TU DELFT, WRU

Main Report Multidisciplinary Project Hanoi, Vietnam

How did they do 'it'?

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The work of this project group consists of the following reports:

I. *Main report*
II. *Case study report*
III. *Fieldwork report*

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Summary

The Thua Thien-Hue province, and especially the area around the city of Hue, is characterized by a small distance between mountains in the west and a flat coast with a coastal barrier in the east. The largest river in the area, the Huong river, flows through the city of Hue and is used for fishery, tourism, sand mining, sewage system and trashcan. The city of Hue is a touristic city and holds an old Imperial City, a quite old sewage system and a lot of agricultural activity in the surroundings, especially the rice paddies around and the fishery in the Cau Hai lagoon. Due to the short distance between mountains and coast, in combination with a distinct wet and dry season and high average precipitation rates, a lot of challenges concerning water related problems can be identified in the Hue area.

For the Water Resources University in Hanoi 22 of those problems (cases) are indicated, to provide future students a topic for their graduation work and presented in the Cases Report by this project group. The selection of cases is performed by talking to different experts in the fields of Disaster Management, Coastal Engineering and Water Management; talking to students of the university and by visiting the actual project area. In this field visit most of the case locations are visited to get a better view on the current state of the problem. All observations are stated in the Field Work Report of this project group.

Although the cases are presented as individual problems, a lot of relations between the problems exist e.g. salt intrusion is influenced by reservoir regulation, while the stability of the inlets is related to the sediment balance of the area. These relations are used to emphasize the need for an integral and multidisciplinary approach towards the individual cases: every proposed solution needs to take into account the impact on other processes in the area.

The cases 'Reservoirs and Dams' and 'Stability of the Thuan An inlet' are elaborated to function as a reference for future students, by applying the steps of the Engineering Process.

There are four major dams in the area around the city of Hue, each with their own regulation scheme. Another dam, the Ta Trach dam, is currently being constructed. The Binh Dien dam, which is already in operation since 2009, and the Ta Trach dam have a major influence on the upstream discharge of the Huong river and require complex regulation schemes. This is enhanced due to the parallel positon of the dams: they are located in two different branches of the Huong river. The problems are complex due to conflicting interests from several stakeholders: most reservoirs are used for waterpower generation, which conflicts with for example flood control and water supply purposes. In 2009 this conflicting interests led to a severe flooding in Hue, when the Binh Dien reservoir needed emergency discharges to reassure the safety of the dam itself. In this research four main functions have been assigned to the Binh Dien and Ta Trach dams; hydropower generation, flood control, water supply and regulation of salt intrusion in the Huong river mouth. From these functions several requirements regarding the reservoir discharge over time have been obtained from a literature study. The requirements have been applied to both dams in different scenarios, after which some general conclusions could be stated. It appeared that the Binh Dien cannot fulfil the requirements on its own, but that with the future Ta Trach dam in operation enough capacity will be available for the water supply and salt intrusion requirements. With the combined reservoirs even more hydropower could be generated than currently without the Ta Trach dam. However, the flood control requirement appears to have major conflicts with respect to other main function requirements, and will be difficult to properly implement in reality without making concessions in the other functions.

In history, the Thuan An inlet has always been a morphologically active inlet, with several openings and closures. The coast surrounding the inlet is a wave dominated coast; and while the inlet is accreting during dry season, it 'flushes' during the wet season. In 2012 several breakwaters and jetties have been built to stabilize the inlet, with limited success due to bad placement of the structures as a whole and failing armour units. For this case the stabilizing criteria are based on the guarantee that a CEMT III class vessel can navigate through the inlet for the coming 30 years. Three solutions are proposed: dredging, extending the current south breakwater and a combination of the previous two. To assess the solutions use is made of the process based model Delft3D. The grid of the model is provided by Lam (2007), and by applying wave- and wind conditions, sediment concentrations and discharge characteristics, a prediction towards the future behaviour could be made. To reduce the time to run the model to one overnight computation, input reduction and morphological factors are applied. From the scenarios dredging seems to be the most appropriate solution, in which the maximum dredging interval (before the inlet becomes unnavigable) is 3 years. Beside the fact that dredging does not need new construction works, it is also the most flexible towards extreme accretion due to extreme weather events. This last reason lead to an advised dredging interval of one year, although the total amount of dredged material in 30 years is larger than dredging every 3 years (17.7 Mm^3 versus 13.8 Mm^3), it provides the highest flexibility. However, before implementing the solution further research should be performed by improving the quality and accuracy of the model. This is possible by reducing the input reduction, apply a lower morphological factor and by doing longer computations in order to oversee the full effects. Finally, the applied model used a too coarse grid near the shoreline to analyse the precise effects on the coastal area, therefore the grid size near the shore should be reduced.

Preface

After two, to say the least, exiting months, this is our final report of our assignment for the Water Resources University in Hanoi, Vietnam. We mainly worked on the project at the university campus in Hanoi, but the actual project location was nearly 700 kilometres more to the south, in Hue. A city we were able to visit in the beginning of October, to see the locations we were already investigation for several weeks with our own eyes.
Although a lot of things that you assume for granted are 'somewhat' different here, we could continuously work on the project, with some time to spare to experience the nice temperatures in this beautiful country. Of course, doing a project in another culture, city and environment was a challenge, but with the excellent facilities and good guidance we are convinced we delivered a report to be proud of. Therefore, we would really thank our mentors: Henk Jan Verhagen and Tranh Tang Tung and of course everyone who helped during the last two months.

We hope you enjoy reading, we certainly enjoyed making it!

Project Group Hue,

Erwin, Jos, Mathijs, Kees and Jelle

The students of the Niche programme, with the Dutch projectgroup. From left to right: Huan, Khoa, Erwin, Linh, Huong, Hanh, Jelle, Tung, Manh, Tung (lecturer), Toan, Jos, Mathijs, Quang and Kees; with regards to Bao Anh for taking the photo.

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Vietnam in context

This chapter is a summary of the book: "Viet Nam, a long history" written by Nguyen Khac Vien during the Spring of 2012 in Vietnamese and translated by L'Hamartan. This summary is written to put the main report of 'Masterproject Hue' into perspective and to give the non-Vietnamese reader some background information.

Early Vietnam

Recent archaeological finds suggest that the earliest human habitation of northern Vietnam was about 500.000 years ago. Primitive agricultures were active as early as 7000 BC. The sophisticated Bronze Age Dong Son culture, which is famous for its drums, emerged sometime around the 3rd century BC. According to mythology, the first ruler of Vietnam was Hung Vuong, who founded the nation in 2879 B.C. China ruled the nation then known as Nam Viet as a vassal state from 111 B.C. until the 15th century. During these ages the early Vietnamese learned much from the Chinese, including the construction of dikes and irrigation works. At that time, Vietnam was a key port for the route between China and India. The Chinese introduced Confucianism, Taoism and Mahayana Buddhism to Vietnam, while the Indians brought Theravada Buddhism.

In 1545 the Portuguese set foot in Vietnam, and after them the Dutch and the French. During the following decades the Portuguese began to trade with Vietnam, setting up a commercial colony alongside those of the Japanese and Chinese at Hoi An. The Catholic Church eventually had a greater impact on Vietnam than on any other country in Asia except the Philippines.

From the 15th till 18th century there was a feudal society, founded by Le Thai To, that really flourished for hundred years. However, between 1527 and 1533 the Le Dynasty was overpowered by the Mạc Dynasty. Even when control came back to the Le Dynasty, they kept competing with the Mạc Dynasty during the period known as Southern and Northern Dynasties. The real power over the regions was in the hands of the Nguyen lords in the South and the Trịnh lords in the North, both ruling in the name of the Le Emperor, while fighting each other.

Colonial Time

In 1788 Nguyen Anh, an expelled war lord, conquers Vietnam with support of the French. He reunites the North and the South and chooses the city of Hue as capital. The Emperors after Nguyen Anh pursued an anti-French policy, concluding in a war and, eventually, a defeat against the French; making the last emperors French 'marionettes'. Meanwhile the French conquered Laos and Cambodia resulting in the Indo-China Empire with their capital in Hanoi.
During the French dominance most of the current infrastructure of Vietnam has been constructed. Complete cities were reorganised and furnished with sewer systems, roads and governmental buildings. Another important tribute is the North-South railway connecting the main cities Hanoi, Hue and Saigon.

Wars

Throughout the colonial period, a desire for independence simmered under the surface. Seething nationalist aspirations often erupted into open defiance of the French. Ultimately, the most successful of the anti-colonialists were the communists, who were able to tune into the frustrations and aspirations of the population – especially the peasants – and effectively channel their demands for fairer land distribution.

During the Second World War the French lost their colony to the Japanese. In 1945, the Japanese domination in the pacific decreased and communistic groups, with Ho Chi Minh as leader, took control of Vietnam. On September 2nd 1945 Ho Chi Minh declared the independence of Vietnam. The French, dedicated to regain control over Vietnam, sent military units to Vietnam resulting in the Indochina War. In 1954 the Viet Minh won the battle of Dien Bien Phu, where after the French troops retreated, to the disappointment of the Americans who financed the French for 80%.

Short after the battle the Conference of Genève decided to split Vietnam at the 17th Parallel line and gave the south under control of the United States and the North under control of the USSR, until the elections in 1956. These elections, however, were never held and the North became communistic under Ho Chi Minh, while the South became anti-communist under Ngo Dinh Diem.

This situation will eventually lead to a war, which started with a campaign to 'liberate' the South in 1959. The armies of the South were initially not able to withstand the strength of the North. The Americans saw this war as important part of a worldwide struggle against communist expansion. Eventually the USA entered the war, with the well-known consequences.

The war between Vietnam and the USA stopped almost all, both economical as social, development on both sides, while destroying and polluting large areas. After 16 years of war the American troops eventually left Vietnam in 1975. In the end 223.748 South Vietnamese soldiers had been killed in action; North Vietnamese and VC fatalities have been estimated at one million. Approximately four million civilians (or 10% of the Vietnamese population) were injured or killed during the war, many of them as a direct result of US bombing in the North. Officially, 58.183 Americans were killed in action.

After the War

In 1976 Vietnam was officially reunited in the Socialistic Republic of Vietnam. Under the rule of Le Duan Vietnam started to reform economically and collectivize the South. All this time Vietnam was not able to trade due to the trade embargo of the United States and other Western countries, which put Vietnam into isolation.

After the death of Le Duan, Vietnam started new economic reformations. This process was enhanced by the collapse of their only partner, the USSR: Vietnam had to strengthen the connections with its neighbours and the West. In 1995 the trade embargo was lifted and Vietnam entered the Association of South-East Asian Nations. This was a big impulse for the economy of Vietnam, but came with the requirement that foreign companies should be able to enter the Vietnamese economic market. Many western countries, like the Netherlands, saw Vietnam as a developing country and therefore a lot of financial aid was provided. However, the Economic growth of the 90's and 00's showed the limitations of the infrastructure made by the French in colonial times. Renewal or upgrading of this infrastructure is the only way to maintain the current economic growth.

1. Content

Part 2b Case 8: Stability of the Thuan An inlet

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2. General introduction

2.1 Introduction to the project

This report is the result of a Niche collaboration between the TU Delft in the Netherlands and the Water Resources University (WRU) in Hanoi, Vietnam. Within this collaboration two groups of 5-6 graduate students from the TU Delft work on a research project at the WRU in Hanoi.

The WRU is establishing an educational program concerning Water Resource Engineering and Coastal Engineering, which includes a master project with a site visit to Hue. For this purpose the WRU would like to have some possible assignments for future master projects, including topics for graduation works. The WRU therefore requested this project group to index and describe problems concerning the Hue area, preferably with an integral approach: the most ideal situation would be the development of an overall solution for the problems in the area by solving the smaller problems in individual project groups.

To meet this request the assignment was split up in two main parts. The first part indexes the problems in the Hue area; presented in an overview including the underlying correlations. The second part of the assignment concerns the elaboration of two problems to serve both as a reference for future students as well as an opportunity for this project group to deliver some more detailed work. The actual case studies are presented as a separate report, to prevent too much disruption in the report itself.

2.2 Introduction to the project area

General overview

This report concerns the Thua Thien–Hue province, which is a delta with several rivers, lagoons, reservoirs and most of all a distinct wet and dry season. The area that is considered is shown in Figure 1, with a mountainous area in the west, the coast in the east and the province capital Hue more or less in the centre. The city of Hue has an old centre (at high ground), with the old imperial citadel as most profound example. The newer parts of the city are built near the Huong river and the surrounding lagoons.

The whole area surrounding the city of Hue is faced with multiple problems concerning mostly Coastal, River, Disaster and Water Management processes. The government acts on some of those problems, mainly with 'hard' measurements as reservoirs, dams, revetments and breakwaters. Although these structures may solve a certain problem, they also complicate other processes in the delta area, making it harder to solve other problems; overall an integral approach is lacking in the area.

Climate

The climate of the region is a tropical monsoon climate, with a dry season from March to August and a wet season from September till February, as seen in Table 1. During the wet season flooding occurs regularly (often in combination with typhoons), with the most devastating being the flooding caused by the typhoon Eve in 1999, where landslides and severe flooding engendered at least 233 deaths and extensive damage to buildings and infrastructure(Villegas, 2004). In addition, typhoons are accompanied by very strong winds that damage forests and buildings.

Table 1: Climate in Hue (Weatherbase, 2013).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Okt	Nov	Dec
Average maximum temperature (°C)	23	24	27	30	33	34	34	34	31	28	26	23
Average minimum temperature (°C)	17	18	20	22	23	25	25	24	23	22	20	18
Average precipitation (mm)	180	90	60	60	80	90	50	130	500	680	640	370
Average humidity (%)	87	87	84	79	74	69	67	70	79	84	84	86

Aqua-infrastructure including the coastal region (rivers, lagoons, inlets).

The Huong ('Perfume') river is the most prominent river in the area, as seen in Figure 1. The origin is located at 1200 meters altitude in the west, and has a total length of 104 km. The first part is called the Ta Trach branch and after merging with the Huu Trach river at the Tuan junction it is called the Huong river. With its large amount of additional branches and streams, a total catchment area of about 2800 km^2 is realised (Phuoc, 2007). The Huong river ends in a small delta with a rather large lagoon, consisting out of several basins. Flowing more or less parallel to the Huong river another river can be observed: the Bo river. Near the coast this river splits up in two branches: one merges with the downstream part of the Huong river, the other branch ends in the lagoon. The lagoon itself is used extensively for fishing, especially in the southern basins. Finally, in the coastal dune system two inlets are present: the Thuan An inlet in the north and the Tu Hien inlet in the south.

Figure 1: Overview of the Thua Thien-Hue province.

‘Hard’ structures in the area

Mainly for waterpower production multiple reservoirs have been created, with the largest being the Ta Trach reservoir in the Ta Trach river, located in the south of Hue. Other reservoirs are located to the southwest (Binh Dien reservoir in the Huu Trach river), north (Huong Dien Reservoir in the Song Bo river) and southeast (Truoi Reservoir) of Hue.
In the city of Hue some dams are built with the large barrage Thao Long, downstream of Hue, constructed specifically against salt intrusion. Finally, some breakwaters with different types of armour units are created near the coastal inlets.

Governmental Structure

The authorities in Vietnam are structured according to the so called ‘hierarchical organisation structure’. This means that the organisation contains several management layers, with a clear structure in the hierarchy. A distinct feature of the political system in Vietnam is the presence of the Socialistic (Communistic) Party in every level of the authorities.

The Ministry of Agriculture and Rural Development (MARD) is the overarching organisation, with the Department Dyke Management and Flood, storm Control (DDMFC) as the coordinating organisation for all water related organisations, as can be seen in Figure 2.
A local department for the dyke services is located in the provinces and districts and there are some specialized units in certain disciplines. There are no relations between departments at the same level, since only ‘vertical’ communication is used. So information exchange is only provided via the overarching organisation. For example: if the Dyke construction unit needs information about the dykes in a certain area, they contact the DDMFC, which in turn requests the information from the Dyke Management Brigades and the province.
The main benefit of this political system is that decisions are made at the manager level, which has an overview over the situation and features the information of all departments. Main drawbacks are the lack of information exchange between the local authorities, bureaucracy (thus loss of time) and the fact that decisions are always made by the highest authorities, where the influence of the local community is negligible.

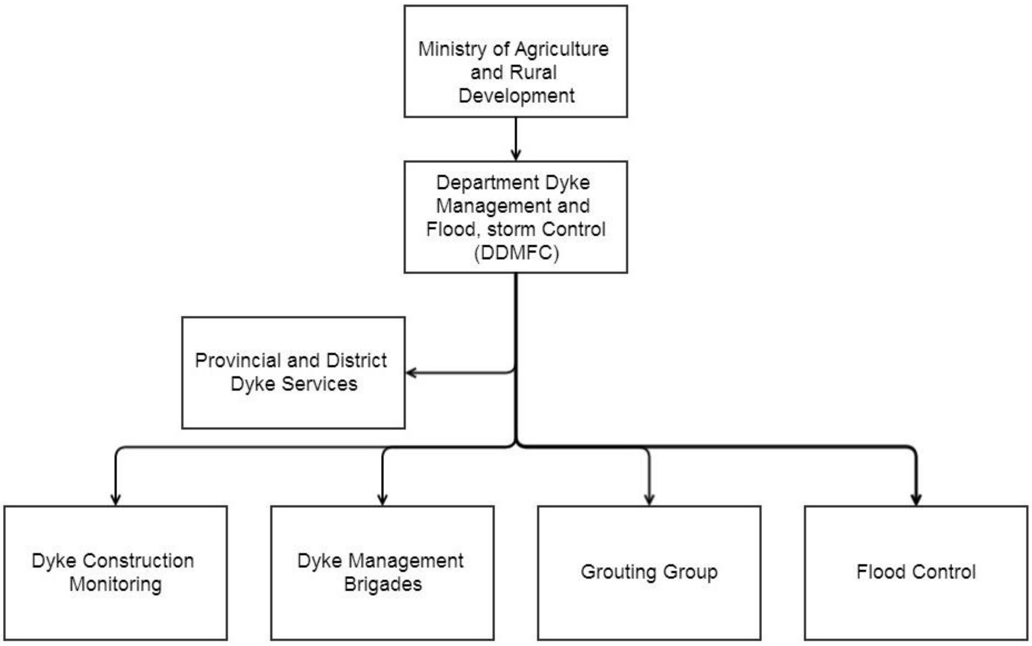

Figure 2: Visualisation of the governmental structure concerning water related issues.

In the regional planning of the authorities extensive use is made of the so-called five-year plans, often with quite ambitious plans. Short term planning is therefore guaranteed, and goals can be set, to which the local authorities can strive. Also, it is easier to raise funds for short term planning since interests can be earned back faster. However, 5 year plans are quite hard to change (agreed is agreed) and maintenance and environmental impact (both are often more long term) are often not taken into account.

In addition to the government there are some public Asian organisations focussing on the first aid in the disaster events, such as the Asian Disaster Reduction Centre (ADRC). Another private organisation is the VVFO-NGO resources centre, which focuses at the improvement of information exchange in both Vietnam itself as with the surrounding countries.

2.3 Project Approach

The Engineering Process is used as a basis for this project, to make sure that a clear structure is maintained. In addition, it makes the project more efficient since it forms a framework in which the information should be processed. The steps which form the Engineering Process are displayed in Figure 3, and can be roughly divided in two sections: preparation and elaboration.
The preparation part consists of the analysis of the problem, the area and the stakeholders. This eventually results in a clear problem description, and via requirements for the solution, an objective of the project.
The second part of the process involves the actual development of a solution. The search towards the (best) solution is an iterative process, which starts with the development of multiple, different solutions. Since not every solution is suitable, or even useful, a feedback loop towards earlier steps is made. Maybe some requirements are changed (which means a new objective), or even new problems can be found (which would result in a new project which starts from the beginning). When there are multiple solutions which can be used, an additional step should be taken: the application of a Multi Criteria Analysis. In this analysis the best solution (or combination of elements) is chosen by the weighing of criteria as described by the Objective.

In this project the Engineering Process will be followed to different extends. In the development of the case studies the actual elaboration needs to be done by the master project group or graduation student, so the case studies will be based on the steps up and until the Objective (indicated by the yellow accolade in Figure 3).
In the second part of this project, the whole process is applied to two case studies: in addition to part one the rest of the steps, indicated by the green accolade in Figure 3. Since there is limited time available, the iterative part of the Process will only be done once, which means that the feedback loop is not used in this project.

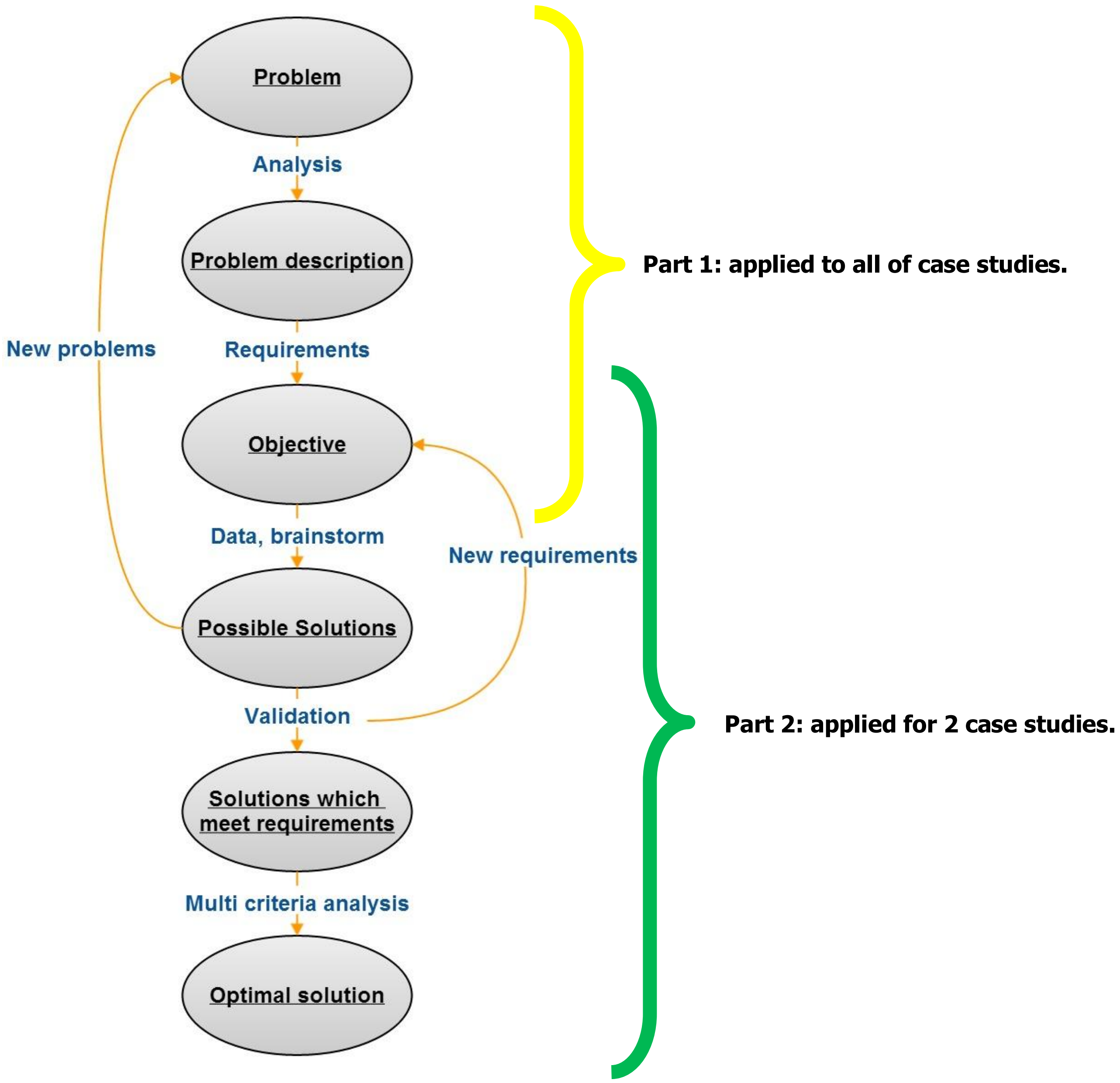

Figure 3: The Engineering Process as used in this project. The case studies are only written down up and until the step 'Objective' (yellow accolade), while all the other steps are used for the two elaborated case studies. Since the elaborated case studies are written for a certain stakeholder, the objective step is also included in the elaboration (green accolade). Due to the limited time, no iterations (the feedback loops) are done.

2.4 Reading Guide

In Part 1 an indexation of the water related challenges in the Thua Thien-Hue province is presented. The description starts with a rough overview of the challenges in Chapter 4, where after an overview of (including the relations between) case studies is given. In Chapters 6 and 7 a discussion respectively a conclusion with some recommendations is written down. In Part 2 two cases are elaborated, namely the Reservoirs and Dams case and the Stability of the Thuan An inlet case. Reading guides concerning those parts of the report are presented there accordingly.

3. References

Phuoc, N. K. (2007). *Flood Hazard Modelling in Thua Thien -Hue Province, Vietnam.* Unesco-IHE.
Villegas, P. (2004). *Flood Modelling in Perfume River Basin, Hue Province, Vietnam.*
Weatherbase, 2013. (n.d.). Retrieved September 10, 2013, from Weatherbase: http://www.weatherbase.com/

Part 1

Challenges in the Thua Thien-Hue province

4. General overview of the area

4.1 Introduction

After a detailed literature study of the Hue area and the collection of expert opinions, a number of problems have been mapped and clustered in three main disciplines: Disaster Management, Coastal Engineering and Water (Resources) Management. This division into disciplines corresponds to the different studies offered at the Water Resources University.

In paragraph 4.2, a short overview of the area introduces the indexed problems, described as a single component of the general processes operating in the area. This context is important since every intervention influences the local system, but may also impact the whole area.

The representative locations of the described problems can be found in Figure 7.

4.2 Overview of the problems

Disaster Management

As mentioned in the introduction, the area can be divided in three subjects. The Disaster Management Cases mainly focus on the short term responses in the river discharge due to intensive rain: precipitation in the mountains reaches the reservoirs (Figure 4), from which the water runs down into the lowland areas. In these areas the rural and urban enclosures are often not able to deal with the enormous amount of water, and therefore experience a certain degree of hindrance.
Prevention against flooding can be done at several stages of the river. Upstream reservoirs can be used to reduce the discharge, while downstream dikes, embankments and spillways can prevent flooding. Another option is to choose for strategies related to accommodate floods, by the use of damage control. Evacuation is a strategy to decrease the number of casualties, but this only works to a certain extent and cannot prevent economic losses, for which improvements to housings and industrial buildings is needed. In flood prone areas often a mix of these strategies is used, so a good indexation of the area is needed to find the best strategy for each region.

Figure 4: Construction of reservoirs (left) and recently flooded houses (right).

Coastal Engineering

In the coastal zone the sea is the driving force (by the impact of tides and waves) for sediment transport. In addition, rivers transport sediment from upstream into the coastal area. As a result, the inlets, dunes and lagoons are deforming according to the sediment balance in the area. There is a lot of urban and rural activity in the coastal zone, which also has large impacts on the dunes and the lagoon, see Figure 5. Therefore, the coastal barrier is not only threatened by the sea, but also by human activities. Breaches in the coastal barrier often occur when there is a combination of storm surge due to typhoons, and a high discharge from the rivers due to intensive rainfall.

Figure 5: Sand excavation (left) and cultivation of land in front of the sand dunes (right).

Water Management

The Water management cases are dealing with the long term river problems, which vary from pollution due to insufficient waste water treatment to salt water intrusion (Figure 6). These are important cases since the available water is of great importance in the Hue area: domestic areas, fisheries and agriculture depend on it.

Upstream, reservoirs can regulate the discharge in the rivers and partly block the flow, where after the flow is kept constant (for power and salt intrusion) downstream of the reservoir. Despite of aiming at a constant discharge, it appears that the downstream river discharge still has high peaks.

Although fishery in the lagoons largely depends on the water quality, it inevitably also harms it: the densely stacked fishing gears hinder the water circulation and thereby the natural purification in the lagoon.

Figure 6: Sewage water running directly in the water (left) and the Thao Long dam against salt intrusion (right).

Climate change

Climate change is an overarching subject, which has a connection with the future prospects of most problems. At the coastal zone sea level rise is the main climate factor, while disaster management is more influenced by the intensity of the precipitation and the intensifying (heavy) storms. Even for water management climate change can be important: the rise of water temperature can, for example, influence the water quality or the salt intrusion.

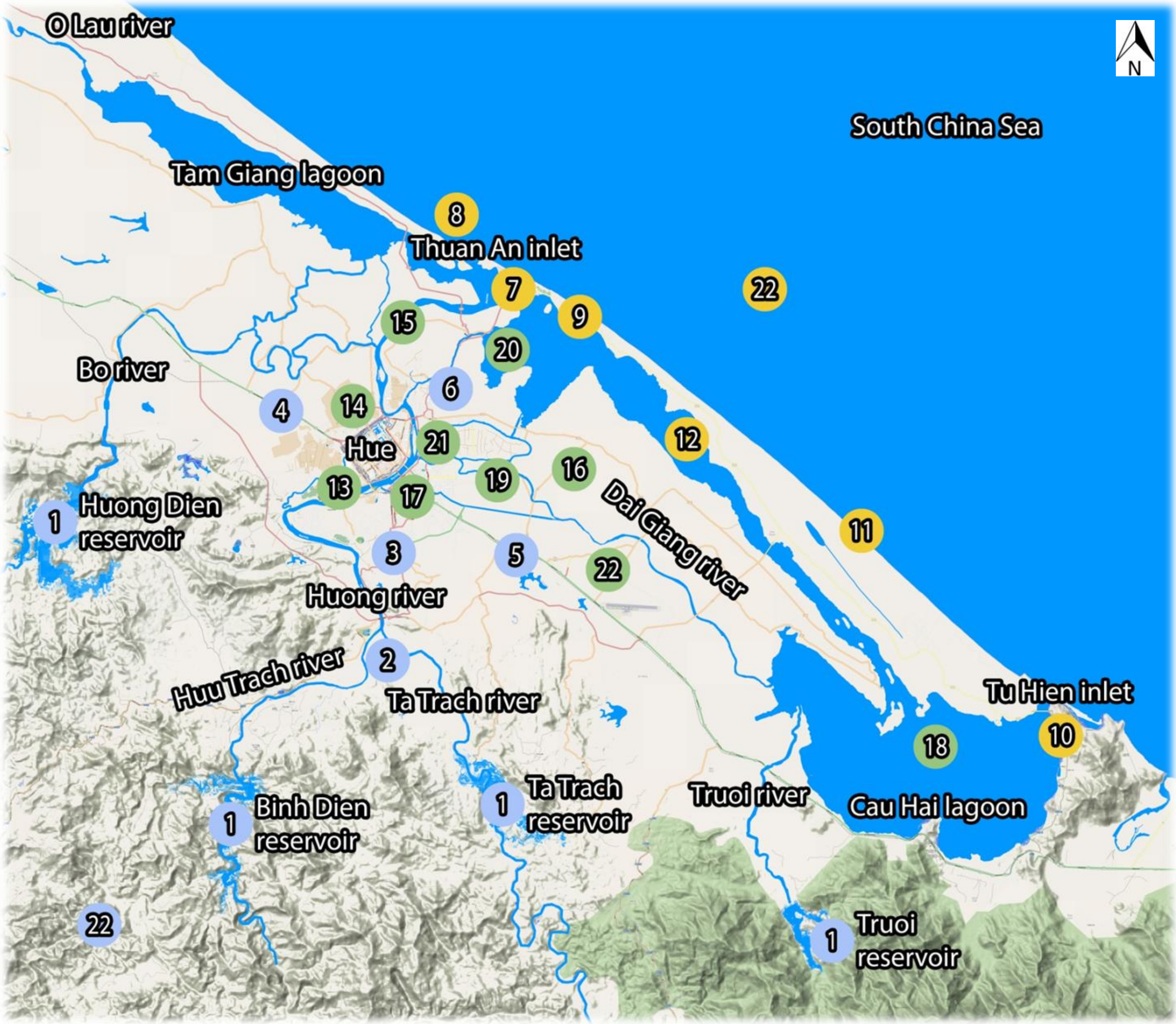

Figure 7: Overview of the problems in the Thua Thien-Hue province, at a representative location. Some cases occur multiple times, since they represent multiple aspects (i.e. Climate change) or due to multiple locations (i.e. reservoirs). The titles corresponding to the numbers can be found in the chapters below or in Table 2, Table 3 and Table 4.

5. Case studies overview

5.1 Introduction

In Chapter 4, a general description of the problems concerning the Hue area was given. The following step is the description of the individual problems, as will be done in this chapter. The topics concerning the described areas (Disaster Management, Coastal Engineering, and Water Management) should be interpreted quite broadly, since not all topics fit in the defined box: most topics also concern River Engineering or even Hydrology, but are all put in one of the predefined areas. A definition of the problem area will be given in the corresponding paragraphs.

The individual problems will be introduced in a flow chart, in which the most import relations between the topics are visualised. This to make sure that the individual problems are read in the context of the global area as described in Chapter 4. While elaborating the actual case study, students should keep in mind which relations are present and with which other topics a solution may interfere. This also means that problems which have (almost) no relation to other topics are not included as an individual case, since they were not considered relevant to the overall problem and therefore not useful for the purpose of the master project at the WRU. An example of such a problem is the 'Preservation of Cultural Heritage against floods'.

To keep an overview, the case studies itself are summarized by presenting only the title and under title of the case study and the corresponding keywords. The complete case studies can be found in the Case Study Report, a separate document handed in together with this report.

5.2 Disaster Management

The Disaster Engineering cases, given in Table 2, are mainly based on the processes that concern the part from precipitation to actual flooding. This chain starts with the influence of reservoirs and climate change (due to intensified precipitation) on the water runoff, where after a high water wave can and probably will occur. The corresponding flood risk and the actual flooding are two cases which are coupled in multiple ways. Overarching is the risk assessment of the floods: what is the actual risk on flooding, and if flooding occurs which part will flood first? When this has been mapped measures can be taken to save as much lives as possible by evacuation plans and by minimizing the damage due to the flooding. The processes are visualised in Figure 8.

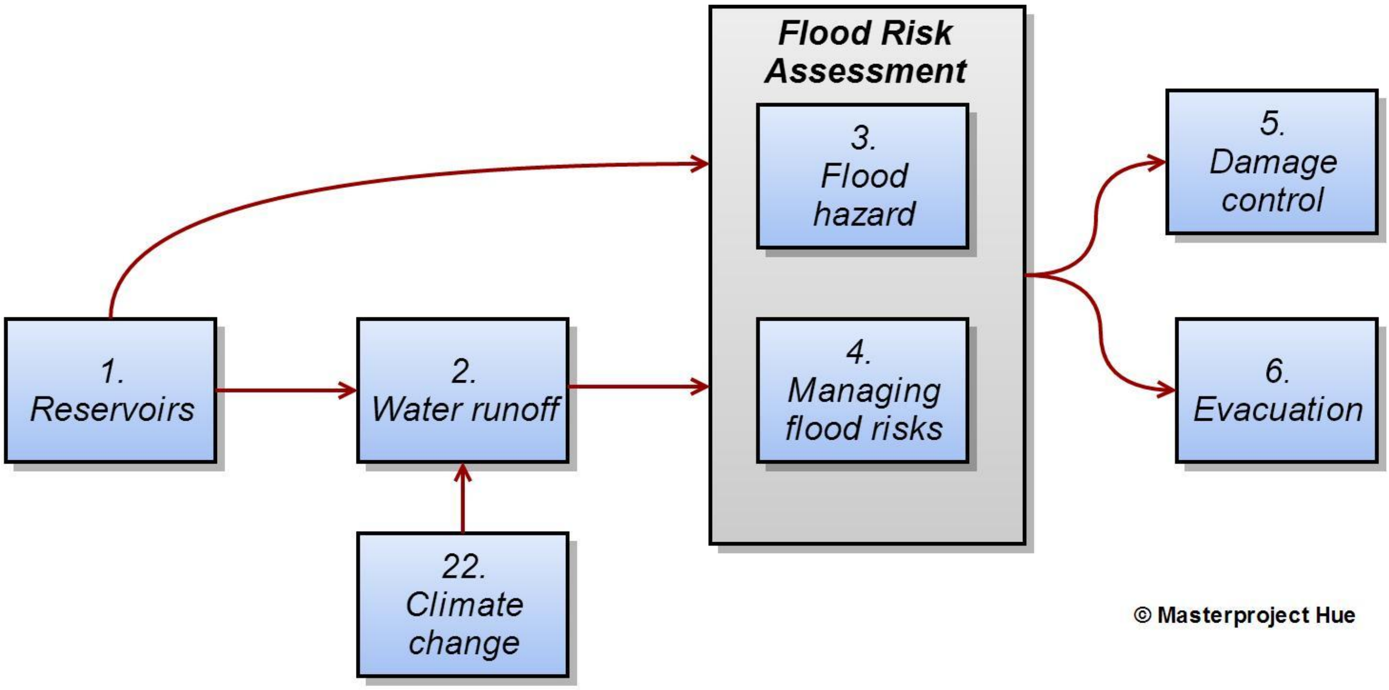

Figure 8: Overview of the Disaster Management cases, with the most impotant relations visualised by the arrows.

