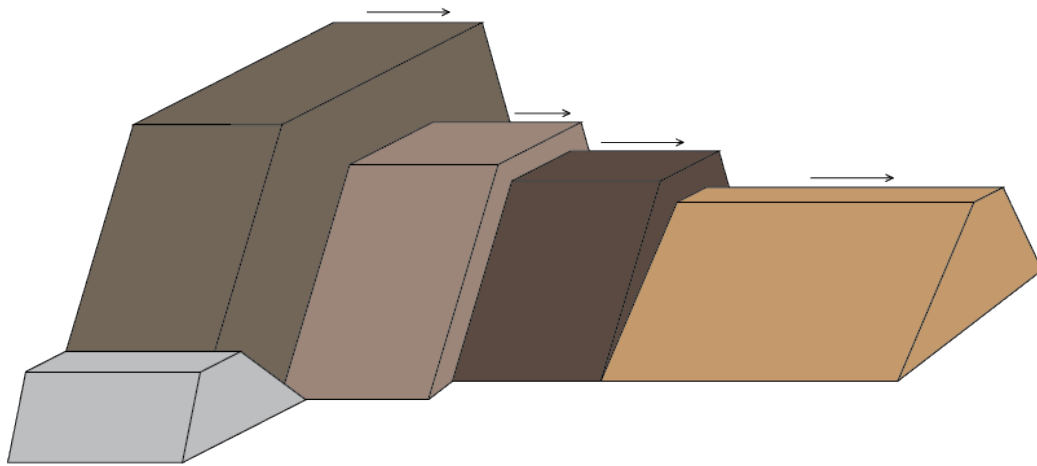


Figure 10.5: Construction method jetty at Tu Hien

For the more off shore part of the jetty it is likely some water going equipment is required. From land it is for instance harder to reach the head of the jetty than from sea. This will bring some extra costs since this equipment is often quite expensive. But, in order to construct a decent jetty, it is required to use the right equipment otherwise the same could happen as has happened to the southern jetty at Thuan An and the jetty will be useless.

10.1.6 Costs

The costs of the jetty are hard to estimate. The material costs are quite unknown and difficult to estimate compared to the costs in the Netherlands. Verhagen and Yap [Verhagen and Yap, 1992] researched the difference in building costs in developing countries compared to European standards.

This research dates from 1992 so it is a bit outdated, but it still gives a rough estimate.

As expected, labour is much cheaper in Vietnam than in Europe, about 10% of the labour costs in the Netherlands. Construction material like sand and rocks are cheaper as well, but the exact costs are not known.

According to [Hauer and Op den Velde, 1995] a normal breakwater with slope 1:1.5 and water depth 3 meters and 500 meters in length will cost in the order of 4.1 million dollars. The Tu Hien jetties are in the order of 200 meters and the crest height is less than the crest height of a breakwater would be. Therefore the costs will be much less as well. Therefore a rough estimate is that the costs of a 200 meter jetty will be about 1.5 million dollars. According to the same report the costs for a breakwater of jetty can reduce up to 34% when a stone quarry is within 25 kilometres of the construction site, which is the case at Tu hien. So the costs reduce to about 1.0 million dollars.

The costs as mentioned above are according to American standards. The building costs in Vietnam will be lower, according to Verhagen and Yap the total costs for a breakwater which is designed according to European standards are in the order of 30% lower in Vietnam compared to a European country.

10.2 Bank Protection

In this section the structural measure of a bank protection will be elaborated in a basic preliminary design.

10.2.1 Existing bank protections in the region

At the northwest side of the Thuan An inlet a bank protection is constructed, which is the down-drift side of this inlet because the net sediment transport is from southeast to northwest. This revetment has been build to protect former shrimp farms behind it. The bank protection is made of loose stones and it is working quite well. In the past a bank protection of concrete slabs was used, but the sand under these slabs eroded, so therefore a protection of stones is used nowadays [Neut and et al., 2013a]. The diameter of the stones is approximately 35 *cm*, see figure 10.6

At the small lagoon, south west of the Tu Hien inlet, there is a small lagoon. This lagoon used to connect the Cau Hai lagoon with the former inlet at Loc Thuy. At the north-east border of this lagoon there is still a bank protection present, as mentioned in appendix A.6.1 on 160. This protection was constructed to prevent erosion of this bank when the Cau Hai lagoon was still connected to the small lagoon. The protection exists of loose rock with an approximate diameter of 35 cm, see figure 10.7. Now that this connection does not exist anymore this protection does not have a function anymore. Maybe it is possible to use the stones of this protection to make a bank protection at the down-drift side of the current Tu Hien inlet.



Figure 10.6: Bank protection at Thuan An inlet



Figure 10.7: Protection at small lagoon

10.2.2 Possible alternatives

Some possible protections for the down-drift side of the inlet will be discussed as well as their advantages and disadvantages for the specific protection at Tu Hien [Schierreck and Verhagen, 2012].

- **Composite mattresses**

Composite mattresses can make good and strong revetments to prevent erosion for instance. For the construction special equipment is needed, what means that for small length revetments the costs may become rather high. Besides the availability of this equipment in Vietnam is also questionable.

- **Asphalt**

An asphalt revetment is especially when waves are high a good solution, which is the case on the sea side of the protection. Disadvantages are the special equipment that is needed and the regular inspection that is necessary. These disadvantages are not wanted because the availability of the equipment might be a problem as well as the regular and proper inspection could be a problem.

- **Placed blocks**

A placed blocks revetment could function well as a bank protection. The revetment could consist of block, columns or other shapes. Block revetments are sometimes preferred when no natural rock is available [CIRIA, 2007], but this is not the case at Tu Hien.

- **Loose rock revetment**

The construction of a bank protection from loose rock has the advantage that no specialized equipment or personnel is needed. The loose rock can be placed on top of a filter for example a geotextile. Furthermore a loose rock protection already has proven to work well in the region, see 10.2.1. Therefore a loose rock revetment will be further elaborated.

10.2.3 Boundary conditions

Over the length of the protection different boundary conditions can be normative. The bank near the smallest cross section of the inlet will be on flow currents through the inlet. During an extreme flood event these values can reach the highest values. At the shoreline the waves will have a large impact on the protection. At the point where the shoreline turns around towards the basin, waves might be larger because of refraction effects. Further into the inlet waves will be smaller again because of refraction and diffraction effects. Loading of the protection as a consequence of ship movement through the inlet will be neglected because only very small vessels, in comparison with the cross-section, pass the inlet.

Waves

For the preliminary design waves values will be taken the same as for the breakwater design, see section 10.1.3. The 2 % highest waves of an $\frac{1}{1000}$ storm event is given as:

$$H_{s2\%} = 4.94m \quad (10.12)$$

To account for shoaling 10 % is added already.

Because this wave is the mean value of the 2 % highest waves while the formula that is needed for the bank protection uses the mean value of the highest 33 % of the waves. Since the 2 % highest waves are almost 5 m high it is assumed that the highest wave is approximately 6 m high during this extreme event. The significant wave height (the mean value of the highest 33 % of the waves) is approximately half of the highest wave [Holthuijsen, 2010]. Further it is assumed that the significant wave in the inlet at some points is half. So for the bank protection the following wave heights are used:

$$H_{s,shore} = 3m \quad (10.13)$$

$$H_{s,inlet} = 1.5m \quad (10.14)$$

Currents

In section 9.2.1 an peak velocity in the inlet for variant A is shown as a result of the hydraulic model.

$$U = 4.17 \frac{m}{s} \quad (10.15)$$

It must be stated that the cross section of the inlet in this model is fixed. What means that the cross section does not increase during high discharges. In practice this does happen, when the flow velocity increases the cross section of the inlet increases due to extra erosion. So that means that the value stated in (10.15) is an overestimate. For further detailed designing of the breakwater better values of the inlet velocity can be calculated with an more extensive model, but because the value is an overestimate we use it here for further calculations.

Subsoil

Unfortunately there is no data of the soil available at the bank location. Therefore it will be assumed in this elaboration that the subsoil is sand. typical sand characteristics, permeability and nominal grain diameter, are used and are given below [Verruijt, 2010]:

$$k = 1 \cdot 10^{-4} \frac{m}{s} \quad (10.16)$$

$$d_{n50} = 0.5mm \quad (10.17)$$

10.2.4 Design

In this section specific parts of the bank protection will be elaborated and designed.

Location

The location where the bank protection is needed to prevent erosion is at the down-drift side of the inlet. The exact length and location of the protection needs to be situated so that no critical erosion takes place after the protection. For now it will be assumed that the protection is needed over a length of 600 *m*. In this a part of the shoreline and a part of the bank of the inlet is included. See figure 10.8. For a further detailed design the erosion after the protection needs to be modelled, based on that eventual the length of the protection needs to be adapted.

Toplayer

In this section the stone size of the top layer will be computed, so that it can withstand the boundary conditions that are mentioned in 10.2.3.

First the normative stone size will be determined that can withstand the occurring currents in the smallest cross-section. This will be done with the approach of Shields [Schierreck and Verhagen, 2012]. The formula of Shields gives a relationship between a dimensionless shear stress and the alleged particle Reynolds-number. This approach leads to the following formula:

$$d_{n50} = \frac{K_v^2 \cdot \bar{u}_c^2}{K_s \cdot \psi_c \cdot \Delta \cdot C^2} \quad (10.18)$$

In which:

\bar{u}_c^2 = the depth-averaged velocity in uniform flow, the value from the model will be taken here, although this is an overestimation = $4.17 \frac{m}{s}$
 ψ_c = the threshold of motion parameter, for bank protections with this typical stone size a value of 0.03 is recommended = 0.03
 Δ = relative density, for stone in salt water $\frac{\rho_s - \rho_w}{\rho_w} = \frac{2650 - 1025}{1025} = 1.59$
 C = the Chezy-coefficient, giving an expression for the roughness, $C = 18 \cdot \log(12 \cdot (h/2 \cdot d_{n50}))$, a water depth of 3 m will be used for this calculation.
 K_s = is a strength reduction parameter for stones on a slope, a slope of 30° will be assumed for now, this will result in a value of $K_s = 0.63$ [Schierreck and Verhagen, 2012]
 K_v = is a correction factor for turbulence, since the inlet looks like a horizontal constriction a mean value for a stream lined abutment will be taken = 1.05

Since d_{n50} is integrated in the C-value, the diameter needs to be calculated by iteration. The correction factors may not interfere the iteration so the correction will be done after the iteration. The result of the iteration gives:

$$C = 29.56 \quad (10.19)$$

$$d_{n50}^* = 0.42m \quad (10.20)$$

With the correction factors this becomes:

$$d_{n50} = \frac{d_{n50}^* \cdot K_v^2}{K_s} = \frac{0.42 \cdot 1.05^2}{0.63} = 0.74m \quad (10.21)$$

Now the diameter of the stones is calculated for the wave attack. They will be calculated for waves as mentioned in section 10.2.3. The calculation for stability under wave attack is performed with the Van der Meer formula. In section 10.1.4 it is also shown that the plunging variant of the Van der Meer equation should be used. To reduce the needed stone diameter the slope of the protection at the shore will be lowered to 15° , in the inlet a slope of 30° will still be used. The formula is given by [Schierreck and Verhagen, 2012]:

$$\frac{H_s}{\Delta \cdot d_{n50}} = 6.2 \cdot P^{0.18} \cdot \left(\frac{S_d}{\sqrt{N}} \right)^{0.2} \cdot \zeta^{-0.5} \quad (10.22)$$

In which:

H_s = design wave height (section 10.2.3)= 3 m on shore and = 1.5 m in the inlet.

Δ = relative density (equation: (10.18))= 1.59

P = notional permeability coefficient, for a bank protection with filter on clay or sand the value = 0.1

S_d = coefficient for damage level, a value for very low damage is used here = 4

N = number of waves during a typical storm, after 7500 waves the increase is not significant anymore, since a typhoon storm will include not less than 7500 waves this value is used = 7500

ζ = Irribarren number, slope steepness versus wave steepness, = $(\tan \cdot \alpha / \sqrt{s})$, in which: $\tan \cdot \alpha_{shore} = 0.267$, $\tan \cdot \alpha_{inlet} = 0.577$, and $s = 0.05$ (section 10.1.3), so $\zeta_{shore} = (0.267 / \sqrt{0.05}) = 1.19$ and $\zeta_{inlet} = (0.577 / \sqrt{0.05}) = 2.58$

If this values are filled in to the equation we get two different nominal diameters over the length of the protection:

$$d_{n50,shore} = 0.93m \quad (10.23)$$

$$d_{n50,inlet} = 0.69m \quad (10.24)$$

On basis of the calculations in equations (10.18) and (10.22) it is chosen that the shore part of the protection needs a stone diameter of 0.93 m and the inlet part of the protection needs a diameter of 0.74 m. The stones with a diameter of 0.93 m is in the stone class 1000 kg - 3000 kg, and the diameter of 0.74 m is in the stone class 300 kg - 1000 kg. For now it is assumed that the shore part of the protection has a length of 400 m, and the inlet part is 200 m. In the last 50 m of the shore part of the protection the slope will increase from 15 ° to 30 °.

Filter

A filter layer under the top layer of armour stones of the protection is needed to prevent the washing away of the underlying layer. This can be done by a granular filter or a geotextile. A granular filter is composed of a couple of layers with grains of varying diameter, so that the grains of the underlying layer can not pass the top layer. A geotextile is a synthetic foil material that can be used to prevent erosion of the underlying layer. Because the grain size of the top layer is rather high, quite a lot of layers are needed to



Figure 10.8: Location of the sections of the bank protection

make a granular filter. This leads to high construction costs and difficult construction. Both of these aspects are not preferred in Vietnam, therefore for now the use of a geotextile is used in this elaboration.

To ensure that no particles of the underlying layer will be washed away the geotextile has to be sandtight. The stability rule that is given for sandtightness of geotextiles is[Verruijt, 2010]:

$$O_{90} < 2 \cdot d_{90b} \quad (10.25)$$

Where O_{90} is a measure for the largest holes in the textile, and d_{90b} is the 10 % largest grains of the underlying sand. A realistic value for this with an nominal diameter 0.5 mm is $d_{90b} = 0.8 \text{ mm}$. This leads to:

$$O_{90} < 2 \cdot 0.8 = 1.6 \text{ mm} \quad (10.26)$$

Another demand for a good functioning geotextile is the permeability. To prevent pressure build-up the geotextile should be ten times more permeable than the subsoil itself. Since the permeability of the sand is assumed to be $k_{soil} = 10^{-4} \text{ m/s}$ (section 10.2.3) the permeability of the textile needs to be $k_{geo} = 10 * 10^{-4} = 0.001 \text{ m/s}$. For the permeability of geotextiles often the permittivity parameter is used, which characterizes the permeability for 1 m. The thickness of the geotextile is assumed to be 2 cm's. The required

permittivity parameter becomes:

$$P > \frac{k_{geo}}{e} = \frac{0.001}{0.02} = 0.05 \text{ s}^{-1} \quad (10.27)$$

Another criteria for the bank protection is the overall stability of the stones that are situated on the geotextile. Therefor the friction force needs to balance the gravity force down the slope:

$$f_u \cdot W \cdot \cos \alpha \geq W \cdot \sin \alpha \quad (10.28)$$

where f_u is the friction between stones and textile, after reworking and filling in the result becomes:

$$f_u > \tan \alpha = \tan 15^\circ = 0.27 \quad (10.29)$$

$$f_u > \tan \alpha = \tan 30^\circ = 0.58 \quad (10.30)$$

An friction factor of 0.27 should be easy to achieve, 0.58 might be trickier. If this is not achievable the angle of the slope could be reduced.

The stability of the whole protection(so textile and stones) should also be checked for sliding off the slope. But this is not done in this elaboration because very few is known about the pressure difference over the textile.

If the outcomes from equations (10.26) and (10.27) are considered it appears that a woven geotextile is a good solution [Schierreck and Verhagen, 2012]. A woven geotextile is a structure of at least two set of threads. The threads are woven together in a lengthwise direction and other threads running across. Different characteristics of the textile can be achieved by using different threads.

Toe

To support the armour layer of the bank protection a toe is needed. For stability calculation of a toe the following formula is used [CIRIA, 2007]:

$$\frac{H_s}{\Delta \cdot d_{n50}} = 8.7 \left(\frac{h_t}{h_w} \right)^{1.4} \quad (10.31)$$

where $\frac{h_t}{h_w}$ is the relative toe depth to the total water depth. The water depth during the wave attack is taken 3 m. Since the armour layer is the same as from the breakwater the same height of the toe is taken $h_{toe} = 1.1 \text{ m}$ (section 10.1.4). At the protection of the inlet the largest stone of the armour layer has a weight of 1000 kg, with an associated diameter of $d = \left(\frac{1000}{2650} \right)^{(1/3)} = 0.74 \text{ m}$.

The height of the toe is taken to be $h_{toe}=0.8$ m. With this input and equation (10.31) this results in diameters of:

$$d_{n50,shore} = 0.41 \text{ m} \quad (10.32)$$

$$d_{n50,inlet} = 0.17 \text{ m} \quad (10.33)$$

For the shore this results in stones of the stone-class 60 – 300 kg. And for the inlet this would result in stones from even an lower weight class, but because the currents through the inlet is the normative loading the same stone class as from the armour layer is taken, 300 – 1000 kg

The result of the calculation and design choices made in this subsection are shown in figures 10.8, 10.9 & 10.10.

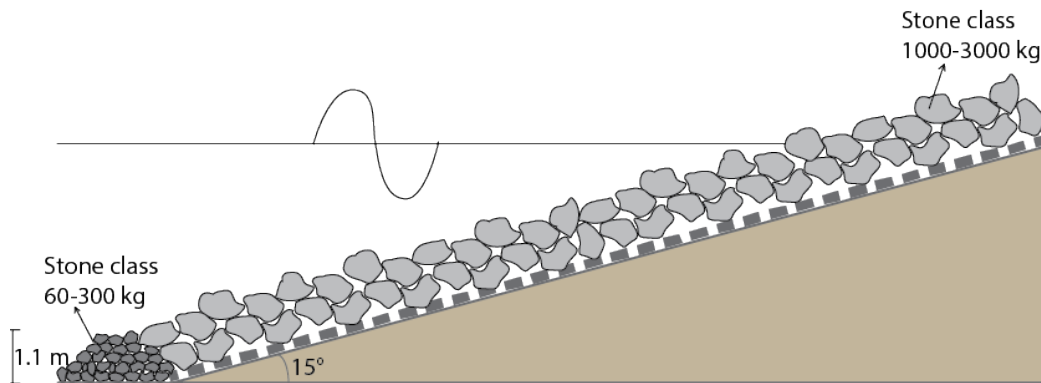


Figure 10.9: Design sketch of bank protection at shoreline

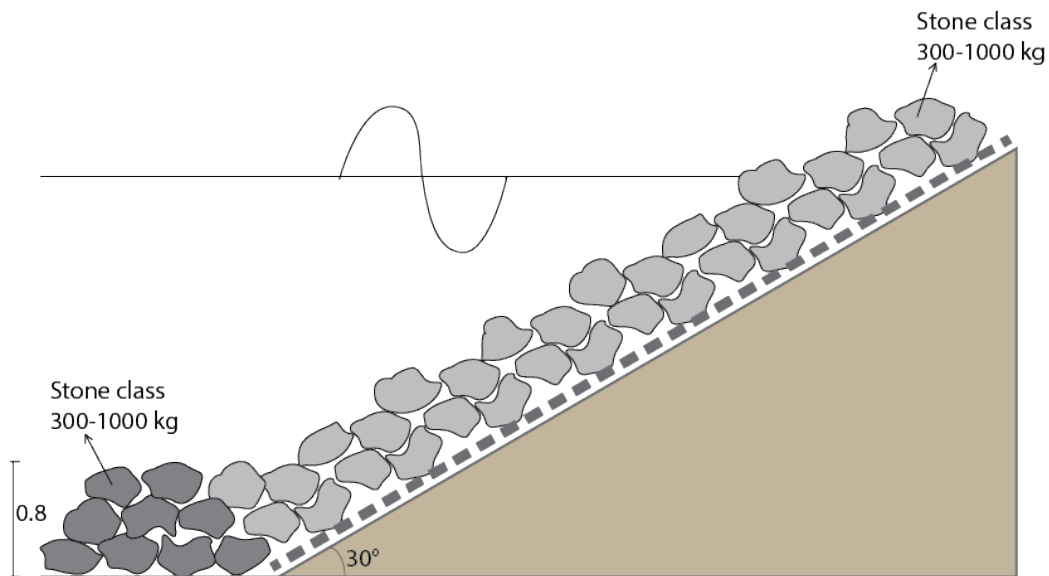


Figure 10.10: Design sketch of bank protection at inlet

10.2.5 Design improvement

For a further detailed design some improvement of the boundary conditions are recommended. The occurring wave heights on the shore and in the inlet could be better identified with a wave model. For the inlet currents during an extreme event, an model that takes the enlarging of the inlet during high velocities into account, should be used. To know the subsoil conditions it is recommended to perform some soil measurements, especially to find a suitable geotextile.

Another improvement of the design could be to use an probabilistic approach. In this probabilistic approach the input variables become probabilistic distributions instead of a deterministic values. By performing an probabilistic design calculation the uncertainties of the boundary conditions and the empirical constants can be taken into account. The bank protection can then be designed for a certain failure probability.

10.2.6 Construction aspects

The construction of the bank protection could best be done in the dry season, because of weather and water conditions in that season. First the slopes of

the bank need to be prepared with the desired angles. Extra attention for the construction of the transitional slopes is needed. After that the geotextile can be mounted. First the top of the textile can be fixed to the top of the bank and afterwards the geotextile can be rolled down the bank. Than the armour layer consisting of stones can be put onto the textile, starting from the toe. This can be done from water, with a floating crane and grab, or from land, for the parts of the bank that is above the water level.

10.2.7 Costs

The cost structure for construction in Vietnam is quite different than in The Netherlands, as mentioned in section 10.1.6. Some special materials in Vietnam can be very expensive. For instance geotextiles, [Verhagen and Yap, 1992] could cost a lot more money in Vietnam than in The Netherlands. Therefore it is an interesting option to use local materials for the function of geotextile, for instance jute filtercloth.

Chapter 11

Conclusion and Recommendations

11.1 Conclusion

The main goal of this research project was to find a feasible solution for the water related problems around the Cau Hai Lagoon. This lagoon is part of a larger system that includes multiple rivers and lagoons, connected to the sea by two tidal inlets. The focus of this research was the Tu Hien inlet, which is known as a highly dynamic inlet.

Local people are highly dependent on the water system. The lagoon provides fish, irrigation for the land and room for aquaculture. The dynamic behaviour of the inlet causes problems in the area. When the inlet closes, the flood evacuation capacity is limited and flood risk increases. Another important aspect is the salt intrusion into the lagoon and the rivers. This has negative effects on the agri- and aquaculture, affecting income and food availability. Also navigability of the inlet, important for fishing, is often limited.

This research proposed solutions for the following problems:

- Stabilizing the inlet
- Stopping erosion
- Decrease flood risk
- Improve navigability
- Control salt intrusion

A list of possible solutions was presented out of which five alternatives have been composed. With the help of a hydraulic model many parameters and their effects could be studied. With an empirical formula the effect of the block littoral drift on the cross-sectional area by the different solutions was estimated. Additionally, as input for the model depth measurements of the inlet and different types of data available were used.

The inlet size proved to be an important parameter regarding water levels in the lagoon. All alternatives improve the maximum water levels by decreasing it a few decimetres. Alternative D with its storm surge barrier behaves differently as it blocks the incoming water during a storm. In a combined storm surge and high discharge event, the alternatives improve the situation due to the larger inlet size. The improvement in alternative E is however insignificant due to the small increase in inlet size.

To estimate the effect on pollution levels, two key indicators were chosen to measure the influence of the alternatives: COD and nitrogen. The COD comes mainly from aquaculture in the lagoon while the nitrogen is largely brought in via rivers and originates from agriculture. Tide and especially the river discharge are important for flushing out pollutants from the lagoon.

When a storm surge causes the gates from alternative D to close, the pollutants remain in the system. The levels of pollution that can be reached in that case can become high. As the storm surge barrier would only close during extreme events this is not considered problematic however. When the storm surge barrier would be used simultaneously as a salt intrusion barrier, pollution can become problematic.

Salt concentrations in the lagoon are dependent on the inlet size as well. Equilibrium salt concentrations increase for the alternatives. This can be seen as a negative effect. The adaptation times reduce however, meaning the salt levels return to equilibrium faster after a flood event, which happens often during raining season. Due to the increased salt levels the final solution might need an additional salt intrusion barrier at the mouth of the Truoi River.

The Multi Criteria Analysis that was performed resulted in alternative A as the most feasible solution. For the breakwater and bank protection incorporated in this alternative, a preliminary design has been made. The alternative with two jetties scored closely to the winning alternative.

It is expected that when alternative A is constructed, the inlet is stabilized, the erosion is stopped and navigability is ensured. Furthermore, flood lev-

els are lower and pollution in the lagoon will decrease. Salt concentrations are expected to rise slightly however. Additional mitigating solutions were presented.

11.2 Recommendations

In this section the recommendations on the model approach and the solution are presented.

11.2.1 Model recommendations

In the model the assumption of uniformly varying water levels has been made. In reality this is not the case and variations can occur. An improvement of the model could be to include these varying water levels. Also friction and inertia are left out the model for simplicity. This could be improved in a more advanced model as well. These phenomena and possibilities are included in many types of existing software.

The model scenarios used in the model are now compiled from historical data to represent realistic events. The years for which the data was available was very limited however, especially for the combined scenarios improvements could be obtained by using more reliable data recorded for a longer period.

Further research is required on the effect of a flood on the river system. Changing water levels in the lagoon will affect the discharge via backwater curves. This effect has been neglected in this model. It is known that many river floods occur in the region however, thus this is an important part of the problem. An improvement in the maximum water levels at the basin does at least not make this problem worse, but if it improves the situation would have to be inquired further.

The model also predicts the pollution in the Cau Hai Lagoon, but only shrimp farms and continuous river pollution are taken into account as sources of pollution. The peak pollution for rain water run-off for instance is not included in the model. The same holds for other pollution sources like agriculture, fishery and domestic waste. Other inputs of pollution should be included to check whether the lagoon reaches an unacceptable level of pollution at any stage. Another improvement for assessing pollution could be a model where the pollution is not assumed to be fully mixed in the basin.

Furthermore it is recommended for a further design of one of the alternatives to model its effects with a morphodynamic model (for instance Delft3D). In such a model the shoreline changes and the development of the inlet could be researched in more detail.

11.2.2 Solution recommendations

The alternatives were scored using a MCA to compare them on sometimes not easily comparable criteria. The MCA could be expanded to incorporate more effects. An example could be the economic effects the alternatives have for local people.

The alternative with two jetties scored closely to the winning alternative of the single jetty combined with a bank protection. The model is based on average littoral transports. With a single jetty during some times of the year there could still arise problems due to a reversed net transport. To be able to conclude whether this is significant, a more elaborate model must be made. This model would allow to make a better choice between the single and double jetty alternatives.

The technical design of the breakwater and bank protection should be done in more detail. A scour protection should be designed and the filter layer should be specified in detail. To accomplish this, more knowledge about all the boundary conditions is needed.

Using a probabilistic approach the failure probability can be computed. This gives better insight in uncertainties in input variables and can improve the design.

Furthermore it is recommended to incorporate regulations concerning land use for agri- and aquaculture. This way pollution output can be controlled. The exact formulation of these regulations should be investigated.

Knowledge about the influence of human actions on the proposed solution could be useful for designing solutions in similar cases. Previous solutions along the coast and at the Thuan An inlet have been undermined due to the behaviour of local inhabitants. Although in this case a fairly robust solution has been chosen, monitoring of the project is important.

The most promising alternative contains a jetty that would block most of the littoral drift. Therefore it is recommended to further study the possible disadvantages of the blockage of the littoral drift. For instance down drift erosion could become a problem when the littoral drift is cut off.

Appendix A

Fieldwork

A.1 Introduction

In order to perform a decent research on the Hue inlet basins a visit to the project site was required. For the research it was important to get a good impression of the environment and the people living in the surroundings of the Tu Hien inlet. Since our project is focused on the southern part of the basin most time was spent in this area.

The goals of the fieldwork were making a depth profile of the inlet, researching flood levels around the basin, interviewing different stakeholders and institutions and see some relevant locations. Especially for the stakeholder interviews the language barrier was a problem since we don't speak Vietnamese and a lot of stakeholders don't speak English. Another problem was that permission was needed from local authorities to perform research activities. To tackle this problem mr. Trung of the Water Resource University in Hanoi has been so kind to join us during the fieldwork for three days to act as guide in the area, a translator and to arrange permission for the research. Together with mr. Trung we flew on Wednesday morning the 10th of december from Hanoi to Hue.

In this section the fieldwork trip to Hue is documented.

A.2 Wednesday

Wednesday morning we arrived in Hue. After the accommodation was arranged for the first two nights we had two appointments in the afternoon, one with the local dike department and one with the Center for social research and development. The appointments were used to ask questions about the area and problems, and to collect additional data. Both institutions gave answers to our questions and provided us with some data.

A.2.1 Local Dike Department

Mr Minh explained that the dike department is responsible for the water allocation, construction and maintenance of the dikes in the Thua Thien Hue province. The dike department is a department of the ministry of agricultural and rural development on province level. The dike department is closely related with the province department of agricultural and rural development as well the department has good contacts with the local communes.

The dike department is responsible for the 128 km long coastline, the Huong River with a discharge of $3000 \text{ m}^3/\text{s}$ in the wet season and a total of $2 * 10^8 \text{ km}^2$ reservoirs volume. The Trung Loy reservoir and hydro dam is managed by the local government. This small reservoir can be neglected according to the dike department when investigating the Cau Hai lagoon. Two other big reservoirs are owned by the Joint Stock Company and completely focused on the economic benefits of the reservoirs. In the lagoon two dams to provide salt intrusion are installed, during the dry season the dams close daily by incoming tide.

The Tu Hien inlet is unstable and the dike department examines the possibilities to implement a structural solution. During the wet season the inlet is flushed by enormous amounts of rainwater, after the wet season the inlet will silt up again, causing navigational problems for the local fishermen.

Approximately 1 million people live in the Thua Thien Hue province and are threatened by floods multiple times a year, in the north a one meter high dike protects the area but is over topped almost every year. The local government tries to prohibit people living in the area near the lagoons, although a lot of inhabitants live here depending on there fishery livelihood. The resettling of the people is supported by the government but due to a lack of financial support the resettling goes rather slow. Local erosion is a big problem, the inlet moves and is located differently every year. The residents in the area are

allowed to use the sand for building and non commercial use. Commercial use is prohibited by the ministry of agricultural and rural development, sand mining is not a problem in the area according to the dike department. The quality of the lagoon water is a big problem due to fishery and aquaculture, recently regulations for the area are implemented but change in mindset and habits of the fishermen goes slowly.



Figure A.1: Appointment at the local dike department

A.2.2 Center for Social Research and Development

In the afternoon Mrs. My introduced the Center for Social Research and Development. This NGO was founded in 2008 and now encounters 15 employees. The focus of the NGO is to support the voice of local minorities, giving them the opportunity to raise their voice against large companies or the government. The second goal of the CSRD is to support the use of environmental friendly energy sources, like solar heating and biogas.

The CSRD tries to implement solutions that protect the local communities against floods and make use of the water in a sufficient way. For example mangroves are planted in the north part of the lagoon for coast strengthening and experiments with elevated farming are carried out. The building of the

hydrodams has worsened the situation in the Cau Hai lagoon. The dams are used for energy generation and are too small to use for flood protection. The Stock Company has agreed on flood prevention use for the hydrodams but the CSRD discovered that the reservoirs were not emptied before the wet season. During the dry season the water supply is limited in combination with the salt intrusion 30-40 km upstream the dams are causing problems for paddy farmers.

Besides the flood problems with the water quality is worsening in the lagoon because of the intensification of shrimp farming and fishing. The provincial government tries to regulate this and prevent that big Thai companies take over the shrimp farming in the lagoon.

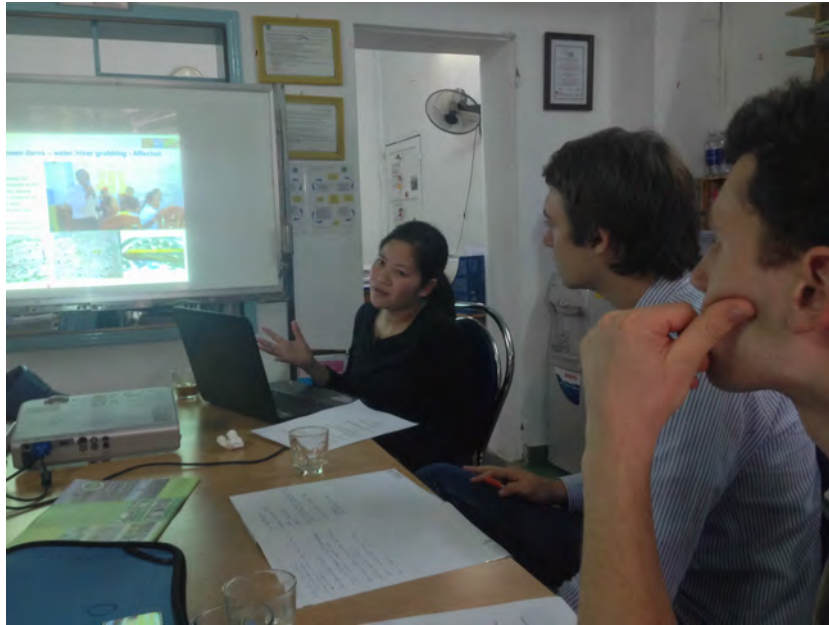


Figure A.2: Appointment with the Center for Social Research and Development

A.3 Thursday

On Thursday several sites were visited by minivan, in the morning both the Thoa Long Dam and the Thuan An inlet and in the afternoon a first visit was made to the Tu Hien inlet. The visit to Tu Hien in the afternoon was mainly to acquire permission for the research in the area. Therefore, we went

with Mr. Minh and Mr. Trung to the local commune house, the military base, and the military post at the inlet. For the traveled routes see the maps in figures: A.3 & A.4.