Table 2: Overview of Disaster Management cases.

Case Number			Keywords
1	*Title*	Dams and reservoirs	*water management, infrastructure, soil erosion, hydropower, irrigation water, flood retention, salt intrusion*
	Subtitle	Master plan for using existing infrastructure to regulate river discharges	
2	*Title*	Rainwater runoff	*management, watershed, runoff, remote sensing*
	Subtitle	Effects of the watershed characteristics on the runoff relationships in the Thua Thien-Hue province	
3	*Title*	Flood hazard	*river engineering, flooding, remote sensing, numerical modelling*
	Subtitle	The assessment of potential flood events, flood frequencies, duration, extent, inundation depths and flow velocities in the Thua Thien-Hue area	
4	*Title*	Managing flood risks	*river engineering, flooding, remote sensing, risk analysis, economic optimization*
	Subtitle	Analyse and reduce the effects of floods in the Thua Thien-Hue area	
5	*Title*	Inland damage control	*river engineering, flooding, damage control, planning*
	Subtitle	Living in a flood prone area: inland damage control in the Thua Thien-Hue province	
6	*Title*	Evacuation planning	*river engineering, flooding, evacuation, planning*
	Subtitle	Master plan for increasing the evacuation progress during a flood event of the city of Hue	
22	*Title*	Climate change	*water management, coastal engineering, river engineering, sea level rise, hydrology*
	Subtitle	Prospects of the future	

5.3 Coastal Engineering

The Coastal Engineering cases are related to the coastal system, so mainly with the dunes, inlets and the lagoon; in Table 3 an overview of the cases is provided. The driving force behind most of the morphology is the sediment transport, and the corresponding sediment balance. The relation between the sediment balance case and the other cases can be seen in Figure 9. Since the lagoon is connected with the ocean by two inlets, similar cases have been developed for both inlets, with the main difference being the influence of the already existing breakwaters on the Thuan An inlet. The dune system is also divided in two cases, namely in a short (breaching) and long (dune erosion) term situation. Finally, Climate change (mainly by sea level rise) influences several processes and can be taken as an additional research towards future prospects.

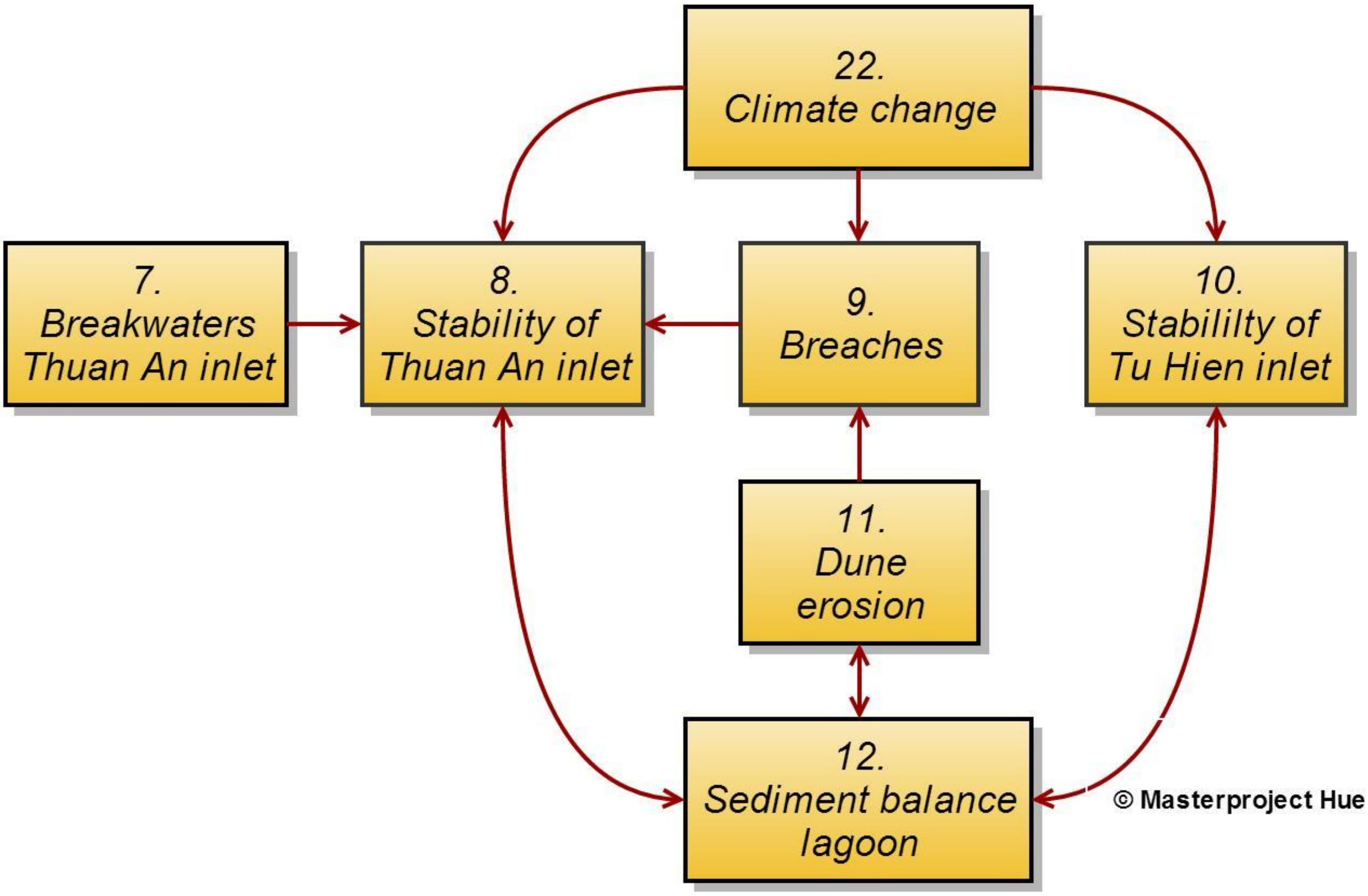

Figure 9: Overview of the Coastal Engineering cases, with the most important relations visualised by the arrows.

Table 3: Overview of Coastal Engineering cases.

Case Number			Keywords
7	*Title*	Breakwaters build in the Thuan An inlet	*coastal engineering, breakwaters, tidal inlet*
	Subtitle	The effect of the breakwaters around the Thuan An inlet on coastal and inlet stability	
8	*Title*	Stability of the Thuan An inlet	*coastal engineering, tidal inlet, numerical modelling*
	Subtitle	Research towards a solution for the instability of the Thuan An inlet and the corresponding navigation problems	
9	*Title*	Breaching of the coastal barrier	*engineering, episodic erosion, breaching, numerical modelling*
	Subtitle	Investigate and limit potential breaching of the coastal barrier system around Hue	
10	*Title*	Stability of the Tu Hien inlet	*coastal engineering, tidal inlet, numerical modelling*
	Subtitle	Research towards a solution for the instability of the Tu Hien inlet	
11	*Title*	Structural dune erosion	*coastal engineering, structural dune erosion, numerical modelling*
	Subtitle	Research towards finding solutions for the structural erosion of the coastal barrier system near Hue	
12	*Title*	Sediment balance lagoon	*coastal engineering, lagoon, sediment balance, coastal zone management*
	Subtitle	Researching the sediment balance in the Tam Giang-Cau Hai lagoon	
22	*Title*	Climate change	*water management, coastal engineering, river engineering, sea level rise, hydrology*
	Subtitle	Prospects of the future	

5.4 Water Management

Water management is a broad discipline, with a lot of possible topics. To provide a flow chart that keeps its function (relating different cases) it is decided to make a secondary division in subjects, namely Water allocation, Water quality and Water application. These three 'branches' of water management are related in the following way: the allocation of water depends on the available water quality, but may also demand a certain quality from the providers and therefore influence each other. When the allocation is known, the water can be applied, after which waste water determines the starting value of the water quality again. All three aspects are influenced by climate change: allocation by sea level rise, quality by increase of temperature and application by a more distinct wet – dry season. This is all visualised in Figure 10.

The second step is to specify the allocation, quality and application part. Within the water allocation, salt water intrusion is an important factor for the possible usage of water, since brackish water cannot be used for most purposes. The salt water intrusion itself is influenced by the reservoir regulation and usage of the Thao Long dam, while the possibilities concerning the distribution of the water influence the possible usage of water.
Water quality is depending on the location of possible pollution (the 'mapping' case), and measures against this pollution. In this report a distinction is made between open water pollution (e.g. floating garbage) and sewage water treatment.
Although water is applied in many sectors, a distinction is made between agricultural use (irrigation for rice paddies, animal stock), fishery in the lagoon and domestic use (e.g. drinking water). The list of cases can be seen in Table 4.

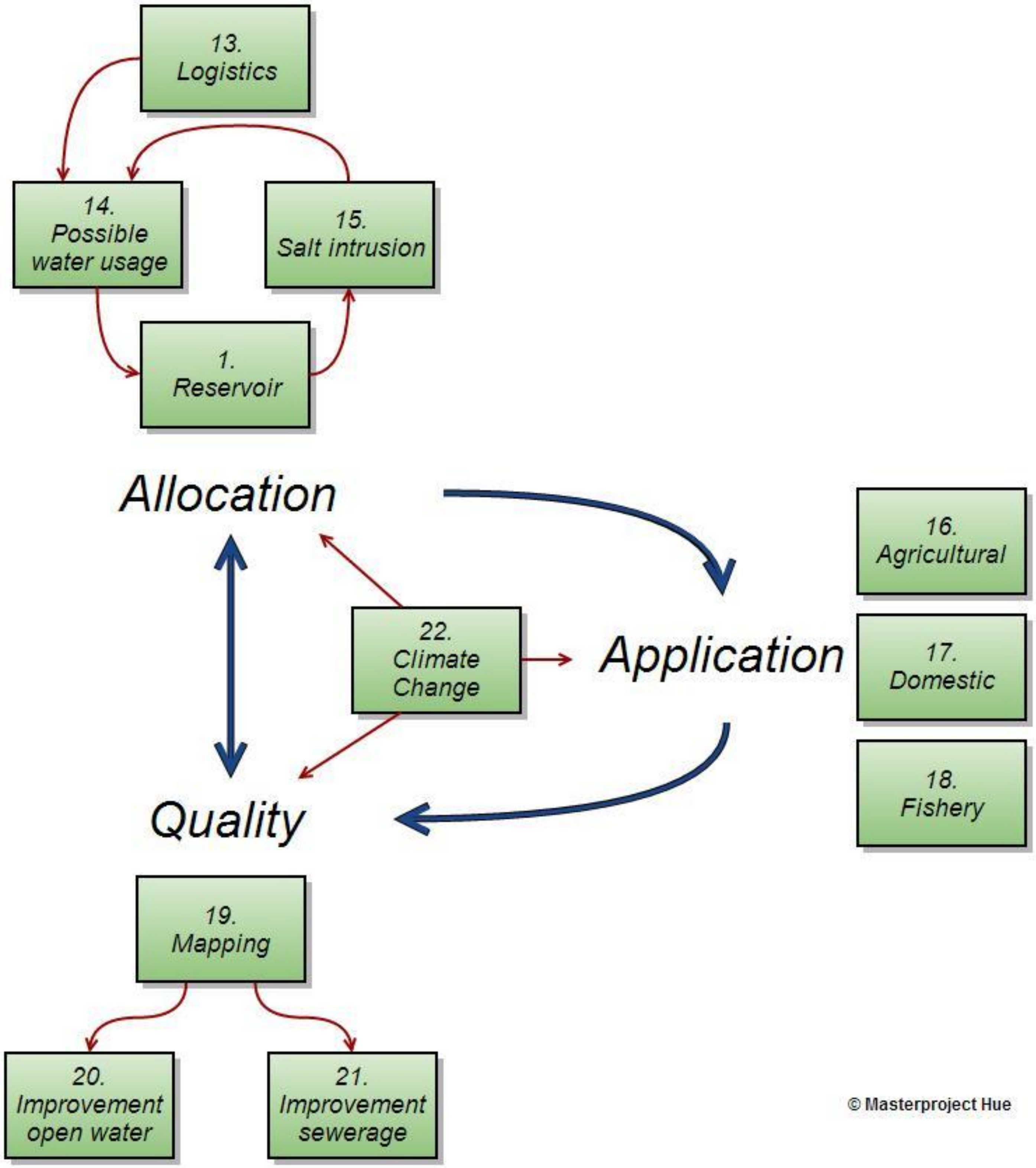

Figure 10: Overview of the Water Management cases, in three subcategories (Allocation, Quality and Application) which are related to each other by the blue arrows. Each of these subcategories represents a number of cases, which in turn are related by the smaller.

Table 4: Overview of Water Management cases.

Case Number			Keywords
1	*Title*	Dams and reservoirs in the Thua Thien-Hue province	*water management, infrastructure, soil erosion, hydropower, irrigation water, flood retention, salt intrusion*
	Subtitle	Master plan for using existing infrastructure to regulate river discharges	
13	*Title*	Logistics of (sewage) water distribution	*water management, sewer system, waste water*
	Subtitle	Improving the sewage system and drinking water system to improve living standards	
14	*Title*	Requirements for water usage	*water management, water allocation, conflicting interests*
	Subtitle	Optimization of water usage by assessing the required quality	
15	*Title*	Saltwater intrusion	*water management, salt intrusion*
	Subtitle	The effects of salt intrusion in the Huong river	
16	*Title*	Agricultural use of water in the Thua Thien-Hue province	*water management, irrigation, rice production, water shortage*
	Subtitle	Requirements and optimization of the agricultural use of water	
17	*Title*	Domestic use of water in the Thua Thien-Hue province	*water management, water allocation, rural areas, water quality*
	Subtitle	Requirements and optimization of the domestic use of water	
18	*Title*	Fishery in the Tam Giang-Cau Hai lagoon	*water management, lagoon, fishery, aquaculture*
	Subtitle	A study towards regulation of fishery and other activities at the lagoon waters to preserve nature values and maintain livelihoods of local inhabitants	
19	*Title*	Indexation of water quality and its polluters	*water management, water quality*
	Subtitle	Master plan for the water quality problems in the Huong river	
20	*Title*	Improvements of open water treatment	*water management, water quality, waste water treatment*
	Subtitle	The analysis and removal of debris in open water	
21	*Title*	Improvements of sewage water treatment	*water management, sewer system, wastewater treatment, hygiene*
	Subtitle	A research to improve the waste water treatment in the future	
22	Title	Climate change	*water management, coastal engineering, river engineering, sea level rise, hydrology*
	Subtitle	Prospects of the future	

6. Discussion

We tried to get to know an, at forehand, unknown area with a different culture in only a short time. This is a challenge, and although a lot of knowledge has been gathered, a certain lack of understanding will always be present; even after two months people sometimes react different than expected in what kind or what part of a subject they find important.

The main outlines of the case studies are described quite well, so the global problem is identified and possible topics can be presented. However, implementation of an accurate stakeholder vision is difficult, just because we do not actually know the impact of problem on society in that specific area. This is something that should be done in a more extensive field campaign, with accompanied with Vietnamese speaking persons. In addition, a lot of knowledge produced from Vietnam is in Vietnamese, and not very foreign oriented. This means that data and more resources are hard to access, a shortcoming which can be (partly) overcome by for example setting up a combined project between Dutch and Vietnamese students.

In this report only the most obvious relations between problems are shown, and only between problems in the same area of interest. This due to the fact that flow charts will become unclear when visualising all relations and that most social-economic aspects (which often relate the different areas) are kept away.

A large number of problems have been found, but of course not all fields of research have been studied. Especially (local) small scale problems 'escape' our view. In addition, not all problems are suitable for this study or are not considered as relevant. The overview of the cases is therefore not as complete as it could be, but as complete as we think is practical at this moment.

A final remark is the depth of some case studies. The stability of the inlets to the lagoon are subjects that have been an inspiration for several PhD theses, it is therefore not realistic to think that a small project group will solve the problem. It might therefore be necessary to further specify some subjects, to make them suitable for the study load as meant for a project at the WRU.

7. Conclusion and recommendations

There is no doubt that the Thua Thien-Hue province is faced with a large number of problems, which needs an integrated approach to be solved. At this moment, a lot of measures that have been taken malfunction or cause even more severe problems somewhere else in the area.

When describing the global area, individual problems can be identified, but often they are strongly related to other problems. Proposed solutions for these problems are therefore often bounded: a certain solution may interfere with the solution for another problem. When students start with a case study as presented in this report, a clear awareness of the (overarching) context should be present. An additional requirement for finding solutions is a clear description of the implementation of the solution. It was often encountered that the design of a certain breakwater was very well, but that the local contractor failed to construct the breakwater according to the design.

While 22 problems are described (extensively in the separate report), more topics could be considered. However, not all topics are relevant (due to being too much on its own) or usable for students of the WRU. In future studies it is therefore recommended to look at other fields of study, to find more clusters of problems or to relate the existing areas of research. Possibilities to improve the current overview are for example including social-economic relations, culture preservation and urban development.

Part 2

Elaborated Case studies

Part 2a Case 1: Dams and Reservoirs

Part 2b Case 8: Stability of the Thuan An inlet

Part 2a

Case 1: Dams and Reservoirs

1. General introduction

1.1 Introduction

The Thua Thien-Hue province is located in the middle of Vietnam and holds a tropical monsoon climate. This means that the province is hit by typhoons several times a year during the rainy season, with heavy rainfall and heavy winds as a consequence. This type of climate also has a dry season with droughts that influences the water supply for the different purposes like agriculture and domestic water uses. Due to the effect of climate change the precipitation in the wet periods will become heavier and the droughts in the dry period will become more intensive (Nguyen P. K., 2009).

The provincial government is the first who is charged with tackling the water related problems in the region. As the main part of the central government, the provincial government is the designated governing body to do something about today's problems and even more important, about the problems in the future. One of the possible options is to take an integral approach and find solutions which make the best use of the current infrastructure and constructions in the province.

This part of the report examines how the current and future dams and reservoirs can be optimally used to, for example, prevent floods, irrigate farm lands, produce hydropower and lessen the overall water related problems in the Thua Thien-Hue province. The result will be an overview of the opportunities and challenges regarding reservoir management, specifically for the current Binh Dien dam and the future Ta Trach dam (ready in 2014). See Figure 11 for an overview of the five major dams in the province.

1.2 Reading guide

This report contains the elaboration of the dams and reservoirs case. The 1st chapter contains a short introduction and what can be expected in the rest of the report. In the 2nd chapter a more detailed description of the problem is given. Also the approach to solve these problems is presented. In chapter 3 different stakeholders and their interests will be discussed, to indicate the complex relations regarding this case. The characteristics of the different reservoirs are treated in chapter 4, including their location in the Thua Thien-Hue province. Chapter 5 treats the different functions of dams. Furthermore, an analysis of the current water distribution from the Binh Dien reservoir is made and possible regulation schemes regarding the combined future regulation of both the Binh Dien and Ta Trach dam are discussed. In the last chapter conclusions and recommendations will be made.

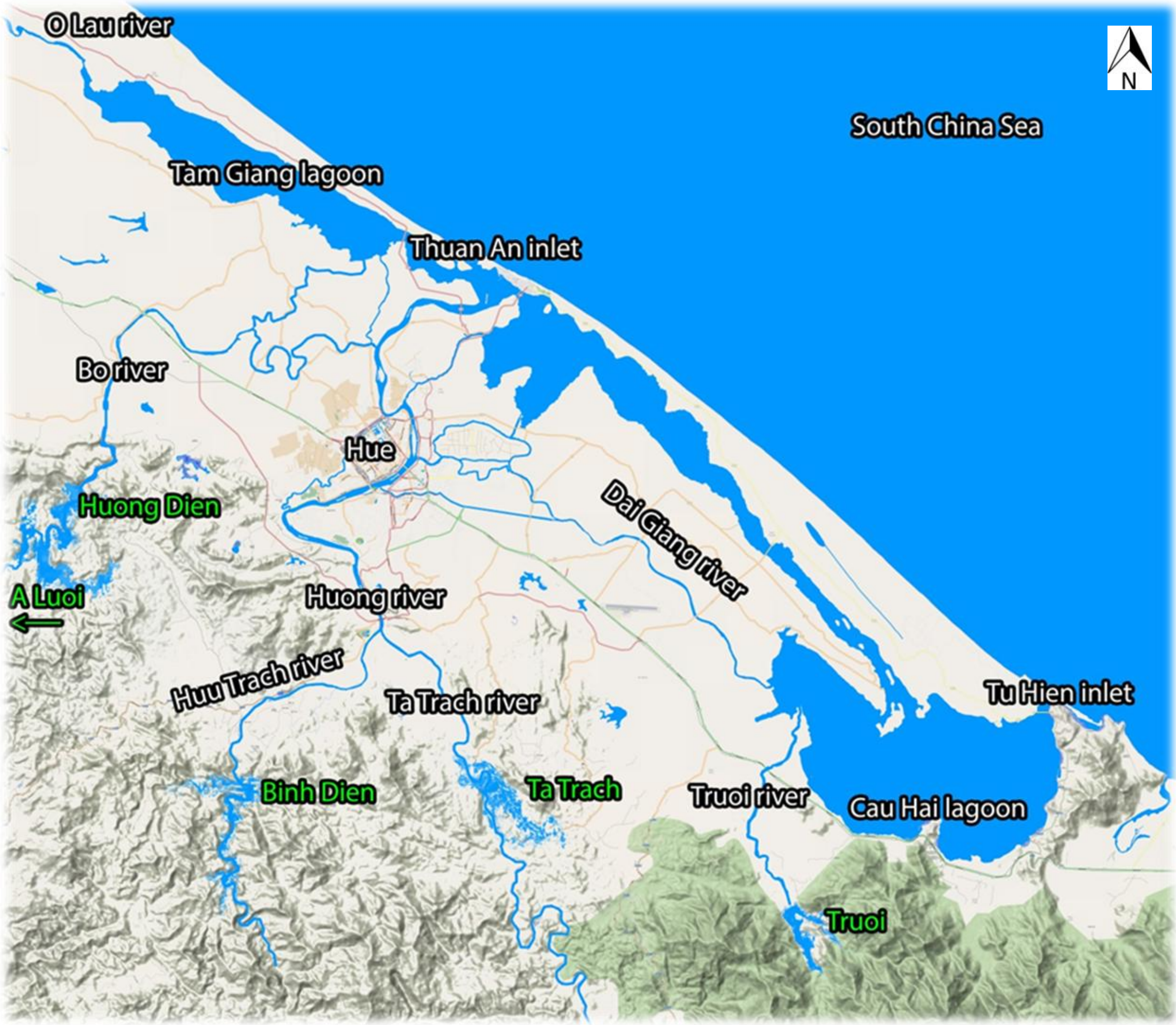

Figure 11: Location of the reservoirs in the Hue area.

2. Problem description

2.1 Introduction

In the past 10 years the energy consumption of Vietnam has roughly increased by 300% (ACB SECURITIES, 2012). To decrease the dependence on energy import, the Vietnamese government has made large investments in new power sources. Amongst others, this resulted in the construction of many hydropower dams throughout the country in the past 10-15 years. In 2011 the electricity production from hydropower plants reached 37.6% of the country's total production (ACBS, 2012), with a total of 260 hydropower plants (Muoi, 2013).
Specifically, in the Thua Thien-Hue province the Truoi (2002), Binh Dien (2009), Huong Dien (2010) and A Luoi (2012) dams have been constructed.

Although hydropower production is the main purpose of the dams, some additional functions can be assigned like water supply (irrigation, domestic use, etc.), flood retention and regulation of salt water intrusion. However, a lack of proper research, knowledge and experience on how to optimally combine all these conflicting functions, a de-centralized management of all the individual dams and too much focus on the hydro-power function has led to several problems. I.e. reservoirs that almost reached their maximum capacity in the wet season consequently followed by high discharges and floods downstream and soil erosion both upstream and downstream of the dams (Vu, 2011).
Additionally, the influence of climate change in the future has not been accounted for in the designs. Moreover, the absence of dam inspections due to a lack of funds increases the risk of failure due to constructional defects (NAM News Network, 2012).

Especially flood control becomes increasingly important for the Vietnamese. The Thua Thien-Hue province has to deal with multiple floods every year due to storms and intensive rainfalls. With increasing economic activities, the strive for higher safety, damage control and health; it is desirable to reduce the frequency and severity of floods. Amongst other things, reservoirs can help in reducing floods through water retention and gradual discharge of the precipitation.

In recent years Vietnam has become more and more aware of the problems surrounding dams and reservoirs. In the Thua Thien-Hue province the Ta Trach reservoir is being constructed with flood control and water supply as main functions (International Rivers Network, 2001).

The provincial government is the governing body who is charged with dealing with the problems in the province. The provincial government has to decide about the policy for the future so they have to determine what the primary and subordinate interests for the well-being of the province are.

2.2 Problem description

Reservoir regulation is often a complicated problem due to the large number of (conflicting) stakeholders involved. Especially in the Thua Thien-Hue province, where multiple reservoirs are acting in the same basin and were a distinct wet and dry season is present, strict regulation should be applied. The water distribution for the city of Hue is arranged by the Binh Dien reservoir, which takes care of the following main interests (Figure 12):

- Hydropower
- Water supply
- Salt intrusion
- Flood control

However, at this moment it appears that the Binh Dien reservoir cannot fulfil all requirements, which led to several problems in the past. Therefore, the government decided to construct a second reservoir (the Ta Trach reservoir), with the main goal to resolve the salt intrusion and flooding problems in the city of Hue. But with this construction, another problem arises: the dams in the Thua Thien-Hue province are not operated by means of an integral management plan, but by individual organizations without collaboration between each other.
The situation with different (private) owners implies that for example hydropower generation will be prioritized above flood control. But where hydropower preferably needs a constant supply of water with a high head, flood prevention asks for an empty reservoir for most of the time.

2.3 Research question and objective

The objective for this research, following the problem description stated above is as follows:

> *Investigate if the water distribution for hydropower, water supply and salt intrusion can meet the requirements from stakeholders by cooperation of the Binh Dien and Ta Trach reservoirs, whereby the flood control function is guaranteed.*

To complete this objective, the following research questions are listed:

- What are the functions and corresponding requirements of the Binh Dien and Ta Trach reservoir?
- To which extend can the Binh Dien dam fulfil these requirements individually?
- How can the individual regulation be improved by combining the Binh Dien reservoir with the new Ta Trach reservoir?

2.4 Structure of the research

In this case study a research is presented on the conflicting interests with respect to reservoir regulation in the Thua Thien-Hue province, and how they impact each other. As will be discussed in

Chapter 4, the province currently counts 4 major dams and has 1 under construction. It is not possible to treat each dam in detail in this research, so only two dams will be considered. The first one is the Binh Dien dam, which is already in operation for several years and specifically designed for hydropower generation. The dam is located far upstream of a branch of the Huong river, and therefore directly impacts the city of Hue. The second is the Ta Trach dam, which is still under construction and is also located far upstream of the Huong river, but in a different branch. It consequently also affects Hue and, more importantly, will have a major influence on the management of the Binh Dien dam since the dams are in parallel positions to each other, see Figure 12. In other words, it is important that the interaction between the dams is researched for a proper regulation of both dams.

To do so, the following subjects will be treated:

- Analyses of the stakeholder and their (conflicting) interests;
- Analyses of the main functions of the dams and reservoirs and the corresponding preferred regulation;
- Analyses of the current regulation;
- Formulate an advice regarding the future regulation of the two reservoirs.

Additional problems such as soil erosion, damage to the environment, property, habitat and water quality are also affecting the area. However, these aspects are not taken into account in this research due to the limited time and recourses available.

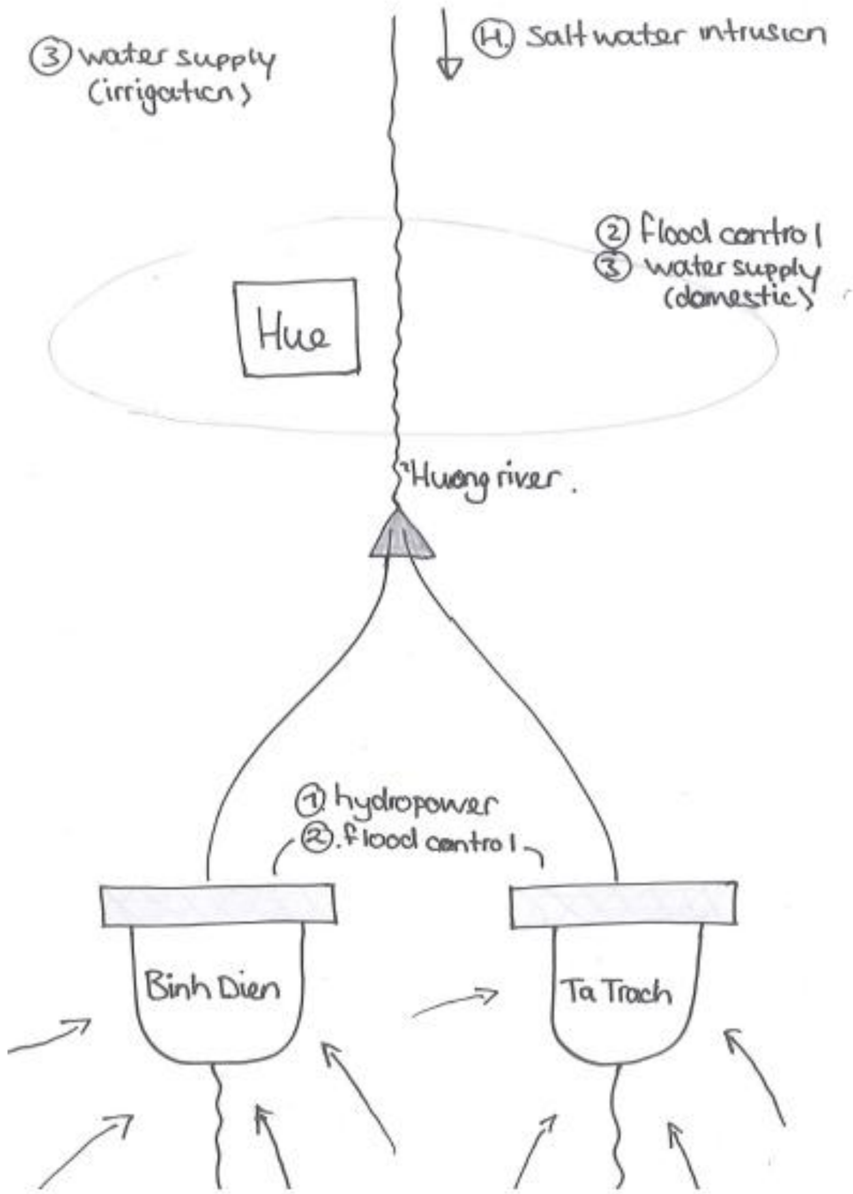

Figure 12: Sketch of the Huong river and the connecting dams.

3. Stakeholders

3.1 Introduction

In the project area there are several stakeholders which are concerned with the regulation of the reservoirs. These stakeholders all have their own demands, interests and wishes. Because there are more than a few stakeholders one can imagine that there are conflicting interests, which will make the process of the project more difficult. In addition, it will often take a lot of time to design a plan on which all stakeholders will agree on.

3.2 Relevant stakeholders

Government

The most important governmental ministries are:

- Ministry of Agriculture and Rural Development (MARD)

The objective of the MARD on the long term is to achieve large agricultural productions, which are modern, efficient, sustainable and which give high quality revenues. This should be done on the basis of advanced technology (MARD, 2009). The floods in the wet periods and droughts in the dry periods are not contributing to the objective of the ministry, their aim is a more evenly distribution of water during the year for the agricultural production. This ministry is also responsible for cooperation with relevant agencies in the field of disaster management (MARD, 2007).
To achieve their objectives MARD built two dams in the Thua Thien-Hue province: Truoi and Ta Trach.

- Ministry Of Natural Recourses Engineering (MONRE)

The MONRE is, amongst other things, responsible for water recourses, water quality and climate change. They try to counteract water pollution and salt intrusion concerning domestic and agricultural purposes. Another aspect is sea level rise, which has effect on, for example, salt intrusion. A sufficient high discharge during the year is in the interest of this ministry to guarantee a good water quality.

Provincial government (Department Of Industry and Trade, DOIT)

The decentralisation of economic development from the central government in Hanoi to the provincial government is an on-going trend in Vietnam. This trend has caused a change in the economic infrastructure and improved the competitiveness of Vietnam (Schmitz, Tuan, Hang, & McCullock, 2012). A high flood risk would not encourage industrial investments in the Hue area, which has a negative influence on the economic situation.

Dam owners/manager

The dam owner is responsible for the water level in the reservoir. This means that during the dry season the amount of water should be sufficient to meet the requirement of hydropower, irrigation, domestic use and salt intrusion. The reservoir is filled during the rainy season to serve in the dry season, but should reserve some space for floods. This gives the manager the responsibility to allocate the water.
Another responsibility is the maintenance of the dam. This is important to guarantee safety for the residents downstream and the functionality of the dam. Clearing the sedimentation in the reservoir is a form of maintenance, since the volume of the reservoir would be reduced by sedimentation otherwise.

Hydropower company

The goal of the hydropower company is producing energy. In the rainy season there is sufficient water available to generate energy throughout the day, but in the dry season the amount of water is limited. For this reason most hydropower dams are not able to generate as much energy as demanded, which sometimes causes power cut-offs (ACB Security, 2012).
Often the hydropower company is the owner of the dam, which makes hydropower the dominant function.

Residents downstream

Residents downstream of the dam would benefit from the dams by good control of discharges in case of floods. Salt intrusion in dry periods should be avoided for irrigation purposes.
The citizens of Hue benefit most from reduction of floods around the city; these floods cause a lot of damage to property and infrastructure. A more regulated discharge, which results in fewer and less severe floods, is also advantageous for tourism and economic development of the city.

Farmers

For farmers along the rivers the amount and distribution of water during the year is important for the success or failure of their harvest. If the harvest fails, the farmers have no income. This makes the amount of water during the year of vital interest for farmers.
In the dry season farmers should have access to enough water for irrigation of their fields. This water needs to be fresh, so salt intrusions should be avoided. In the wet period the fields are often flooded, which means that there is income from the fields. On the other hand, the water brings a lot of sediment and other minerals onto the field, which keep the land fertile.

Industries

Water has positive and negative influences on the industries in the Hue area. Water has a positive influence because it can be used to cool machinery, so in the dry periods there should be enough water available for this purpose. The negative influence of water occurs in the wet periods, during which there is a reasonable risk for flooding of the industrial area.

Environmental organizations

Environmental organizations monitor if human interventions do not negatively influence the natural environment of the Thua Thien-Hue province in too much degree and/or that proper mitigation measures are taken. The Tam Giang-Cau Hai lagoon is an area where a lot of animals live with a very diverse ecosystem; an area which should be protected according to the environmental organizations. The areas more upstream of Hue are also very rich in nature and ecosystems.

4. Reservoir characteristics

4.1 Introduction

At the moment the Thua Thien-Hue province counts five reservoirs, of which four are already in operation: the Ta Trach reservoir is still under construction. The reservoirs are built in the mountain area by use of dams in rivers and can be seen in Figure 11. The watershed of the province is shown in Figure 13.
After the dams are finished the reservoirs can fill with precipitation from the mountains. Most dams have been built for the generation of hydropower. The reservoirs can also be well used for flood control and water regulation in the downstream regions. An additional advantage of the reservoirs is the attraction of tourists, which can be beneficial for the local people living around the reservoirs. The five main dams and reservoirs in the Thua Thien-Hue province are listed in Table 5.

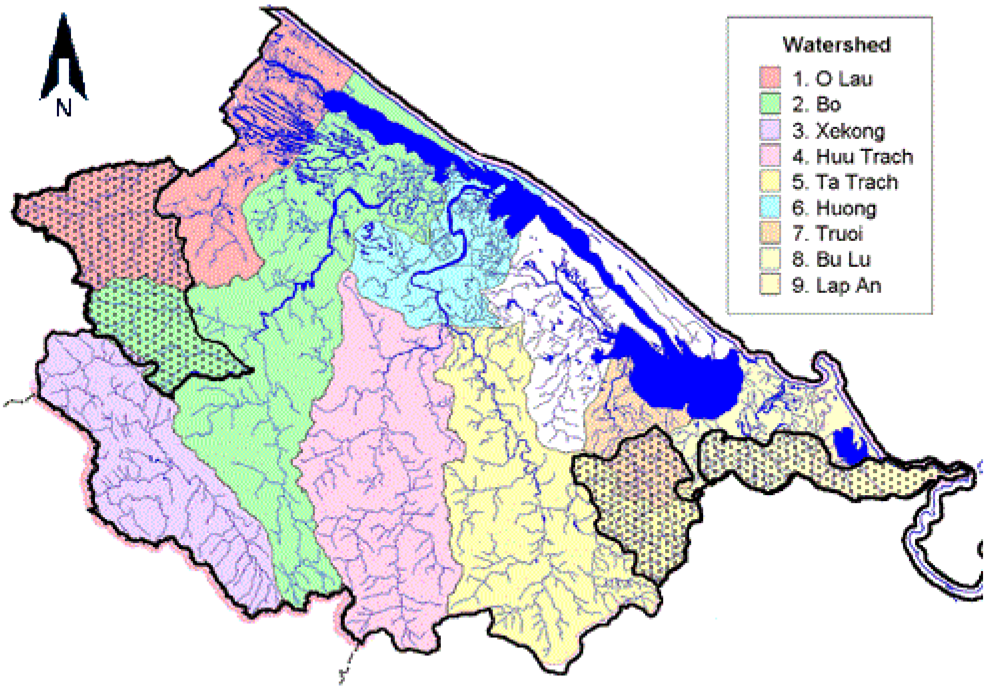

Figure 13: Watershed areas of the reservoirs.