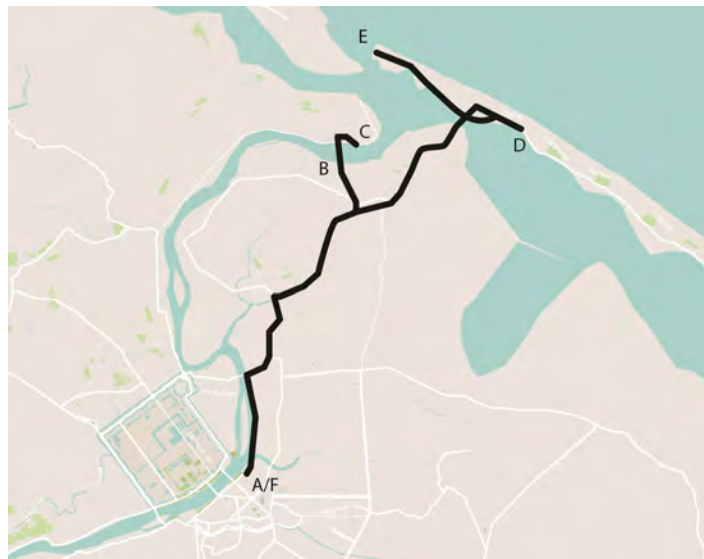


Figure A.3: The route map of Thursday morning

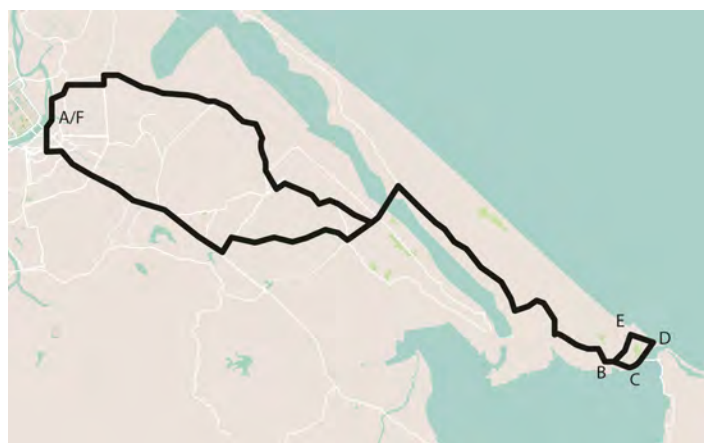


Figure A.4: The route map of Thursday afternoon

A.3.1 Thoa Long Dam

Located north east from Hue city is the Thoa Long Dam, this construction prevents salt intrusion in the Huong river. The dam closes during low tide and

in the dry season it is closed every day, which was told by one of the operators during the visit to the dam control center. The dam consists of 17 weirs, movable by hydraulic jacks, which are controlled and monitored manually. In figure A.5 the Thoa Long Dam can be seen. At that moment almost all weirs are in open position, except for two that were under maintenance.

The weirs prevent salt intrusion that caused problems for irrigation upstream before the construction of the dam was finished in 2008. The improvement of the roads decreased the numbers of boats passing the sluice at the Thao Long Dam. During our visit the sluice could not be used as one of the doors was under maintenance. Large parts of the mechanical system and the other door were affected by corrosion.



Figure A.5: Thao Long Dam

A.3.2 Thuan An inlet

The next stop was the Thuan An inlet. The upstream dominant longshore sediment transport side, that is the south east side, was visited. A large sand spit has developed on the upstream side of the inlet. The groyne at this side, probably constructed to keep the inlet open during dry season, further increased the amount of sand on this side. The groyne is for the largest part covered by sediment, seen in figure A.7 and A.8. Some of the used blocks are moved, but not yet in such a way that the groyne will not fulfill its function anymore. Since the relatively short part of the groyne that

still remains uncovered by the beach, the blocked sediment transport must be greatly reduced.

The inlet is used for fishery by using small boats and nets from the sand spit, which can be seen in figure A.6.

The north west side of the inlet was not visited, but has quite a large amount of structures, revetments and multiple groynes, in order to decrease the erosion and shoreline retreat.



Figure A.6: Sand spit at the Thuan An inlet



Figure A.7: Groyne on south east side



Figure A.8: Part of groyne covered by sediment

A.3.3 Formal Hoa Duan inlet

A short visit was made to a formal inlet, Hoa Duan, which was breached during the large storm of 1999. Part of the structures that helped closing the inlet in the years after are still visible, see figure A.9.



Figure A.9: Pillar heads used to close the Hoa Duan inlet

The land at that point is still low-lying. There are no visible significant dunes to protect the barrier island.

A.3.4 Tu Hien inlet

The Tu Hien inlet has a opposite erosion scheme than the Thuan An inlet. At the Tu Hien inlet, no hydraulic structures have yet been built to prevent erosion. Besides this the Tu Hien inlet is much smaller and big boats can not pass the inlet. The harbor situated near the inlet cannot be reached by large vessels anymore because of the sedimentation, the depth here is less than one meter.

In figure A.10 the inlet mouth can be seen. In the middle of the inlet mouth a sand bank can be spotted. The part north of the sand bank is very shallow, which was found during the depth measurements (on Sunday).



Figure A.10: Tu Hien inlet

At the inlet and at the shoreline of the lagoon, a lot of garbage is present, see figure A.11. This indicates that water quality and pollution of the estuary can be a significant problem. In the period visited, the end of the rainy season, flushing of the lagoon has been high for the past months. In the dry season pollution and the water quality can be a larger problem.

At the northern bank of the inlet a sand spit is developing. The erosion side of the inlet was visited on Sunday, see section A.6.



Figure A.11: Garbage close to the inlet

A.4 Friday

For Friday morning a appointment with the Center of Natural Resources, Environment and Sustainable Development in Hue was scheduled. Unfortunately they let us know that they did not have time to receive us. Instead Mr. Trung made an appointment with the Geology Department of the University of Hue for us. Later a final visit was paid to the dike department to collect some maps and buy the statistical year book of the Thua Thien Hue-province. After lunch Mr. Trung flew back to Hanoi and we traveled to our residency for the coming 3 days near the Tu Hien inlet.

A.4.1 University of Hue

The faculty of geology of the Hue university did research in the area of both the inlets, Tu Hien and Tuan an. Mrs. Nguyen Thi Thuy explained that the Tu Hien inlet more than 20 years ago, before the flood in 1999, was unstable and the people moving around the lagoon were kind of nomads who moved all the time. The stability of the inlet now is unknown since the research that has been done is quite old. The university did some studies based on

historical data, but prediction studies were not carried out on the lagoon system.

The groundwater in the area is a great source for minerals nevertheless the salt intrusion is threatening the usability of the groundwater. Over the past 10 years the water quality decreased in the area.



Figure A.12: Appointment with the geology department of the University of Hue

A.5 Saturday

Saturday the group split-up to do as much as possible. Luc, Tessa and Orson drove a big lap around the lagoon while Yoeri and Jochem stayed closer to Tu Hien.

The day was dominated by rain. A typhoon in the Philippines also had its effects on the Hue area. The result was heavy rainfall in the area for the whole day. This was not very pleasant while sitting on the scooters but it gave a great opportunity to look at the area when flooded. Although this was a small flood compared to which the inhabitants normal face, it still gave a decent image of the potential impact of a more severe flood.

The goals of Saturday were to discover the area in detail, visit some large dams and talk to local people about the problems they face. Most of the goals were accomplished, not all dams were visited due to the bad weather and therefore bad driving conditions. The road from the inlet to the connection between the northern and southern lagoon was extremely bad. Due to rainfall and bad maintenance the road was full of holes and driving faster than 20 km/h was not possible. It sketches the problems the people in the area have during floods and heavy rains.

For the traveled routes see the maps in figure A.13 & A.17



Figure A.13: The route map of the big tour

A.5.1 The Big Tour

Arrived at the connection between Cau Hai and Tam Giang lagoon it was not as expected. The connection was supposed to be nearly closed; however reality showed it clearly wasn't. (see figure A.14). A severe part of the area was flooded and there was quite a strong flow from north to south. A dike between the two lagoons prevented most of the water from flowing from one side to the other and an inlet system regulates the flow. Interesting was that not a lot of people seem to care about the flood (see figure A.15), they kept doing their work and did not mind the water.

Next stop was the town of Cau Hai, a town that is located close to the lake. Some inflowing rivers were visited and the potential hazard and impact to



Figure A.14: The connection between the Cau Hai and Tam Giang lagoon

the village was investigated. The people in the village explained that the water in an average flood causes water levels in their houses up to 50 cm. The 1999 storm caused the water to rise up to 2-2,5 meters. The speed of the currents of the small rivers were quite high, however the cross sections were relatively small and could not be a major contribution to the water level in the lagoon. In the town however this could cause some local floods so it is something to take into account for local flood calculations.

After Cau Hai a short visit to the inlet was made and some pictures of it were taken from the bridge. The rain didn't seem to have a lot of impact on the flow conditions in the inlet. There seemed to be very few changes compared to other visits with different weather conditions.



Figure A.15: Inundated area's around the lagoon



Figure A.16: Song Truoi river, which flows into Cau Hai Lagoon.

A.5.2 The Small Tour

In the morning we set out on our motorbikes to discover the area and speak to local people.



Figure A.17: The route map of the small tour

The heavy rain made it hard to see everything due to bad sight and inaccessible roads, on the upside the high water levels were clearly visible. In the lagoon and inlet there were still many fishermen trying to catch their fish. Our goal however was to head further land inwards to speak some of the local fishermen and to get a good look at the area there. The flooded roads made it hard to move quick and thus decreased our range for the day. Luckily we found a ferry that could take us back to our hostel so we shouldn't have to worry about coming back anymore. (see figure A.18)

At a moment we drove of the main road towards some shrimp farms. We saw some activity there: a father fishing in the farm and his son collecting and binding the crabs.(see figures A.19 & A.20) When we approached the two they were completely ok with it and we were happy to see that the son spoke some English. We asked the son to fill in our prepared form. He told us that they earn a moderate income in the months January - April and that the wet/dry season doesn't have much influence on the production. Furthermore he told us that there are about 5 floods each year and the biggest problem related to the floods are loss of property and lives.

Afterwards we drove further towards the connection of the Tam Giang and



Figure A.18: The ferry back to Tu Hien.



Figure A.19: The boy that we interviewed.



Figure A.20: The shrimp farm of the interviewee.

the Cau Hai lagoon. At this place there were a lot of aquaculture farms. Later when we drove back we found a nice village. After asking about 10 people we finally found someone willing to fill in our prepared form. She told us that there are about 4 floods each year. Unfortunately she could not tell us much more. From this village we took the ferry back to the barrier island. When we drove to a village over there we saw some people making big fykes for fish farming.

A.6 Sunday

On Sunday morning the group was split up again. The first group made a tour to the other side of the inlet(south side) and to the old inlet near Loc Thuy. The other part of the group made some preparations for the depth measuring of the inlet, which was planned in the afternoon. To arrange the hiring of the boat and to help us with some interviews Mr. Minh from the Local Dike Department in Hue was so kind to help us on Sunday afternoon. After a lunch very close to the inlet and the hiring of a boat from local fisherman the group split up again. Two group members went with mr. Minh to interview some local stakeholders, and the other group members performed an echo sounding of the inlet.

A.6.1 Tour to South Side of the Inlet

From the residency a trip was made to the south side of the Tu Hien inlet and the former inlet location near Loc Thuy (see map in figure A.21) . On the way the very small harbor in the Cau Hai lagoon was seen from the bridge (see figure A.22).

Next to the south side of the current inlet there is still a small lagoon that is connected with the sea at Loc Thuy. In this lagoon there are also aquaculture and fish farms present (see figures A.23 & A.24). The continued existence of these farms depend on the condition of the inlet near Loc Thuy. If this inlet would close, the lagoon would become a lake and the yields of the farms would become unsustainably low. At the sea side of the small lagoon there was a bank protection over a length of approximately 100 m (see figure A.25). The stones of this protection have diameters around 35 cm. According to mr. Minh of the local dike department this bank protection has been build to protect erosion when the inlet of the Cau Hai lagoon was still located at Loc Thuy. Some part of this protection can also be seen on the soil surface between the small lagoon and the inlet of Cau Hai (see figure A.26). During the inspection of the inlet it appeared that it was very narrow (see figure A.27). The inlet is flowing in some curves to the sea, at the down-drift side of the inlet the channel has a steep slope and is quite deep. At the other side there is gentle slope and it is shallow. At that moment it was low tide and the currents were towards the sea. The channel was at the narrowest section approximately 10 m wide and the current was in the order of 0.5 m/s. At the south side of the inlet there is erosion(see figures A.28 & A.29), which causes the falling down of trees. At the opposite side a sand spit is growing. At this side there is also a groyne that should protect silting up of the inlet. The state of the groyne is not good, as several parts are missing. The diameter of the stones is approximately 30 cm, which seems not large enough to withstand the sea state conditions over there. According to Mr. Minh this groyne was build quite a long time ago, and was commissioned by the local government.

At the south side of the Tu Hien inlet near Vinh Hien(see figures A.31 and A.32) also some erosion can be seen (see figure A.33). The place of the erosion here is only 25 meters away from the road. So if erosion continues here the stability of the road can become uncertain.

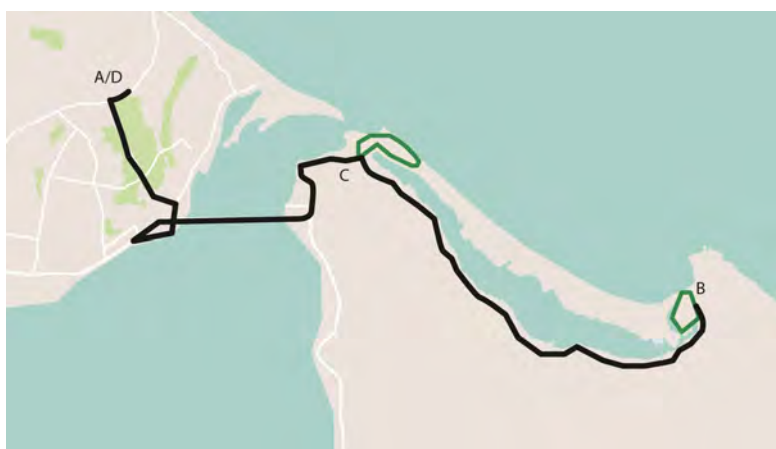


Figure A.21: The route map of sunday morning

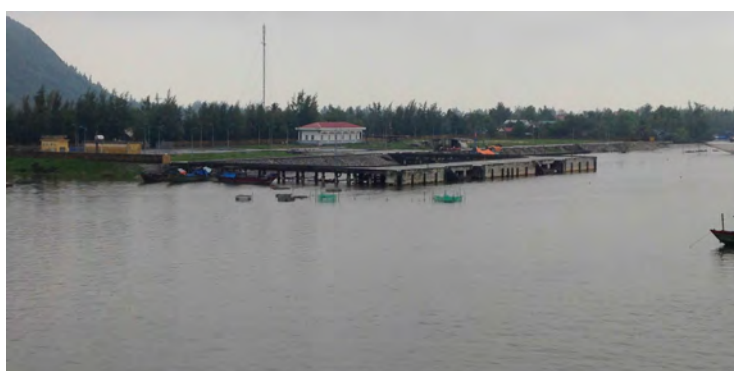


Figure A.22: Small Harbor in Cau Hai lagoon, close to Vinh Hien



Figure A.23: Shrimp farm in small lagoon



Figure A.24: Fish farming in small lagoon



Figure A.25: Bank protection small lagoon



Figure A.26: Bank protection also situated at accreted area



Figure A.27: Inlet near Loc Thuy



Figure A.28: Erosion on down drift side of inlet near Loc Thuy



Figure A.29: Erosion on down drift side of inlet near Loc Thuy



Figure A.30: Groyne near Loc Thuy inlet

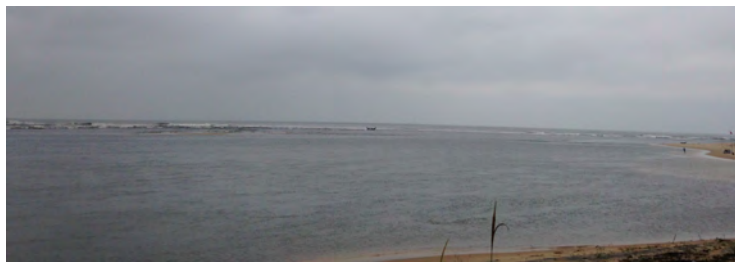


Figure A.31: Inlet Tu Hien



Figure A.32: Inlet Tu Hien



Figure A.33: Erosion at down drift side of Tu Hien inlet

A.6.2 Water Depth Measuring of the Inlet

Sunday afternoon a part of the group went with a local fishermen on his boat to perform depth measurements with an echo-sounder borrowed from the WRU. When the pipe with the sonar sounder attached to it was mounted to the boat we sailed towards the inlet. Once we got acquainted with the device and understood how to read it, we performed a total of 80 measurements. We measured the depth and coupled it with its GPS coordinates and time to adjust for the tidal influence. At first the measurements seemed quite inaccurate, so we wanted to verify our measured depth. To do this we also brought some fishing line with a weight attached to it: we stopped the boat to sink the weight and measured the distance between bottom and average water line. The results appeared to match well.