Table 5: The five main dams and reservoirs in the Thua Thien-Hue province.

Name	Operated since	Operator	Capacity [Mm^3]	Catchment area km^2	Hydropower capacity [MW]
Truoi	2002	Ministry of Agriculture and Rural Development (MARD)	51	75	-
Binh Dien	2009	Song Da Corp. - Bac Ha Investment JSC - Bitexco - Agrimeco	423	515	44
Huong Dien	2010	Huong Dien Hydropower JSC	820	-	81
A Luoi	2012	-	-	-	170
Ta Trach	Expected in 2013	Ministry of Agriculture and Rural Development (MARD) and Peoples Committee Thua Thien-Hue province	435	729	21

4.2 Characteristics per reservoir

Truoi

The Truoi reservoir is located in the south east of the Thua Thien-Hue province. Building of the dam in the Truoi river started in 1996. After the dam was finished, first the reservoir needed to fill before it could be operated, which was in 2002. Water flows from the Truoi reservoir through the Truoi river to the Cau Hai lagoon. The reservoir is used for irrigation and flood control downstream. With the reservoir an attempt is made to reduce the flood wave in the Truoi river from 2350 m3/s to 1719 m3/s (Corporation of Irrigation, Construction and Consulting Vietnam - JSC, 2012). The Truoi reservoir is one of the smaller reservoirs in the province.
Recently the infrastructure around the reservoir has been upgraded for tourism purpose. With some hiking routes in the nature and the Truc Lam Bạch Ma monastery, the province hopes to attract tourism to the area.

Binh Dien

The Binh Dien reservoir is located in the centre of the Thua Thien-Hue province. The dam is built in the Huu Trach river, which connects the reservoir with the Huong river. The reservoir is in use since 2009 and is used for the production of hydropower, irrigation and flood control (Quynh, 2013) . At the moment the city of Hue and its areas depends largely on water from the Binh Dien and Huong Dien reservoirs, because the discharge coming from the Ta Trach river is low due to filling of the reservoir.

Huong Dien

The Huong Dien reservoir is located in the west of the Thua Thien-Hue province. The reservoir is located in the Bo river which transports the water partly to the Huong river and partly to the Tam Giang lagoon. The reservoir was taken into use in the year 2010, with main purposes being hydropower, flood control and tourism. The Huong Dien reservoir is one of the largest in the province.

A Luoi

The A Luoi reservoir is located to the southwest of the Binh Dien reservoir and is used for hydropower, flood control of A Luoi city and regulation of the amount of water in the Huong Dien reservoir for maximum hydropower output. Since the reservoir is located upstream of the Huong Dien reservoir, it does not directly influence the area around Hue and will not be taken into account in this case study.

Ta Trach

The Ta Trach reservoir is the newest reservoir in the Thua Thien-Hue province and is located in the middle of this province. The Ta Trach reservoir is a multi-purpose reservoir for flood control, irrigation, power generation and domestic and industrial water supply (International Centre for Environmental Management, 2001-2002). The reservoir is connected to the Huong river via the Ta Trach river. Also the Binh Dien reservoir is connected to the Huong river, which means that in the future Hue receives water from both the Ta Trach and Binh Dien reservoir. During the years a well-designed management plan should be developed for the reservoirs regulation to correspond to the water demand of the city of Hue.
At the moment the dam is ready, but the spillway is still under construction. For this reason it is questionable if the dam will be able to operate at the end of the year.

5. Applications and analyses

5.1 Introduction

Most of the dams in the Thua Thien-Hue province have been built for the purpose of hydropower. Considering the possible changes in the climate it is important that the province should be protected against the effects that may occur, like flooding or salt intrusion. The dams can be used to counteract or mitigate these changes. For the provincial government it is important to check in which way the dams could be used. In paragraph 5.2 an explanation is given of the functions of the dams and in paragraph 5.3 a theoretical analysis of current application of these functions for the Binh Dien reservoir is made. In 5.4 the opportunities and challenges regarding reservoir management for the current Binh Dien dam and the future Ta Trach dam are discussed.

5.2 Analysis of the functions of the dams

A hydropower dam may have more than one function. All the dams in the Hue area have been built to contribute to solving other problems: irrigation, salt water intrusion and flooding. A broader description about these problems is given below.

Hydropower

Most of the dams in Vietnam are designed with hydropower as its main application. In the 80's and 90's the government of Vietnam set the goal to be self-regulating in its energy needs (Trading Economics, 2010). With a high potential for hydropower development and the world's desire for sustainable energy, a lot of funds for the hydropower dams were made available. Nowadays, the opinion about the hydropower dams has slightly changed because of disruptive ecological and social effects of large impoundments. Therefore more comprehensive studies and stricter regulations are needed before construction of a new dam. A lot of plans to increase the number of dams still exist because the supply does not yet meet the demand of energy in Vietnam, but due to the economic crisis investors in projects of this scale are hard to find. Another factor is the economic growth of Vietnam over the last years; this decreases the amount of money coming from development aid funds. The described processes are visualised in Figure 14.

The hydropower dam gains energy from the stored water in the reservoir behind it. When the water is discharged it is accelerated by gravitational forces which lead to high flow velocities. These flows set the turbines in motion and energy is generated.
The water level in the reservoir determines the maximum water pressure head, which, in combination with the discharge, determines the amount of energy that is generated. For this reason the reservoir should be as full as possible to reach a maximum energy output. The water level height is often limited by the dimension of the dam itself. In this case only already existing dams are discussed, thus the dimensions are already available.
A full reservoir is the best solution for energy generation, but this is not feasible for the energy consumption. The consumption has some kind of regularity during the week, but is very variable from hour to hour. The precipitation (filling) is on the other hand almost bounded by the rainy season, which means that the water for energy generation throughout the year should be collected in this season.
Another risk of a full reservoir is precipitation. When the inflow in the reservoir is too large, the normal discharge through the turbines will not be sufficient and the water will flow through the spillways. In these spillways no turbines are placed, so there will be a loss of potential energy.

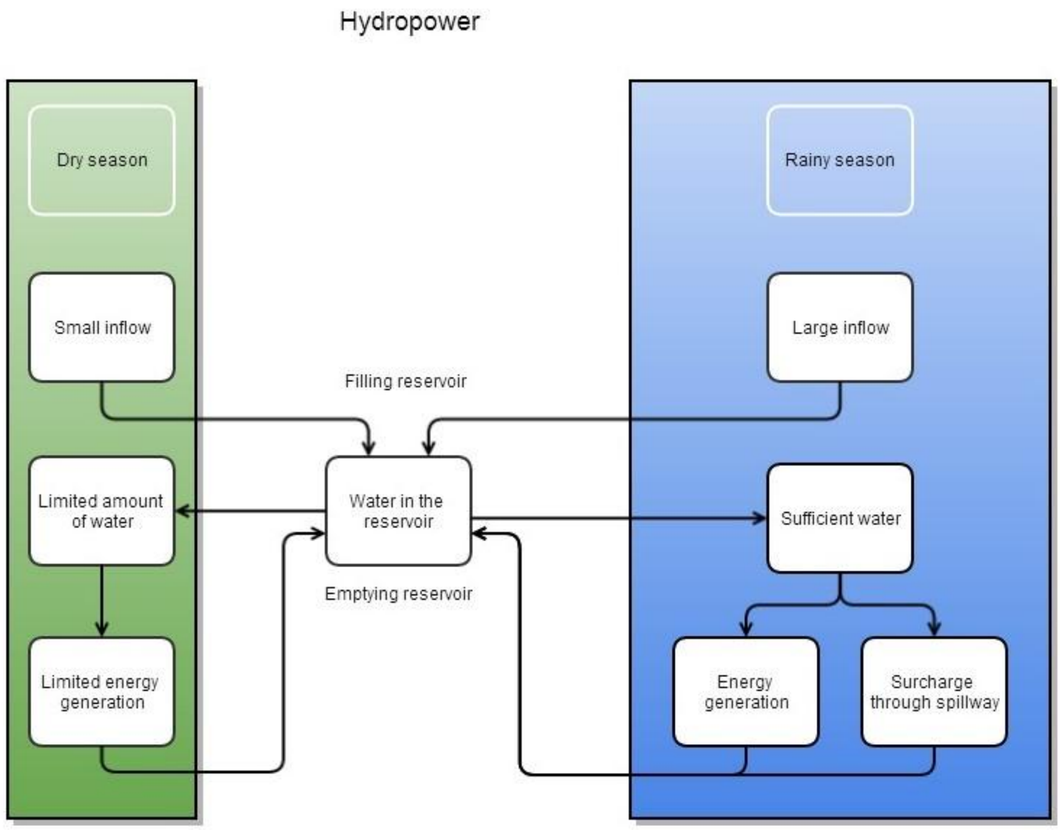

Figure 14: Flowchart about discharge scheme hydropower.

Flood control

In the rainy season the precipitation is locally very intense. In this season, lasting from September till December, the wind is directed inland, driving the clouds from sea in the east to the mountains in the west. To pass the mountains, the clouds need to rise and enter a colder environment. Precipitation is the result of condensation in a colder environment. The short land base and the high mountains make the rain very intensive which leads to large amounts of water that flows rapidly to the lowlands leading to a flooding.

It is difficult to stop the large amount of rain and thereby prevent the area from flooding, however, the dams can collect some of the precipitation into the reservoirs. In this manner the peaks of the rivers are reduced and although this is a small portion of the flood peak, it can reduce the chances of failure, see Figure 16. In the dry season the reservoir will be emptied and therefore the collection of water in the rainy season is often beneficial for more functions.
A problem is that it is difficult to indicate when the reservoir should be used to top off the river peaks. Often all the extra rain in this season is collected in the reservoir, which implies that sometimes the reservoir is already filled in the first months of the rainy season. And although there is a flood surcharge in the reservoir to collect water during intensive precipitation, it appeared in 2011 that the surcharge is not always sufficient and the reservoir had to discharge large amounts of water to protect the dam. The discharge procedure was so intensive and abrupt that it led to a flooding where the citizens in the lowlands did not expect an increase in water level.

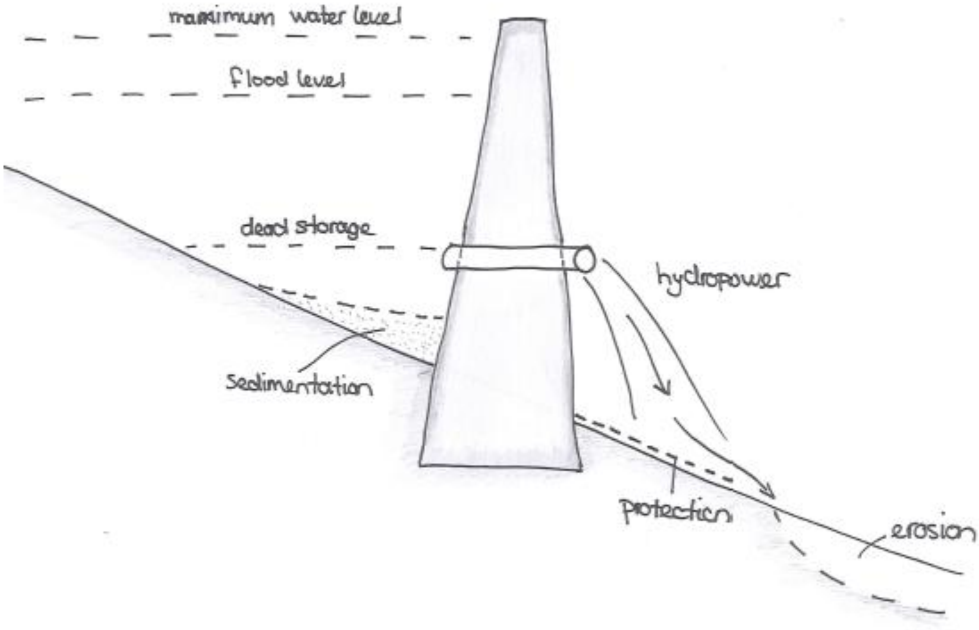

Figure 15: Definition of reservoir water levels.

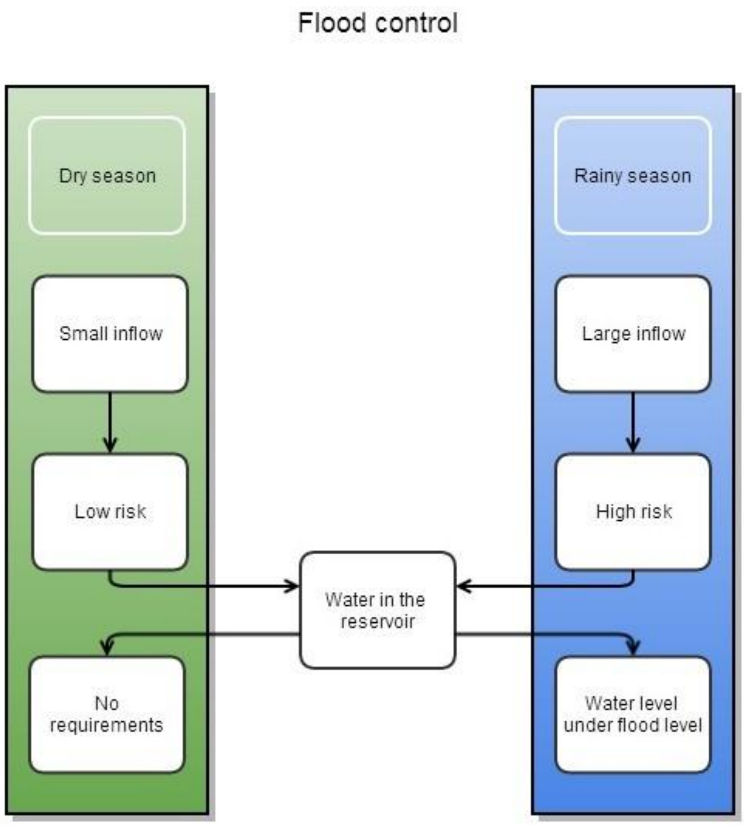

Figure 16: Flowchart about discharge scheme flood control.

Water Supply

For centuries people use the land for agriculture. The most important factor for growing crops is the available amount of water. To have sufficient water for agriculture people started to live along the river. With the growth of the population the food consumption also increased, thus the production had to increase as well. The people started to build irrigation systems to attract water out of the river and bring it further inland.

Another water demanding branch is the domestic use and industry, which has grown massively the last century. The water for the industry is for example used for cooling of machines and washing of products.

After the construction of the dams, the amount of water can be regulated; this changed the discharge of the river and thereby influenced the irrigation systems. In the rainy season the amount of water stays large, which means that the fields are still flooded. This can be seen as a negative influence, because the field cannot be used for agriculture, but the floods are important to restore the amount of nutrients. In the dry season the discharge of the river can be enlarged, which opens the opportunities to grow water intensive crops (rice) and introduce new types of crops which demand a constant amount of water. Of course, this can be beneficial for the agricultural economy, but the land use is more intensive and people rely on the discharge of the dam, which is limited. This can lead to future conflicts.

The construction of dams causes huge changes in water usage. The daily required amount of water has increased where the local irrigation systems remained the same. Efficiency of water supply has decreased because the deficit of water is smaller. An optimisation of the irrigation system could decrease the required amount of water needed for agriculture. Solutions like night reservoirs (a small local reservoir which can collect the water during the day and distribute water when needed) can be used to collect spilled water.

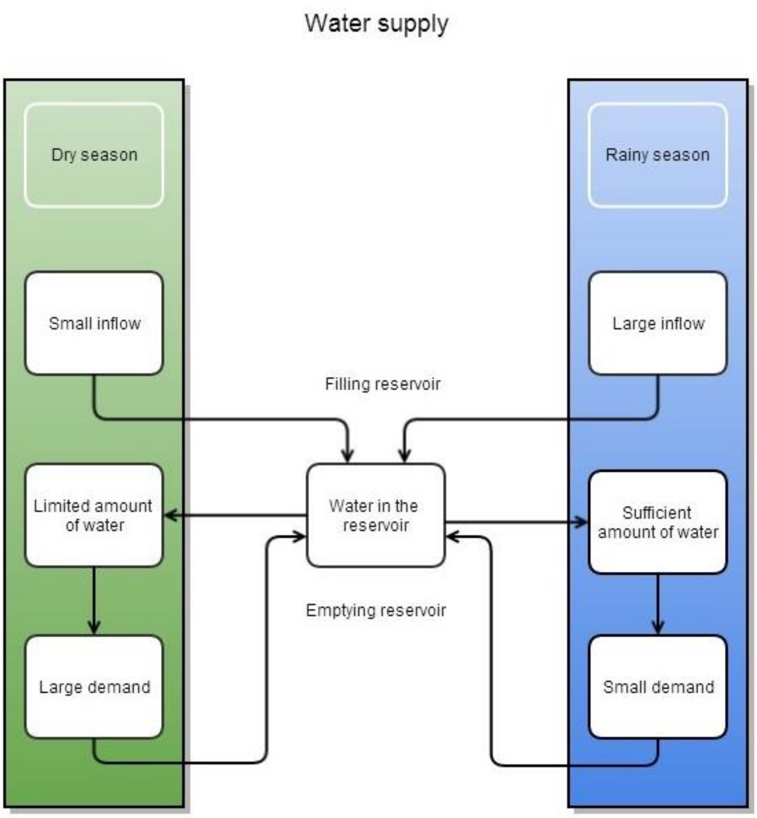

Figure 17: Flowchart about discharge scheme water supply.

Salt intrusion

Similar to the irrigation, the dams upstream have a large influence on the salt intrusion. In the rainy season, the discharge of the river is large enough to keep the salty water in the lagoon, but in the dry season, when there is less precipitation, the discharge of the river is also low. With a low flow velocity, the denser salty water starts to flow from the lagoon into the river see Figure 18. With the changes in precipitations every year it is difficult to determine how far upstream the salt wedge will reach. Due to the dams the discharge of the rivers can be regulated to keep the salt wedge at a certain location. The salty water is a big problem for growing crops; at places where the amount of dissolved salt is too high, the crops will die. Strangely, the biggest threat is irrigation in combination with the drought. When too much water from the river is used for irrigation, the river becomes weaker and salt intrusion appears. The Thao Long dam has been made to reduce salt intrusion, but without a sufficient discharge the structure is useless.

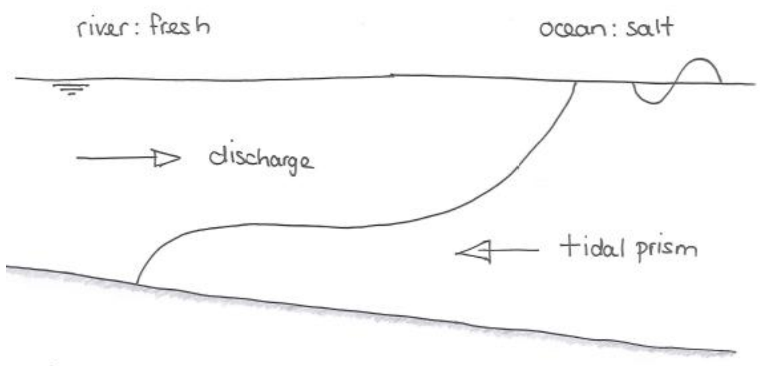

Figure 18: Sketch of process salt intrusion.

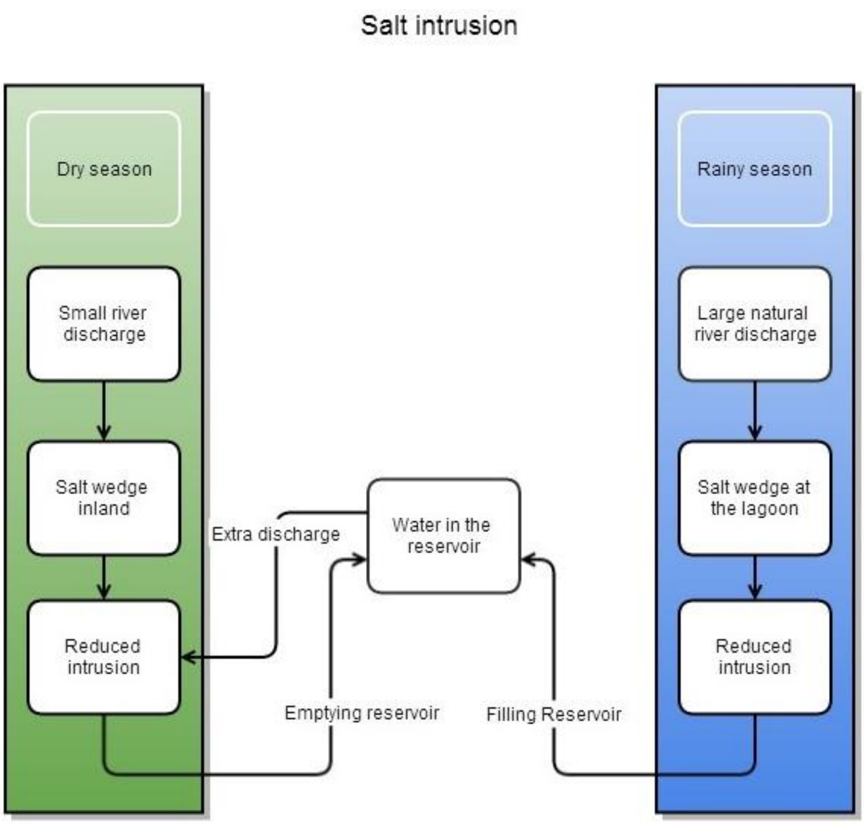

Figure 19: Flowchart about discharge scheme against salt intrusion.

5.3 Present regulation of the Binh Dien dam

The way in which a reservoir is managed is determined, on one hand, by the flow of water into the reservoir, and on the other hand by the functions of the reservoir. In this paragraph an overview of the main functions and their corresponding requirements of the Binh Dien dam are given, without the presence of the Ta Trach dam, since this one is still under construction. The reservoir volume over time is calculated for an average year between 1979 till 1999. To be able to make these calculations, the main functions are expressed in a qualitative way, which are derived from a literature study. The main functions are: hydropower, flood control, water supply and salt intrusion (regulation), as discussed in paragraph 5.2.

Main functions

- Hydropower

The Binh Dien hydropower company has set some goals to generate hydropower. They want to ensure a flow of 22 m3/s during 90% of the time throughout the year and the maximum capacity is 72 m3/s (Binh Dien Hydropower JSC, sd).

- Flood control

For the function of flood control 70 million m^3 of reservoir storage capacity is reserved in the rainy season in case of large flows into the reservoir. During the dry season this requirement is not necessary due to the distinct character of the dry and rainy seasons (Binh Dien Hydropower JSC, sd).

- Water supply

Water needs to be supplied to the region for different purposes. The purposes that are interesting for this research are the ones that extract water from the river systems, these are:

- Domestic uses
- Irrigation
- Industry

The Hue region counts 3 domestic water treatment plants, which all extract their water from the Huong river, (Cat, 2011) & (Lieu). The irrigation and industry sector extract their water directly from the Huong river, since no additional requirements for the water quality are needed.The water requirements are given in Table 6.

Table 6: Water supply requirements for the Binh Dien dam, based n Cat, 2011.

	Dry season [Mm^3]	Rainy season [Mm^3]	Total [Mm^3]	Percentage of total [%]
Domestic	8.9	4.4	13.3	4.0
Irrigation	297	13	310	95.4
Industry	1.2	0.6	1.8	0.6
Total	307	18	325	

- Salt intrusion

Salt intrusion is a problem in the lower areas of the Huong river since it penetrates too far into the river under variable tide and river discharge, creating problems for the agriculture industry. Maintaining a sufficient river discharge by using reservoirs can solve this problem. The required discharge is not a straightforward given fact, but needs to be determined with complicated formulas. This is already done by Cat (2011), which resulted in a minimum discharge of 25 m^3/s during the dry season. Since the natural discharge through the river mouth is much higher in the rainy season, there are no requirements in this season.

To summarize, the requirements for the four main functions are given in Table 7 below.

Table 7: Requirements for the main functions of the Binh Dien dam.

Type	Requirement	Value	Unit
Hydropower	Ensure flow (dry season)	22	m^3/s
	Maximum flow (rainy season)	72	m^3/s
Flood control	During dry season	0	m^3
	During rainy season	70.0	Mm^3
Water supply	During dry season	307.1	Mm^3
	During rainy season	18.0	Mm^3
Salt intrusion	During dry season	25	m^3/s
	During rainy season	0	m^3/s

Reservoir restrictions

The reservoir has a maximum and a so-called dead storage capacity. In case the reservoir capacity reaches the maximum, all excess water is released over the spillway and in case the reservoir reaches the dead storage capacity, no more water can be discharge out of the reservoir. The requirements for flood control basically impose an extra restriction to the maximum storage capacity of the reservoir during the rainy season, since 70 million m^3 of storage capacity has to be reserved during the entire rainy season in case of floods. See Table 8 for these restrictions. This has also been visualised in Figure 20.

Table 8: Binh Dien storage volume restrictions.

Type	Requirement	Value [Mm^3]
Maximum storage capacity	Year-round	423.68
Dead storage capacity	Year-round	79.29
Flood control	Dry season	0
	Rainy season	70.00

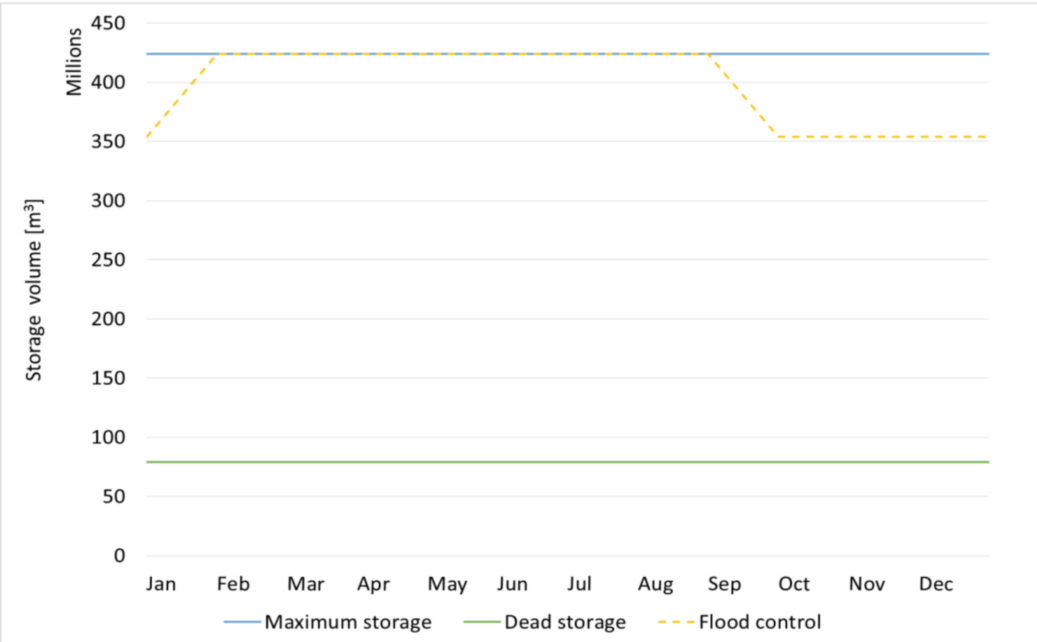

Figure 20: Figure 10: Binh Dien storage volume restrictions.

Flow into the reservoir

The flow of water into the reservoir originates from precipitation upstream of the dam. Daily precipitation data from 1979 till 1999 at approximately the location of the Binh Dien reservoir is available for this project and will be used to estimate water flow into the reservoir, see Figure 21 for the average daily precipitation for 1979 till 1999.

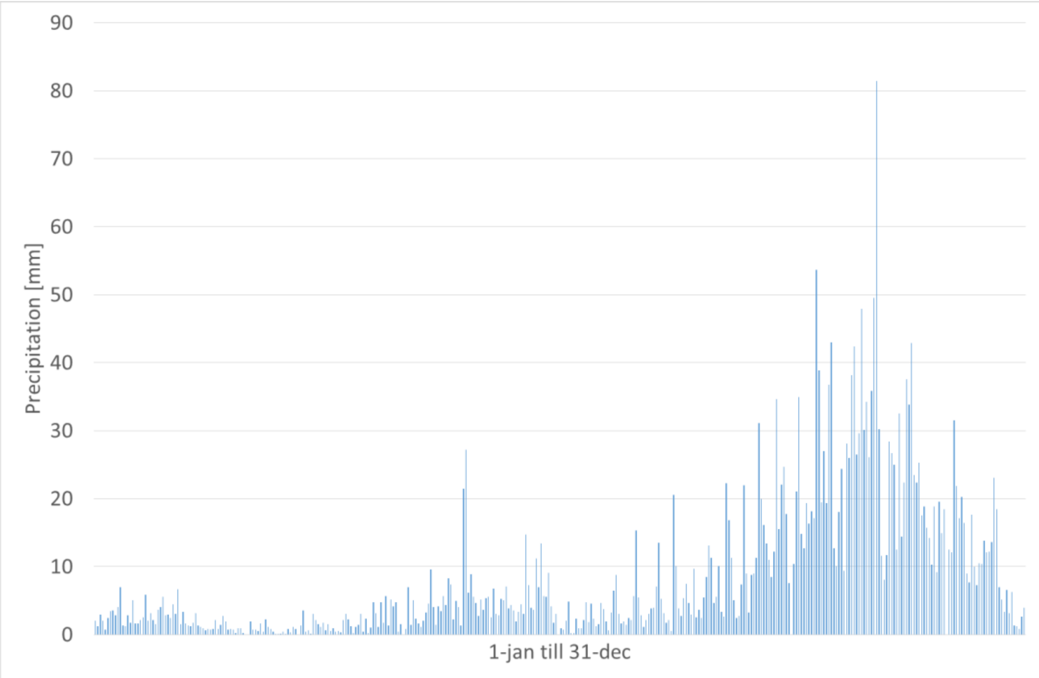

Figure 21: Average daily precipitation for the period 1979 – 1999, Binh Dien catchment area (WRU,2013).

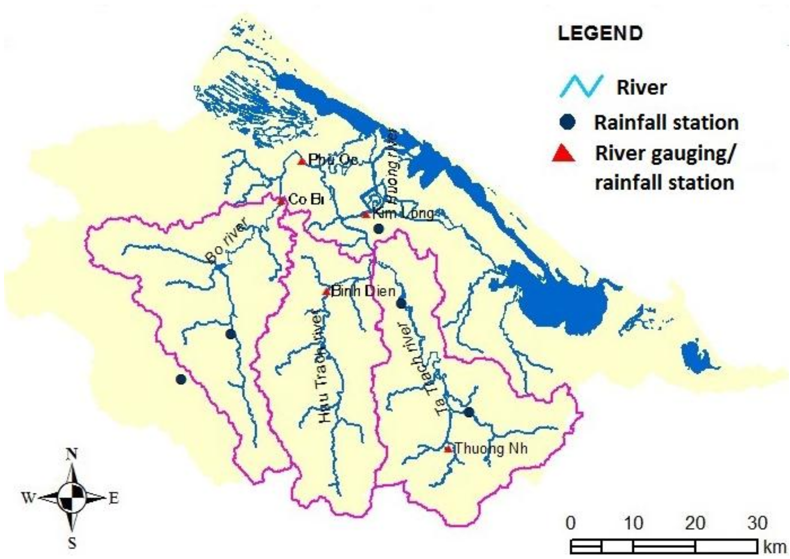

Figure 22: Location of the rainfall stations.

To translate the average daily precipitation data into a discharge flowing into the reservoir over time, an extensive runoff model of the catchment area is needed. Since the use of such a model is out of the scope of this research, two simple assumptions are made:

- The recorded precipitation at the Binh Dien rainfall station (see Figure 22) is representative for the entire catchment area upstream of the Binh Dien dam;
- All precipitation will eventually flow into the reservoir.

The first assumption allows for the precipitation data to be multiplied with the catchment area (515 km^2), as to arrive at a daily precipitation in m^3 for entire catchment area.
The second assumptions states that this is representative for the discharge into the reservoir. But the daily precipitation in m^3 cannot be directly translated in a daily discharge in m^3/day, since the time needed for runoff to reach the reservoir is in the order of hours to days. Or, in other words, precipitation will result in a gradual discharge of water into the reservoir. This can be clarified by the fact that there are enough days where no precipitation falls at all, but the runoff into the reservoir never stops completely. Because of this, the daily precipitation (in m^3) is summed to monthly precipitation data, and is assumed to be representative for the monthly discharge of water into the reservoir (in m^3/month). This is done due to the fact that a month is far larger than the runoff time, which is in the order of hours to days. Summing the daily data to monthly data represents a loss of information, i.e. extremes (high and low) in discharges during the month are lost. This needs to be kept in mind in order to make valid conclusions.

An average discharge for each month over the period 1979 – 1999 is given in Figure 23.

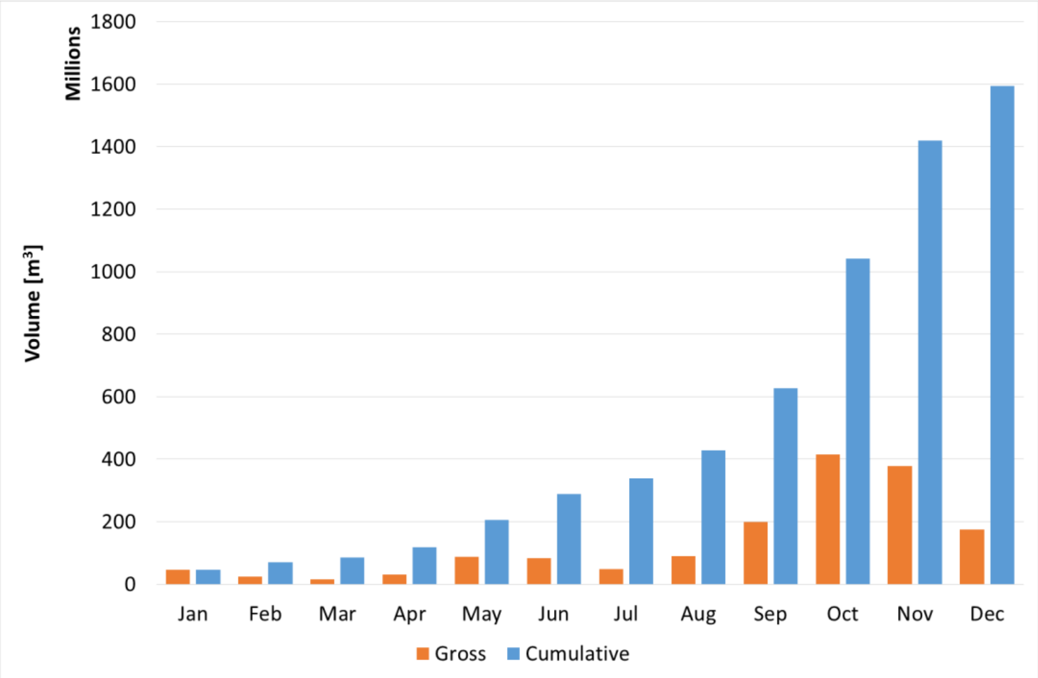

Figure 23: Flow into the Binh Dien reservoir.

Flow out of the reservoir

The flow of water out of the reservoir is determined by the main functions of the dam. For now, it is assumed that all the requirements from Table 7 will be applied. Since the precipitation data is transferred to monthly data, the same will be done for the hydropower and salt intrusion requirements, which are given in m^3/s. The water supply requirement is given in m^3 for the entire season, and it is assumed that this can be evenly distributed over the months, see Table 9 and Figure 24.
The flood control requirement cannot be expressed in a discharge out of the reservoir, since it is actually a requirement to reserve reservoir capacity in case of a flood, and has already been treated separately.

Table 9: Requirements for the main functions of the Binh Dien dam.