What we found is that there are large portions of the lagoon too shallow to reach by boat, during our measurements our boat grounded 2 times at different points. There also seems to be a distinct ebb/flood canal in the southern part of the lagoon, with ripples at the spit. The beach slope seems to be quite high as the depth increased fast at sea, this is in accordance with the type of waves we observed earlier.

In appendix B on page 178 the results and methodology of the measurements is discussed.



Figure A.34: Performing the measurements at the boat.



Figure A.35: Fishermen working in the inlet.

A.6.3 Stakeholder Interviews

The stakeholder interviews were performed to retrieve general information about the area and to understand how the different stakeholders depend on the lagoon. The locations of the different interviews are indicated in the following map and table.

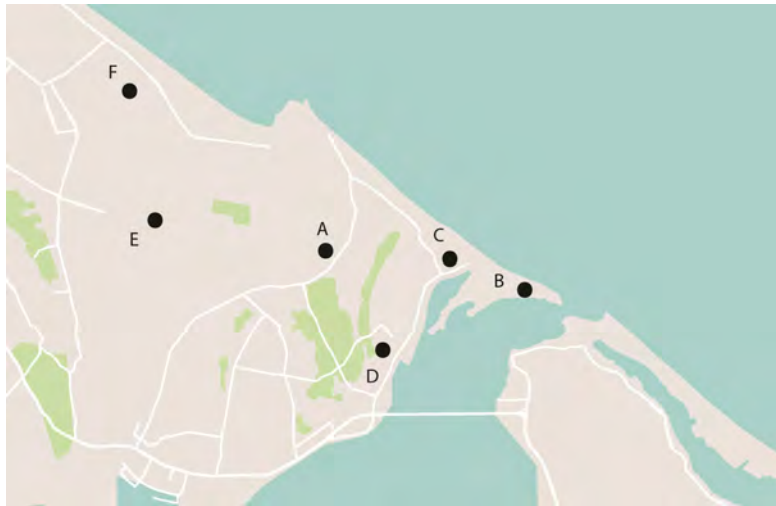


Figure A.36: Locations of the different stakeholder interviews.

Table A.1: Locations of stakeholders

Locatie:	Stakeholder:
A	Local inhabitant
B	Fisherman with small boat
C	Fisherman with big boat
D	Fish farmer
E	Farmer
F	Shrimp farmer

Local inhabitant

Close to our residency there was a man who spoke some English. With help of a form with questions in Vietnamese the man provided us with some information. (see figure A.37)

What is your job?

I own a shop, where I work.

Can you live of one job only?

Yes.

Where do you live?

Vinh Hien.

Are there troubles with droughts or floods in the area?

Yes, with floods they occur 1-5 times per year on average.

Do you think problems become bigger/stay same/smaller in the near future?

I think the problems become bigger.



Figure A.37: Interviewing a local inhabitant

In the afternoon Mr. Minh came to help as a translator. Therefore we could ask some more questions during the following interviews. Close to the inlet there were a lot of fishermen, some fished with big boats (see figure A.38) and some with small ones (see figure A.39). We talked with both.

Fishermen with big boat

Where do you live?

Tu Hien, very close to the inlet. Because I fish here everyday. We live in temporary houses (see figure A.40) because during typhoons and flooding it is not safe here. With help of governmental support we also have a second permanent house a couple of kilometers north west of the inlet. Because of safety reasons no permanent housing is allowed here anymore. The old houses close to the inlet are all demolished (see figure A.42).

Where do you fish?

During the wet season I fish in the inlet, and during the dry season I fish on sea 30-40 km's offshore. In the wet season I fish twice a day when the tidal



Figure A.38: Large fisher boat



Figure A.39: Small fisher boat

currents enter the lagoon.

What is your income?

Enough to live.

Can you go to sea by boat?

Yes, if in the dry season the bigger fisher boats can not sail through the inlet the local fisher commune dredges the inlet.

What kind of fish do you catch?

During the dry season I catch tuna and squid. During the wet season I catch sea bream, sardines and mullet.

Was the inlet closed?

A total closure is a long time ago(+/- 30 years ago). At that time the fishermen could not go to sea, which was a big problem.

Do floods occur often?

Yes, 1 to 5 times per year. During floods people flee to the mountains. In 1999 the water was more than 2.5 high in the temporary house (see figure A.41). The recent flood of 2013 came to 70 cm high.

Are there problems with the water quality?

No not really, only sometimes the fishing nets get dirty.

Where do you throw your garbage?

In the lagoon or the sea

Fishermen with small boat

Where do you live?

We live in the village 2 kilometres north west from here, close to the mountain.

What kind of fish do you catch?



Figure A.40: Temporary house near the inlet



Figure A.41: Local fisherman indicating flood level of 1999

We catch mullet, sea breams, sardines, anchovy, spinefoots, spotted scat and red snapper

Where do you fish?

In the wet season we fish in the inlet, in the dry season we fish on sea, around 3-4 kilometers offshore.

Can you go to sea by boat?

Yes, the inlet is always open, and we have very small boats.

Do floods occur often?

Yes, a few times per year, which is a problem because we can not fish then and the fish disappears.

How are you warned for typhoons and floodings?

The local commune warns for floods and typhoons. All people move towards the mountain close to the inlet when a flood or typhoon is coming.

Where do you sell the fish?

People from bigger cities as Danang and Hue come and buy our fish and sell it to the people on the market.

Fish Farmer

What is your main source of income?

Fish farming is main income, I used to be a fisherman but now i am older



Figure A.42: Old demolished house close to the inlet

and only catch fish in front of my house with fykes (see figure A.43). As a fisherman you have to be very healthy and strong and you have to invest in a boat.

What kind of fish do you catch?

Spotted scat, halfbeaks and snappers

What is your income?

We can live from the fish farm.

Do you have all year income from the fish farm?

Yes.

Do floods occur often? Every year floods occur. Is quite a big problem for fish farmers because the fish in the fykes die during floods because the water becomes to fresh.

Are their problems with the water quality?

In this area there are no problems with the water quality due to the close by inflow of sea water. Other aqua farms in the lagoon that are far away from the inlet have sometimes problems with the water quality during the dry season. Because there is very less fresh water that flushes the lagoon.

Can you tell us something about the use of aqua farms in the lagoon?

Yes, close to the inlet there are only fish farms because the water is to salt for shrimps or crab. Farther away from the inlet where the water is brackish there are mostly shrimp and crab farms. (see illustration)



Figure A.43: Fyke constructions for fish farming

Farmer

What is your main source of income?

Main source of income is farming

Do you have a second job out of season?

Yes, I also work as a construction worker sometimes.

What crops do you produce and when?

Rice and watermelon. Rice from January till April. And in the rest of the year I produce watermelon. (see figure A.44)

How many harvests do you have per year?

Rice only 1 harvest only when there is enough water and watermelon 2 harvests. *What other crops are produced in the region?*

A lot of rice, and also peanuts, cassava, sweet potatoes, chicken, duck and pork.

Is there irrigation available in the region?

No there is no irrigation available. Because for the production a lot of water is needed, so sometimes when it is too dry no rice will be planted but watermelon.

Have you suffered from droughts?

Not often. During droughts the harvest could fail because of a lack of water. But the harvests hardly fail.

Have you suffered from floods?

Yes, the region is every year hit by floods and typhoons. The water levels come very high during a flood. So we have to flee to the mountains during floods.

Can the harvests fail from floods of salt water?

When the farm is inundated by salt water it is not good for the production of the crops. So we use a lot of fertilizer when this happens.



Figure A.44: Rice paddies close to the interview location

Shrimp Farmer

What is your main source of income?

Our main source of income is the shrimp farm. (see figure A.46)

Do you have a second job out of season?

No

Can you tell something about your shrimp farm?

Yes, the shrimp farm here is a bit different then other shrimp farms. Most shrimp farms are next to the lagoon and take brackish water from the lagoons in their basins and cultivate the shrimps in those basins. Since this shrimp farm is on the land we take in salt water from sea and fresh water and mix it to good proportions in the basin.

Do floods occur often? Once in the five years, which is less than other places closer to the lagoon because the ground is here higher. What do you do to prevent yourself against floods?

One person stays at the farm to protect it, the rest escapes to the mountain. To keep the shrimps in the basins we put nets over the basins.

How many harvests do you have per year?

During the dry season we have two large shrimp harvests. One from February till May and one from May till August. In the wet season we have a smaller harvest because of the occurrence of floods and typhoons.

How much do you earn in comparison with other professions, and which professions are the most common?

Most peoples income depend on fishery. But the income of shrimp farming is a bit higher, if the water condition in your basins are good.

Are all the shrimp farms in the province private or are their also companies cultivating shrimps in the region?

Most shrimp farms are private. In the north of the Thiam Gang lagoon there are also some Thai companies, that cultivate shrimps. Their shrimps are exported to Thailand.

Can you tell something about the influence of the water quality on the cultivation of shrimps?

Yes, for shrimp farms that use the water out of the lagoon the water quality is very important because when the water quality is bad the revenues will decrease.

How is the water quality developing in time?

The water pollution is increasing in recent years, which is not good for the shrimp farmers. Excreta of shrimps cause a decrease of the water quality and thus the yields of shrimps. This is especially a problem in the dry season when the lagoon is not flushed with run-off water. Floods have a beneficial impact on the water quality because it flushes out all pollution from the city and excreta of the shrimps. Because of the high flood of 2013 the yields of the shrimpers is this year quite high.

What kind of devices are used to cultivate shrimps?

I use a device to measure the water quality and its salinity. By checking the device we can optimize the water quality. Furthermore we use aeration units (see figure A.45) to improve the water quality.



Figure A.45: Shrimp farm of the interviewee, with devices for aeration of the water



Figure A.46: interviewee shows shrimps in the basin

Appendix B

Depth Measurements

In this appendix the results and the methodology of the depth measurements of the inlet are shown.

B.1 Survey Results

Three cross-sectional profiles have been made with our measurements, see figures B.1, B.2, B.3. In these figures, the points represent the exact measurements. A yellow trendline is added to the plot because it gives a better idea of the profile, the corners shown in the blue line obviously doesn't exist in reality. The location of the profiles are shown in a map, see figure B.4. Also the average depth and cross-sectional areas have been calculated. It can be clearly seen that the average depth of the inlet decreases towards the lagoon, while the width increases. The area of the cross-sections also increases. Results are shown in table B.1.

Cross section	Width	Hydraulic radius	Average depth	Total area
1	126	128	4,87	614
2	320	320,2	2,31	742
3	400	400,5	2,53	1015

Table B.1: Table showing values corresponding to the profiles 1-3.

What we found is that there are large portions of the lagoon too shallow to reach by boat, during our measurements our boat grounded 2 times at

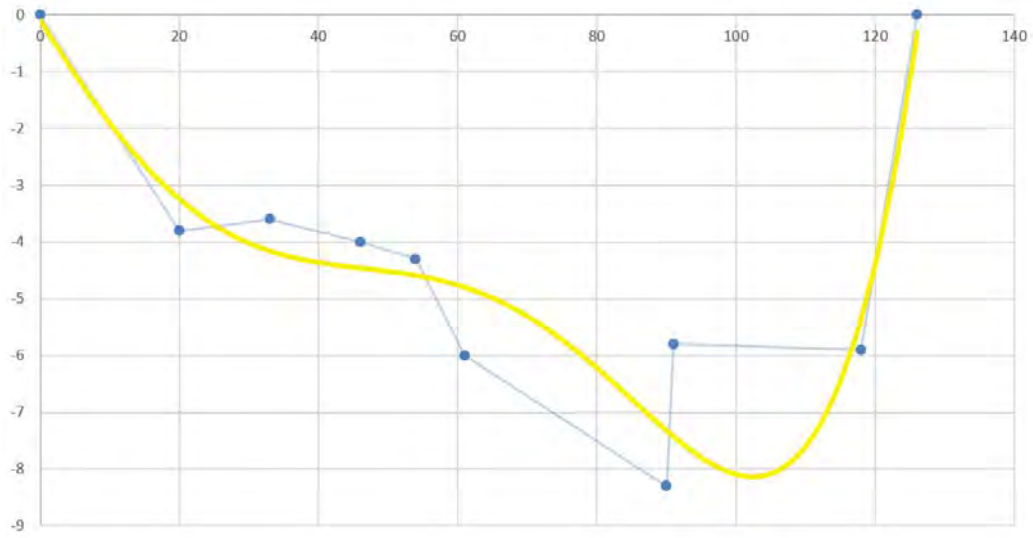


Figure B.1: Cross-sectional Profile 1

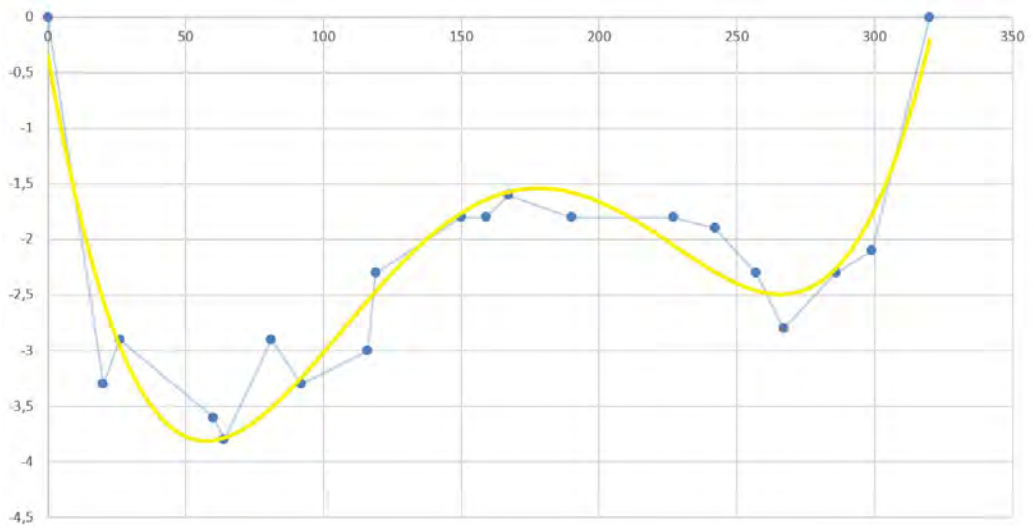


Figure B.2: Cross-sectional Profile 2

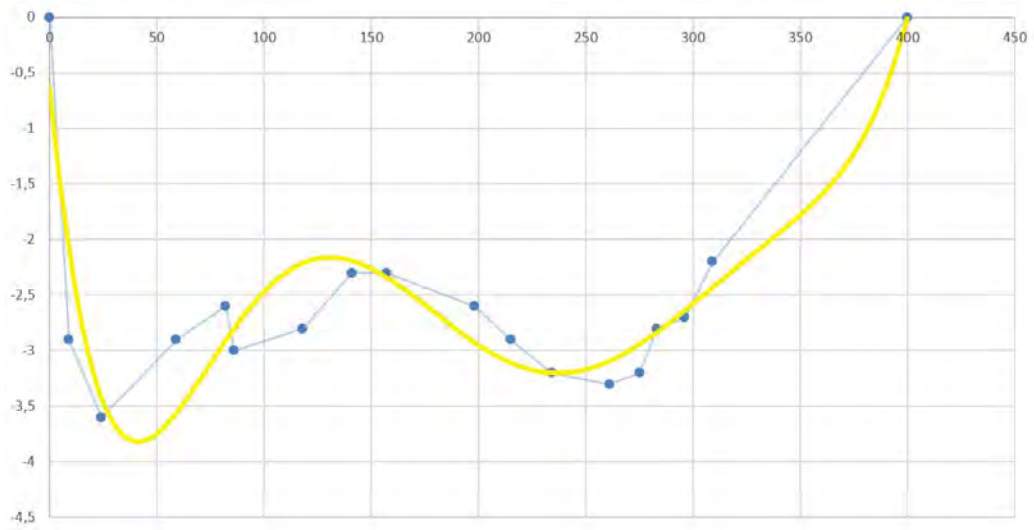


Figure B.3: Cross-sectional Profile 3



Figure B.4: Locations of the cross-sections.