Type	Requirement	Value [Mm^3/mnd]
Hydropower	Dry season	57.0
	Rainy season	186.6
Water supply	Dry season	38.4
	Rainy season	4.5
Salt intrusion	Dry season	64.8
	Rainy season	0

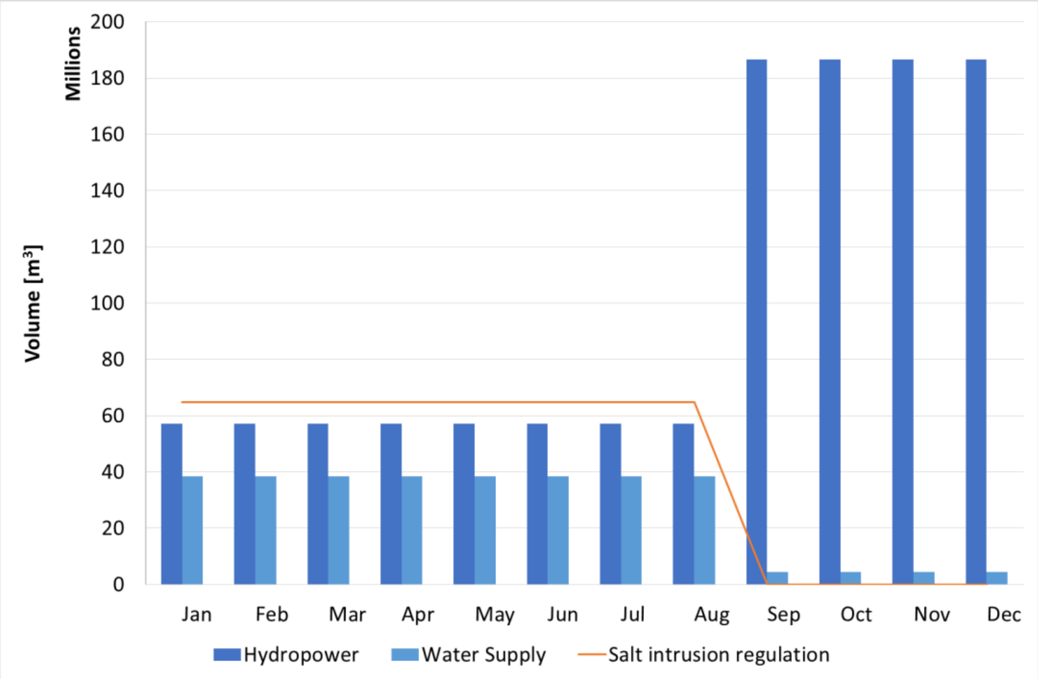

Figure 24: Requirements for the main functions of the Binh Dien dam.

The salt intrusion requirement is represented as a line in Figure 24, since it is a requirement that can also be fulfilled by the discharge for hydropower. Discharging for hydropower will naturally also result in a higher river discharge. Discharge for water supply, on the other hand, does not contribute to a higher river discharge, since this volume of water will be extracted from the river downstream of the dam.

In the same way as for the flow of water into the reservoir, a monthly flow out of the reservoir can be constructed from Figure 24, see Figure 25.

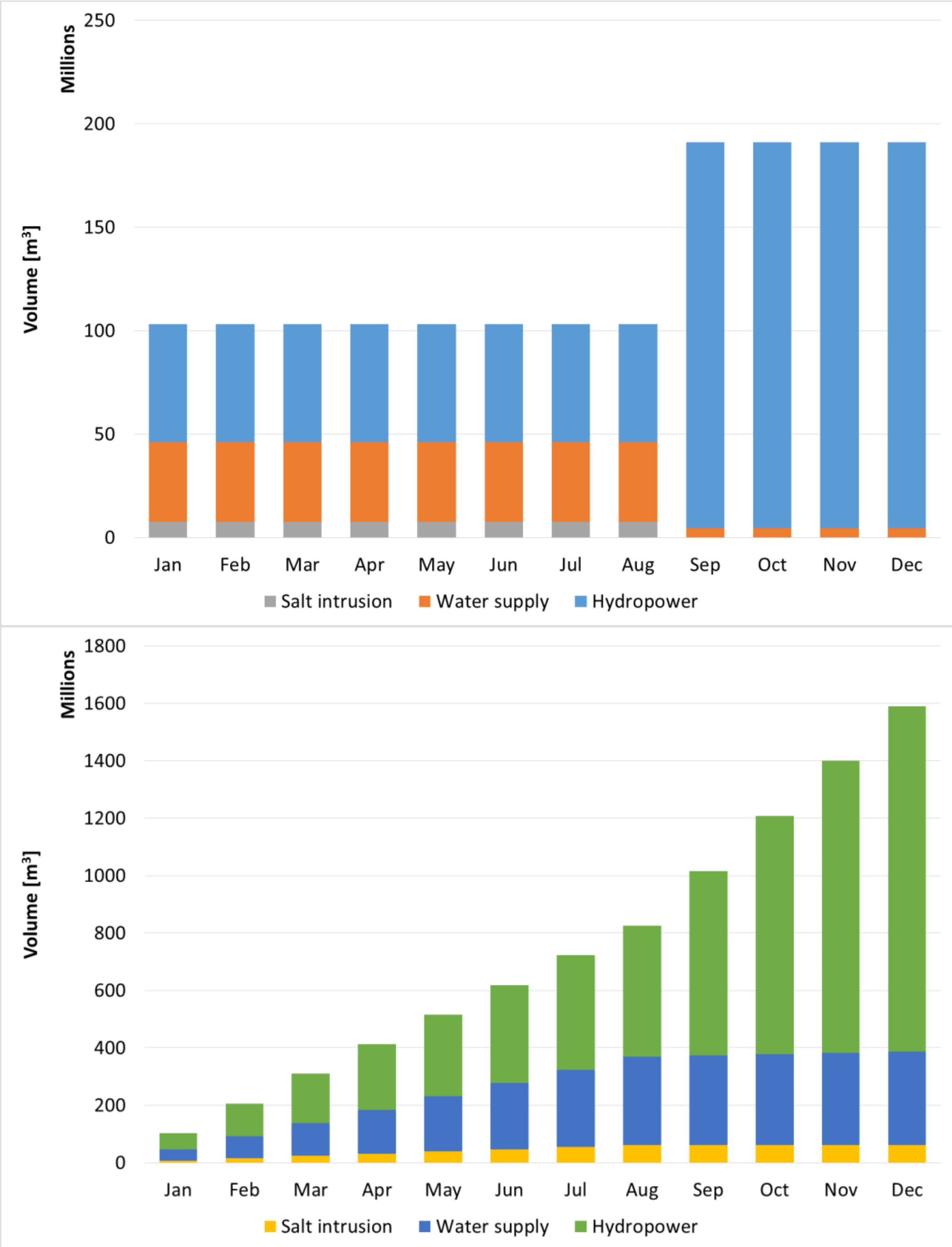

Figure 25: Gross (above) and cumulative (below) flow out of the Binh Dien reservoir.

Net flow in/out of the reservoir

Combining Figure 23 and Figure 25, a net flow in/out of the reservoir can be constructed, see Figure 26. Negative net values mean that more water needs to be discharged out of the reservoir than there flows into the reservoir in that month, and vice versa.

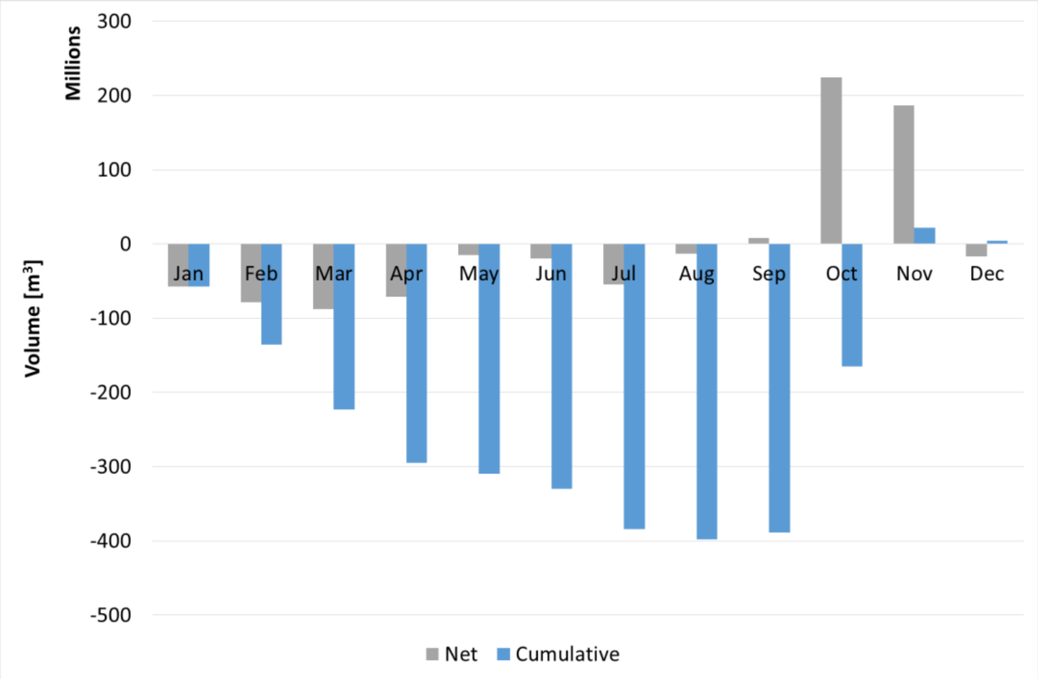

Figure 26: Flow in/out of the reservoir.

From Figure 26 it can be clearly seen that during the entire dry season the net flow in/out of the reservoir is negative (i.e. more water flows out of the reservoir than in). During the first 3 months of the rainy season this is the other way around and in a much more exaggerated way. In the last month of the rainy season already a little shortage can be observed.

From the same figure the minimum volume of water that needs to be stored in de rainy season and released during the dry season can be read. This amounts to about 400 million m^3 (cumulative flow in August). Already a problem can be noticed at this stage, since the effective storage capacity (maximum storage minus dead storage, see Table 8) is less than 400 million m^3.

The storage volume restrictions from Figure 20 can be applied to the cumulative flow in/out of the reservoir from Figure 26, basically combining the two figures in one. For this, one additional assumption had to be made; what is the reservoir volume at t=0? In this case t=0 is at the first of January, the beginning of the dry season. In this report, it is assumed that the reservoir is at its maximum capacity at t=0 (taking into account the flood control requirement, see the dotted line in Figure 20), see Figure 38.

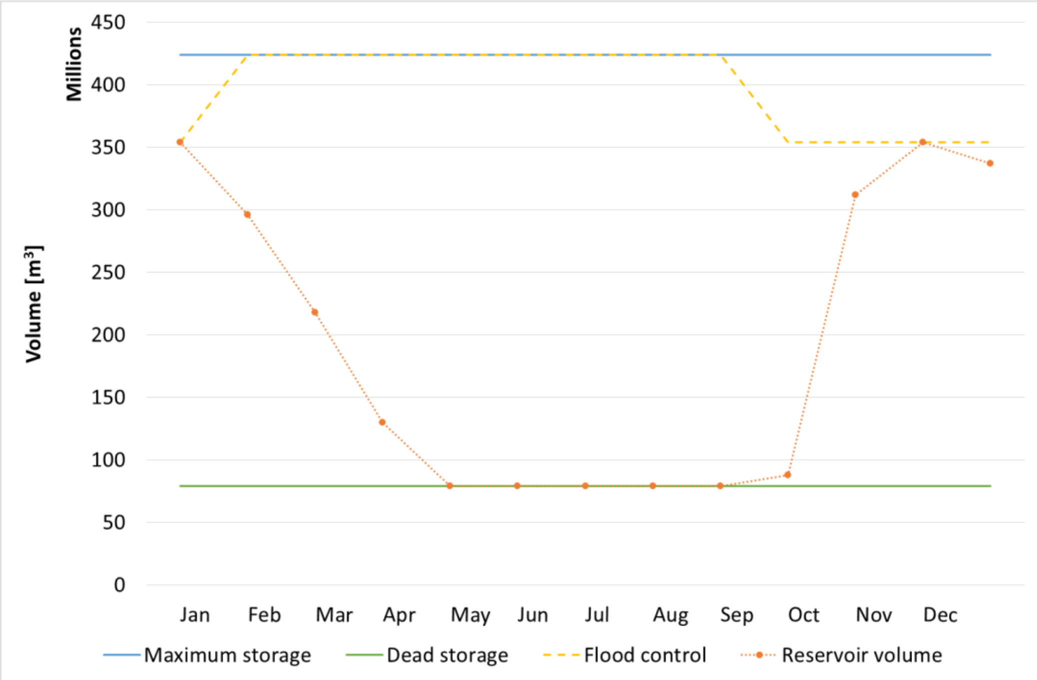

Figure 27: Binh Dien reservoir storage volume.

From Figure 27 it is clear that if one wants to satisfy the requirements following from the main functions, conflicts arise in the management of the reservoir volume. With the current goals and the made assumptions the reservoir will be empty approximately at the end of April, resulting in the fact that it cannot carry out its functions. Water will have to flow over the spillway during the rainy season. Because of these restrictions, the discharge will be different from the set goals in Figure 25, see Figure 28 for the actual discharges.

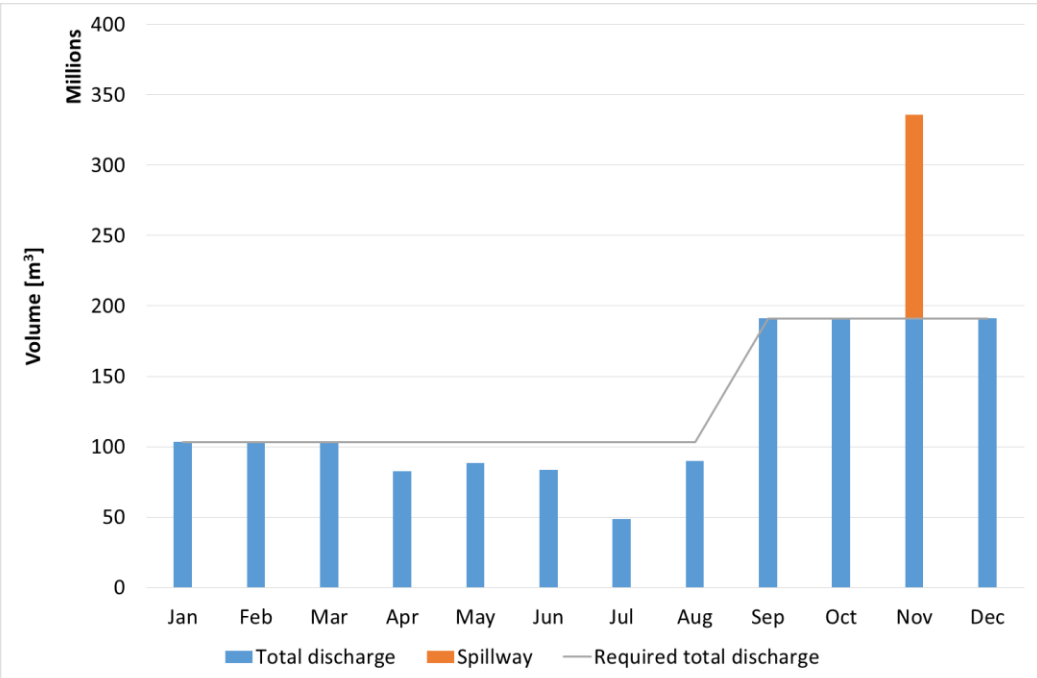

Figure 28: Actual discharge out of the Binh Dien reservoir.

During the months April to August, concessions have to be made in at least one of the requirements. Usually this results at least in neglecting the flood control requirement (which increases the potential output for hydropower generation, increasing revenues), which increases the risk of flooding downstream, but with the result that the reservoir volume at the beginning of the dry season will be larger and more water is available until the rainy season starts again. Hydropower, on the other hand, is the function that at present is utilized most, since it generates the most profit compared to the other functions. The reservoir volume over time, without the flood control requirement, is shown in Figure 29.

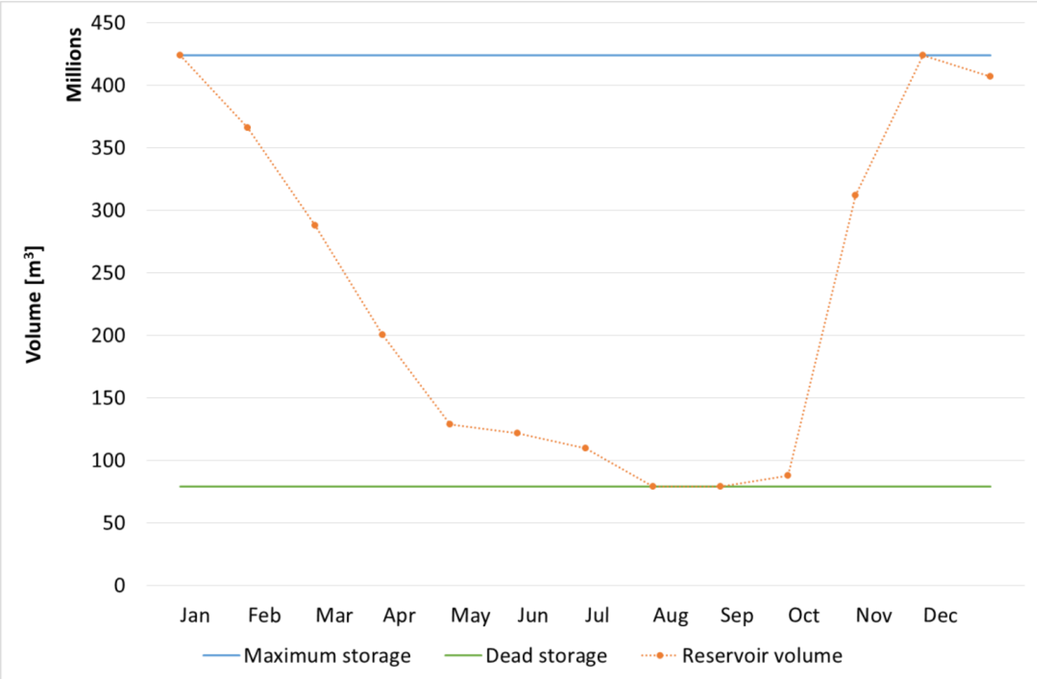

Figure 29: Binh Dien reservoir storage volume without flood control.

5.4 Advice for future regulation of the Binh Dien & Ta Trach dams

In the same way as for the Binh Dien dam, the (future) regulation of the combined reservoirs is analysed on basis of main functions of both dams and the corresponding requirements. This analysis is useful, since both dams will have to cooperate in the future, as discussed before. Most of the discussion from the previous chapter will not be repeated here, so mostly tables and figures will be presented. First the reservoir restrictions and the flow into the reservoir for the Ta Trach dam are given, see paragraph 5.3 for the Binh Dien dam.

Reservoir restrictions (Ta Trach)

Table 10: Ta Trach storage volume restrictions.

Type	Requirement	Value [Mm^3]
Maximum storage capacity	Year-round	646.0
Dead storage capacity	Year-round	73.4
Flood control	Dry season	0
	Rainy season	435.9

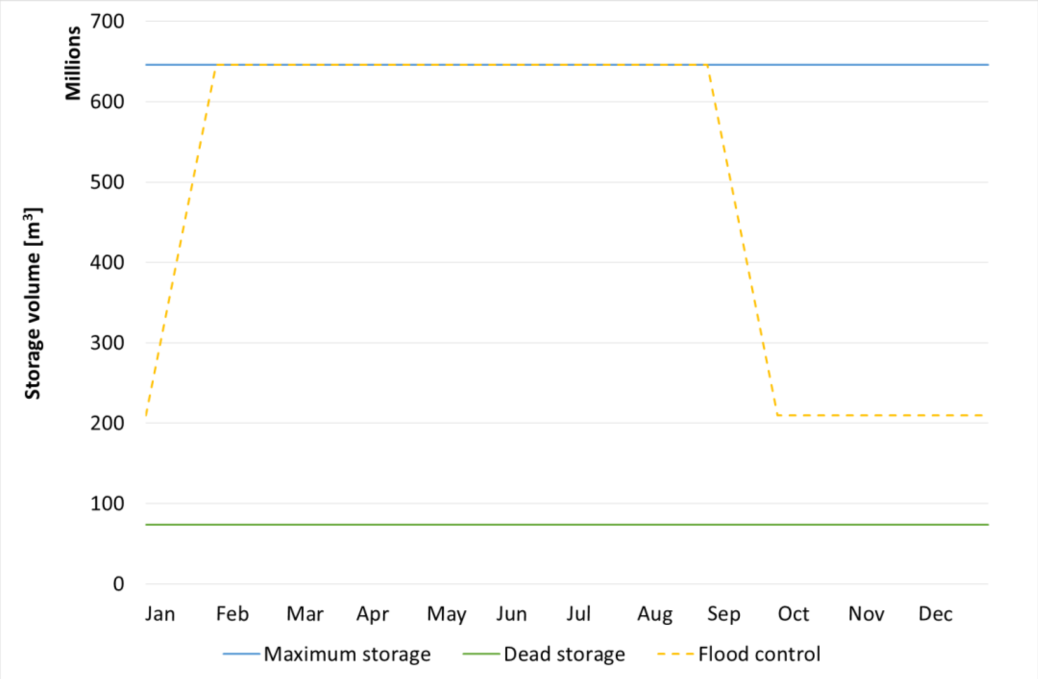

Figure 30: Ta Trach storage volume restrictions.

Flow into the reservoir (Ta Trach)

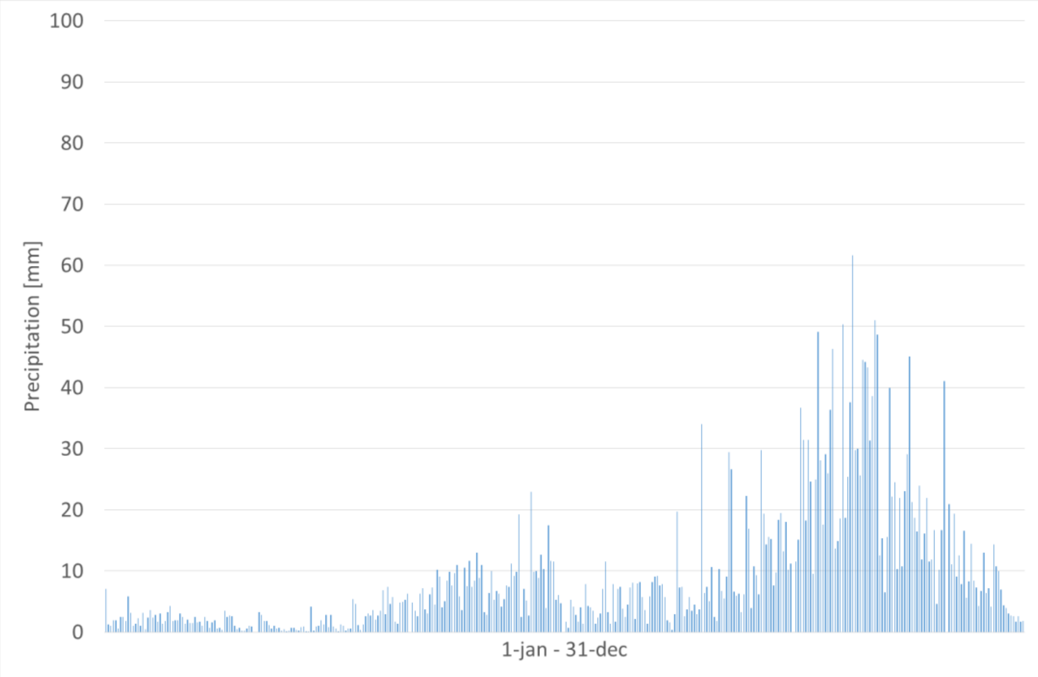

Figure 31: Average daily precipitation for the period 1979 – 1999, Ta Trach catchment area.

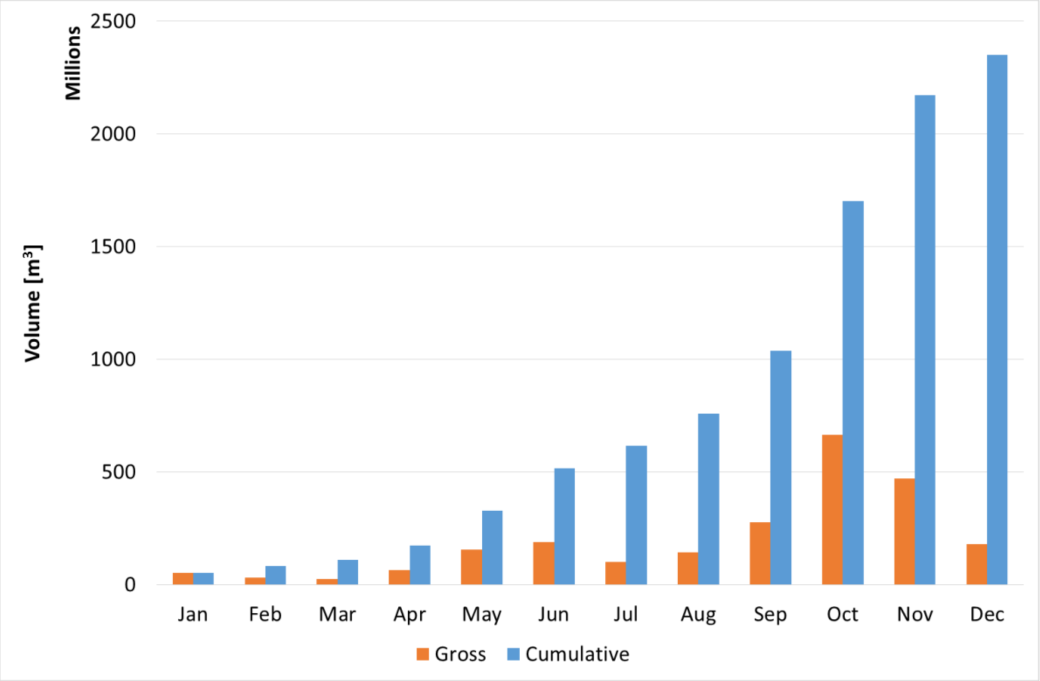

Figure 32: Flow into the Ta Trach reservoir.

Main functions

- <u>Hydropower</u>

Figures for the hydropower requirement are not straightforwardly available, and are estimated on the basis of some simple calculations. The maximum discharge for hydropower has been calculated by:

$$P = c \cdot Q \cdot H$$

In which,	P = Power installed	[kW]
	Q = Discharge	[m^3/s]
	H = Average water column	[m]

The constant c has been estimated with the Binh Dien parameters giving a value of c = 8.66. With a water column of 45 m and the installed generator good for 18 MW, the maximum discharge of the Ta Trach dam for hydropower is 46 m^3/s. Since the main functions of the Ta Trach dam are those of flood control and water supply, it is assumed that no minimum discharge for hydropower generation is required. For the hydropower function of the Binh Dien dam, see paragraph 5.3.

- <u>Flood control</u>

The requirements for flood control of the Ta Trach dam are basically the same as for the Binh Dien dam, but with different values. For the flood control function of the Binh Dien dam, see paragraph 5.3.

- <u>Water supply</u>

Since the Ta Trach dam is still under construction, and will have to operate for many years into the future, the requirements for water supply are based on predictions for 2020 made by Cat (2011). These are the total requirements for both the Binh Dien and the Ta Trach dams. An extra requirement for the water supply function is the aim to provide the aquaculture industry in the lagoon with the necessary amount of water, and to simultaneously improve the environment of the lagoons.

- Salt intrusion

The requirement for salt intrusion is a general one, and is the same as in paragraph 5.3.

Table 11: Water supply requirements.

	Dry season [Mm^3]	Rainy season [Mm^3]	Total [Mm^3]	Percentage of total [%]
Domestic	29	14.3	43.3	7.8
Irrigation	328	12	340	61.4
Industry	16	8	24	4.4
Aquaculture	0	146.3	146.3	26.4
Total	373	181	554	

Source: (Cat, 2012)

Table 12: Requirements for the main functions of the Binh Dien and Ta Trach dams.

Type	Requirement	Value	Unit
BD Hydropower	Ensure flow (dry season)	22	m^3/s
	Maximum flow (rainy season)	72	m^3/s
BD Flood control	During dry season	0	m^3
	During rainy season	70	Mm^3
TT Hydropower	Ensure flow (dry season)	0	m^3/s
	Maximum flow (rainy season)	46	m^3/s
TT Flood control	During dry season	0	m^3
	During rainy season	435.9	Mm^3
Water supply	During dry season	373.0	Mm^3
	During rainy season	180.6	Mm^3
Salt intrusion	During dry season	25	m^3/s
	During rainy season	0	m^3/s

Downstream reservoir restrictions

One of the main reasons that floods occur in the Hue region is due too extreme discharges through the Huong river. Implementing a maximum on the discharges out of the Binh Dien and Ta Trach dams may thus reduce the risk of floods.

Due to a lack of information of the Huong river some assumptions have been made to calculate the maximum allowed discharge in the Huong river. The only available discharge data available is from the Thuong Nat gauging station (seeFigure 22). This station is far upstream (circa 50 km) on the Ta Trach branch of the river. Because it was the only available data, it has been chosen to assume that a large discharge at this station is equal to a large discharge downstream in the city of Hue. With the number of floods during a year known, it was possible to indicate the discharges at Thuong Nat belonging to a flood. With this method it was also possible to find the highest discharge in a year that did not lead to a flood. For example, if there are 3 floods in a year, there was searched for the 4th cluster of high discharges. In this manner the values for the year 1981 till 1999 are estimated. Although the values of the flood discharges at Thuong Nat are available, a transformation has to be applied to determine the values belonging to the Ta Trach and Binh Dien reservoir. It has been assumed that the distribution of water in the region only depends on the catchment area. This gives the values as described in Table 13. Translated to monthly averaged values, the values become as described in Table 14.

Table 13: Estimated river discharges by their catchment area.

	Catchment area [m^3]	Q max, no flood [m^3/s]
Binh Dien	515	190
Ta Trach	717	260
Thuong Nat gauging station	208	76,5

Table 14: Maximum river discharges.

	[Mm^3/mnd]
Binh Dien	490
Ta Trach	670
Total	1160

Flow out of the reservoir (Binh Dien & Ta Trach)

Table 15: Requirements for the main functions of Binh Dien & Ta Trach dams.

Type	Requirement	Value [Mm^3/md]
BD Hydropower	Dry season	57.0
	Rainy season	186.6
TT Hydropower	Dry season	0
	Rainy season	119.2
Water supply	Dry season	46.6
	Rainy season	45.2
Salt intrusion	Dry season	64.8
	Rainy season	0

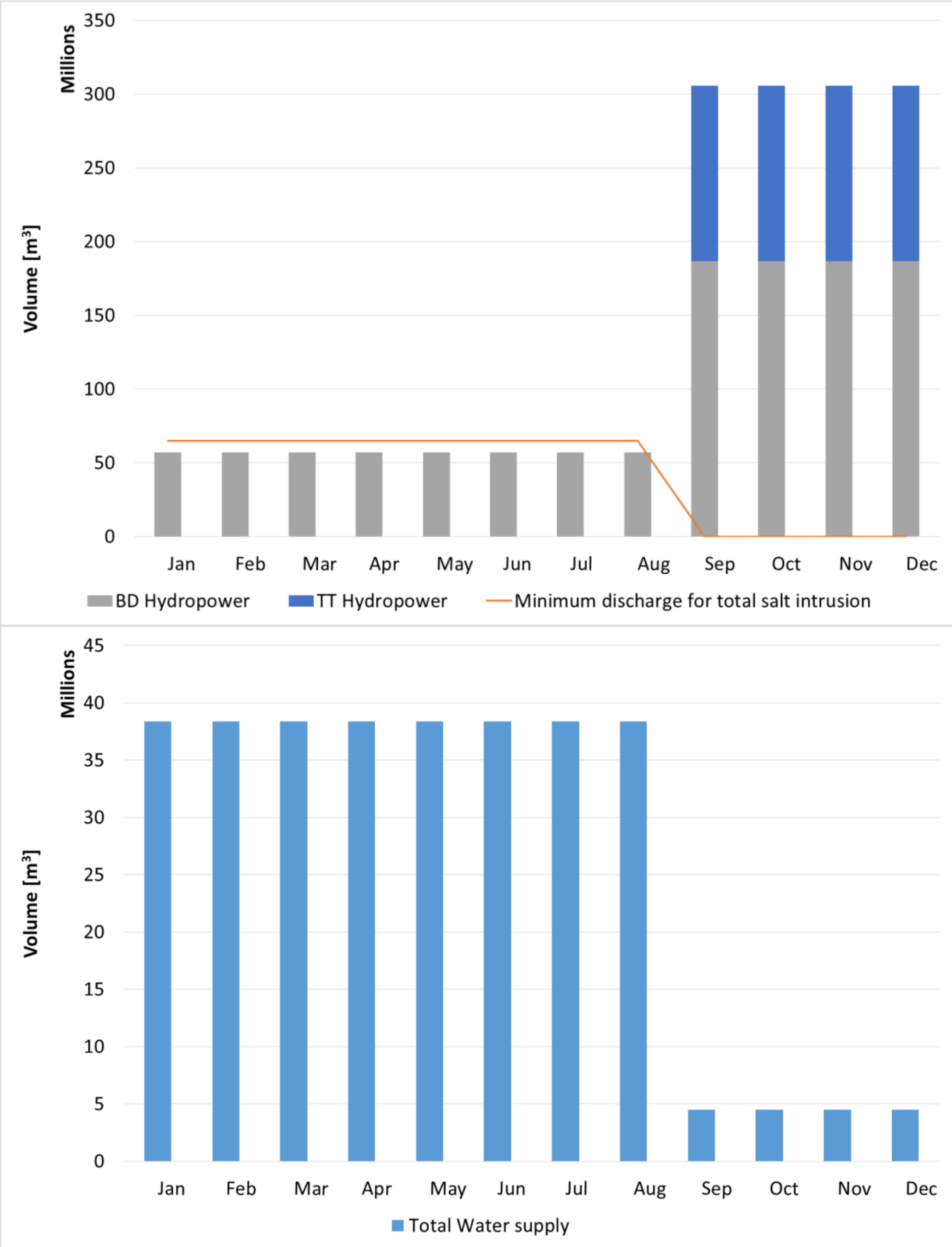

Figure 33: Requirements for the main functions of the Binh Dien & Ta Trach dams.

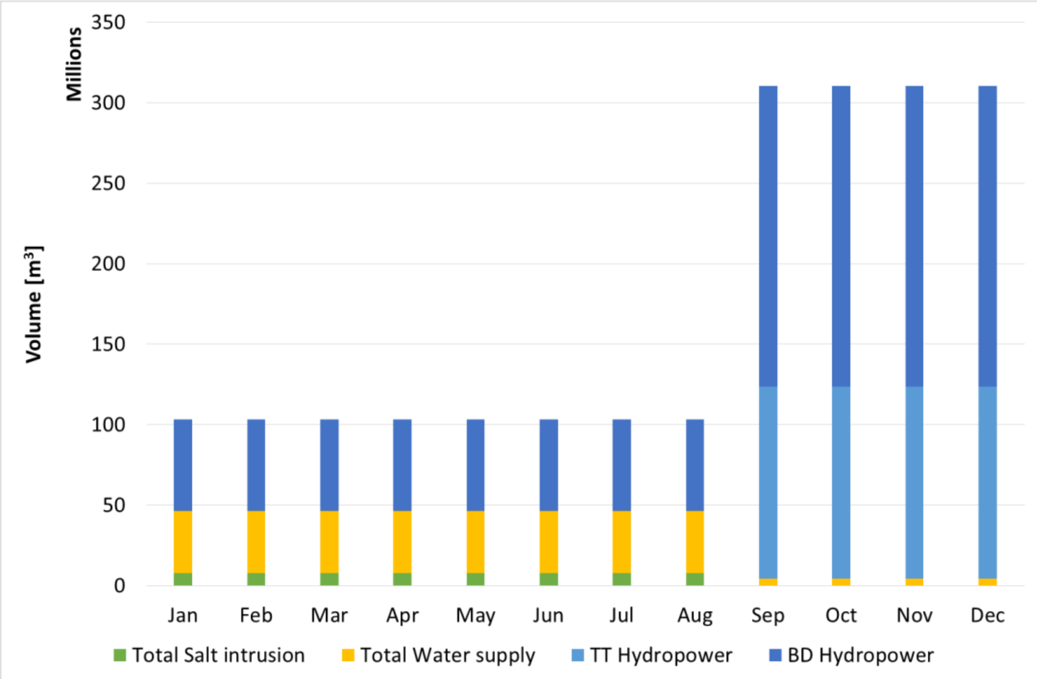

Figure 34: Gross flow out of the Binh Dien & Ta Trach reservoirs.

Net flow in/out of the reservoir

To calculate the net flow in/out of both reservoirs, decisions have to be made on how the two dams interact with each other. Specifically, the water supply and salt intrusion are total requirements for both dams, and a distribution over the two dams has to be made. With the concept that the Ta Trach is mainly constructed for flood control and water supply, two scenarios have been developed. On the basis of these two, four additional scenarios have been developed, see Table 16.