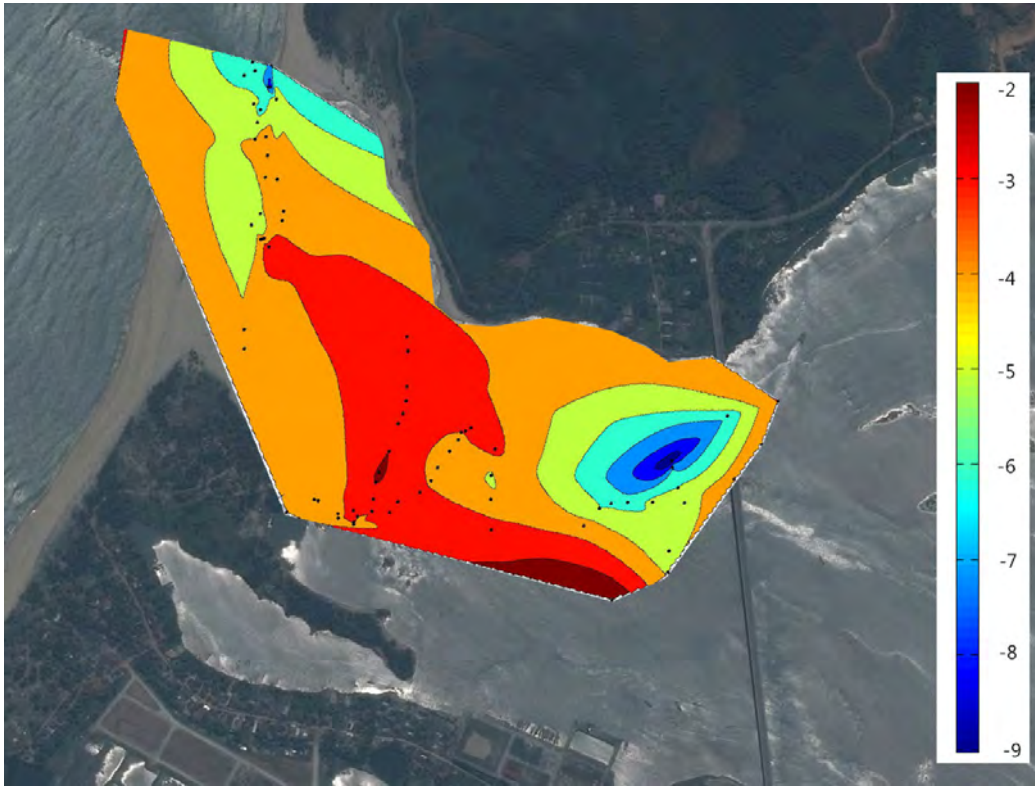


Figure B.5: Contourmap of measurements

different locations. There also seems to be a distinct ebb canal in the southern part of the lagoon, with ripples at the spit. The beach slope seems to be quite steep as the depth increased fast at sea, this is in accordance with the type of waves we observed earlier.

The inlet is assumed to be in a dynamic equilibrium. This means that the inlet is constantly adapting, but within certain boundaries. Our measurements were performed after the wet season, so it can be assumed that the inlet is adapted to it's wet-seasonal profile to a certain extend.

The contour map in figure B.5 shows the location of the measurements together with the interpolated data. It can be clearly seen that there were 3 separate areas where there were a lot of measurements, say 3 'sweeps'. A contour map interpolating between the separate areas obviously shows large areas with heights that have not been measured, and thus might not be the most correct way of representing the data.

B.2 Method

The data has been processed using Matlab, Google Earth, Excel and some GPS-transformation software. First, the raw data was corrected for tidal influence and put into .csv format using excel. With excel the cross-sectional profiles were made, estimating the distance from the border measuring points to the shore. Using GPS Babel, an open source GPS conversion tool, we could transform the data to the right coordinate- and file-format (.gpx). This data was loaded into Google Earth to check if everything went fine, the points were showing up on the right location. To transform the GPS-coordinates into an Cartesian coordinate system the 'Geodetic Toolbox' for Matlab was used. Now that the depth was coupled with points in a Cartesian frame, the points could be interpolated so that surface and contour plots could be made. Extrapolation was turned off as it gave no extra information.

B.3 Discussion on the Results

As with every measurement, sources of errors are present. The total error made consists of several parts:

Accuracy of the echo sounder The accuracy of the echo sounder has a large influence on total error. The echo sounder we used was an older model fish finder by Garmin, it used dual band frequencies but with a predefined speed of sound and returned the depth in 1/10 m accuracy. Also the measuring interval was sometimes very long if no good measurements could be done for a period of time.

GPS-accuracy Also the accuracy of the GPS-device is important. The GPS-device we used showed an accuracy of 15 meters, that means that 95% of the measurements is within this range. This range is however a 'worst case' number and the error should be smaller on average.

Human errors Another source of inaccuracy are human errors. The data on the echo sounder was presented in small dots in a graph, together with drops of rain on the screen made the reading conditions less than perfect. The screen was continuously read and communicated to the person noting them on paper, also with this communication things could have gone wrong.

Measurement set-up The sonar-device was mounted to a pole attached to the edge of the ship so that it was just under water the whole time. Due

to the sailing speed of the ship the pole would sometimes rotate a bit around its attachment point. This was corrected a few times during the measurements but could have introduced errors in some measurements. Also the type of boat we used had its influence on the results: it was large enough to come close to the rough sea, but also the draught was too large to measure the whole lagoon as it got stuck.

Tidal influence The height above the reference datum needs to be accounted for. With literature, tidal data of the day and tidal charts obtained from our supervisor we estimated the tidal amplitude at the day we performed our measurements. Errors could be made in either one of these sources and our estimations.

Other than the accuracy of the measurements the way of presenting the results is also an important aspect. The cross-sectional profiles give detailed information of a small area but lack the overview, while the contour map gives a lot of information but lacks the data from shallower areas to support it.

B.4 Measured Data

For completeness, the raw data of the measurements is presented in table B.4.

Table B.2: Table with raw measured data.

Name	Latitude	Longitude	Depth	Time
1	16 21 26.9	107 55 17.4	-3	13:32:00
2	16 21 26.1	107 55 20.5	-2,9	13:35:00
3	16 21 19.5	107 55 17.8	-6	13:40:00
4	16 21 18.5	107 55 17.5	-6,1	13:41:00
5	16 21 19.3	107 55 15.7	-6,2	13:41:00
6	16 21 19.5	107 55 15.2	-4,2	13:42:00
7	16 21 19.7	107 55 14.5	-4	13:42:00
8	16 21 19.3	107 55 12.8	-3,5	13:43:00
9	16 21 19.7	107 55 11.3	-4,1	13:43:00
10	16 21 19.8	107 55 10.2	-3,4	13:45:00
11	16 21 19.6	107 55 10.2	-4	13:46:00
12	16 21 19.7	107 55 10.2	-4,1	13:46:00
13	16 21 21.1	107 55 05.7	-3,5	13:50:00

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Table B.2 – *Continued from previous page*

Name	Latitude	Longitude	Depth	Time
14	16 21 19.5	107 54 58.4	-3,5	13:53:00
15	16 21 18.9	107 54 58.0	-3,1	13:54:00
16	16 21 16.8	107 54 57.7	-3,1	13:55:00
17	16 21 16.0	107 54 57.3	-3,2	13:55:00
18	16 21 16.0	107 54 57.4	-2,8	13:55:00
19	16 21 16.0	107 54 57.9	-2,5	13:55:00
20	16 21 14.9	107 54 58.2	-2	13:55:00
21	16 21 14.7	107 54 58.9	-2	13:56:00
22	16 21 14.5	107 54 59.3	-1,8	13:56:00
23	16 21 13.9	107 55 00.1	-2	13:57:00
24	16 21 13.3	107 55 01.2	-2	13:57:00
25	16 21 13.0	107 55 01.6	-2,1	13:57:00
26	16 21 12.8	107 55 02.1	-2,5	13:57:00
27	16 21 12.7	107 55 02.7	-3	13:58:00
28	16 21 12.5	107 55 04.2	-2,5	13:58:00
29	16 21 12.5	107 55 04.8	-2,3	13:58:00
30	16 20 59.0	107 54 57.3	-8	14:11:00
31	16 20 59.0	107 54 57.3	-9,1	14:11:00
32	16 20 59.0	107 54 57.0	-6	14:12:00
33	16 20 58.8	107 54 56.1	-5	14:12:00
34	16 20 59.5	107 54 53.5	-4,9	14:14:00
35	16 20 59.6	107 54 52.6	-4,1	14:14:00
36	16 21 00.2	107 54 52.2	-3,5	14:14:00
37	16 21 02.7	107 54 51.9	-1	14:16:00
38	16 21 03.9	107 54 55.3	-3,5	14:18:00
39	16 21 03.0	107 54 55.9	-5	14:19:00
40	16 21 02.4	107 54 56.0	-5,3	14:19:00
41	16 21 01.5	107 54 55.9	-5,4	14:20:00
42	16 21 00.2	107 54 55.7	-4,8	14:20:00
43	16 20 58.5	107 54 55.4	-4,1	14:21:00
44	16 20 55.8	107 54 56.0	-3,5	14:22:00
45	16 20 54.2	107 54 57.2	-3	14:23:00
46	16 20 53.1	107 54 58.9	-2,9	14:24:00
47	16 20 55.9	107 54 58.7	-5,8	14:25:00
48	16 21 08.8	107 54 55.9	-2,5	14:30:00
49	16 21 08.7	107 54 57.2	-3,8	14:30:00
50	16 21 08.6	107 54 58.2	-4,2	14:30:00
51	16 21 08.3	107 54 59.3	-2,6	14:31:00

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Table B.2 – *Continued from previous page*

Name	Latitude	Longitude	Depth	Time
52	16 21 09.5	107 55 00.4	-2,4	14:32:00
53	16 21 09.8	107 55 00.3	-2,9	14:32:00
54	16 21 10.0	107 55 00.3	-3	14:33:00
55	16 21 10.2	107 55 00.0	-3,4	14:33:00
56	16 21 10.7	107 54 59.6	-3,5	14:33:00
57	16 21 11.4	107 54 59.0	-3,4	14:34:00
58	16 21 11.8	107 54 58.5	-3,1	14:34:00
59	16 21 12.4	107 54 58.1	-2,8	14:34:00
60	16 21 13.6	107 54 57.9	-2,5	14:34:00
61	16 21 14.1	107 54 57.5	-2,5	14:35:00
62	16 21 15.0	107 54 57.7	-3	14:35:00
63	16 21 15.8	107 54 57.6	-3	14:35:00
64	16 21 16.8	107 54 57.9	-3,5	14:36:00
65	16 21 17.8	107 54 58.6	-3,8	14:36:00
66	16 21 18.0	107 54 58.7	-4	14:36:00
67	16 21 21.0	107 55 06.5	-4	14:39:00
68	16 21 19.4	107 55 09.8	-2,5	14:41:00
69	16 21 18.6	107 55 10.8	-3,4	14:42:00
70	16 21 18.5	107 55 11.2	-3,3	14:42:00
71	16 21 18.7	107 55 12.6	-3,9	14:42:00
72	16 21 19.1	107 55 13.7	-3,8	14:43:00
73	16 21 19.1	107 55 14.5	-3,8	14:43:00
74	16 21 19.6	107 55 16.0	-4,5	14:44:00
75	16 21 20.0	107 55 17.3	-5,5	14:44:00
76	16 21 19.4	107 55 17.4	-5,4	14:44:00
77	16 21 18.8	107 55 16.6	-6	14:45:00
78	16 21 18.7	107 55 16.6	-8,5	14:46:00
79	16 21 18.4	107 55 16.0	-4,2	14:48:00
80	16 21 20.2	107 55 10.9	-5	14:37:00

Appendix C

Additional Data

C.1 Overview typhoons

Table C.1: Table of tropical depressions for the years of 1989 up to 2011. Wind is in knots. Proximity refers to proximity to the province, estimated on storm paths. (approximate distance eye to province: close: 100 – 200 km, very close: ≤ 75 km, in path: ≈ 0 km) [Biezen, 2014]

Year	Type	Number	Max wind	Category	Start	End	Proximity
2011	Subtropical storm	24	25		07-Nov	10-Nov	Close
	Tropical storm	21	35		24-Sep	27-Sep	In path
2010	Subtropical storm	18	30		10-Nov	14-Nov	Close
	Typhoon	6	65		20-Aug	25-Aug	Close
2009	Typhoon	17	90	2	25-Sep	29-Sep	Close
2008	Tropical storm	20	55		27-Sep	30-Sep	Close
2007	Typhoon	16	70	1	29-Sep	04-Oct	Close
	Subtropical storm	6	30		01-Aug	07-Aug	Close
2006	Typhoon	23	125	4	07-Nov	15-Nov	Close
	Typhoon	18	125	4	25-Sep	02-Oct	In path
2005	Subtropical storm	17	30		21-Sep	25-Sep	In path
	Typhoon	22	85	2	27-Oct	02-Nov	In path
	Subtropical storm	20	30		06-Oct	08-Oct	Very close
	Tropical storm	16	50		14-Sep	18-Sep	Close
2004	Typhoon	8	75	1	05-Jun	13-Jun	Close
2003	Typhoon	25	75	1	11-Nov	19-Nov	Close
2002	Tropical storm	24	55		21-Sep	28-Sep	Close
2001	Tropical storm	13	40		08-Aug	11-Aug	Close
2000	Typhoon	23	95	2	04-Sep	10-Sep	Close
	Tropical storm	19	45		18-Aug	23-Aug	In path
	Subtropical storm	4	30		29-May	01-Jun	Very close
1999	Tropical storm	27	35		14-Oct	19-Oct	In path

Table C.2: Table of tropical depressions for the years of 1980 up to 1988. Wind is in knots. Proximity refers to proximity to the Thua Thien-Hue province, estimated on storm paths. (approximate distance eye to province: close: 100 – 200 km, very close: ≤ 75 km, in path: ≈ 0 km) [Biezen, 2014]

Year	Type	Number	Max wind	Category	Start	End	Proximity
1998	Subtropical storm	15	30		02-Oct	05-Oct	Close
	Subtropical storm	12	30		16-Sep	19-Sep	In path
1997	Tropical storm	25	40		27-Sep	05-Oct	In path
	Typhoon	22	75	1	17-Sep	26-Sep	In path
1996	Tropical storm	35	40		31-Oct	04-Nov	Close
	Typhoon	24	45		16-Sep	23-Sep	Close
1995	Super typhoon	29	155	5	20-Oct	07-Nov	Close
	Typhoon	28	120	4	21-Oct	02-Nov	Close
	Subtropical storm	16	30		03-Sep	11-Sep	Close
1994	Tropical storm	25	50		06-Sep	14-Sep	Close
	Tropical storm	23	45		30-Aug	08-Sep	Close
1993	Tropical storm	18	45		19-Aug	29-Aug	Close
	Typhoon	8	85	2	04-Jul	13-Jul	Close
1992	Typhoon	26	80	1	15-Oct	29-Oct	Close
1991	Typhoon	12	95	2	08-Aug	18-Aug	Close
1990	Super typhoon	27	150	5	06-Nov	18-Nov	Very close
	Typhoon	19	90	2	07-Sep	20-Sep	In path
1989	Super typhoon	30	140	5	13-Oct	22-Oct	Close
	Typhoon	29	70	1	06-Oct	13-Oct	Close
	Typhoon	27	80	1	28-Sep	03-Oct	Close
	Typhoon	26	130	4	28-Sep	10-Oct	Very close
	Typhoon	4	75	1	22-May	26-May	In path
1988	Typhoon	24	125	4	03-Nov	12-Nov	Close
	Typhoon	23	125	4	20-Oct	28-Oct	Close
	Tropical storm	19	45		19-Sep	23-Sep	Close
1987	Typhoon	10	85	2	07-Aug	24-Aug	Close
	Super typhoon	9	140	5	07-Aug	17-Aug	Close
1986	Tropical storm	22	60		07-Nov	11-Nov	Very close
	Tropical storm	21	55		18-Oct	23-Oct	Close
	Tropical storm	18	45		09-Oct	12-Oct	Close
1985	Typhoon	22	100	3	12-Oct	16-Oct	Very close
	Super typhoon	21	150	5	11-Oct	21-Oct	Close
	Typhoon	19	70	1	27-Sep	02-Oct	Close
1984	Typhoon	27	120	4	30-Oct	08-Nov	Close
	Tropical storm	16	40		24-Sep	27-Sep	Close
1983	Typhoon	17	70	1	22-Oct	26-Oct	Close
	Tropical storm	1	35		19-Jun	26-Jun	In path
1982	Typhoon	24	155	4	10-Oct	18-Oct	Close
	Tropical storm	17	60		04-Sep	06-Sep	Close
1981	Typhoon	25	100	3	12-Nov	23-Nov	Close
1980							