Table 16: Overview of scenarios.

Scenario	
1	50% of water supply and salt intrusion from the Binh Dien reservoir 50% of water supply and salt intrusion from the Ta Trach reservoir
2	0% of water supply and salt intrusion from the Binh Dien reservoir 100% of water supply and salt intrusion from the Ta Trach reservoir
3	Based on scenario 2, with extra hydropower generation
4	Based on scenario 3, with a flood control requirement based on a flood wave volume with a return period of 1 year
5	Based on scenario 3, with a flood control requirement based on a flood wave volume with a return period of 3 years

The 1st scenario aims to fulfil all requirements from Table 12, with 50% of the total amount of discharge for water supply and salt intrusion coming from the Binh Dien reservoir and 50% from the Ta Trach reservoir. The 2nd scenario has a distribution of 0 / 100% (Binh Dien / Ta Trach).

The 3rd scenario is based on the second scenario, while trying to maximise hydropower output. The 4th and 5th scenarios are based on the fact that it is statistically not known how much reservoir capacity should be reserved for flood control. Until now, it was assumed that the figures given by the dam owners are sufficient for the flood control requirement, but as stated before, dams have been known to worsen floods. For that reason the required flood control capacity for each month has been calculated with respect to a certain safety level.

The calculation is based on the highest consecutive rainfall for each month, in the period from 1979 till 1999. The highest flood volumes have been plotted as in Figure 35 for each month. Figure 35 is specifically for January. The same has been done for the other months, see Appendix B for a more detailed description.

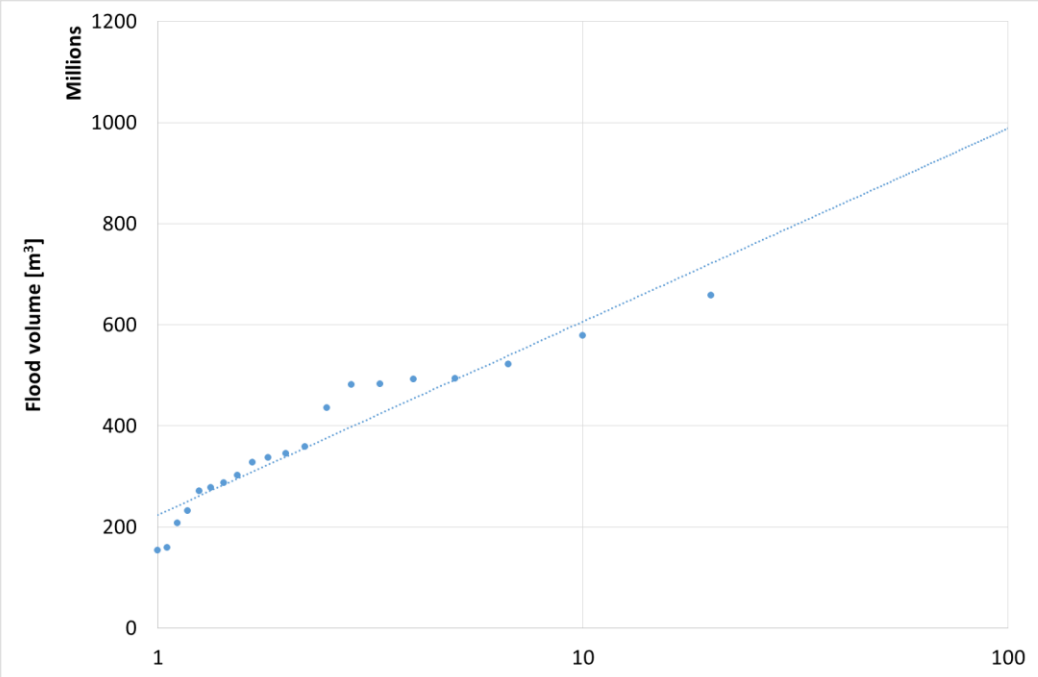

Figure 35: Flood volume per year with the return period.

Scenarios 4 and 5 are based on scenario 3 with a flood control requirement based on the above described calculation with a return period of 1, 3 and 5 years respectively (see Appendix B).

The scenarios are discussed on the next pages, with just some of the figures presented for clarification. The rest of the figures for each scenario can be found in Appendix B.

Scenario 1

With 50% of the discharge for water supply and salt intrusion coming from the Binh Dien reservoir, it appears that in an average year the capacity is enough to fulfil all requirements. At the end of December, however, the reservoir is not completely filled, making the assumption of a full reservoir at t=0 not entirely correct.

The Ta Trach reservoir on the other hand, has a surplus of water during the entire dry season, resulting in a full reservoir at the beginning of the rainy season. This has as a consequence that large amounts of water have to be discharged out of the reservoir to satisfy the flood control requirement. The average discharges in the months September and October exceed the maximum as specified in Table 14, resulting in a high risk of floods. To counteract this, the redundant amount of water should be gradually discharged prior to the rainy season.

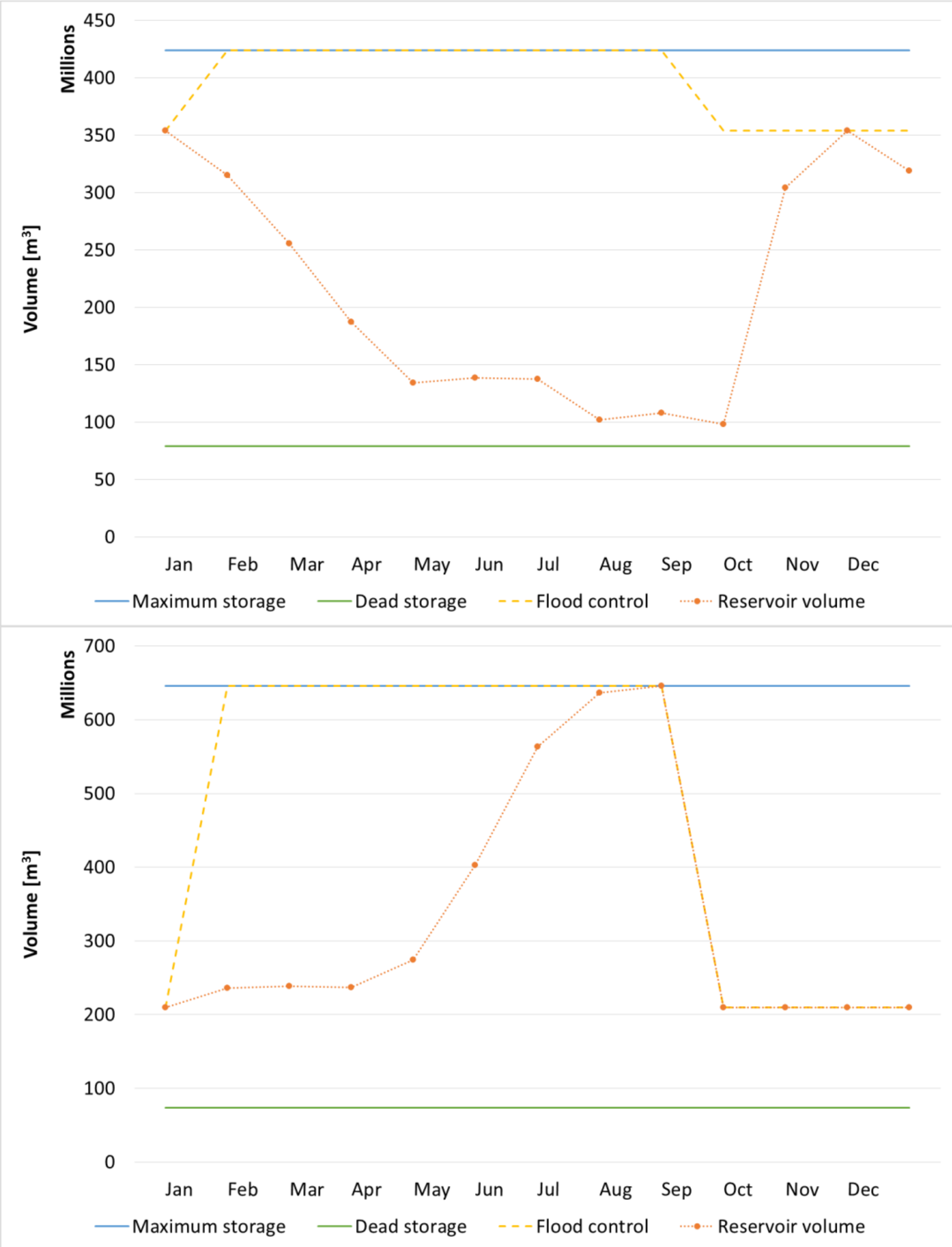

Figure 36: Binh Dien (above) and Ta Trach (below) reservoir storage volumes, scenario 1.

Scenario 2

As can be expected from the results of the 1st scenario, the Binh Dien reservoir now has plenty of capacity during an entire average year, but this does not lead to unnecessary use of the spillway during the rainy season. In addition, the maximum discharge downstream is not exceeded.

The Ta Trach reservoir still has a surplus of water during the dry season as in scenario 1, although in a lesser degree. Again leading to high discharges during the rainy season.

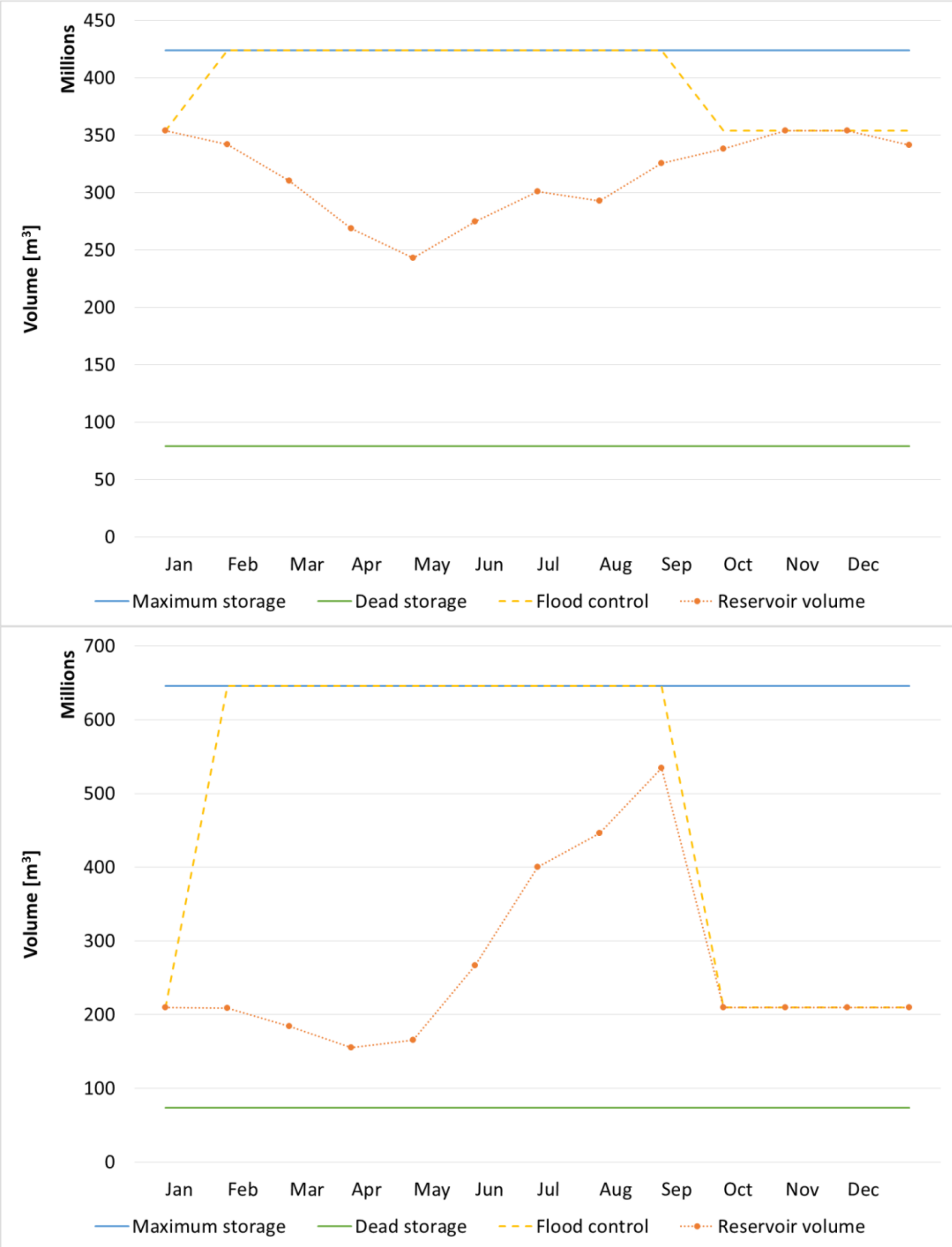

Figure 37: Binh Dien (above) and Ta Trach (below) reservoir storage volumes, scenario 2.

Scenario 3

In this scenario, based on scenario 2, the discharge for hydropower during the second half of the dry season (May till August) has been increased. The discharge for the Binh Dien dam has been increased to 45 m^3/s to make full use of the reservoir capacity during an average year. For the Ta Trach dam the discharge has been increased to the maximum of 46 m^3/s Table 12). This also increases the output for hydropower, but more importantly, decreases the reservoir volume from nearly full at the beginning of the rainy season, to nearly empty. Due to this, the spillway is not used in September, keeping the discharge downstream of the dam ample within the limits. However, no change can be seen in the discharge during the month October (see Appendix C), attributing the high discharge during this month entirely to precipitation upstream of the dam.

Scenario 4
This scenario uses the calculated requirements for flood control based on a return period of 1 year. The rest of the requirements are as described in scenario 3. It can immediately be noticed that the reserved capacity for flood control for the Ta Trach dam is much smaller than in the previous scenario. From this it can be concluded that the Ta Trach dam is either designed for the retention of floods with a higher return period (i.e. larger flood volumes), or that it also (partly) substitutes the flood control function of the Binh Dien dam. This last function allows the Binh Dien dam to largely discharge a flood wave instead of storing the water volume to gradually discharge it at a later stage.

On the other hand, the requirement for the flood control function of the Binh Dien reservoir seems to be larger than previously assumed. This confirms the fact that this dam was not designed for flood control. Applying this flood control requirement imposes a relatively large restriction on the reservoir capacity during October and November, resulting in very large discharges during these months, even exceeding the limits as determined in Table 14. On top of this, it also results in a not fully filled reservoir at the end of the rainy season. On the other hand, when a flood arrives in November, the reservoir volume will exceed the flood control line, and one would not empty the reservoir after the flood has past. Resulting in a full reservoir at the beginning of the dry season.

Scenario 5
The same requirements have been applied as in scenario 4, but now with a return period for the flood control requirement of 3 years. As can be seen from the results, the reservoir capacity that should be reserved for flood control in November for the Binh Dien dam is almost as large as the total reservoir capacity. This already indicates that this scenario is almost impossible to implement, because of very high discharges during the rainy season and a high probability that the reservoir will not be full at the end of the rainy season due to the high flood control restriction during the rainy season.
The flood control requirement for the Ta Trach dam in November is about the same as previously assumed in scenarios 1 till 3. Indicating that the Ta Trach is designed for a flood wave volume with a return period of about 3 years.

5.5 Discussion and implementation

The scenarios above have been made on the basis of monthly averaged precipitation from 1979 till 1999. This averaging gives a fair amount of uncertainty in the results, due to the following limitations:

- The flow into the reservoir is calculated directly from the precipitation data, without the use of a runoff model;
- The flow into the reservoir is only calculated as monthly averaged values, from 1979 till 1999, and consequently the outflow is also given as monthly averaged discharges;
- Extreme years are not taken into account (for example an extreme dry or wet year);
- Daily discharge data are not available, so the above scenario's cannot be (back)tested;
- Parameters for the input requirements have been mostly obtained from literature study and assumed correct.

Due to the limitations described above, care should be taken to state most conclusions in a qualitative, instead of quantitative, way.

In years when there will be more, or less, rain than in an average year, measures should be taken to distribute water and to provide more safety against floods. In years of less rain the reservoirs contain too less water after the rainy season, which results in the fact that the reservoirs cannot fulfil all the functions of hydropower, water supply and salt intrusion. In one of these three functions concessions should be made to distribute the present amount of water; strict guidelines should be presented about how to act in such a situation. In years with more rain than in the average year reservoirs have to discharge water during the rainy season, due to the filling of the reservoirs. This water is discharged into the Huong river, which could cause floods in the city of Hue. Measurements to prevent the city of Hue against floods include protecting the city by dikes or by construction a bypass around the city.

6. Conclusion and Recommendations

From the analysis of the current regulation of the Binh Dien dam it becomes clear that the dam cannot fulfil all the requirements set for hydropower, flood control, water supply and salt intrusion in an average year; let alone in very dry year. Even when neglecting the flood control requirement entirely, there is not enough water available for the remaining functions.

When the construction of the Ta Trach reservoir will be finished in the future, it appears that there will be enough water available during the entire dry season for water supply and salt intrusion (again in an average year), as long as the reservoir is full at the beginning of the dry season. The Binh Dien dam can then even be relieved from part of its current functions and generate more hydropower.

Concerning this last statement, three remarks can be made. The first is the implementation of the flood control function: the Ta Trach reservoir has the capacity for the retention of a flood wave with a return period of about 3 years, while the Binh Dien reservoir cannot. This means that the Binh Dien reservoir is the 'weakes link' and therefore governing for the safety.
The second remark is the amount of reservoir volume that should be reserved for flood control. The reservoirs have enough capacity reserved for a flood with a return period of 3 years, which means that the reservoir will be completely filled (statistically) every 3 years. In the remaining two years a lack of water will be present, since the reservoir is not completely filled at the end of the rainy season, and thus a lack of water will occur.
The last remark is the occurrence of a dry, respectively wet year. In a dry year the (combination of) reservoirs will certainly not be able to fulfil the requirements, while in a wet year an additional risk for flooding will be present due to emergency discharging of the reservoir.

For these, not average years, additional measures can be taken to reduce the impact. Possibilities are larger concessions towards water distribution, for which strict guidelines should be developed, or preventing damage during floods by heightening dikes or by creating an (emergency) bypass around the city.

Because of limited time and resources available, this research has been limited to indicating the opportunities of the dams and the associated challenges arising from assigning conflicting functions to the dams. To get into more detail and to be able to make quantitative conclusions, the following should be done in further research:

- Make use of (more up-to-date) measured discharges over time into and out of the existing dams or translate measured precipitation into discharges flowing into the reservoir with runoff models, which take into account runoff time, evaporation, etc.
- Research into the future function requirements should be made, to properly assess the discharge requirements of the reservoir over time;
- The implementation of the functions should be tested on at least daily averaged values and over several years, to take into account all the extremes that can occur during and between years;
- The discharges following from the imposed functions should be put into a (1D) hydrological model, to assess the influence of the changed discharge regime on the downstream area. This should be done for all reservoirs influencing the Huong river;

- Effects from climate change on future discharge schemes should be taken into account;
- Other dam and reservoir related problems should be analysed, including their effect on the functioning of the dam should be determined, such as, but not limited to: changing runoff characteristics, reservoir sedimentation, soil erosion in the downstream river due to changing discharge regimes, influences on water quality and the structural status of the dams.

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Part 2b

Case 8: Stability of the Thuan An inlet

1. General introduction

1.1 Introduction

In Part 1 of this report, 22 different cases were presented; one of them being the case 'Stability of the Thuan An inlet', a case which will be elaborated further in this part of the report. The Thuan An inlet is subject of multiple researches, mainly in the context of the whole Tam Giang-Cau Hai lagoon, each of them being too complex to evaluate in this short term. Therefore, this research focuses on only one stakeholder: the shipping industry. Ships passing the Thuan An inlet need a certain depth, but due to ongoing sedimentation this is not guaranteed. In this research possible options to maintain a depth of 4.5 metres are presented, when possible by using the current infrastructure in the inlet.
This case will be elaborated further by following the Engineering Process as described in Chapter 2, which is used to structure the research. Although the case description in Part 1 includes the first steps of this process all steps will be presented in a more specific way (again) in this part of the report, starting with a problem description and finishing with the best solution for this specific problem. For assessing the solutions Delft3D software is used, for which some additional explanation is given. Each model uses assumptions to simplify reality. Therefore, the implementation of the used (Delft3D) model, especially about the made assumptions, is written down in Chapter 4. In addition, a discussion is presented with recommendations for further research.

1.2 Reading guide

In this part of the report an elaboration of the Thuan An inlet case (nr. 8) is made. After the general introduction above, a problem description is stated in Chapter 2, where after an analysis of the inlet, including a short literature study, is presented in Chapter 3. In Chapter 4 the implementation of the used Delft3D model is given, with the results of the model runs towards the proposed solutions, including a multi criteria analysis, in Chapter 5. Finally, in Chapter 6 a conclusion about the best solution in combination with a discussion about the research is stated.

2. Problem description

2.1 Introduction

The Thuan An inlet has always been a morphological active inlet, with several closures and openings in the last ages. Mainly due to this morphological activity it has always been a subject for human intervention: the opening and closing of the inlet was often accompanied by migration and shoaling; thus preventing the construction of buildings near the inlet. This phenomenon was more and more undesirable as the region is economically developing. In addition, the wish to fixate the inlet followed from the transport and fishery sector: the constantly deforming inlet made it hard for ships to navigate (due to ever-changing depth), or for new (larger) ships to enter. For this reasons breakwaters and jetties were constructed in the inlet, as seen in Figure 38.

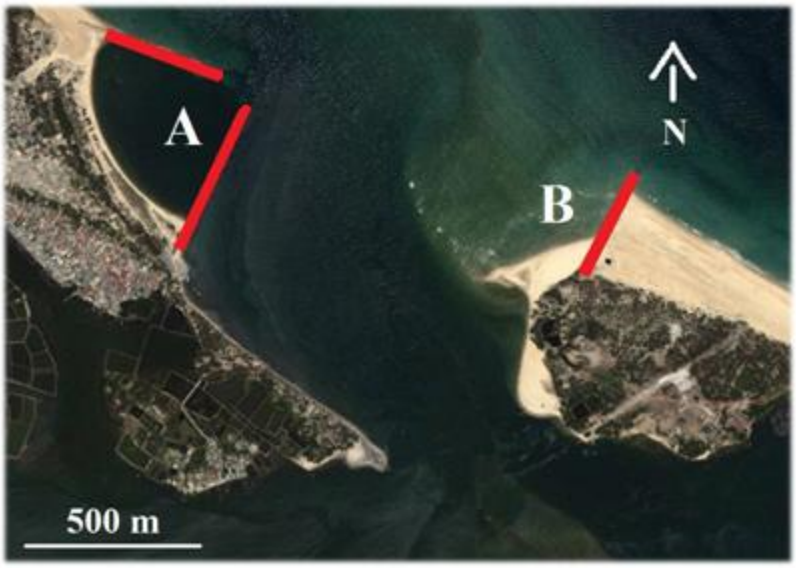


Figure 38: Map with the constructed breakwater and jetties (A & B, build in 2012) in the Thuan An inlet indicated with red.

The fixation of an inlet is something that might be done quite easily in an unvarying environment, with throughout the year more or less the same flow velocities in the inlet, the same longshore transport and the same sediment supply. But unfortunately, this is not the case for the Thuan An inlet. Due to a strong dry-wet season, in combination with typhoons and varying wind and wave directions it is a highly dynamic inlet which is influenced by different processes in different seasons. This variability in forcing during the year makes it particularly difficult to fixate the inlet and to guarantee good navigation channels: while the inlet is accreting rapidly in the dry season, it is flushed during the wet season, but not on a regular basis. The current breakwaters cannot handle these conditions sufficiently: sedimentation in the inlet still occurs and both barrier island show signs of accretion. To guarantee a certain depth and with for the coming years the current infrastructure should be improved or new solutions should be proposed.

2.2 Research questions and objective

The objective for this research, following the problem description stated above is as follows:

Optimize the current infrastructure, or develop a new solution, which provides sufficient surroundings for navigational purposes of the Thuan An inlet for the coming 30 years.

The 30 years is an assumption, but based on the observations in the harbour and the economic development. From these observations it is not expected that larger ships than presently active will moor in the Thuan An harbour any time soon, and especially since no new harbours are build at this moment, it is safe to assume that no major changes to the requirements will occur for the coming 30 years.

To complete this objective the following research questions are listed:

- What is the natural behaviour of the Thuan An inlet?
- What is (and has been) the influence of the constructed breakwaters?
- What is the best way to guarantee a sufficient depth for navigation, the coming 30 years?

2.3 Required navigation depth and width of the inlet

This research focuses on the ships passing the inlet, and therefore requirements concerning the depth and width are needed. These requirements are based on theory of port approach channels, as described by Ligteringen & Velsink (2012) based on the PIANC method (1995). As a reference, ships of the CEMT III class are used, which has been observed in the field (Masterproject Hue, 2013). The characteristics of this class are listed in Table 17.

Table 17: Characteristics of a CEMT III vessel.

Characteristic	Value	Dimension
Length	67-80	meter
Beam	8.2	meter
Draught	2.5	meter
Tonnage	650-1000	ton

Use is made of two equations, one for the required depth (Equation 1, Figure 39 without a tidal window) and one for the required width of the channel, and thus the inlet (Equation 2, Figure 39, for a two-way channel). The two way channel equation is not explicitly used to facilitate a navigation channel for two ships at any time, but mainly due to a lack of regulation: although not much shipping is present, and therefore the chance that two ships will cross is minimal, it is not guaranteed that this crossing will *not* happen at all. So to be safe, a two way navigation channel is assumed.

The meaning and chosen values of Equation 1 and 2 can be found in Table 18.

$$h_{gd} = D + s_{max} + 0.5 \cdot a + h_{net} \qquad \textbf{(1)}$$

$$W = 2 \cdot (W_{bm} + W_b + \Sigma W_a) + W_p \qquad \textbf{(2)}$$

Using the described equations, this result in a required depth of 4.5 meters and a required width of 95.12 meters.

Table 18: Used values of the coefficients in Equation 1 & 2. The values are based on Ligteringen & Velsink (2012).

Abbreviation	Meaning	Value	Dimension
h_{gd}	Guaranteed depth	n.a.	meter
D	Design depth	2.5	meter
s_{max}	Squat	0.5	meter
a	Significant wave height	2.0	meter
h_{net}	Safety margin	0.5	meter
W	Width of the channel	n.a.	meter
W_{bm}	Basic width	13.9	meter
W_b	Bank clearance	4.1	meter
W_a	Additional width due to other factors as wind, waves and currents.	22.9	meter
W_p	Separation distance	13.12	meter

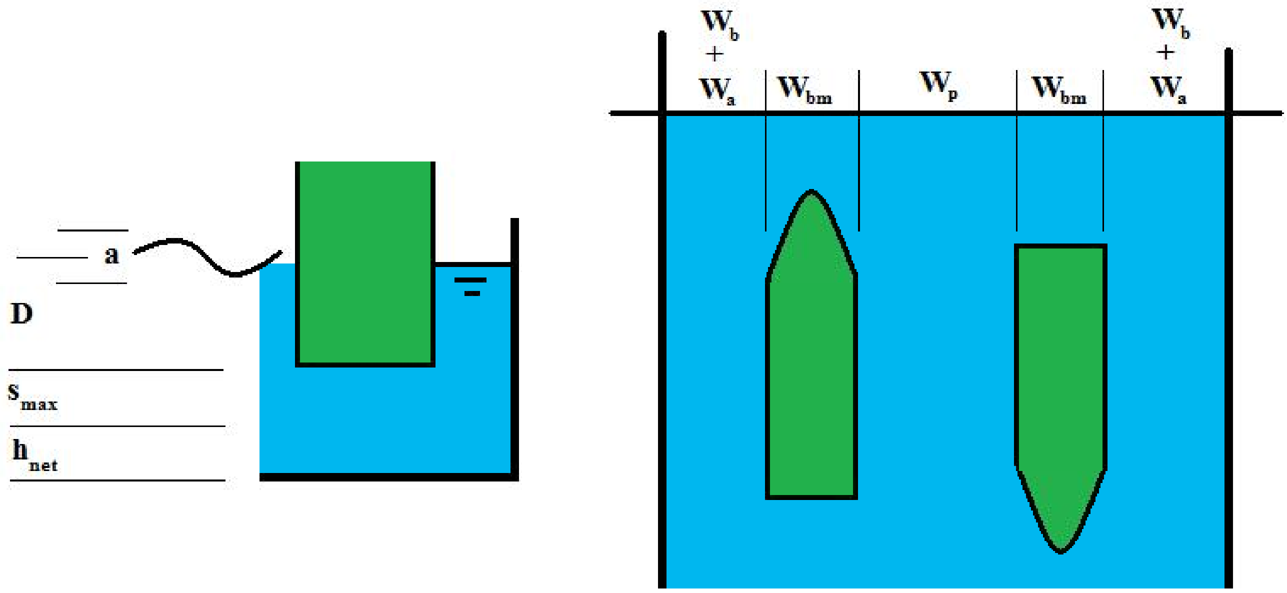


Figure 39: Visualization of the depth and width coefficients.

2.4 Past research concerning the Thuan An inlet, and available literature

Most of the articles about the Thuan An inlet are made by cooperation between scientists of the Water Resources University in Hanoi, Vietnam and Delft University of Technology in Delft, the Netherlands. Almost all research, including models, is performed in the PhD dissertation of three persons: Nghiem Tien Lam, Quang Tuan and Tran Thanh Tung, seen in Table 20. Their research is mainly focused on morphodynamics and hydrodynamics of the inlets. In these researches topics as inlet behaviour due to wave dominance and river discharges, bottom changes, reorientation of the inner inlet channel, the occurrence of breaches and the overall stability of the inlets are discussed. The main purpose of these articles is to investigate the mechanism behind the different phenomena; almost no information is available about practical solutions towards experienced problems in the region.
In addition to the specified research, general information about tidal inlets, sedimentation and hard structures is available by several books, shown in Table 19.

Table 19: Useful books in this research.

Author(s)	Year	Title
L.C. van Rijn	2005	Principles of Sedimentation and Erosion Engineering in rivers, Estuaries and Coastal Seas
H.J. Verhagen, K. d'Agremond, F.C. van Roode	2012	Breakwaters and Closure Dams
G.J. Schiereck, H.J. Verhagen	2012	Bed, bank and shore protection
J. Bosboom, M.J.F. Stive	2013	Coastal Dynamics I

Table 20: Relevant researches towards the Thuan An inlet.

Author(s)	Year	Title	Type
N.T. Lam	2002	A preliminary study on hydrodynamics of the Tam Giang – Cau Hai lagoon and tidal inlet system in the Thua Thien-Hue province, Vietnam	M.Sc. Thesis
N.T. Lam, H.J. Verhagen, M. van der Wegen	2003	Hydrodynamic modelling of tidal inlets in Hue, Vietnam	Article
N.T. Lam, M.J.F. Stive, H.J. Verhagen, Z.B. Wang	2007	Morphodynamics of Hue tidal inlets, Vietnam	Article
N.T. Lam, M.J.F. Stive, H.J. Verhagen, Z.B. Wang	2007	Morphodynamics of tidal inlets in a tropical monsoon area	Article
T.Q. Tuan	2007	Seasonal breaching of coastal barriers	PhD Thesis
N.T. Lam, M.J.F. Stive, H.J. Verhagen, Z.B. Wang	2008	Seasonal behaviour of tidal inlets in a tropical monsoon area	Article
N.T. Lam	2009	Hydrodynamics and morphodynamics of a seasonally forced tidal inlet system	PhD Thesis
T.T. Tung	2011	Morphodynamics of seasonally closed coastal inlets at the central coast of Vietnam	PhD Thesis

2.5 Structure of the research

As stated in the introduction, the whole Engineering Process (Figure 3) will be executed in this research. In the past paragraphs the problem description the objective are presented, which include the main requirements. The next step is to find historical data to come up with possible solutions.

To assess the proposed solutions, use is made of the software Delft3D. Before any solution can be assessed, a model including wind, wave and flow characteristics needs to be built. When the model is ready, implemented solutions will be balanced against the so called 'zero-solution', a model run with no adaptations. From comparison between the different model runs a preferred solution can be chosen.
In most engineering processes iterations are made between solutions and requirements, but due to the restricted time only one iteration will be done in this research.

3. Introduction to the Thuan An inlet

3.1 Inlet area

The Thuan An inlet is the most northern inlet connecting the Tam Giang-Cau Hai lagoon to the South Chinese Sea. The lagoon is an important living area for thousands of people, and provides possibilities for navigation, agriculture and fishery. The water is brackish due to saline water from the ocean, while several rivers (Huong river, O Lau river, An Xuan river, Truoi river and the Cau Hai river) provide a fresh water income, as can be seen in Figure 40.

The area is located in a tropical monsoon region, which means that tropical storms regularly occur. In addition, the distinct wet and dry season causes flood waves from the rivers which results in an irregular fresh water supply in the lagoon during the year. Influences from for example wind, waves and river discharges make the inlet (and its surroundings) very dynamic, with constantly changing topography (Lam, Stive, Verhagen, & Wang, 2007).

Figure 40: Map of the close surroundings of the Thuan An inlet, with the most distinct features being the lagoon and the Huong, Bo and Dai Giang river. Other rivers are located more to the east and west (like the Truoi river), out of the scope of this figure.

3.2 Inlet history

The Thuan An inlet arose around 1402, when the sand barrier in front of the lagoon was breached during a storm. Its development since then is visualised in Figure 41 and described here. Before this breach the more southern located Tu Hien inlet was the only inlet of the lagoon. Due to the additional opening the Tu Hien inlet declined, which eventually led to the Thuan An inlet becoming the main inlet, with the largest discharge. In the ages following the initial breach, people tried to close the Thuan An Inlet to preserve the Tu Hien inlet, but without success (Lam, Stive, Verhagen, & Wang, 2008).
From 1928 to 1953 a closure dam was build in the inlet, which prevented tides to enter the lagoon. As a result of this closure dam, a sand spit of 4 kilometres toward the northwest developed. When the dam was destroyed during severe flooding, the sandpit was quickly washed away.
Although tropical storms influence the topography, most breaches occur due to extreme river discharges. The large amount of water supply results in large water level differences between the ocean and the lagoon, causing extreme water velocities (Tung, 2011). This also occurred in 1999, when flooding caused the Thuan An inlet to become much wider and deeper. In addition, the flooding resulted in a new breach in the sand barrier at Hoa Duan. Due to this additional breach the Thuan An inlet declined severely, which led to the decision to close the new breach to preserve shipping.
Around 2012 two jetties were built into the Thuan An inlet for stabilizing purposes, which, in combination with the river discharges, keep the inlet open. But still, sedimentation between the jetties remains a problem. A short overview of relevant historical events is presented in Table 21.

Table 21: Relevant historical events related to the Thuan An inlet. Based on Lam (2002).

Year	Event
1402	Arising of the Thuan An inlet
15th – 19th century	Several times the Thuan An and Hoa Duan inlet closed and opened again, the Tu Hien inlet was dredged occasionally
1904	Closure of the Hoa Duan inlet
1930	Construction of a closure dam in the Thuan An inlet completed, to prevent salt intrusion. As a consequence a large sand spit developed
1953	Due to flooding the closure dam was destroyed
1999	Heavy flooding; opening Hoa Duan inlet
2000	Closing of Hoa Duan inlet
2012	Construction of breakwaters

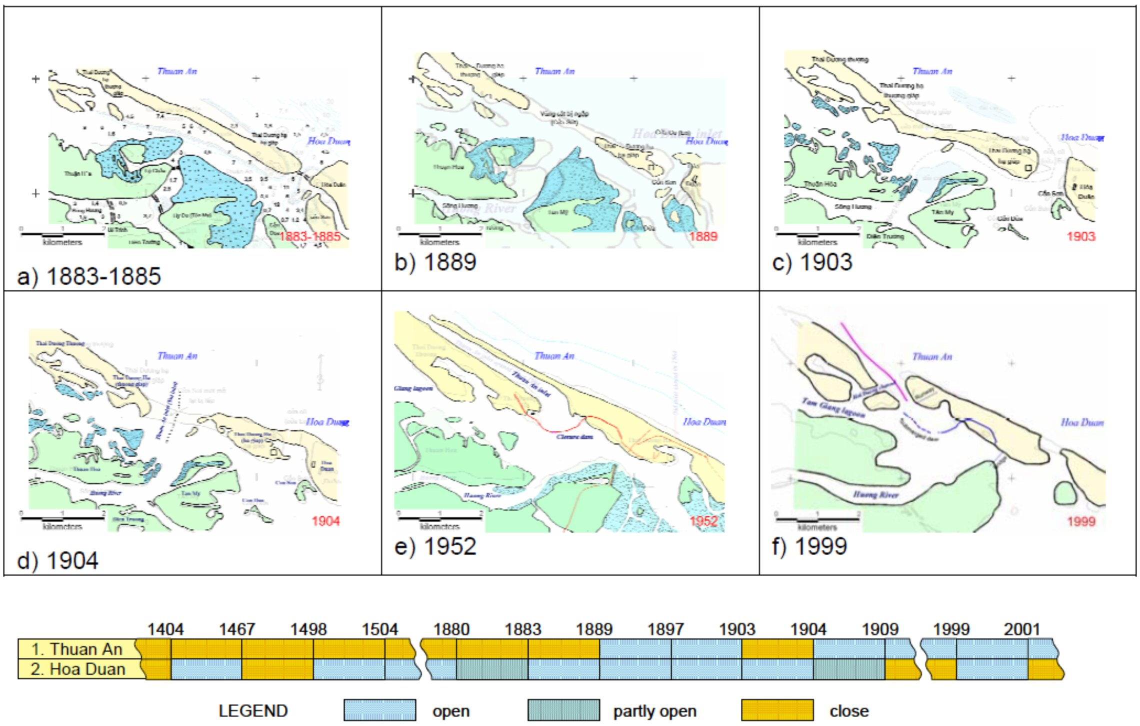


Figure 41: Historical development of the Thuan An inlet. In 1952 the closure dam caused the development of a 4 km long sand spit. In 1999 an additional breach occurred (f), which was closed some time after (Lam, 2008).

3.3 Current inlet situation & morphological features.

Before any modelling can be applied, the system has to be understood. This is done by indexing characteristics of the coast, as well as forcing applying on the inlet.

The central coast of Vietnam is a marginal sea coast, since it is protected by barrier islands and almost no tectonic activity is present (Bosboom & Stive, 2013). In addition, the tidal elevation at the Thuan An inlet is around 0.4 meters, while the significant wave height is in the range of 1.5 - 2.0 meters (Tung, 2011). Following the hydro dynamical classification of Hayes (1979) the coast can be described as wave dominated with a micro tidal regime, as can be seen in Figure 42. Since it is a wave dominated coast, the wave induced longshore transport has major influence on the position of the inlet: accretion and erosion of the opposite barrier islands cause the inlet to migrate in longshore transport direction (when no fixation structures would be present). However, during the flood season a so called jet occurs in the inlet, due to the large fresh water discharges from the rivers. This jet interrupts the longshore transport and facilitates sedimentation on both sides of the inlet.

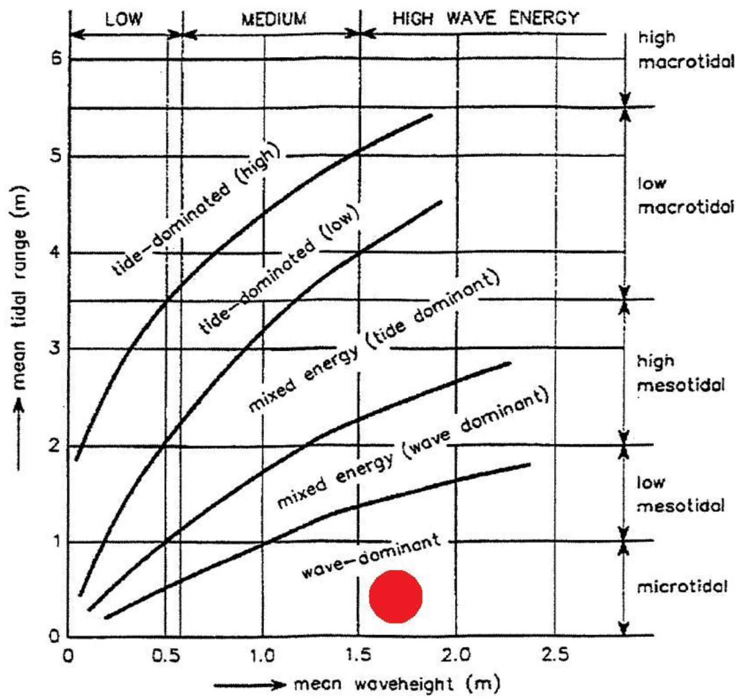


Figure 42: Hydrodynamic classification according to Hayes (1979). The red dot roughly indicates the regime at the Thuan An inlet.

As stated earlier, the inlet is forced by several (external) factors. The most important driving forces are listed below, and visualized in Figure 45.

The tide

Tidal streams cause a constant movement of sediment in and out of the lagoon and are therefore an important forcing of the cross-sectional area of the inlet. The magnitude of the tidal stream is mainly characterized by the tidal frequency and the tidal prism (which in turn is influenced by the size of the basin/lagoon and the tidal elevation).
In this particular situation, the tidal elevation is quite small (order 0.4 metres) with a large lagoon (surface 216 km^2). According to Lam (2002) a tidal prism of order $36 \cdot 10^6$ m^3 is present in the Thuan An inlet, although this might have changed somewhat due to the dynamic behaviour of the lagoon. In addition, the tide is fully semi diurnal. The flow velocity (only due to the tide) in the Thuan inlet is then in the order of 0.4 m/s (Lam, 2008).

River Discharge

Due to the strong seasonal behaviour of the runoff, the river discharge has a large influence on the sediment transport through the Thuan An inlet. During the dry season the discharge is not sufficient to influence the flow velocities in the inlet, while large water level differences between the lagoon and the ocean occur in the wet season. These differences result in extreme flow velocities (order 3-4 m/s, Lam, 2008) which cause major sediment transport due to the exponential relation between flow velocity and sediment transport. Due to the large flow velocities in one direction the flood tidal delta (at the landward side of the barrier) is not completely developed.
The difference in water level can also result in additional breaching in the sand barrier as happened in 1999: a new breach was formed near Hoa Duan, which resulted in faster drainage of the lagoon, but also caused declination of the Thuan An inlet.

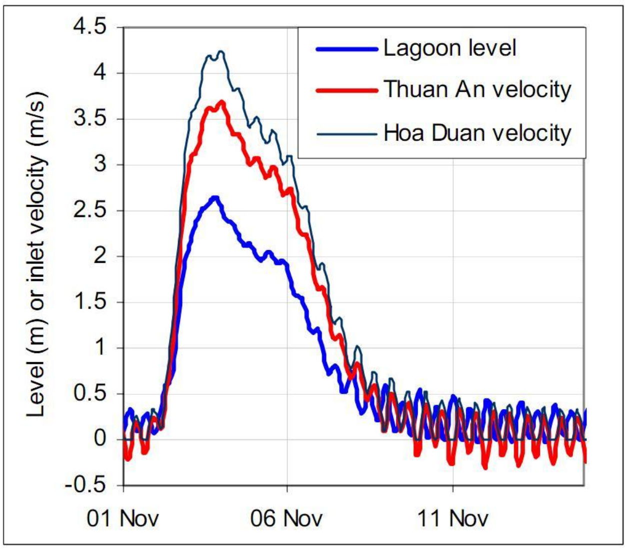


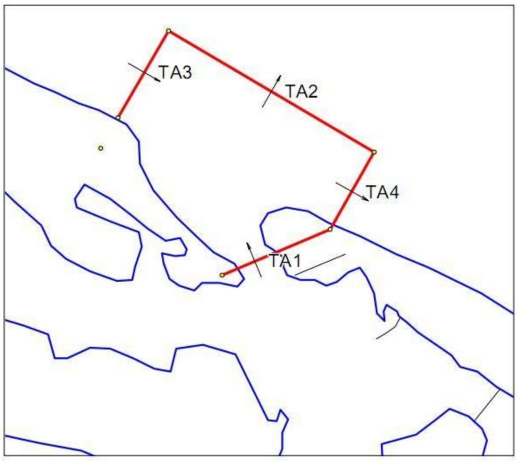
Figure 43: Computed flow velocities in the Thuan An (and the then open Hoa Duan) inlet during the flood of 1999. Due to the high velocities the tidal influence is almost negligible, while a few days later the flow velocities turn back to normal, e.g. order 0.5 m/s. By Lam, 2008.

Wind & Waves.

Wind directions, wave heights and wave directions are, just as the river discharges, strongly bound to the season: in January, February and March northeast winds and waves are dominant, while in the months June, July and August the dominant wind directions are from southwest to northeast, with waves coming from southeast direction. Especially the varying wave directions (and thereby varying angles with the coast) result in different magnitudes of the longshore transport and therefore inlet instability. The full wind and wave roses, including velocities, heights and directions, can be found in Appendix C.

Longshore Transport

During the dry season, the longshore transport is dominated by the wave climate. Accretion of the upstream and erosion of the downstream barrier head causes a migration of the inlet in downstream direction. Several computations of the longshore transport have been made in the past, mainly by Lam et al. (2008), as can be seen in Figure 44. The main observation from this figure is the difference in sediment transport between the upstream and downstream boundary: in the downstream boundary more sediment is transported, which can be explained by the sediment brought into the system by the rivers. With high river discharges a jet stream might occur, sheltering the downstream barrier island and creating the opportunity for sediment to settle. In fact, the coast becomes a river dominated coast for a short period of time, a type of coast which normally results in large deltas.
Although jetties have been built, the Thuan An inlet still has a variable morphodynamic character: in the dry season, from January to August, the inlet tends to incoming sediment from the longshore transport, without sufficient flow velocities to flush the additional sediment. The result is instability of the Thuan An inlet due to shoaling and migration (Lam et al. 2008). In the wet season from September to December, the high discharges from the rivers flush the inlet and change the cross section by widening and deepening. Due to this widening and deepening the inlet stays open, but a flood tidal delta cannot develop (Lam et al. 2007).



Period	Transport	Thuan An			
		TA1	TA2	TA3	TA4
Jan-Mar	(+)	0.098	0.032	0.186	0.193
	(-)	-0.017	-0.035	-0.147	-0.137
	Net	0.081	-0.003	0.038	0.057
Apr-May	(+)	0.065	0.027	0.032	0.033
	(-)	-0.003	-0.075	-0.046	-0.047
	Net	0.062	-0.048	-0.014	-0.014
Jun-Aug	(+)	0.184	0.036	0.005	0.006
	(-)	-0.004	-0.017	-0.034	-0.034
	Net	0.180	0.019	-0.028	-0.028
Sep	(+)	0.523	0.767	0.022	0.024
	(-)	-0.003	-0.046	-0.043	-0.040
	Net	0.520	0.721	-0.021	-0.016
Oct-Dec	(+)	0.562	0.635	0.384	0.403
	(-)	-0.048	-0.075	-0.719	-0.651
	Net	0.514	0.560	-0.335	-0.248
Yearly	(+)	1.432	1.497	0.629	0.659
	(-)	-0.075	-0.248	-0.990	-0.909
	Net	1.357	1.249	-0.360	-0.249

Figure 44: Sediment transport rates as computed by Lam et al. (2008): the sediment transport is computed with Van Rijn (1984a; 1984b) formula for bed load and suspended load carried by river flows and Bijker (1971) formula for waves and currents. Two grades of the sediment particles D_{50} = 200 μm and D_{50} = μm are used.

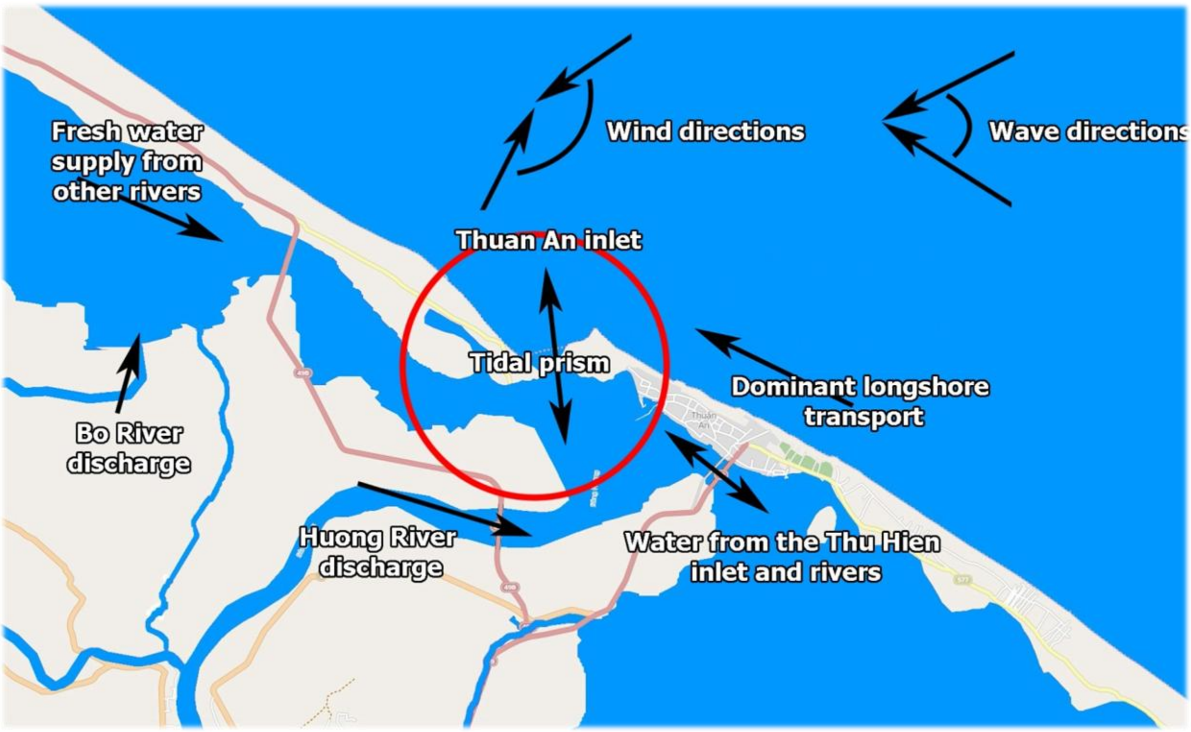


Figure 45: Schematisation of the driving forces and processes on the Thuan An inlet.

Sediment transport patterns

In case of obliquely incident waves one side lobe will be exposed, and the other lobe will be sheltered. The ebb-tidal delta will affect the dominant wave direction, which results in diffraction of the waves. The result is accretion at the sheltered side, and the barrier will propagates towards a drumstick kind of shape, as seen in Figure 46.

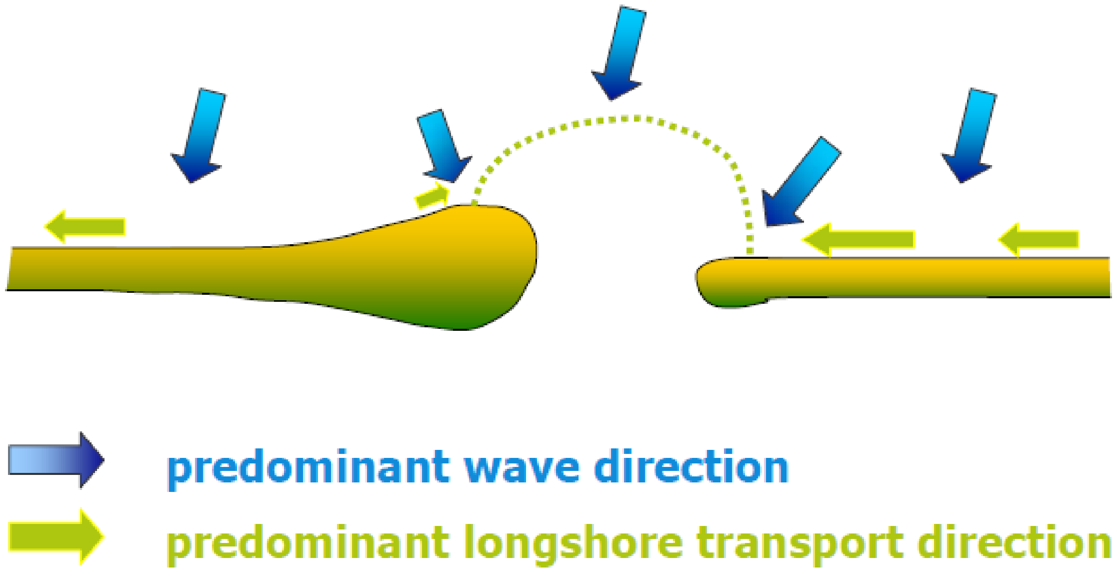


Figure 46: Sheltering and exposure to obliquely incident waves will result in a drumstick shaped barrier (Bosboom & Stive, 2013).

Along the Thuan An inlet the dominant longshore transport direction is from the south to the north. There are two bypassing mechanisms for the river of sand along a tidal inlet (Figure 47), of which the first is bar-bypassing. This may occur under influence of high wave conditions. The second mechanism is tidal bypassing, in which the tide is the most important aspect (Bosboom & Stive, 2013).

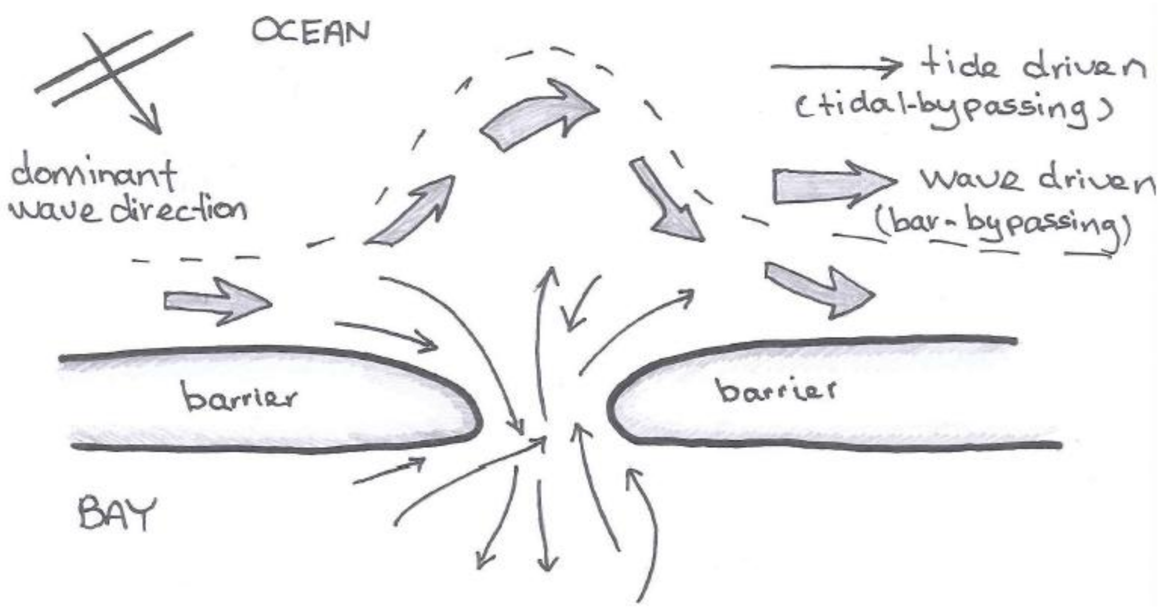


Figure 47: Two bypassing mechanisms near a tidal inlet, based on Bosboom & Stive, 2013.

Human interventions

The Thuan An inlet has always been a morphological active inlet, with several closures and openings in the last ages. Mainly due to this morphological activity it has always been a subject for human intervention. In Vietnam mostly 'hard' structures are constructed, which means that there is actually something build to intervene in the natural system. Examples are groins, jetties, breakwaters and revetments. This in contradiction to soft solutions, which are more about overacting towards human processes; examples are dredging and sand suppletion. The reason that Vietnam builds hard structures is twofold: the government wants to show people that their actually doing something by constructing structures, and often they experience hard structures to be more effective ('experience' since this is not always the case): soft solutions need to be repeated every once in a time.

The human interventions in the area of Hue have all been observed in the field (Masterproject Hue, 2013).

- *Revetments on the east side of the inlet*

The revetments on the east side of the sand barrier have been constructed to protect the shrimp farms behind it. In the past the revetments were constructed with concrete slaps. This eventually failed, because of fact that sand eroded under the slabs. Now, only loose stones are used, which works adequately

- *Recent construction of the east jetty*

This jetty (about 550 meters long) consists of large armour units (modified Haros of about 5-10 ton) which are placed on a sandy bottom, often without (a proper) foundation. When a foundation is present it is unequal in height and not serried. These facts combined result in severe erosion between the armour units and consequently cause sagging of individual units. The jetty as a whole does not function as a jetty anymore, and can be characterized by a bunch of loose concrete blocks. In the recent past year however, some accretion can be observed, as seen in Figure 48.

- *Recent construction of the northern breakwater on the east side of the inlet*

The northern breakwater is relatively well designed (it is sturdy enough, but has limited functionality due to bad positioning of the breakwater as a whole) with about four layers of regularly placed Tetrapod armour units of 1.5-2.0 metres high. Near the coastline a lot of accretion can be observed.

- *Recent construction of the west jetty*

At the tip of the sand barrier a jetty is constructed, which consists of two parts. The first part, most directed landwards, is constructed with modified Haros. The second part, at the seaward side, is constructed with Tetrapods. This construction has been carried out only one year ago, but already bypassing of the jetty occurs. The jetty is completely filled-up with sediment. Besides this sedimentation process also the structural integrity of the jetty is failing.


Figure 48: Sedimentated jetty on the most northwest part of the east-side of the barrier.

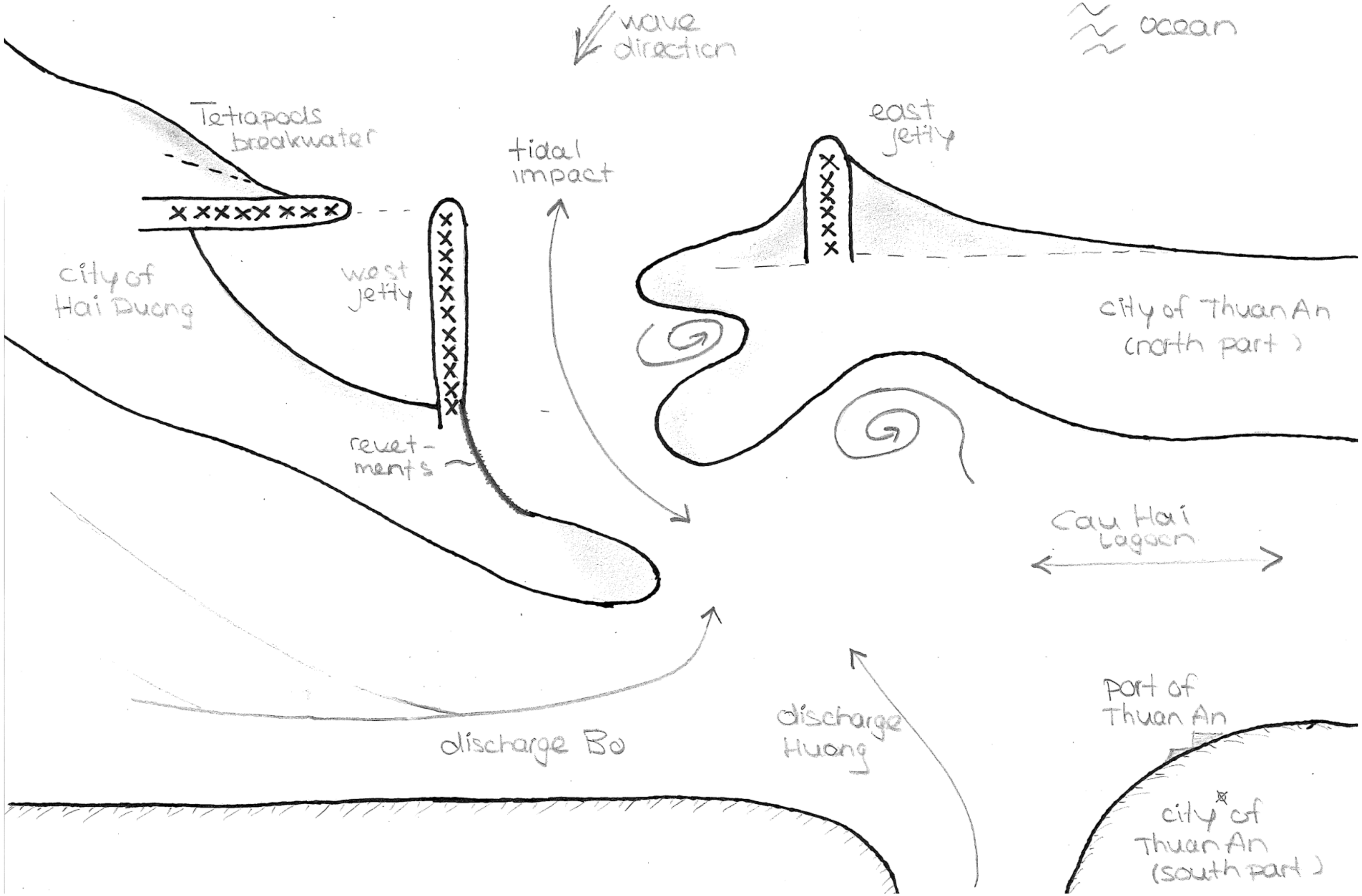


Figure 49: Impression of the current situation (Masterproject Hue, 2013).

3.4 Empirical relations

Escoffier curve

A well known method for estimating the stability of a tidal inlet is provided by Escoffier (Bosboom & Stive, 2013), who developed a stability curve, shown in Figure 50. The equilibrium velocity u_{eq} (which is more or less constant at 0.9 m/s is used as boundary for sediment transport: velocities lower than u_{eq} are unable to transport the sediment out of the channel, while velocities larger than u_{eq} cause erosion and thus an enlargement of the cross sectional area. This process results in a stable equilibrium point D, shown in Figure 50. The corresponding cross sectional area with this equilibrium point is given by Equation 3.

$$A_{eq} = CP^q, \text{ with } C = 7.8 \cdot 10^{-5}, q=1 \text{ and } P= 36 \cdot 10^6; A \approx 2800 \text{ m}^2 \qquad \textbf{(3)}$$

With

P the tidal prism	[m^3]
A the cross sectional area of the inlet	[m^2]
C and q coefficients	[-]

For the Thuan An inlet, the velocities during dry season are around 0.4 m/s (as stated in paragraph 3.3), which is lower than u_{eq}. In combination with the fact that the calculated equilibrium cross sectional area of the Thuan An inlet is smaller than described by Lam (2002), the inlet should be placed on part D-E of the Escoffier Curve. With this information, the (historical) behaviour of the inlet can be explained: during the dry season, with low flow velocities in the inlet and a relatively large cross sectional area, the inlet is accreting. However, during large discharges of the river the net tidal prism increases, and therefore the equilibrium cross sectional area. As a consequence, flow velocities may reach values above 3.0 m/s (see paragraph 3.3). In 1999 an additional breach developed, which placed the Thuan An inlet (just after the flooding) at the A-B part in Figure 50. As a result, the inlet started to close, which eventually led to the need of closing the newly developed breach, in order to keep the Thuan An inlet open.

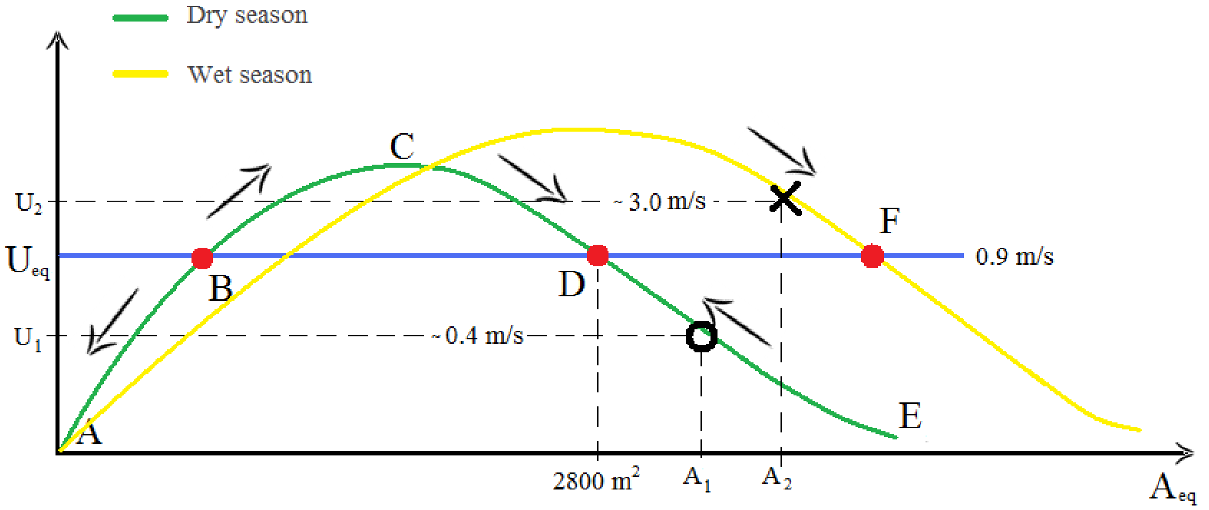


Figure 50: Simplified Escoffier curve for the Thuan An inlet during the dry (green curve) and the wet (yellow curve) season. In the dry season, the inlet is characterized by the O sign. During large river discharges the curve will deform, with a larger equilibrium cross sectional area (point F). The wet season is characterized by the x sign. The Figure is not to scale.

Type of bypassing

It can be concluded that part of the littoral drift continues it is way over the ebb-tidal deltas o the down-drift coast, while another part is diverted into the tidal inlet by flood. The ratio between the volume littoral drift that are bypassed directly and that are bypassed by the ebb-tidal delta depends on the ratio between the tidal prism and the littoral drift (Bosboom & Stive, 2013).

$$r = P / M_{tot}, \text{ with } P = 36 \cdot 10^6 \text{ and } M_{tot} \approx 0.305 \text{ Mm}^3/\text{y} \qquad \textbf{(4)}$$

With

P	the tidal prism	[m^3]
M_{tot}	the total littoral drift	[m^3/y]
r	coefficient	[-]

For the Thuan An inlet a value of 118 is founded. Normally for values of $r > 300$ the bypassing of sand is predominantly via the inlet. For smaller values of r the bypassing is via the shoals of the ebb-tidal delta and thus wave dominant.

4. Input in Delft3D

4.1 Introduction

To get a better understanding of the systems behaviour and to be able to predict what will happen with the hydraulic and morphological aspects in case of an intervention, a numerical model (Delft3D) is used. The basis of this model, like the grid, the bathymetry and the astronomic forcing at the boundaries were provided by Lam (2007). In order to use this model in a correct way first a research of the accuracy and restrictions of the model is carried out. Secondly the model is improved and adapted in order to make it applicable for the research of an intervention in the Thuan An inlet. This is necessary because on top of the hydrodynamics, which were included in the model of Lam, the morphodynamics are also needed to describe the stability of the Thuan An inlet.

4.2 Model set-up

In this case study the complete tidal basin is modelled in a macro scale model. This is done with the process-based model Delft3D. Process-based models can describe waves, currents, sediment transport and bed level changes via a set of mathematical equations.

In order to discretise the shallow water equations in space an orthogonal grid is used to cover the model area. The grid contains 898 x 146 cells with a minimum grid size of 50 x 50 meters. The smallest grid cells are used near the two inlets to be able to represent the physical processes in an accurate way. The grid is presented in Figure 51.

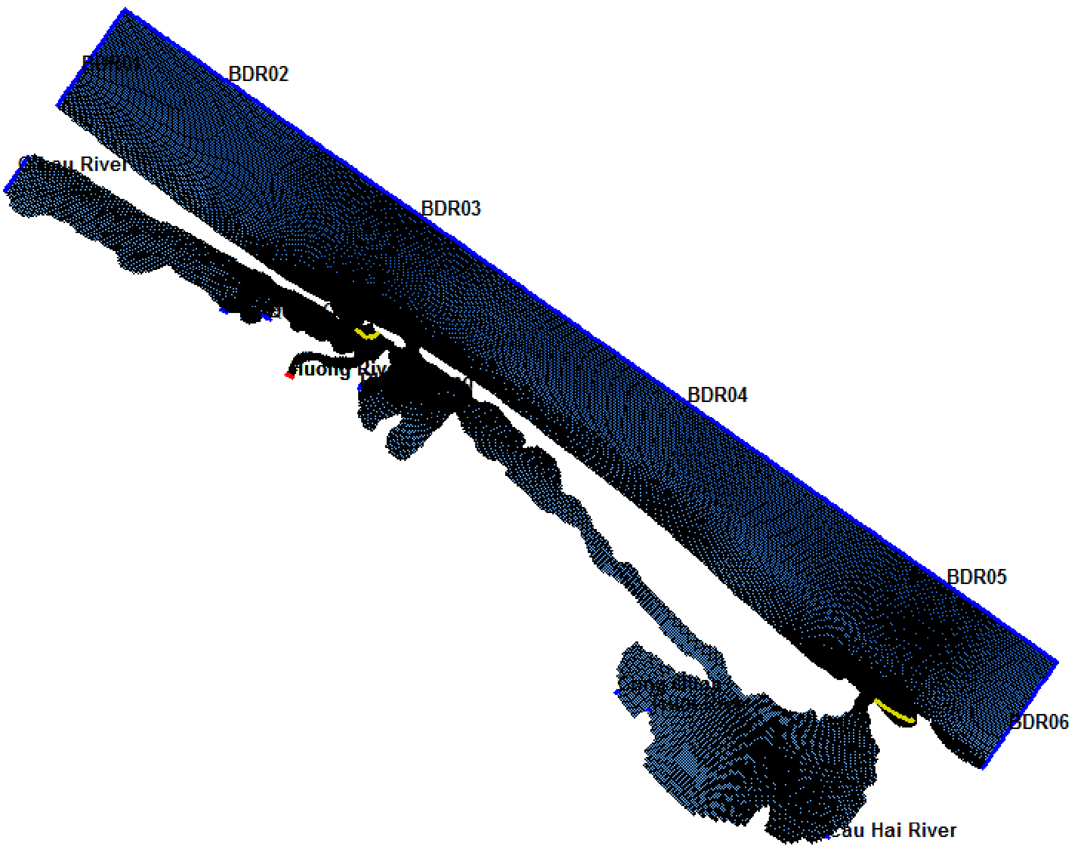


Figure 51: Grid of the model area.

The maximum time step for accuracy depends on the Courant conditions. Delft3D uses the ADI-method which is a combination of an explicit and implicit scheme. The different conditions are based on the Delft3D FLOW user manual. The area of interest where each of the different Courant conditions is applicable is presented in Table 22. More information about the different conditions can be found in the Delft3D FLOW user manual.

Table 22: Courant conditions.

Courant conditions	Equation used	Location	Needed time step
Accuracy ADI for complex geometries	$C_f = 2\Delta t \sqrt{gH \left(\frac{1}{\Delta x^2} + \frac{1}{\Delta y^2}\right)} < 4\sqrt{2}$	Thuan An inlet	≈ 0.2 minutes
Flow Courant number	$\frac{u\Delta t}{\Delta x} < 8$ and $\frac{v\Delta t}{\Delta y} < 8$	Huong river	≈ 4.5 minutes
Wave Courant number	$\frac{\sqrt{gH}\Delta t}{\Delta x} < 8$ and $\frac{\sqrt{gH}\Delta t}{\Delta y} < 8$	Offshore, near the boundary	≈ 0.5 minutes

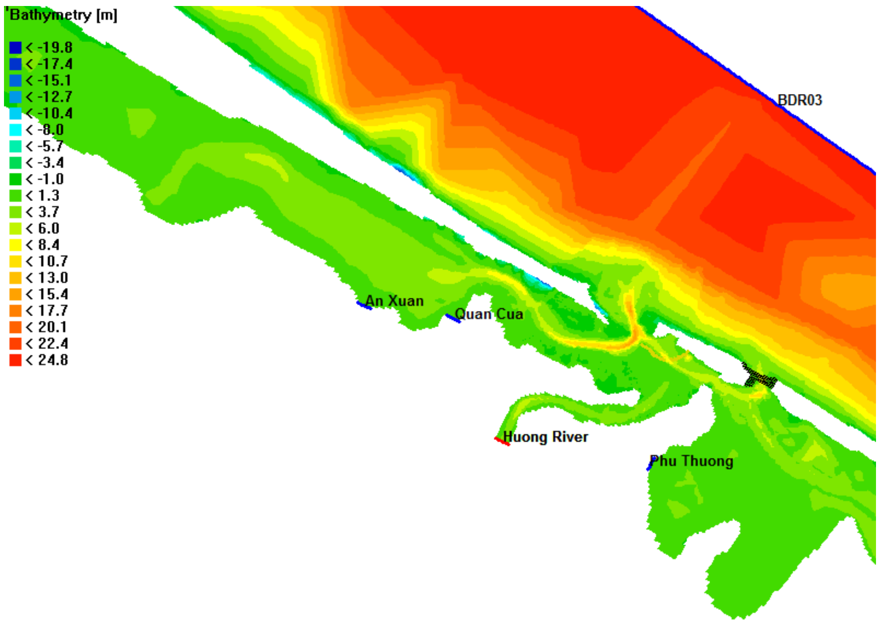


Figure 52: Bathymetry of the inlet and lagoon.