C.2 Wind roses per month

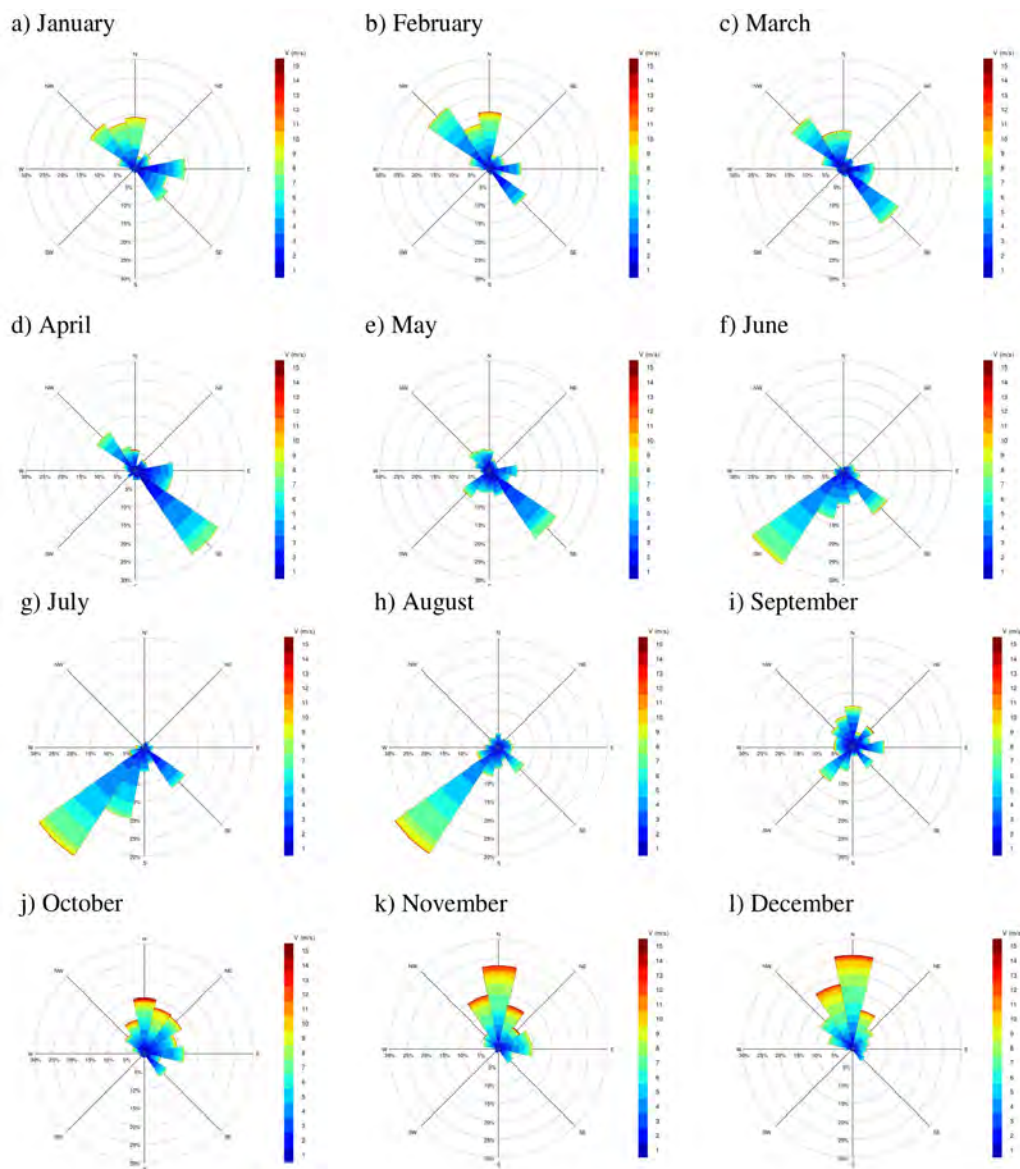


Figure C.1: Overview of wind roses at Con Co island from 1992-2001 [Lam, 2009]

C.3 Wave roses per season

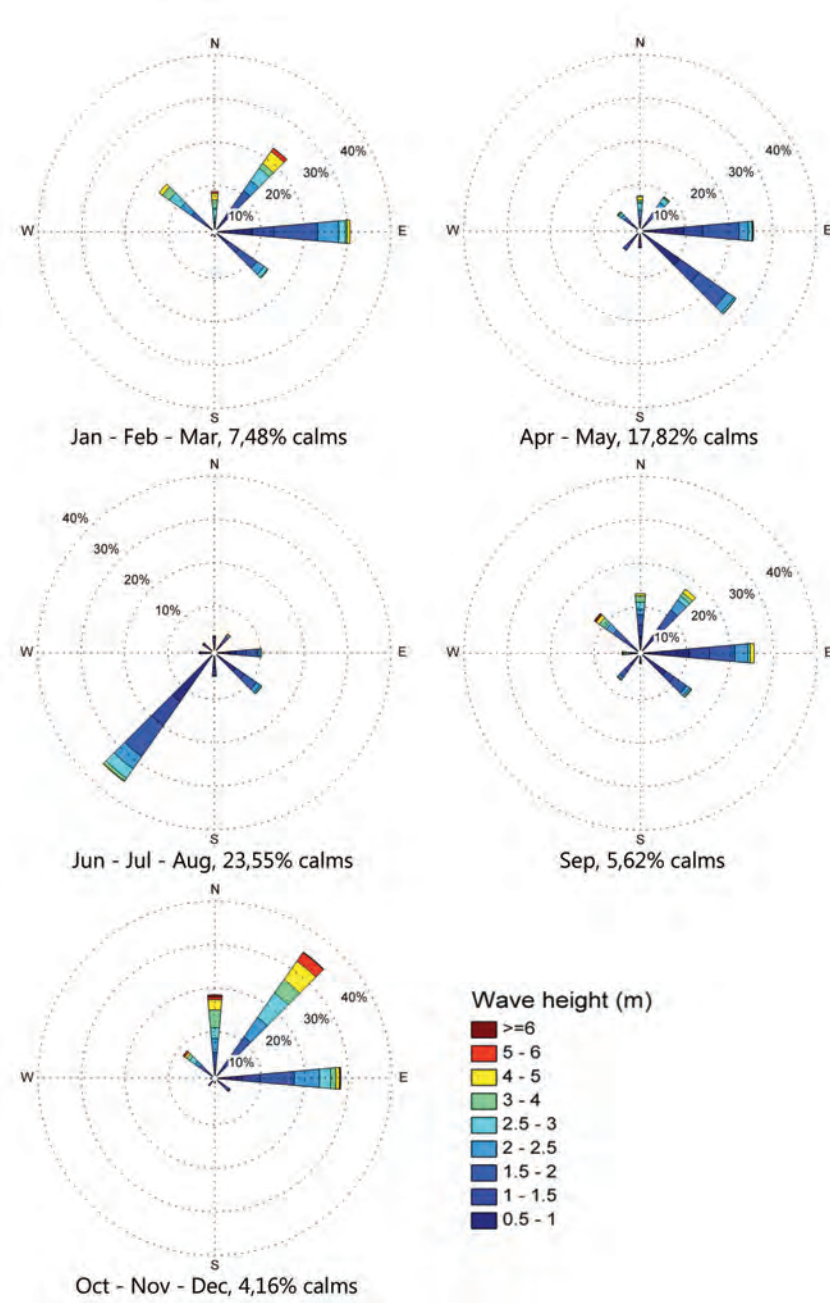


Figure C.2: Overview of wave roses at Con Co island from 1980-1996 [Biezen, 2014]

C.4 Elevation data around Cau Hai lagoon

For the hydraulic model it was necessary to determine the elevation of the flood plain areas around the lagoon. This was needed to know the extra storage in the model when certain water levels are exceeded. The data is collected by analyzing the maps of the local dike department in Hue. In table C.3 the surfaces between the elevation are shown, the area of elevation data collection is shown in figure C.3

Table C.3: Overview of low elevations around Cau-Hai lagoon

Elevation [m]	Surface [km ²]
0.0 - 0.5	3
0.5 - 1.0	33
1.0 - 1.5	18
1.5 - 2.0	8
2.0 - 3.0	13
3.0 - 4.0	10



Figure C.3: Area of the elevation data

Appendix D

Additional Calculations

D.1 Calculation of storm surge levels

In this section the calculation of the storm surge levels based on the available typhoon data is elaborated. For this calculation the typhoon data from appendix C.1 on page 186 is used. ¹

The first step to modify the data is to adjust the wind speed to the proximity of the typhoon path to the Tu Hien inlet location. It is known that maximum wind speeds in a typhoon occur around the eye, and the eye has a typical size of 80 km's [Secretariat of the World Meteorological Organization, 2011] [Broersen, 2010]. Besides the range for different proximity levels is known from table C.1. Therefor correction factors for the wind speeds are chosen as follows: *in path* = 0.9, *very close* = 0.8 and *close* = 0.7. This is an approximation since different typhoons have different paths. The factor for typhoons that lie in path is not 1.0 because when the path crosses the province, the eye does not necessarily also cross the inlet.

The next step is to take only the extreme wind speeds from this data, this is done with the peak over threshold method [CUR, 1997]. An advantage of taking only extremes is that different physical processes can be distinguished. The threshold level is taken for the minimum wind speed of 'a tropical storm' which has a minimum wind speed of $17 \frac{m}{s}$

¹No storm surge measurements seemed to be available. Therefor a probabilistic calculation was performed on basis of typhoon wind speeds to find storm surge levels. During the end presentation Prof. Tuan mentioned that storm surge levels on basis of water level measurements were available. The 100 year storm surge level appeared to be 2.5 m. In this report the values from appendix D.1 are used.

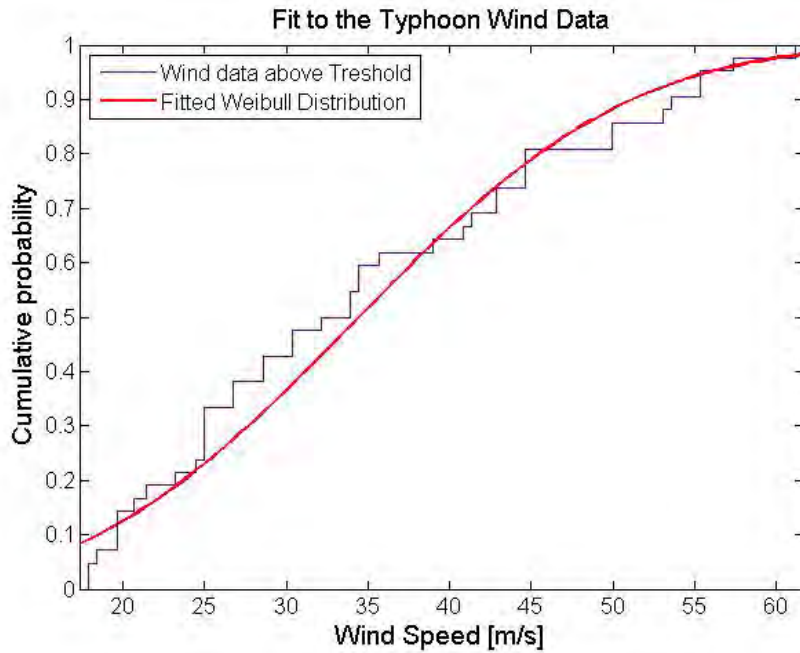


Figure D.1: Weibull distribution fit to extreme wind data

[Secretariat of the World Meteorological Organization, 2011]. The peak over threshold method is applied with help of Matlab.

The next step is to fit a distribution to the extreme wind speeds, chosen is for a Weibull distribution since it is often used for wind data [CUR, 1997]. The result of the distribution fitting to the data can be seen in figure D.1 and in table D.1

Table D.1: values of the weibull distribution

Parameter	Estimate	Standard dev.
A	38.89	2.09
B	3.03	0.36

To determine the return wind speeds the probabilities of exceedance have to be determined for the return periods. This is done by a comparison with the distribution which is based on data of a number of years and a number of storms.

$$\Delta T = \frac{\text{years of data}}{\text{number of storms}} = \frac{32 \text{ years}}{42 \text{ storms}} = 0.76 \quad (\text{D.1})$$

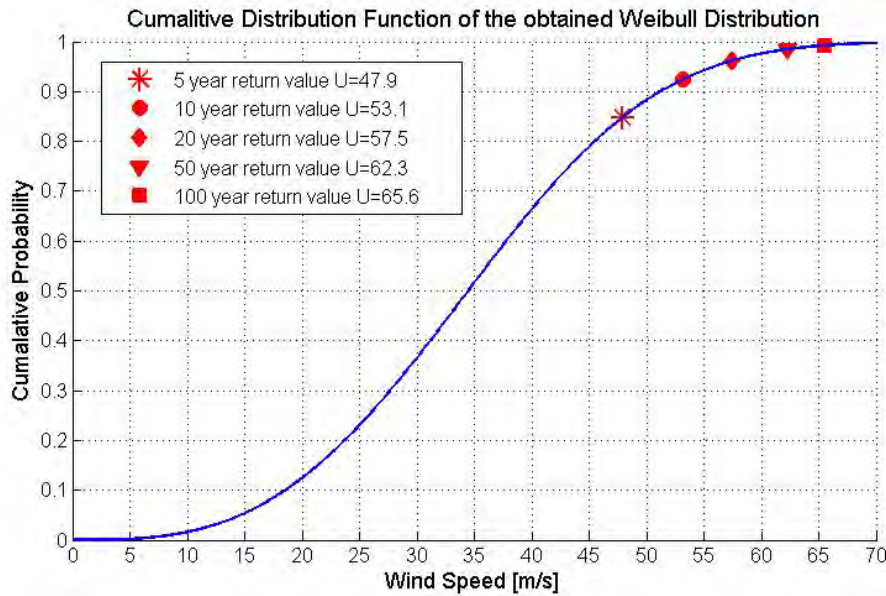


Figure D.2: Return values indicated on the weibull distribution

Next this value is inserted into the following equation, to retrieve the exceedance probabilities.

$$P = 1 - \frac{\Delta T}{Return\ Period} \quad (D.2)$$

The computed probabilities are filled into the distribution. The results of this can be seen in figure D.2 .

The calculation of the wind set up is done with the following formula [Bretschneider, 1969]:

$$S_w = \sqrt{2\kappa \cdot \frac{u^2}{g} \cdot F + h^2} - h \quad (D.3)$$

The set up is calculated for two sections, one for the shallow coastal zone and one for the deeper part of the sea. The total set up is the sum of the deep water set-up and the shallow water set up. For the shallow part different values are used for the fetch and the water depth, namely the depth of the shallow zone and width of the shallow zone. The following values are used and are based on information from figure 10.2 and [Broersen, 2010]

$d = \textit{waterdepth} = 85 \textit{ m}$, which is the average
waterdepth over the fetch length
 $F = \textit{fetch length} = 250 \textit{ km}$, which is typical fetch
length during typhoon event
 $W_s = \textit{width shallowzone} = 200 \textit{ m}$, based on coastal
profile
 $h_s = \textit{depth shallowzone} = 2 \textit{ m}$, based on coastal
profile

For this values and the different wind speeds the calculations are performed with cress² and are summarized in table D.2

To determine the total set up also the set up due to low atmospheric pressure has to be taken into account. The matching atmospheric pressures for the different wind speeds are shown in table D.2

[Secretariat of the World Meteorological Organization, 2011]. The set up afterward is calculated with the following formula [Broersen, 2010] :

$$S_z = 0.01 \cdot (1013 - p_a) \quad (\text{D.4})$$

The results of this calculation are shown in D.2. The total windset up is obtained when the wind and atmospheric setups are summed up. The result of this summation is viewed in table D.2.