According to the Courant conditions a time step of 0.5 minutes is sufficient to fulfil the accuracy and stability conditions. However the ADI conditions will result in a much smaller time step. In order to check validity several test runs were made using time steps of 0.25, 0.5, 1.0, 2.5 and 5.0 minutes. It is preferred that a large time step will be applied, because of the reduction in computational time. The output for the water levels in the Thuan An inlet resulted in a needed time step of 2.5 minutes. However, the calculations for the bed level change of the inlet resulted in a time step restriction of 1.0 minute. In Appendix B all the results of the executed calculations are presented.

4.3 Reduction of input parameters

The open model boundaries are applied as far away as possible from the area of interest (lagoon and the inlets). Multiple rivers are entering the lagoon of which the Huong river is the most important one. Open-sea boundaries are located far away from the inlet in relative deep water. The sea boundaries are forced with an astronomic tidal signal based on Lam (2002).

Besides the tidal signal also waves from the deep sea, wind and discharges from the rivers are forcing the system. In order to be able to limit the computational effort an input reduction is necessary. The input reduction will be based on the seasonal fluctuations: the model will contain five different time periods in order to be able to represent yearly variability.

The different waves from the sea will be characterised as one single wave per time period as seen in Figure 23. This averaging of wave height, period and direction is based on the variation of the wave signal derived from ARGOSS (2013). This averaging is based on the CERC-formula which suggests that the longshore transport is proportional to $Hs^{2.5}$. In Appendix C the complete wave roses are presented.

Table 23: Wave height, period and direction per time period.

Period	Wave height [m]	Wave period [s]	Direction [degrees]
January, February, March	2.91	6.3	67.5
April, May	1.49	6.0	90.0
June, July, August	1.51	6.0	135
September	2.30	6.0	67.5
October, November, December	2.91	6.3	67.5

The different wind speeds and directions will be characterised as one single wind per period. This averaging of wind speed and direction is based on the variation of the wind signal based on ARGOSS (2013). In Appendix C the complete wind roses are presented.

Table 24: Wind speed and direction per time period.

Period	Wind speed [m/s]	Direction [degrees]
January, February, March	7.0	45
April, May	5.2	90
June, July, August	5.0	180
September	4.8	67.5
October, November, December	8.5	45

The different discharges from the rivers will be characterised as one single discharge per period. The discharges are averaged over time, which means that extreme events will be excluded from further analysis. The sediment concentration is taken as a constant throughout the year in kg/m3. For the Huong river a sediment concentration of 0.15 kg/m^3 will be used and for the other rivers a value of 0.08 kg/m3 is applied based on Lam 2002.

Table 25: Discharges per time period per river in m^3/s .

Period	Huong river	An Xuan	Truoi river
January, February, March	92.5	30.65	24.5
April, May	59.9	19.42	15.6
June, July, Augusts	63.8	18.0	16.5
September	113.7	29.3	30.4
October, November, December	226.5	73.3	60.6

4.4 Model adjustment and calibration

In theory one should iterate between the schematisation of the wave climate, schematisation of the river discharge and the schematisation of the tidal forcing. In this research this is *not* done because of the limited amount of time. The time calculated is simply just chosen to be able to make an overnight calculation. This means that 4 complete days of hydrodynamics in Delft3D will be simulated which will be extrapolated with the help of the morphological factor (MorFAC) to the morphological response of one year. The first simulated day, so 25% of the calculation, is used to get rid of spin-up effects.

It is important to notice that extreme events are not included in this approach due to the averaging process of discharges, waves and wind. On top of that the schematisation of the tidal impact will result in a less tide-dominant system than the Thuan An inlet in reality is. This is because the system will be calibrated on the longshore transport and will thus be more accurate in the wave-related processes. This is a safe assumption because an extreme event like a typhoon will result in higher discharges and thus erosion of the inlet.

Before the Delft3D model can be used it needs to be calibrated. Because there are no measurements of the water levels and currents, this will only be done based on the longshore transport around the Thuan An inlet. The cross sections of which measurements are available are presented in Figure 44, based on Lam (2007).

In Delft3D the elongated online approach with morphological factor is used. This process is described in Figure 53.

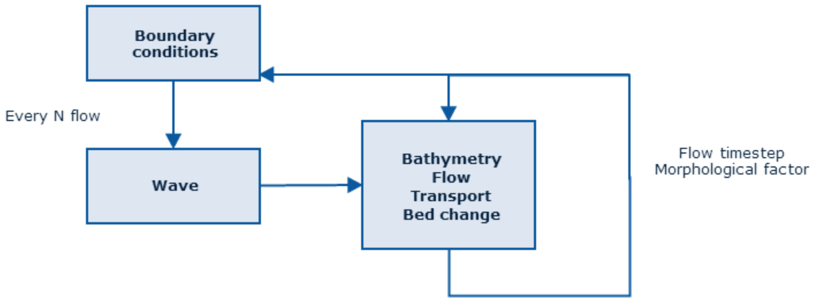


Figure 53: Schematization of the process of the elongated online approach, with N being the number of the iteration.

A complete calculation run is made (which resulted in Table 26) in which an average value of the cross-sections is used. All the sediment transport rates measured at the locations are given in Figure 44. The MorFAC can be calculated by dividing the average transport measured by the average sediment transport calculated. The needed MorFAC is about 10 in the first nine months of the year. Only during the months with typhoons a much higher factor is needed. This is what was expected on forehand, because extreme events, like a high discharge or high waves, are not represented in the model.

Table 26: Sediment transport per time period.

Time period	Average transport calculated [m3]	Average transport needed [m3]	MorFAC needed
January, February, March	1.800	23.750	13
April, May	435	4.667	11
June, July, Augusts	793	14.000	18
September	410	3.083	8
October, November, December	3.629	145.750	41

The simulations for one year are used to be able to represent more detailed processes. In order to get a better understanding of the system on longer timescales, simulations for three years are also carried out. These simulations are able to reproduce les detail. This is done by applying the time series three times in a row, but with a reduced length in order to reduce computational time. To represent the real morphological behaviour the MorFAC is increased with a factor three. The results for three years will be simply extrapolated to represent the complete thirty years which was assumed to be the design life time.

The Thuan An inlet has always been a morphological active inlet, with several closures and openings in the last ages. Measurements of the years 1999 and 2002 show an accretion of sediment on both sides of the inlet, as seen in Figure 54. The rate of accretion on the northwest is about 300 meter in 3 years and on the southeast it is about 100 meter.

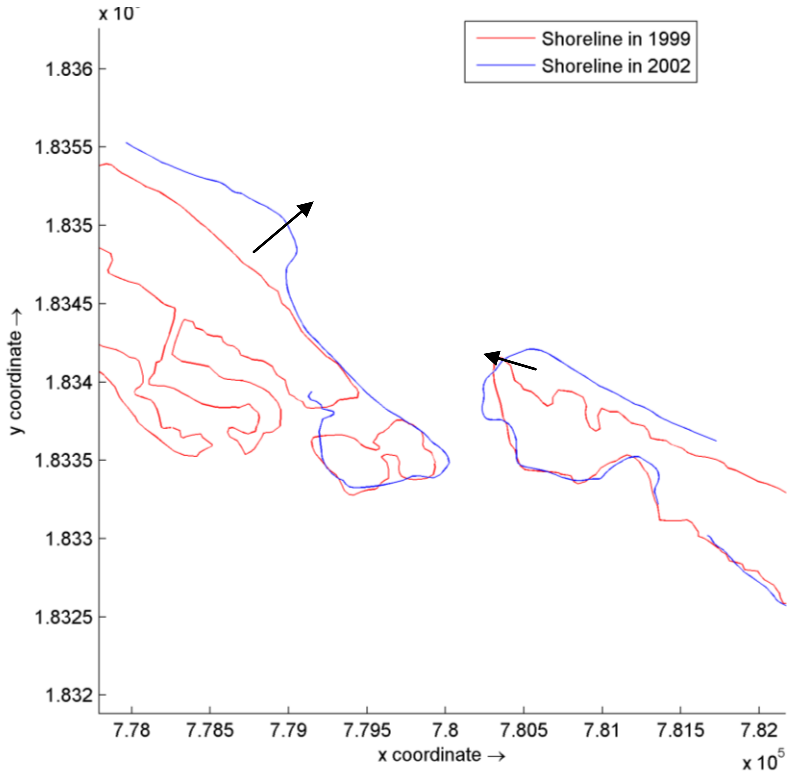


Figure 54: Shoreline in 1999 (red) and 2002 (blue).

4.5 Scenarios with short description

Process-based models like Delft3D are typically used as a numerical lab, in which what-if questions can be tested. The way of using this software is by assessing the relative effects rather than the absolute predictions. Therefore, different scenarios are developed in order to understand and optimise the solution for the Thuan An inlet, see Table 27 and Figure 55.

First of all, it is interesting to look at the natural behaviour of the system by simulating the 'zero scenario'. This can be used to see if the system will act as expected. The Thuan An inlet is wave-dominant and has a micro tidal impact. Therefore, it is expected that the coast will propagate towards a long, linear barrier island with a cuspate or lobate kind of shape.
After understanding the natural system the measures taken by the local authorities are implemented. At this moment, there are two jetties and one breakwater constructed, probably aiming to stop the longshore transport to the northwest, to stabilise the bend in the west bank and to protect erosion from the west barrier during a flood event. It is expected that the east jetty, constructed to stop the

longshore transport, will not fulfil its goal, since satellite images already show bypassing at the southeast jetty. The bathymetry and profile of the natural system for the first two scenarios were provided by Lam, and verified with the help of Google Earth. In order to model the current situation, also satellite data from Google Earth was used. With these images it is possible to reconstruct the length of the jetties.

For the scenario with dredging (3) the build-in features to model dumping and dredging in Delft3D will be used. A minimum water depth of 4.5 meter and minimum width of 100 meter is used to satisfy the requirements for navigation purposes. This is based on the European standards for a CEMT III class vessel and a two-way navigation channel, as described in paragraph 2.3. Dredging is used in all the options at the beginning of the simulations to construct an approach channel and to fulfil navigational requirements. This is a 'soft' solution.
For scenario 4, with a longer east jetty, the structure of the current situation is made longer in order to reduce the sedimentation in the inlet. The length and spacing will be determined in an iterative manner. This is a 'hard' solution, which is preferred in Vietnam.
In the last scenario (5) knowledge of both scenarios three and four are used in order to optimize the solution. A combination of both principles might result in the best solution when applying a multi criteria analysis. This is a combination between a 'soft' solution and a 'hard' solution.

Table 27: Different scenarios (solutions) assessed.

#	Scenario	Measures	Remarks
1	Zero scenario	Nothing	See how the system operates
2	Current situation	Nothing	What is the current situation?
3	Option 1	Dredging	High maintenance costs
4	Option 2	Longer jetty	High construction costs
5	Option 3	Combine a longer jetty with dredging	Maybe the best of two worlds?

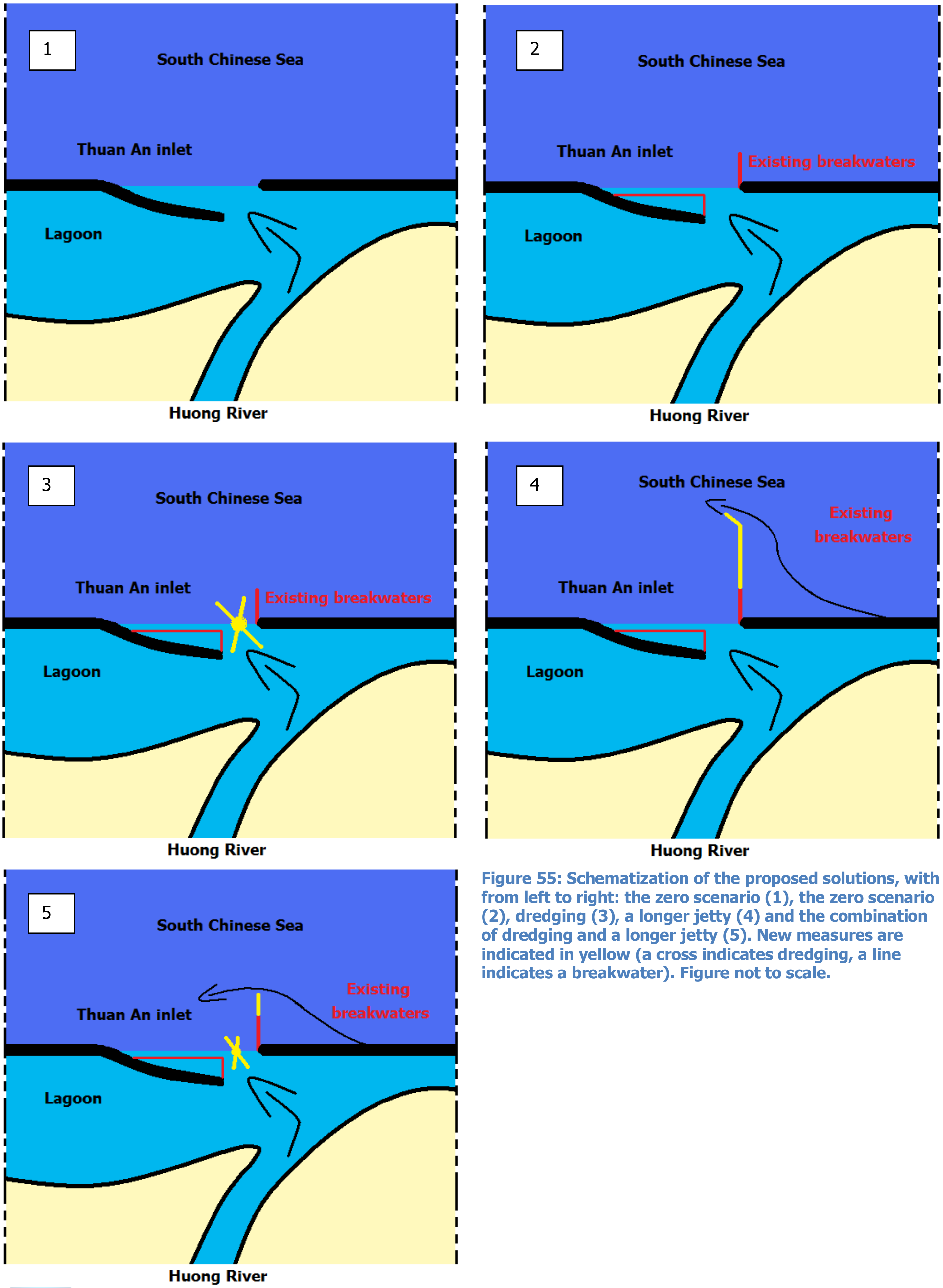


Figure 55: Schematization of the proposed solutions, with from left to right: the zero scenario (1), the zero scenario (2), dredging (3), a longer jetty (4) and the combination of dredging and a longer jetty (5). New measures are indicated in yellow (a cross indicates dredging, a line indicates a breakwater). Figure not to scale.

5. Simulations in Delft3D

5.1 Zero scenario

Introduction

A simulation of one year is carried out for the natural system of the Thuan An inlet without any measures taken by the local authorities. This is done in order to understand the natural behaviour of the system. In this analysis first the development of the bed level changes and of the cross-section of the navigation channel will be analysed. After that it is tried to make a link between the theoretical sediment transport pattern from Chapter 3 and the patterns represented by the model.
This chapter will be completed with an analysis of the longitudinal cross-section and the ebb-tidal delta.

Development of the bed levels of the Thuan An inlet

The rate of sedimentation of the inlet occurs at relatively the same rate during the year, only during the rainy season the spit grows more quickly, the channel deepens and it moves towards the northwest. The reason for this is the combination of severe waves hitting the coast (and thus more longshore transport), more discharge from the rivers and more sediment from the upstream parts of the system. The results can be seen in Figure 57. The velocities in the inlet behave like expected and can be found in Appendix G.

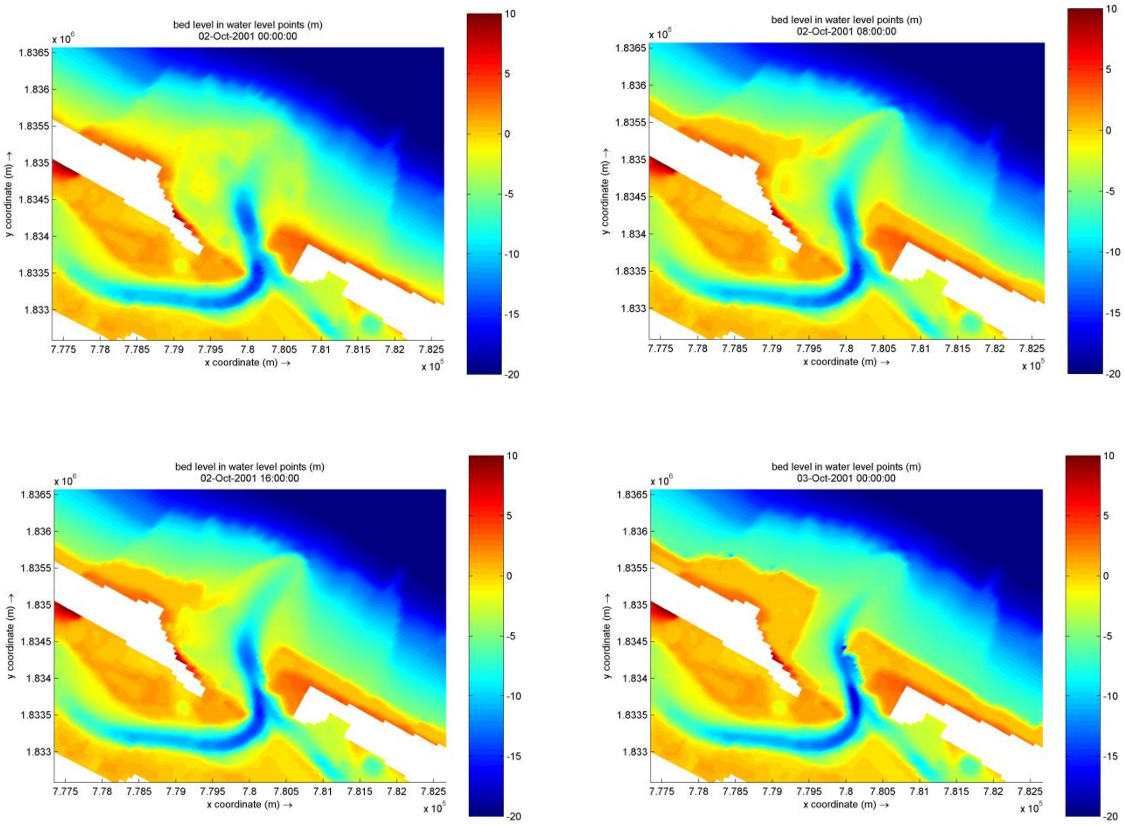


Figure 56: Bed level at the start of the simulation (top left), after 4 months (top right), after 8 months (bottom left) and after one year of simulation for the zero scenario (bottom left).

Development of the cross-section of the navigation channel

The profile of the inlet is slightly propagating towards the west. The major reason for this is the orientation of the waves, which hit the tidal inlet at an average angle of 45 degrees. The effect of this impact is the growth of a spit on the east barrier and some accretion of sediment at the west barrier. The navigation channel trough the inlet narrows a little bit, because of sedimentation at the banks, and propagates towards the northwest. On longer timescales this propagating towards the northwest will continue and the inlet will deepen even more.

It is not expected that the ongoing sedimentation will result in a natural closure of the Thuan An inlet. The sedimentation in one year of computation is the effect of an inlet which is too large for the discharge through it. This is what was expected based on Escoffier's curve, presented in paragraph 3.4.

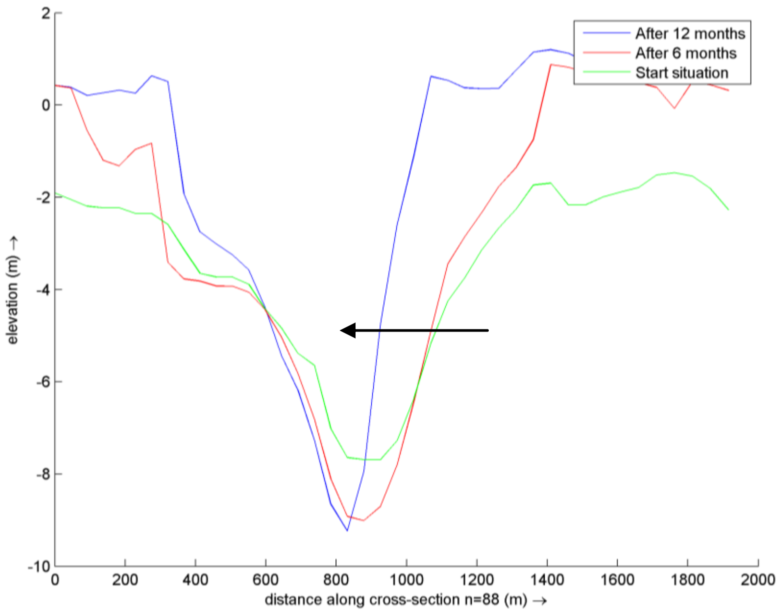


Figure 57: Cross-section of the navigation channel at the start of the simulation, after 6 months and after 12 months of simulation for the zero scenario.

Sediment transport patterns

An interesting phenomenon occurs at the northeast side of the inlet. The accretion will result in a large area of new land in the shape of a drumstick. This is what was expected based Paragraph 3.3. It was even possible to reproduce the wave direction like the theory described.

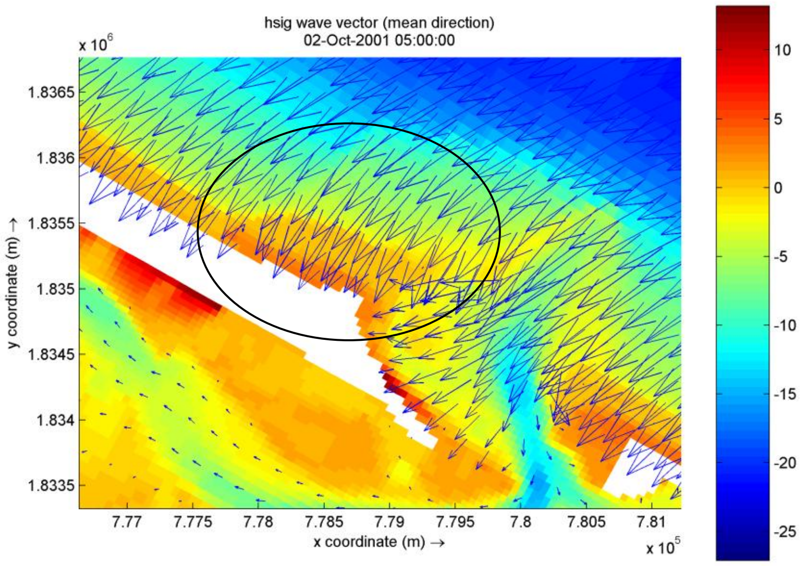


Figure 58: Calculated mean wave direction at the Thuan An inlet for the zero scenario.

Along the Thuan An inlet the dominant longshore transport direction is from the south to the north. There are two bypassing mechanisms for the river of sand along the coast, namely bar-bypassing and tidal bypassing. According to the theory the bar-bypassing will be the most important one.
In the Delft3D model it was possible to reproduce both bypassing mechanisms. From Figure 58 it is clear that the longshore transport is from south to north. The most active zone is, logically, within the inlet itself, but also more offshore sediment is transported. The circle in Figure 58 indicates the bar-bypassing, which occurs between 1000 till 2000 meters offshore; as can be seen in Appendix G.

It was also possible to reproduce the theory of tidal-bypassing in the inlet. In Figure 60 both the situation during ebb as the situation during flood are represented. It is clear that during ebb the outflow of water takes sediment out the inlet. This is restored during flood. The arrows in Figure 59 represent the total sediment magnitude in $m^3/s/m$.

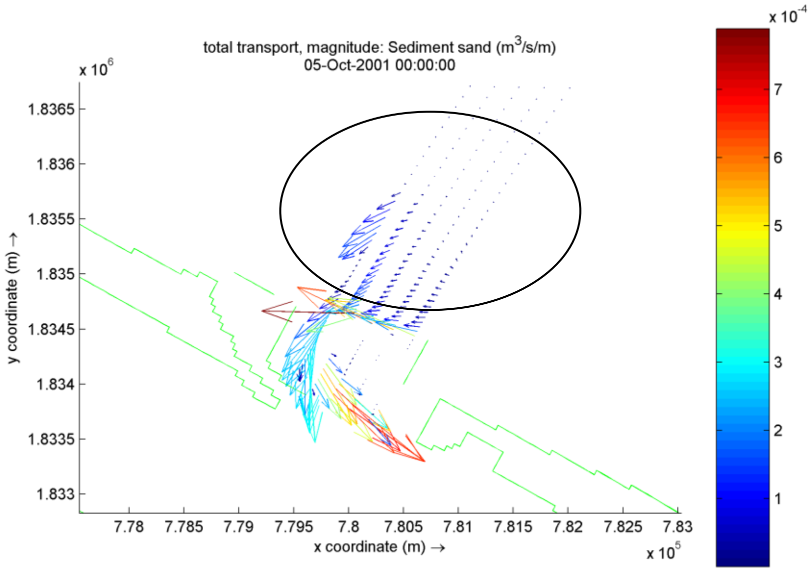


Figure 59: Bar-bypassing in the Thuan An inlet in progress for the zero scenario.

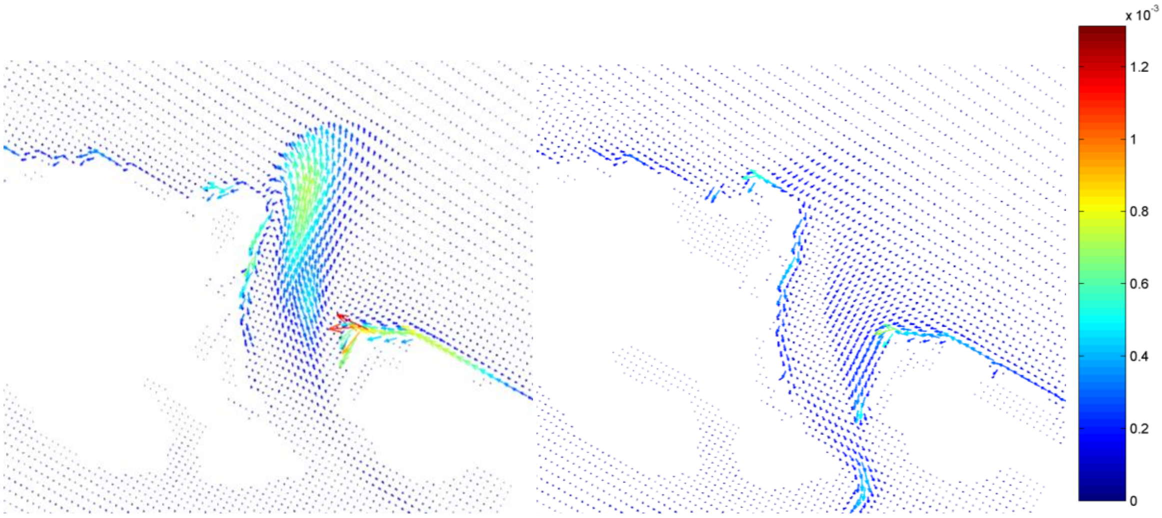


Figure 60: Tidal bypassing in the Thuan An inlet during ebb (left) and flood (right) for the zero scenario.

Development of the longitudinal cross-section

On the long-term the tidal inlet will propagate towards a stable situation with a minor ebb-tidal delta. This is what was expected based on the characteristics of an inlet within a micro tidal impact regime. The water level at this point will reach 5 meters, which is sufficient for navigational purposes. Further offshore no relevant processes for this research are occurring, as can be seen in Figure 61.

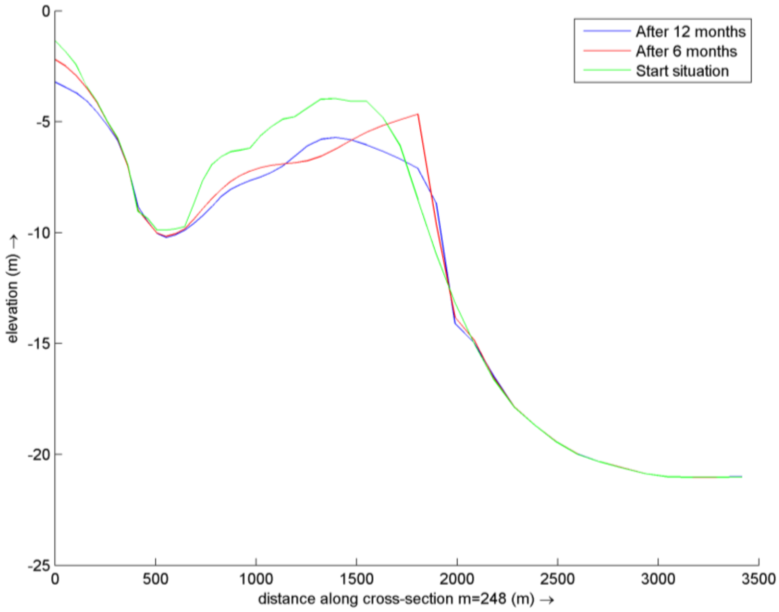


Figure 61: Longitudinal cross-section of the navigation channel at the start of the simulation, after 6 months and after 12 months of simulation for the zero scenario.

Conclusion

Concluding this chapter the following observations can be made:

- Coast is transforming into a linear barrier island in a cuspate / lobate kind of shape;
- Spit from the east bank grows into the west direction. The rate of the growth is the highest during the rainy season
- Cross section of the channel narrows due sedimentation at both bank;
- Accretion at the west bank will result in a drumstick shape;
- The two bypassing mechanisms are reproduced.

5.2 Current situation

Introduction

The first part contains a simulation of one year for the current situation of the Thuan An inlet in which the measures taken by the local authorities are implemented. This is done in order to understand the effects of the new jetties and breakwaters. In this first part a comparison between the bed level changes and the cross-sections is made. Based on the experiences in the field it was expected that the measures taken by the local authorities would hardly help to stabilize the inlet.

In order to get a better understanding of the current system on longer timescales, also a simulation for three years carried out. In this second part the development of the bed level changes and of the cross-section of the navigation channel will be analysed.

Comparison of the bed levels of the Thuan An inlet

The simulation for one year partly confirms the hypothesis. The east jetty is completely sedimentated and bypassing around the east jetty results in a spit which is comparable in size as in the zero scenario, as seen in Figure 62. The north breakwater doesn't really seem to have a function and the west jetty results in a shift of the navigational channel towards the east.

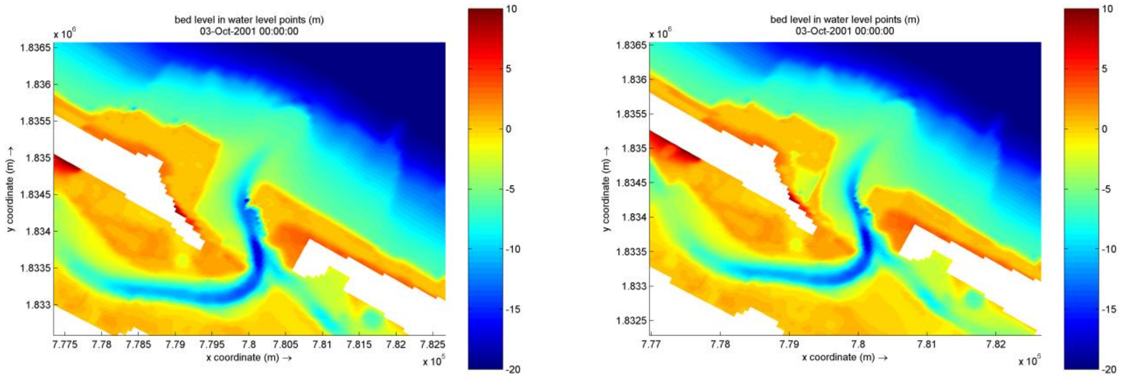


Figure 62: Comparison of the bed level after one year for the zero scenario (right) and current situation (left).

Comparison of the cross-section of the navigational channel

The accretion process north of the newly placed Tetrapods occurs at the same rate as the zero scenario. The reason for this is the fact that the waves and thus longshore transport are not influenced. However, the amount of sedimentated material behind the breakwater is somewhat reduced. It can be questioned if the authorities have foreseen this effect. The reduction is in the order of 25%.

More interesting is the location of the west bank of the inlet. The west jetty will have an impact on the navigational channel, because it is shifted 50 meters towards the east. Therefore, the cross-section of the navigation channel differs somewhat at the west side, as can be seen in Figure 63. On top of that, sedimentation process of the west barrier will occur at a lower rate. This is a positive effect for the known problems with structural dune erosion at the coast of Hue.

At the east side of the inlet the growing of the spit is slowed down. This is due to the sedimentation at the east jetty. Therefore, the cross-section of the navigation channel differs a lot at the eastside, as can be seen in Figure 63. After 1 year the location of the east bank is 400 meters more to the east. It is however a matter of time, due to bypassing at the jetty tip, for the current situation to propagate towards the zero scenario. The longitudinal cross-section and the depth-averaged velocities in the inlet do not differ a lot with the zero scenario and can be found in Appendix G and H. In Appendix the shoreline profiles of the inlet are compared to the current situation and thereby confirm the general view of this analysis.

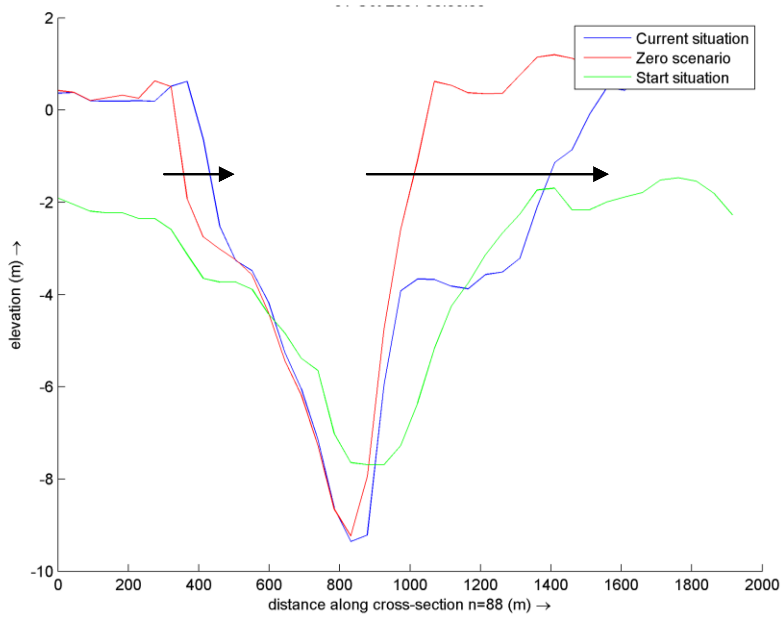
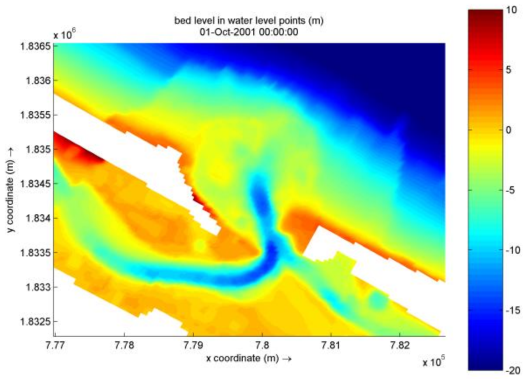
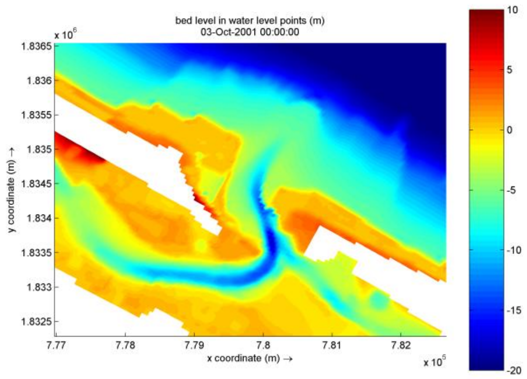


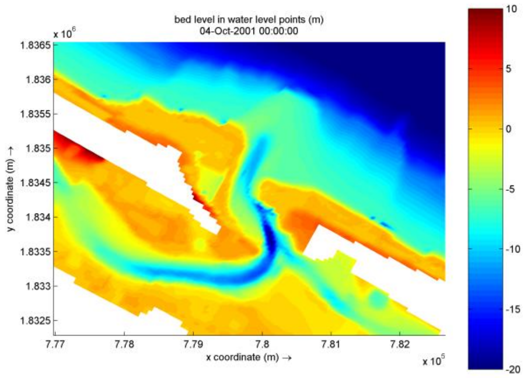
Figure 63: Cross-section of the navigation channel after one year for the zero scenario (red) and current situation (blue).