Table D.2: Overview of the calculated set up values

	Wind speed [m/s]	Atmospheric pressure [hPa]	Wind set up [m]	Atmospheric set up [m]	Total set up [m]
5 yr return value	47.9	967	1.67	0.46	2.13
10 yr return value	53.1	958	2.05	0.55	2.60
20 yr return value	57.5	946	2.41	0.67	3.08
50 yr return value	62.3	936	2.82	0.77	3.59
100 yr return value	65.6	933	3.13	0.80	3.93

D.2 Calculations on salinity intrusion length

In this section the salinity intrusion length is calculated with Rieger's and Fisher's Equations with data gathered from [Lam, 2009] and [Biezen, 2014].

²Available at www.cress.nl

After this comparison the output values from the hydrodynamic model are used to calculate the salinity intrusion length for the different alternatives.

D.2.1 Calculations with Rigter and Fisher

For the salinity intrusion length in the Cau Hai lagoon the formulas by Rigter and Fisher were used.

Rigter:

$$L^{LWS} = 1.5\pi \frac{h_0}{f} (F_d^{-1} N^{-1} - 1.7) \approx 4.7 \frac{h_0}{f} F_d^{-1} N^{-1} \quad (D.5)$$

Fisher:

$$L^{LWS} = 17.7 \frac{h_0}{f^{0.625}} F_d^{-0.75} N^{-0.25} \quad (D.6)$$

The discharge from the rivers during the wet season, dry season and annual discharge are used (see table D.3). The three cross-sections are represented in appendix B.1. And the input parameters can be found in table D.4.

Table D.3: Accumulated discharge of the Truoi, Dai Giang, Nong and Cau Hai river for the wet season, dry season and annual discharge. source[Lam, 2009]

	Parameter	unit
Discharge wet season	Q_{fw}	10.49 m^3/s
Discharge dry season	Q_{fd}	68.94 m^3/s
Annual discharge	Q_{fa}	29.97 m^3/s

Table D.4: Input parameters (source: [Lam, 2009][Biezen, 2014].)

		Unit
Tidal period	T	44712 s
Velocity amplitude	v_0	0.68 m/s
Density sea water	ρ	1025 kg/m^3
Density difference	$\Delta\rho$	25 -
Gravitational constant	g	9.81 m/s^2
Darcy Weisbach coefficient	f	0.02 -
Tidal Excursion	E_0	10452 m/s

$$E_0 = 1.08v_0 \frac{T}{\pi} \quad (\text{D.7})$$

$$N = \frac{Q_f T}{P_t} = \frac{-Q_f T}{A_0 E_0} = \frac{\pi}{1.08} \frac{-Q_f}{A_0 v_0} = \frac{\pi}{1.08} \frac{-\mu_0}{v_0} \quad (\text{D.8})$$

$$F_d = \frac{\rho v_0^2}{\Delta \rho g h_0} = \frac{\rho}{\Delta \rho} F \quad (\text{D.9})$$

The velocity amplitude v_0 is taken constant while in fact this varies over the seasons and with the width and depth of the inlet. The value used, is found by [Lam, 2009] for a inlet cross-section of $821m^2$, which lies within the measured cross-section used. N is the Canter-Cremer's number and F_d the Densimetric Froude number. Further elaborations of the equations can be found in the chapter theoretical background section 4.4.

Presented in table D.5 the results for the salinity intrusion length can be found making use of Fishers equation. In table D.6 the salinity intrusion length calculated with Rigter. It can be seen that the intrusion lengths for Fisher are much smaller, this is due to the small Canter Cremer's number which weights less in Fisher's equation than in Rigter's equation.

Table D.5: Fisher's salinity intrusion length in km

with	A0=615m, h0=4.9m	A0=1015m, ho=2.5m	A0=742m, ho=2.3m
Wet season discharge	2.41 km	0.84 km	0.67 km
Dry season discharge	3.87 km	1.34 km	1.08 km
Annual discharge	2.97 km	1.03 km	0.83 km

Table D.6: Rigter's salinity intrusion length in km

with	A0=615m, h0=4.9m	A0=1015m, ho=2.5m	A0=742m, ho=2.3m
Wet season discharge	4.14 km	1.62 km	0.70 km
Dry season discharge	38.16 km	16.23 km	9.74 km
Annual discharge	12.08 km	5.03 km	2.81 km

D.2.2 Salinity intrusion length for the alternatives

The model output for the tidal excursion, and tidal velocity are used to compute the intrusion length for the 5 alternatives and the current situation. All are computed with the dry season discharge and different water levels

h_0 and surface area A_0 in the cross section for the alternatives. The tidal prism is than calculated with the tidal excursion and the surface area of the lagoon. The Densimetric Froude number and the Canter Cremers number are calculated to use Rigter's equation to estimated the salinity intrusion in the lagoon system.

Table D.7: Intrusion length for the five alternatives and the current situation

	Parameter	Alternatives						Unit
		0	A	B	C	D	E	
Tidal excursion	E_0	0.19	0.18	0.29	0.18	0.29	0.248	m
Tidal velocity	v_0	2.1	2.3	2.17	2.3	2.17	2.25	m/s
Tidal prism	Pt	$2 \cdot 10^6$	$3.23 \cdot 10^6$	$3.6 \cdot 10^6$	$3.2 \cdot 10^6$	$3.6 \cdot 10^6$	$2.77 \cdot 10^6$	m^3
Water level	h_0	4.8	6.18	6.62	8.8	6.62	5.8	m
Canter Cremers number	N	0.023	0.015	0.013	0.015	0.013	0.017	-
Densimetric Froude number	Fd	2.89	2.69	2.24	1.89	2.24	2.74	-
Intrusion length	L^{LWS}	14.77	34.83	50.81	71.30	50.81	27.08	km

D.3 Weibull calculation design wave height

The design wave height for the breakwater design is calculated using a Weibull distribution. The Argoss wave-climate as found by [Biezen, 2014] is used to calculate this design wave height. The Weibull calculation in Appendix 1 of the breakwater and closedams book [d'Angremond and van Roode, 2001] is used as example for the calculation at Tu Hien. The results are presented in table D.8. The calculations lead to a Weibull distribution, which can be extrapolated in order to find the right value. The distribution is presented in figure D.3.

From the linear approach of the distribution follows:

$$A = 1,5379$$

$$B = 6,7742$$

$$\beta = \frac{1}{A} = 0,650237337 \quad (D.10)$$

$$\gamma = -\frac{B}{A} = -4,404837766 \quad (D.11)$$

With a probability of exceedance of 1/1000 per year this leads to the following

Table D.8: Weibull calculation design wave height Tu hien

	Revorded	Cumulative	Probability	Q	s/y	ln(s/y)	Ws	Ws (2)
0.25-0.5	280	280	0,0455	0,954	696,71	6,54	-4,01	0,10
0.50-0.75	1276	1556	0,2077	0,7466	545,03	6,30	-3,90	0,40
0.75-1.0	911	2467	0,1483	0,5982	436,73	6,07	-3,80	0,61
1.0-1.5	1456	3923	0,2370	0,3611	263,66	5,57	-3,56	1,01
1.5-2.0	768	4691	0,1250	0,2361	172,36	5,14	-3,36	1,31
2.0-2.5	615	5306	0,1001	0,135	99,25	4,59	-3,09	1,66
2.5-3.0	334	5640	0,0543	0,0815	59,55	4,08	-2,83	1,97
3.0-4.0	343	5983	0,0558	0,0257	18,78	2,93	-2,21	2,61
4.0-5.0	128	6111	0,0208	0,0048	3,56	1,27	-1,19	3,44
5.0-6.0	11	6122	0,0017	0,0030	2,25	0,81	-0,85	3,66
6.0-7.0	11	6133	0,0017	0,0013	0,95	-0,05	0,10	4,06
7.0-8.0	1	6134	0,0007	0,0011	0,83	-0,18	0,28	4,12
8.0-9.0	4	6138	0,0006	0,0004	0,35	-1,03	1,02	4,49
9.0-10.0	3	6141	0,0004	0	0			

value for $H_{s,2\%}$:

$$H_{s,2\%} = \gamma + \beta \cdot \left(-\ln \frac{1}{1000} \right)^{\frac{1}{\alpha}} \quad (\text{D.12})$$

In which α is a factor which determines the value of R^2 in the distribution. The closer R^2 is to 1, the more accurate the calculation is. In this case α is set to $\alpha = 0.74$. Which leads to $H_{s,2\%} = 4.45$

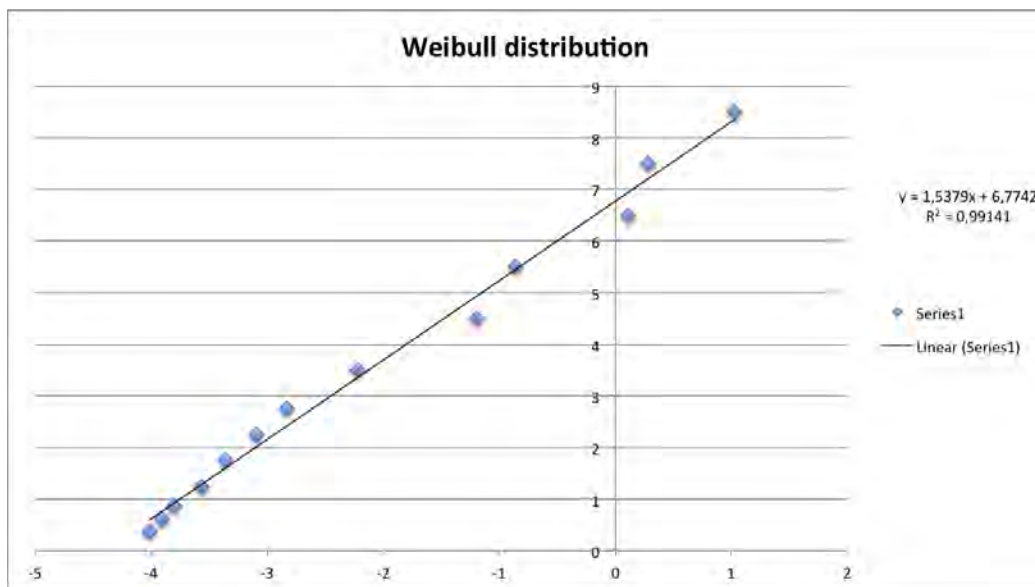


Figure D.3: Weibull distribution wave climate near Tu Hien

Appendix E

Multi Criteria Analysis

To be able to compare the different alternatives with each other, a Multi Criteria Analysis has been made. With such an analysis it is possible to compare otherwise non-comparable criteria to obtain the best option.

First the tables with the input for the analysis are presented, after that the elaborations and descriptions on all the criteria are listed.

E.1 Tables

Table E.1: Multi Criteria Analysis with scores

	Alternatives					
	0	A	B	C	D	E
C1: Construction costs	0	1.9	2.2	10.7	152.2	0.55
C2: Flood risk	0	0.66	0.78	0.73	1	0.25
C3: Salinity concentration lagoon	+	0	-	--	++	+
C4: Salinity intrusion in Truoi river	14.8	34.8	50.8	71.3	50.8	27.1
C5: Water quality	--	++	++	++	0	0
C6: Influence for ecology	0	-	-	--	-	+
C7: Maintenance	-	+	-	+	--	-
C8: Navigability of the inlet	4.88	6.18	6.62	8.80	6.62	5.88
C9: Durability	--	+	+	+	+	0
C10: Sustainability of the construction	-	-	-	--	--	+

E.2 Elaborations & comments on the criteria

The five alternatives and the current situation are scored for the 10 set criteria, the criteria are briefly described and the scores are elaborated.

Costs

The construction costs for the different alternatives are important in the decision making process. The alternative needs to be affordable in perspective to the local economy. The transportation costs and man hours are excluded in this criterion.

In [Hauer and Op den Velde, 1995], a typical rubblemound breakwater was constructed and the total costs were calculated. The breakwater design was split-up in multiple sections. The breakwater from the alternatives A and C could be described as part VII from [Hauer and Op den Velde, 1995] with half its length. From [Schierreck and Verhagen, 2012] it can be seen that construction costs in developing countries are much cheaper, order 70%. The breakwater is thus assumed to cost 1.1 million \$.

The double breakwater from alternatives B and D have the same breakwater as in A and C but with another one at the opposite side of the inlet. The costs are now doubled, so 2.2 million \$.

The bank protection at the erosion side of the inlet is incorporated in alternatives A and C. For a first cost estimation a simple bank protection using stones is assumed. In [Schierreck and Verhagen, 2012] some costs are presented, with these figures an estimation of 0.8 million \$ is made for the shore protection.

Maintenance dredging in the channel that is incorporated in alternative B is a small expense item compared to the construction costs, especially because it is distributed over several years. Moreover, it brings large uncertainties at this stage so it is neglected here.

The barrage is a special structure incorporated in alternative C. Because of its size and the remote location where it needs to be built, the costs are estimated to be rather high, in the order of 10 million \$.

The movable storm surge barrier from alternative D is a large project that also includes dikes at the barrier island. Looking to comparable projects the costs are estimated at 250 million \$. Because the idea is to make changes

to the bridge to lower the costs the estimated costs are set at 150 million \$.

The dredging in combination with the nourishment from alternative E are estimated at 200.000 \$.

The mangrove planting project costs are estimated at 350.000 \$, for that money the project can take 2 years with 2 managers and a group of people for seeding in the initial stage.

Flood risk

The main focus of the solution for the problems in the Cau-Hai lagoon is improvement of the flood safety and is therefore a major criterion in the MCA. The flood risk is depicted by the likeliness of floods to appear. With the hydrodynamic model the flood levels for a small storm and big storm are compared for the alternatives and the current situation. For flood risk the water levels in the basin are chosen as the governing parameter. The values from an high discharge event and the combined event (high discharge and high storm surge level) are used for this criteria. This is done because this are the events that are most common and impose the largest consequences, as can be shown in historic data. Alternative E has an inlet cross section that is dredged every couple of years, it is assumed that the results for this alternative are the average cross-section between alternative A and the current situation. The flood risk criterion is derived from the water levels in the lagoon for the different alternatives. The alternative with the storm surge barrier performs best on this criterion, where the current situation gives the most threatening water levels.

Salinity concentration in the lagoon

This criterion is important for the aquaculture in the lagoon. The salinity in the lagoon is modeled using a completely mixed system approach. The ideal salinity concentration for shrimp harvest lies within 15-25‰ [Truong et al., 2013]. It should be noted that the completely mixed approach is underestimating the values that can occur locally. The salinity concentration for the different alternatives is compared on storm surge, the time to set back at equilibrium and the dry season concentration. Alternative C with the biggest cross section has overall the highest salinity concentrations followed by alternative A and B. Alternative D is slightly better during storm surge because the storm surge barrier closes preventing salt intrusion. The best however are the current situation and alternative E, the concentration is lowest for these

alternatives during the dry season.

Salinity concentration Truoi river

The concentration of the Cau Hai lagoon influences the salinity intrusion in the rivers, the river water is used for irrigation of mostly rice paddy's. The tolerance of rice to saline irrigation water is maximum 2 ‰ and yield loss will occur at higher salinity concentrations. The salinity intrusion length is computed with the input variables from the continuous model and the empirical equation by Rieger. The results show that the salinity intrusion length is highly influenced by the depth and the width of the inlet cross section. Alternative C has the largest cross section and depth and therefore causes the highest salinity concentrations in the lagoon and intrusion in the rivers. The intrusion length is given in kilometers, it should be noticed that the gradient of the Truoi river is much steeper than the lagoon therefore the intrusion length is in reality shorter than represented. But the output is used to indicate the highest and lowest changes caused by the different alternatives instead of using the real intrusion lengths.

Water quality

Water quality is important for the livelihood of many people living around the Cau Hai lagoon. Bad water quality can influence the health of people and the food purchased from the lagoon and is therefore an important criterion to take into account. The influence of the different alternatives on the water quality parameters are modelled by a continuous model. It contains the following parameters: BOD, COD, Nitrogen and Phosphorus. In the results BOD and Nitrogen are chosen as key parameters, as distinction between the other two was not possible. The pollution produced in the shrimp farms are estimated and used as an input for the Cau Hai lagoon. The pollution is flushed during storm and high discharge events, therefore the values from the dry season scenario are used as governing in this analysis. From the model output for COD and BOD it can be noticed that, with a bigger inlet cross section the COD/BOD will be lowered in the lagoon because of flushing, therefore alternatives A, B and C score high on water quality in the dry season. During a storm surge the barrier from alternative D will be closed, limiting the outflow of COD/BOD. The relative high levels of COD/BOD lower the dissolved oxygen in the lagoon, which can do harm to fishes and other species. When there is no storm surge alternative D will act the same as alternatives A, B and C. Alternative E will improve the quality of the water due to the mangrove forest, but when the water is too polluted this

can threaten the forest. Because of these withdrawals alternative D and E score slightly lower than alternatives A, B and C.

Influence for ecology

The alternatives may influence the ecology in the area in a positive or negative way. For example habitats of different species can be disturbed, destroyed or created. The breakwaters from alternatives A, B, C and D are not expected to have a large influence on the ecology in the area, as they basically just shift the beach profile seawards. The other measures like the spillway and the movable storm surge barrier however, are expected to influence the habitat of some species. Not only during construction but for the rest of its lifetime the structures form a barrier between land and water, and can decrease the area needed for breeding. Alternative E scores well on this criteria as the mangroves form a habitat for fish and birds and the regulations for limiting pollution in the lagoon are beneficial for ecology as well. The score is somewhat tampered by the dredging that is incorporated in this alternative.

Maintenance

The expected maintenance is an important criteria in judging the alternatives as it can seriously increase costs or decrease usability. Alternative D scores lowest on this aspect, the movable gates need maintenance and inspection regularly and moreover, a control system that monitors the sea and shuts the gates accordingly. Also alternative B scores somewhat lower as the sand bypass is an extra object to be inspected. The rest of the alternatives score more or less the same on this criteria. The structures as well as the mangrove forest require inspection to prevent failure during storms.

Navigability of the inlet

The navigability is part of the main focus of this research. Boats should be able to pass the inlet at all times during the dry and wet season. The water level in the inlet is therefore the standard for the criterion navigability. With the depth measurement described in B the inlet is measured and the current situation has been determined. For alternative A the inlet is enlarged by 66% and for alternative B and D with 90%, see section 9.1.1. The depth is enlarged by the square root of these values. Alternative C is set at a constant depth 8.8 m because of the structure. For alternative E the depth is enlarged with 1 m due to the dredging works compared to the current situation.

Durability

The lifetime of the alternatives is considered important in Vietnam because of the intense typhoons and storms in this area. The durability of the alternatives concerns the expected lifetime and its resistance to storms. The durability of all structural elements like the breakwaters, the barrage and the gate highly depend on the construction method. Assuming a good design and well executed construction these alternatives all score well on durability. The exception is alternative E, considering the fact that mangrove forest have been cleared or eliminated on multiple locations in Vietnam, this alternative scores less on durability.

Sustainability

With sustainability the alternative is rated on its performance in sustaining mankind on earth. In practice this means that a high score is given when natural resources are used and carbon footprint is limited. Alternative E scores best at this aspect as it improves nature and limits pollution. Alternative A and B score less than E because of the stones that are use here. Finally, the alternatives C and D score even worse at sustainability because of the large construction works involved with these alternatives.

E.3 Normalization and weighting rates

In this section the use of the standardization and the weighting rates are elaborated.

Normalization

To compare the alternatives on the different criteria the scores need to be normalized. This is done by the following simple equation that rates all alternatives with a value between zero and one.

$$value = \frac{item - lowestscore}{highestscore - lowestscore} \quad (E.1)$$

The first criterion is scaled from 0 – 25 because the highest alternative is 15 times more expensive than the second highest alternative, when this criterion is not scaled the different alternatives can not be compared because they all score about the same. So instead of the lowest score 25 is used in the equation for normalization.

Table E.2: Multi Criteria Analysis with Normalized scores

	Alternatives					
	0	A	B	C	D	E
C1: Construction costs	1.00	0.92	0.91	0.57	0.00	0.98
C2: Flood risk	0.00	0.66	0.78	0.74	1.00	0.25
C3: Salinity concentration lagoon	0.75	0.50	0.25	0.00	1.00	0.75
C4: Salinity intrusion in Truoi river	1.00	0.65	0.36	0.00	0.36	0.78
C5: Water quality	0.00	1.00	1.00	1.00	0.50	0.50
C6: Influence for ecology	0.67	0.33	0.33	0.00	0.33	1.00
C7: Maintenance	0.33	1.00	0.33	1.00	0.00	0.33
C8: Navigability of the inlet	0.00	0.35	0.45	1.00	0.45	0.25
C9: Durability	0.00	1.00	1.00	1.00	1.00	0.67
C10: Sustainability of the construction	0.33	0.33	0.33	0.00	0.00	1.00

Weighting rate

The ten criteria are now compared to each other and given a weight factor. The economic feasibility is of high importance in this case. The cost criterion therefore has the highest weight factor, equal to 9. With that weight factor, the importance of the cost criterion is equal to the importance of reducing flood levels (weight factor: 5) together with one of the other main criteria: salinity intrusion or navigability (weight factor: 4).

After the mentioned criteria, water quality has a weight factor of 3. Improving the water quality is not defined as the main focus of this project, although still one of the more important problems in and around the lagoon.

Maintainability, durability and sustainability all have a weight factor of 2. The costs of maintenance are already included in the cost criterion. Constructions with less need of maintenance and high durability are preferred.

There will always be influence on ecology when measures are taken and this should be taken into account, but will not be the lead criterion in the decision making process and is given a weight factor of 1.

Table E.3: Multi Criteria Analysis: Alternatives scored and weighted for the criteria

	Weight	Alternatives					
		0	A	B	C	D	E
C1: Construction costs	9	9.00	8.32	8.21	5.15	0.00	8.80
C2: Flood risk	5	0.00	3.32	3.88	3.65	5.00	1.27
C3: Salinity concentration lagoon	2	1.50	1.00	0.50	0.00	2.00	1.50
C4: Salinity intrusion in Truoi river	2	2.00	1.29	0.73	0.00	0.73	1.56
C5: Water quality	3	0.00	3.00	3.00	3.00	1.50	1.50
C6: Influence for ecology	1	0.67	0.33	0.33	0.00	0.33	1.00
C7: Maintenance	2	0.67	2.00	0.67	2.00	0.00	0.67
C8: Navigability of the inlet	4	0.00	1.38	1.82	4.00	1.82	1.00
C9: Durability	2	0.00	2.00	2.00	2.00	2.00	1.33
C10: Sustainability of the construction	2	0.67	0.67	0.67	0.00	0.00	2.00
Total scores alternatives		14.50	23.31	21.79	19.79	13.37	20.63

Appendix F

List of meetings

In table F.1 an overview of the meetings that took place in the framework of this project is displayed.

Table F.1: list of meetings

Date:	With:	Subject of meeting:
14-11-14	Mr. Verhagen	Discussing project subject
24-11-14	mr. Tung, mr. Tuan, ms. Nguyen, mr. Kat, mr. Trung, students	Start meeting
01-12-14	mr. Tung , mr. Tuan, ms. Nguyen	Discussing Research Proposal
02-12-14	mr. Tuan, mr. Trung	Discussing fieldwork
10-12-14	mr. Trung, mr. Minh	Meeting with Local Dike Department
10-12-14	mr. Trung, ms. My	Meeting with Social Centre
12-12-14	mr. Trung, ms. Thuy	Meeting with Geology department of Hue University
05-01-14	mr. Tuan, students	Progress meeting
16-01-14	mr. Tuan, mr. Tung, mr. Trung, students	End presentation

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References

- [Baptist, 2006] Baptist, M. (2006). Water quality modelling. lecture notes CT4400, TU Delft, Faculty of Civil engineering.
- [Battjes and Labeur, 2014] Battjes, J. and Labeur, R. (2014). *Open Channel Flow CTB-3350*. TU Delft.
- [Berchum, 2014] Berchum, van, e. a. (2014). The framework for integrated water management in the thue thien-hue province. Technical report, Delft University of Technology.
- [Biezen, 2014] Biezen, v. d. (2014). Climate change and the morphological stability of the tu hien inlet, vietnam. Master's thesis, Delft University of Technology.
- [Bil, 1995] Bil, F. (1995). A flood in hue, a report on the causes of the damage on tam giang lagoon dyke. Technical report, Quang Tri Holland Development and Friendship Association.
- [Bird, 2008] Bird, E. (2008). *Coastal geomorphology, an introduction*. John Wiley and Sons Ltd.
- [Borsje, 2003] Borsje, C. (2003). Cross-sectional stability of a two inlet bay system. Master's thesis, Delft University of Technology.
- [Bretschneider, 1969] Bretschneider (1969). Engineering aspects of hurricane surge. *T Ippen, Estuary and coastline hydrodynamics, McGraw-Hill, New York*, 0(1):231–245.
- [Broersen, 2010] Broersen, W. (2010). Analysis of boundary conditions and concept design for port dong lam, thua thien-hue province, vietnam. Master's thesis, Delft University of Technology.
- [CIRIA, 2007] CIRIA, CUR, C. (2007). *The Rock Manual. The use of rock in hydraulic engineering (2nd edition)*. C683, CIRIA, London.

- [CUR, 1997] CUR (1997). *CUR Publicatie 190 "Probabilities in civil engineering, Part 1: Probabilistic design in theory*. Stichting CUR, Gouda.
- [d'Angremond and van Roode, 2001] d'Angremond, K. and van Roode, F. (2001). *Breakwaters and closedams*. Delft University Press, P.O. Box 98, 2600 MG Delft, The Netherlands.
- [et al., 2007] et al., T. D. (2007). Typhoons and technical solutions recommended for existing and new houses in the cyclonic regions in vietnam. Technical report, Vietnam Institute for Building Science and Technology.
- [Food and Organisation, 2003] Food and Organisation, A. (2003). The role of local institutions in reducing vulnerability to recurrent natural disasters and in sustainable livelihoods development. Technical report, Asian Disaster Preparedness Center, Thailand.
- [Goslee, 2011] Goslee, S. C. (2011). Analyzing remote sensing data in R: The landsat package. *Journal of Statistical Software*, 43(4):1-25.
- [Hauer and Op den Velde, 1995] Hauer, M. and Op den Velde, W. (1995). Comparison construction costs conventional rubblemound breakwaters. Technical report, Delft University of Technology.
- [Holthuijsen, 2010] Holthuijsen, L. (2010). *Waves in oceanic and coastal waters*. VSSD.
- [IMHEN, 2008] IMHEN (2008). Climate change impacts in huong river basin and adaption in its coastal district phu vang, thua thien hue province. Technical report, Institute of Meteorological, Hydrological and Environment.
- [IPCC, 2001] IPCC (2001). Climate change 2001: Synthesis report. Master's thesis, Cambridge University Press, Cambridge.
- [Kable, 2014] Kable (2014). A luoi hydropower plant, thua thien hue, vietnam.
- [Lam, 2007] Lam, N. (2007). The influence of river floods on coastal inlet morphology. Technical report, Delft University of Technology.
- [Lam, 2002] Lam, N. T. (2002). *A Preliminary Study on Hydrodynamics of the Tam Giang -Cau Hai Lagoon and Tidal inlet System in the Thua Thien-Hue Province, Vietnam*. PhD thesis, Unesco IHE, Delft.
- [Lam, 2008] Lam, N. T. (2008). Seasonal behaviour of tidal inlets in a tropical monsoon area. Technical report, PIANC - COPEDEC VII.

- [Lam, 2009] Lam, N. T. (2009). *Hydrodynamics and Morphodynamics of a Seasonally Forced Tidal Inlet System*. PhD thesis, Delft University of Technology.
- [Lambert, 2012] Lambert, T. (2012). A brief history of vietnam. localhistories.org, consulted 12/2014.
- [Marchand, 2008] Marchand, M. (2008). Mangrove restoration in vietnam. Technical report, WRU/TU Delft.
- [Marconi et al., 2010] Marconi, M., Sarti, M., and Marincioni, F. (2010). Sustainability assessment of traditional fisheries in cau hai lagoon (south china sea). *Marine Environmental Research*, 70:253 – 263.
- [Michigan State University, 2014] Michigan State University, A. S. C. (2014). Windows on asia,. Online, consulted 12/2014.
- [Neut and et al., 2013a] Neut, v. d. and et al. (2013a). Fieldwork report multidisciplinary project hanoi, vietnam. Technical report, Delft University of Technology.
- [Neut and et al., 2013b] Neut, v. d. and et al. (2013b). Main report multidisciplinary project hanoi, vietnam. Technical report, Delft University of Technology.
- [Nguyen et al., 2004] Nguyen, V., Nguyen, X., Tu, V., Pham, H., Yasaka, Y., and Tanaka, M. (2004). Surface water quality in the thua thien hue province. Technical report, Osaka University.
- [O'Brien, 1969] O'Brien, M. (1969). Equilibrium flow areas of inlets on sandy coasts. *Waterway Port Coast Ocean Eng*, 95(1):43–52.
- [Parry et al., 2007] Parry, M., Canziani, O., Palutikof, J., van der Linden, P., and Hanson, C. (2007). *Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK.
- [Pham, 2014] Pham, M. (2014). Notes about cau hai region provided to dutch project group.
- [Pham et al., 2010] Pham, T., Kroeze, C., Bush, S., and Mol, A. (2010). Water pollution by intensive brackish shrimp farming in south-east vietnam: Causes and options for control. *Agricultural water management*, 0(97):872–882.

- [Pilarczyk and Nuoi, 2005] Pilarczyk, K. W. and Nuoi, N. S. (2005). Experience and practices on flood control in vietnam. *Water International*, 30(1):114–122.
- [Sang et al., 2012] Sang, L. T., Diem, N. N., Suu, L. T. H., and Quoc, T. B. (2012). Climate change risk assessments in hue city vietnam. Technical report, Southern institute of sustainable development and centre for social research and Development.
- [Savenije, 1993] Savenije, H. (1993). Predictive model for salt intrusion in estuary. Technical report, International institute for infrastructural, Hydraulic and Environmental Engineering.
- [Savenije, 2005] Savenije, H. (2005). *Salinity and tides in alluvial estuaries*. Elsevier.
- [Schierreck and Verhagen, 2012] Schierreck, G. and Verhagen, H. (2012). *Introduction to Bed, Bank and Shore Protection*. VSSD.
- [Secretariat of the World Meteorological Organization, 2011] Secretariat of the World Meteorological Organization (2011). Typhoon committee operational manual. Technical report, World Meteorological Organization.
- [Smyle and Cooke, 2014] Smyle, J. and Cooke, R. (2014). Comprehensive environment and climate change assessment in vietnam. Technical report, IFAD.
- [Stive and Bosboom, 2013] Stive, M. and Bosboom, J. (2013). *Coastal Dynamics*. Delft Academic Press/Vssd, Delft, The Netherlands.
- [Takahashi and van Duijn, 2012] Takahashi, B. and van Duijn, A. P. (2012). Operationalizing fisheries co-management: Lessons learned from lagoon fisheries co-management in thua thien hue province, viet nam. *FAO Regional Office for Asia and the Pacific, Bangkok*, 0(RAP Publication 2012/02):131 pp.
- [Thanh, 2011] Thanh, T. K. (2011). Flood in thua thien hue province and control measures. Department of Agriculture and Rural Development in Thua Thien Hue Province.
- [Tran and Shaw, 2007] Tran, P. and Shaw, R. (2007). Towards an integrated approach of disaster and environment management: A case study of thua thien hue province, central viet nam. *Environmental Hazards*, 7:271 – 282.
- [Trung Tiên, 2013] Trung Tiên, N. (2013). *Statistical Yearbook Hué*. Thua Thien Hué statistics office.

- [Truong et al., 2013] Truong, H., Lyne, M., and Woodford, K. (2013). Managing water pollution to revitalise the shrimp supply chain in tam giang cau hai lagoon, vietnam. *Procedia, Elsevier*, 0(1):50–56.
- [Truong et al., 2014] Truong, H., Lyne, M., and Woodford, K. (2014). Managing water pollution to revitalise the shrimp supply chain in tam giang cau hai lagoon, vietnam. *International Agribusiness Marketing Conference 2013*, 1(0):50 – 56.
- [Tuan, 2007] Tuan, T. Q. (2007). *Seasonal breaching of coastal barriers*. PhD thesis, Delft University of Technology.
- [Tung, 2001] Tung, T. T. (2001). Coastal erosion along the sand barrier, case study in hue, vietnam. Master’s thesis, Unesco IHE, Delft.
- [Tung, 2011] Tung, T. T. (2011). *Morphodynamics of seasonally closed coastal inlets at the central coast of Vietnam*. PhD thesis, Delft University of Technology.
- [Tuyen et al., 2010] Tuyen, T. V., Armitage, D., and M, M. (2010). Livelihoods and co-management in the tam giang lagoon, vietnam. *Ocean and Coastal Management*, 53(7):327 – 335.
- [van State, 2009] van State, R. (2009). Besluit kwaliteitseisen en monitoring water 2009. Paragraph 2, article 4-6.
- [Verhagen and Yap, 1992] Verhagen, H. and Yap, J. (1992). Coastal zone management with relation to low investment solutions. In *Second Seminar on Ports and Inland Waterways, Surabaya Indonesia*. International Institute for Hydraulic and Environmental Engineering, The Netherlands.
- [Verruijt, 2010] Verruijt, A. (2010). *Soil Mechanics*. Delft University of Technology.