Development of the bed levels of the Thuan An inlet

In order to get a better understanding of the system on longer timescales, also a simulation for three years carried out. The effect on long term is the continuous growing of the spit towards a northwest direction. The effect on the navigation channel is a deepening channel, which will tend to migrate towards the northwest. The Thuan An inlet will not accreted completely, which confirms the research earlier carried out by for example Lam (2008).







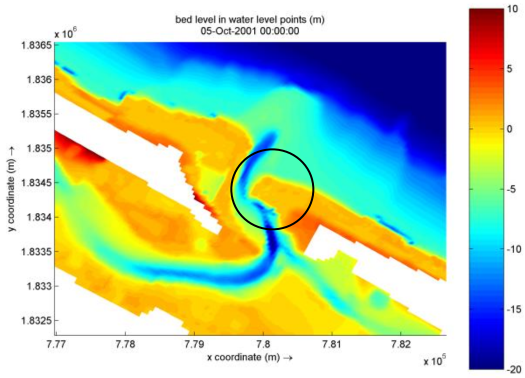


Figure 64: Comparison of the bed level at the start (top left), after one year (top right), two years (bottom left) and three years (bottom right) for the current situation.

Development of the cross-section of the channel and longitudinal cross-section

The cross section of the navigational channel shows the effect of accretion on both the west as the east bank. After the first year the accretion rate at the west bank is low compared to the east bank. The reason is that after the formation of the drumstick shape the east bank is in a relative stable position.

The accretion at the east bank occurs continuously every year in the first years. The spit grows at a rate of 100 meter each year. It is not expected that this will continue, because the velocities in the inlet increase due the decrease in cross-sectional area. This effect can already been seen in the model, because the channel is deepening trough the first three years. The depth increases from 7 meters at the start situation, to 10 meters after 1.5 years, till 14 meters after 3 years.

The longitudinal cross section (Figure 66) shows that the ebb-tidal delta will go towards a stable 6 meters in depth, which is sufficient for navigation purposes. The reason that the ebb-tidal delta deepens are the higher velocities due the growing of the spit. The analysis can be found in Appendix H. When this behaviour is extrapolated it can be seen that after about 9 years there will be navigational problems with the width and manoeuvrability, which should be prevented. The analysis can be found in Appendix H.

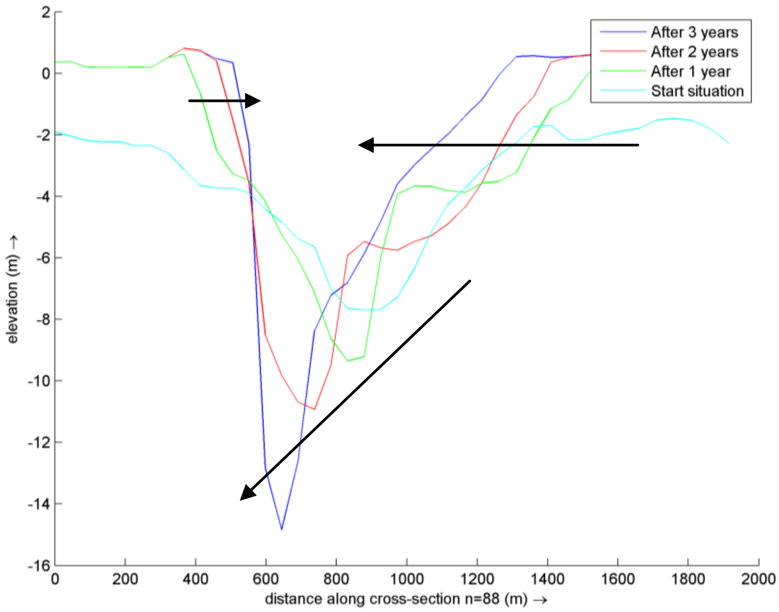


Figure 65: Cross-section of the navigation channel for the current scenario for several simulations periods: start (cyan), 1 year (green), 2 years (red) and 3 years (blue).

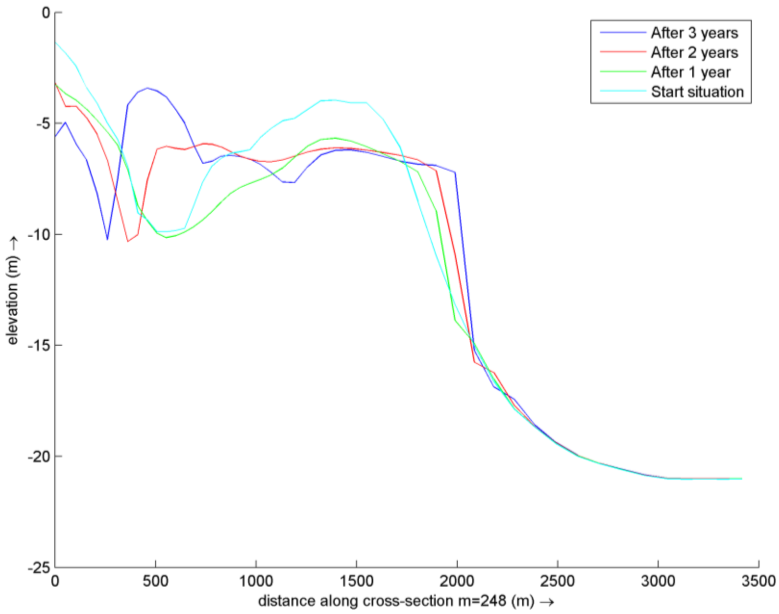


Figure 66: Longitudinal cross-section of the navigation channel for the current scenario for several simulations periods: start (cyan), 1 year (green), 2 years (red) and 3 years (blue).

Conclusion

The 2 constructed jetties and the north breakwater will have limiting effect on the stability of the Thuan An inlet. Concluding this chapter the following observations can be made:

- West jetty: reduces the speed of the growing of the spit that will partly block the straight entrance of the Thuan An inlet. This effect is however temporary, because bypassing is already occurring;
- East jetty: fixate the navigation channel 40 meters towards the east in order to reduce the cross sectional area and thus partly stop the sedimentation of the inlet. However at the moment the structural integrity is failing. (Masterproject Hue, 2013);

- Tetrapods breakwaters: reduce of the amount of sedimentated material at the west side of the inlet behind the breakwater with 25%;
- It was not possible to reproduce the erosion at the south part of the west barrier. This is probably because of the fact that extreme events like typhoon are not included in the model.

5.3 Option 1: Dredging

Introduction

The first part of this chapter contains a simulation of three years for the current situation in the Thuan An inlet, in combination with continues dredging. This is done to understand the effect of dredging on the tidal inlet. In this first part a comparison between the bed level changes and the cross-sections is made. On top of that also an estimation of the amount of dredged material and an analysis of the effects on the surrounding coast are presented.

In reality the dredging operation will be carried out each year or each three years. This process is also modelled in Delft3D and presented in the second part of this chapter under the name realistic dredging. The analysis contains the development of the bed levels, cross-sections and the amount of dredged material.

Comparison of the bed levels of the Thuan An inlet

The effect of the continuous dredging operation is a channel that is suitable for navigational use. The width, depth and manoeuvrability are CEMT III proof. In Figure 67 the bed level is presented for the current situation and the situation with dredging every year after three years. The depth averaged velocity for the case with dredging is much lower when compared to the current situation. For the current situation the flow velocity will propagate, because of sedimentation in the inlet, to a value of 0.9 m/s. For the situation with dredging the depth-averaged flow velocity has a maximum of about 0.4 m/s. In Appendix I the time series are presented. In addition, the shoreline profiles of the inlet compared to the current situation are presented in Appendix I.

The growing of the spit at the east bank is completely dredged away. The effect is that the navigational channel meanders much less and is less deepened. The drumstick shape is still presented, but is somewhat more peaked.

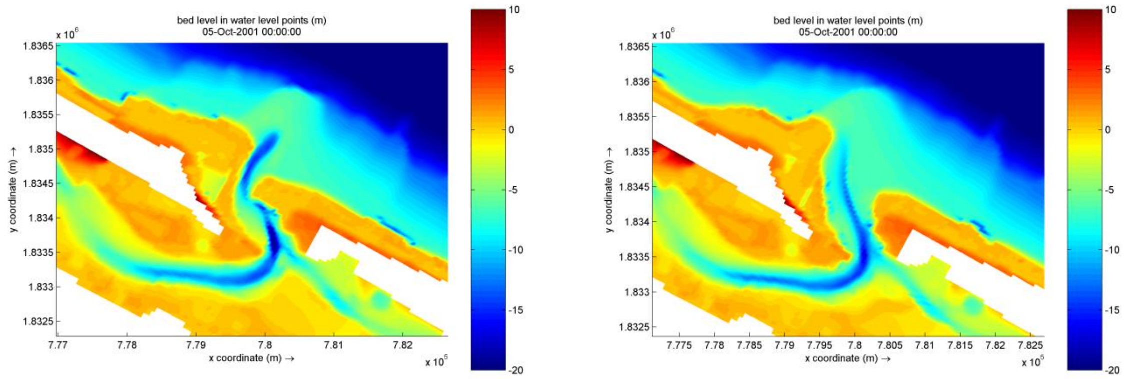


Figure 67: Comparison of the bed level after three years for the current situation scenario (left) and option 1 with continuous dredging (right).

Comparison of the cross-section of the navigational channel

The dredging operation will result in a much wider navigational channel. This means that the cross sectional area of the inlet is too large based on the Escoffier curve. The result is sedimentation and dredging will be needed to take away this material. Such a large cross sectional area is an advantage during extreme conditions with high discharges. The west bank is shifted 100 meters and the east bank is shifted even more with 400 meters. The channel has a depth of 11 meters compared to 14 meters with the current situation.

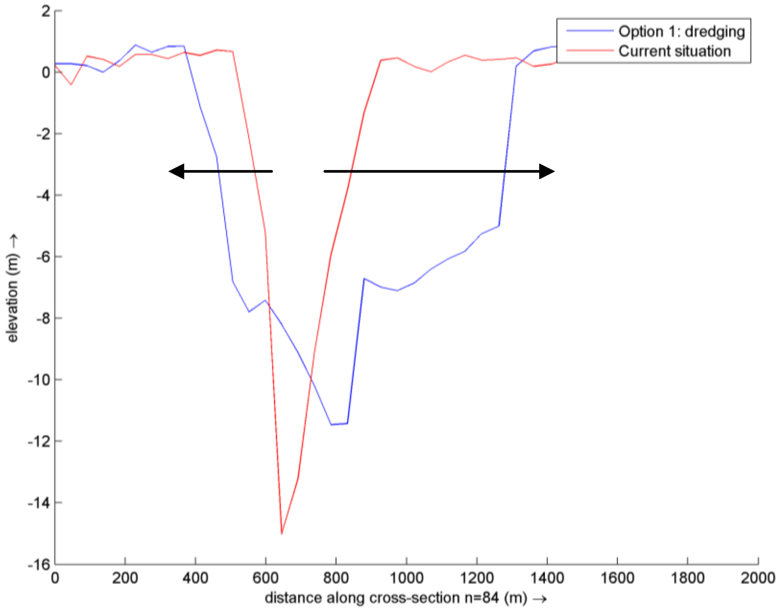


Figure 68: Comparison of the cross section after three year for the current situation scenario (red) and option 1 with continues dredging (blue).

Development of the amount of dredged material for continues dredging

The dredging operation was first modelled continuously in order to maintain enough navigational depth and width. For a period of thirty years of dredging this will mean a total volume of 25.60 Mm^3 of sediment. Most sedimentation occurs in the rainy season when the longshore transport is the largest, as can be seen in the black oval in Figure 69.

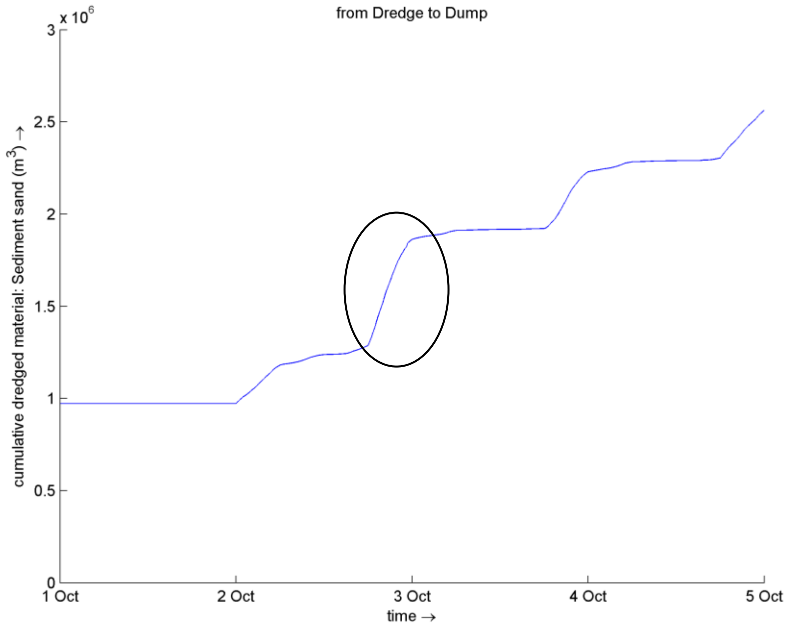


Figure 69: Development of the amount of dredged material in the navigation channel for option 1 with continues dredging for a simulation of three years.

Effects on the surrounding coast

A major concern of a dredging operation is the fact that the natural system is undermined. Along the Thuan An inlet the dominant longshore transport direction is from south to north. From the empirical relation derived by Bruun, see Chapter 3.3, it followed that bypassing mostly occurs via the ebb-tidal delta. It is already shown in the longitudinal cross-section that the ebb-tidal is not influenced and therefore it is expected that the effects of dredging will be minimal. This cross-section can be found in Appendix I.

In order to analyse this effect two longitudinal cross-sections are taken about 1 kilometre north and 5 kilometres south from the Thuan An inlet. The effects of the dredging operation are indeed minimal, as seen in Figure 70. The longitudinal cross-section north differs a bit compared to the current situation. The longitudinal cross section to the south is used as reference. This means that the ebb-tidal delta is only influenced to a minor degree by the dredging operation.

What the complete impact of dredging will be on the coast of Hue should be analysed in next studies, because the grid is too coarse near the coastline to accurately state something about the erosion. An option to counteract the effects of dredging would be to nourish the dredged material directly on the eroding paths of the coast.

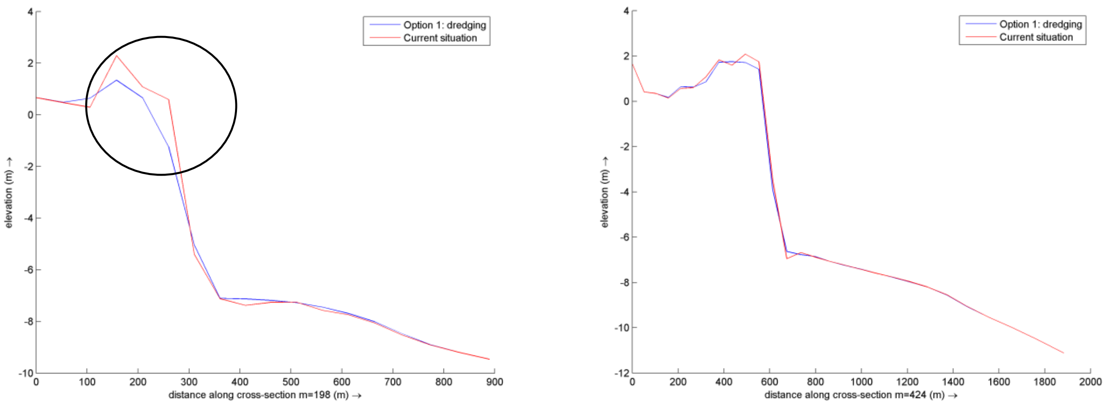


Figure 70: Longitudinal cross section 1 kilometre north (left) and 5 kilometres south (right) of the Thuan An inlet for option 1 with continues dredging for a simulation of three years.

Development of the bed levels of the Thuan An inlet for continues dredging

After the comparison between the current situation and the dredging option, it is possible to understand the behaviour of the system under influence of a continuous dredging operation. First a navigational channel, that is suitable for CEMT III, is constructed. This means that the ebb-tidal delta needs to be deepened, as seen at the top right in Figure 71. After that operation the navigational channel tends to deepen towards the northwest, as seen at the location of the circle in Figure 72.

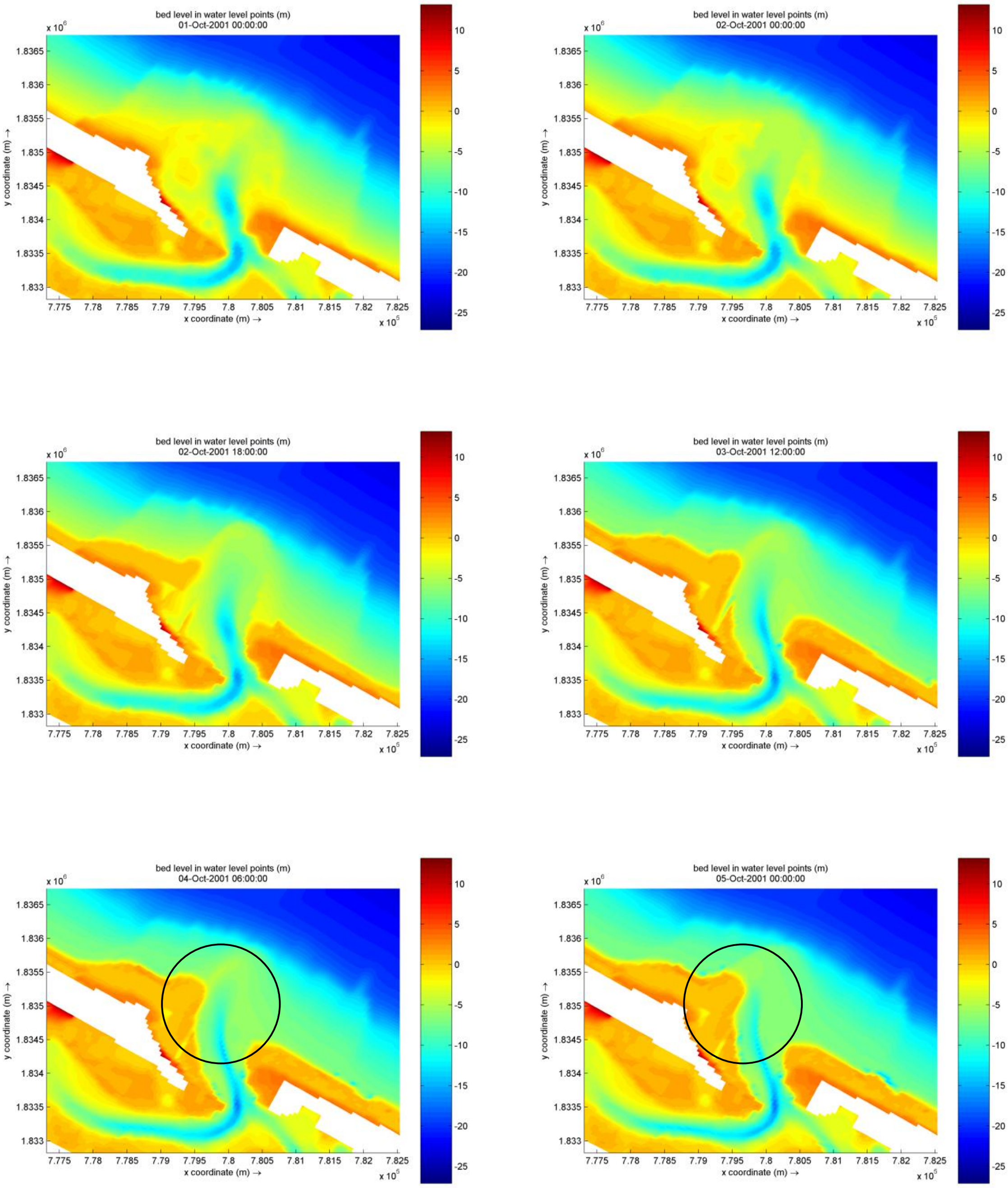


Figure 71: Comparison of the bed level at the start (top left), after the first dredging operation (top right), after 9 months (middle left) and 18 months (middle right), after 27 months (bottom left) and 36 months (bottom right) for option 1 with continuous dredging.

Development of the cross-section of the navigational channel for continues dredging

The cross-section of the navigation channel will tend to deepen at the northwest side of the inlet. Most sedimentation and thus dredging occur at the southeast side of the inlet. This is what was expected based on the earlier analysed process of the growing spit. The longitudinal cross section shows that offshore no dredging is required after the first dredging operation to make the approach channel, which can be seen in Appendix I.

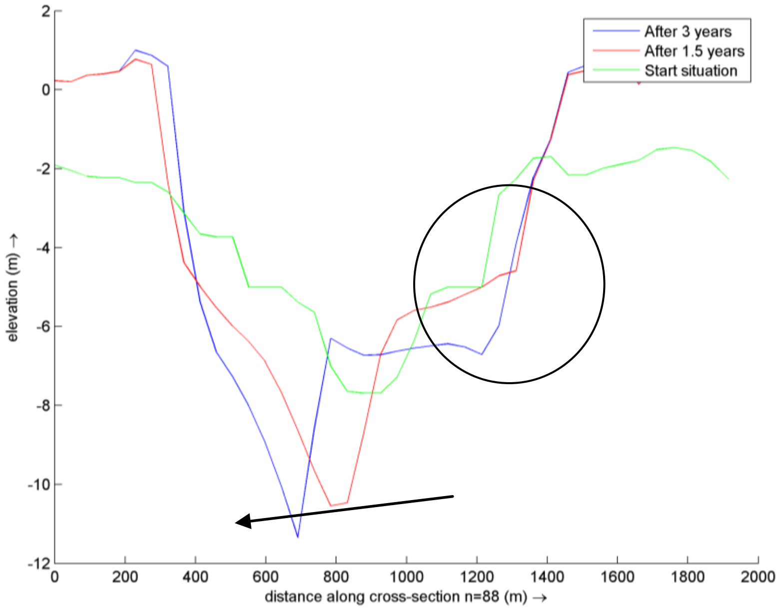


Figure 72: Development of the cross section of the navigation channel for option 1 with continuous dredging and for a simulation of three years.

Development of the bed levels of the Thuan An inlet for realistic dredging

After the first part with the analysis of continuous dredging the second part continues. In this part the dredging operation is operated each year or each three years and called realistic dredging.

When dredging is applied each year the growing of the east spit will propagate less far in the navigational channel compared to dredging each three years. A growing spit has two major downsides. The first is the decrease of navigational width due to sedimentation. The second is the fact that the channel will deepen at the west side of the inlet. This is a potential threat for the area during an extreme event like a typhoon, because during high discharges the water cannot easily flow into the sea and thus the water level in the Cau Hai lagoon will rise. The minimal navigational width during operation for dredging each year will be +200 meter. When dredging each three years, this will decrease till about 150 meters.

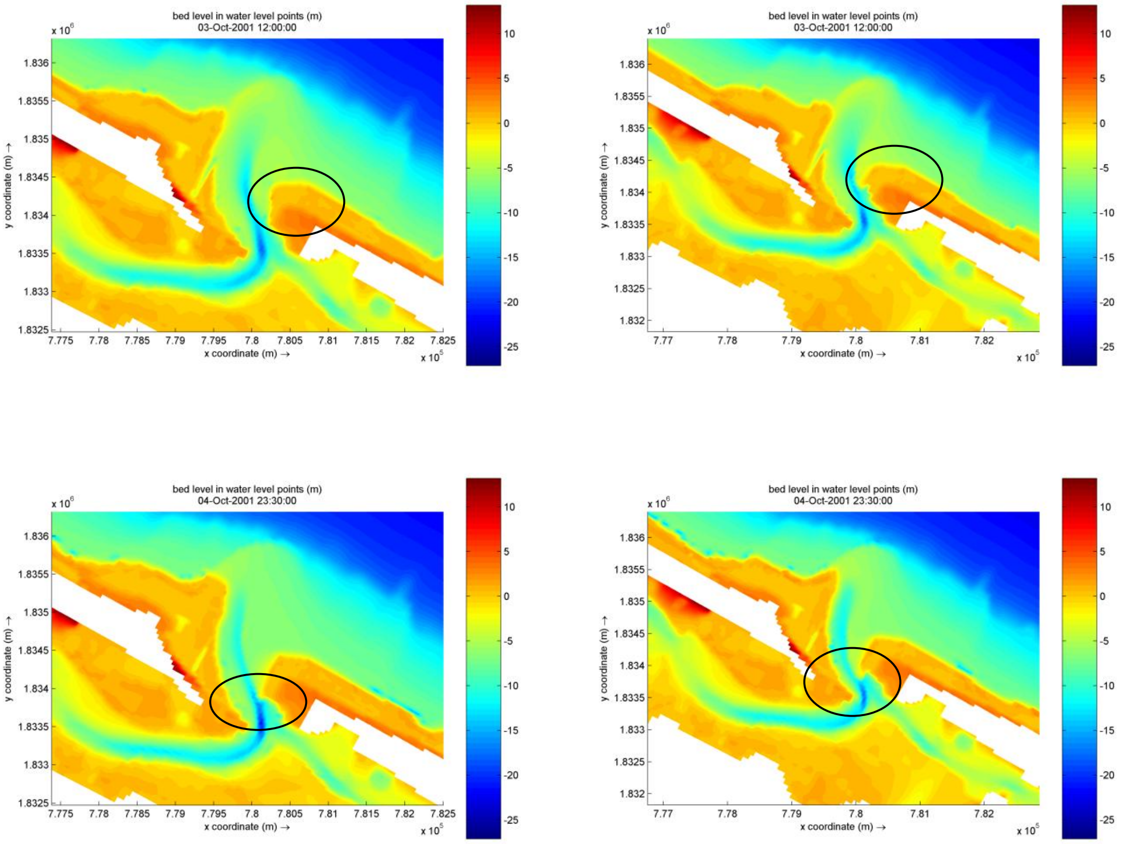


Figure 73: Comparison of the bed level for each year dredging after 1.5 years (top left), for each three years dredging after 1.5 years (top right), for each year dredging after 3 years (bottom left) and for each three years dredging after 3 years (bottom right).

Development of the cross-section of the navigational channel for realistic dredging

The cross-section of the navigation channel shows the sedimentation process at the outer banks of the Thuan An inlet for a dredging operation repeated each three years compared to a dredging operation each year. On top of that the navigational channel will deepen. The longitudinal cross section shows that offshore no dredging is required after the first dredging operation to make the approach channel. This can be seen in Appendix I.

Both channels will behave more are less similar across time. The major difference is the fact that more sedimentation can occur for the situation with a dredging operation each three years. This will result in a narrower and deeper channel. The channel will shift in the order of 10 meters at each bank. The comparison of the development of the cross section of the navigational channel can be found in Appendix I.

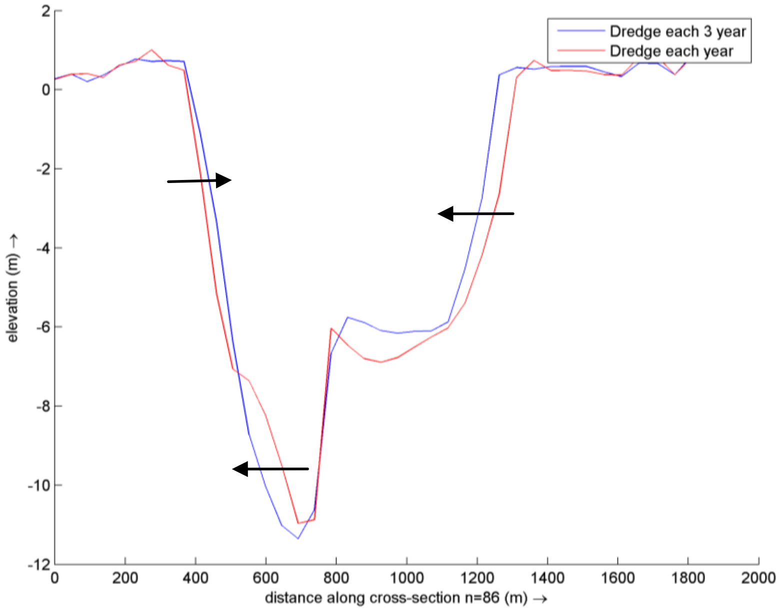


Figure 74: Cross section of the navigation channel with dredging each year (red) and dredging each 3 years (blue).

Development of the amount of dredged material for realistic dredging

When dredging is carried out each year a total of 17.7 Mm^3 will need to be dredged and when dredging is applied each three years a total of 13.8 Mm^3 will need to be dredged. This means that the needed amount of dredged material increases with 28% when the dredging operation is repeated each year instead of each three years. This occurs because sedimentation will result in higher velocities and thus less sedimentation. This means that the less dredging operations per period, the less material to dredge. All the numbers are based on 30 years of simulation.

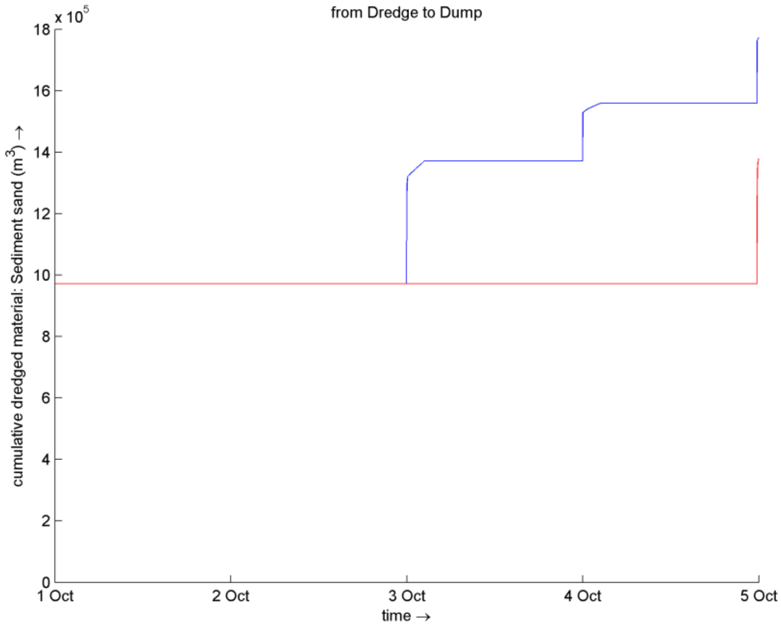


Figure 75: Development of the amount of dredged material in the navigation channel with dredging activity each year and each three years for a simulation of three years.

Conclusion

Dredging the Thuan An inlet is an easy and effective way of stabilizing the inlet. Concluding this chapter the following observations can be made:

- Most material needs to be dredged at the west bank;
- Most sedimentation occurs in the rainy season;
- Dredging will result in a wide and less deep navigational channel;
- Some erosion at the northwest of the Thuan An inlet expected;
  - In order to state quantitative additional research is needed;
  - Probably beach nourishments (supplied by the dredged material) will be needed to stabilise some parts of the coast;
- When the amount of dredging operations per period decreases, the amount of total dredged material also decreases;
  - Dredging each year means a total of 17.7 Mm^3 needs to be dredged;
  - Dredging each three years means a total of 13.8 Mm^3 needs to be dredged;
- It is possible to reduce the frequency of dredging till an operation each three years;
  - It is however recommend using the flexibility of a dredging operation to counteract; the variability of typhoons and thus variability of the navigation channel.

5.4 Option 2: Longer jetty

Introduction

A simulation of three years is carried out for the situation with a longer jetty for the Thuan An inlet. The jetty now reaches more than 1000 meters further into the sea and has a nod in order to reduce the wave impact on the ebb-tidal delta. This is a potential advantage for traffic in the navigation channel due to the decrease of wave height. On forehand it was expected that these measures will result in a blockage of the longshore transport and thus stop the sedimentation on the east bank of the Thuan An inlet. When this sedimentation stops, the inlet should be more stable.

At first a comparison for the bed levels of the Thuan An inlet and the cross-section of the navigational channel is made between the current situation and option 2. Next the effects on the wave heights and direction are analysed. After this an analysis is carried out on the surrounding coasts in order to look if the coast is eroding / accreting. The last parts will contain the development figures of the bed level and the cross-section.

Comparison of the bed levels of the Thuan An inlet

The system behaves as expected. The longshore transport from south to north will result in accretion at the longer jetty at the east bank. On very long timescales the sedimentated material at the southeast jetty should be dredged, because eventually bypassing will occur. The active period of this solution can probably be extended up to the design life time of 30 years. The calculation is based on the analytical approach for accretion near breakwaters and can be found in Appendix J, but should be analysed in more detail.

The depth averaged velocities for option 2, with a longer jetty, are lower compared to the current situation. For the current situation the velocity will propagates, because of sedimentation in the inlet, to a value of 0.9 m/s. For the situation with a longer jetty the velocity has a maximum of about 0.7 – 0.8 m/s. The time series are presented in Appendix K.

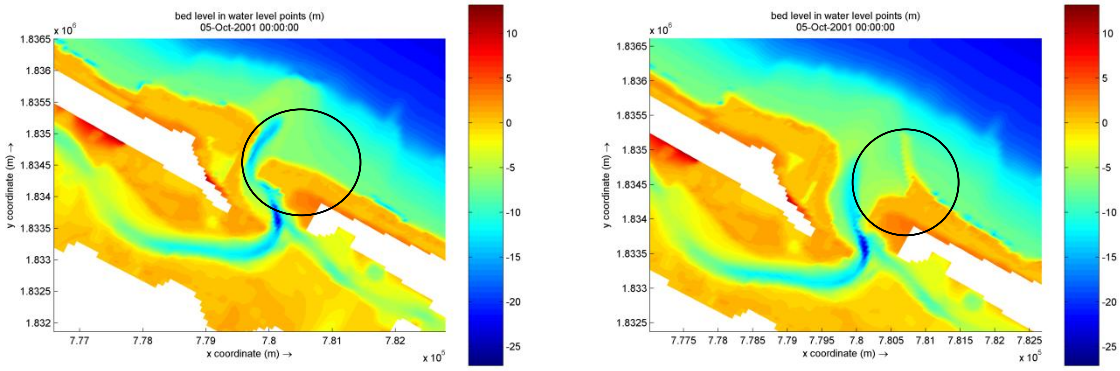


Figure 76: Comparison of the bed level for the current situation (left) option 2 (right) for a simulation of 3 years.

Comparison of the cross-section of the navigational channel

Material will be accreted at the east jetty, which means that the spit grows much slower. An additional effect of slowing down the growing of the spit is that the navigation channel does not propagate towards the northwest and does not deepen (see Figure 76 and Figure 77). This means that the channel is in a more stable position for navigational use. The deepest point in the channel decreases from 14.5 meters till 11 meters and the east bank is shifted 500 meters towards the east.

The longitudinal cross-section confirms these findings and can be found in Appendix K. The reason that still some accretion may occur is the fact that sediment is provided from upstream regions, but also because of the effect of some bar-bypassing near the jetty. The magnitude of this transport is small compared to the current situation, but for option 2 most sediment is transported near the ebb-tidal delta at 1000 till 2000 meter offshore. This figure can be found in Appendix K. Also the shoreline profiles of the inlet are compared to the current situation, presented in Appendix K.

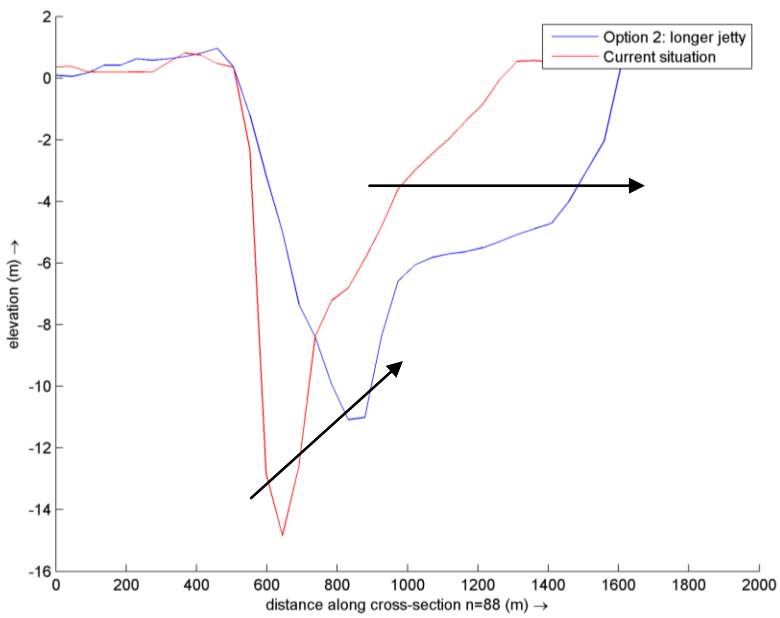


Figure 77: Cross-section of the navigation channel for the current situation and option 2 for a simulation of 3 years.

Effects on the wave height and direction

It was expected that the wave height in the inlet will be reduced because of the construction of a jetty with a nod (more or less a combination between a jetty and breakwater). The simulation does not confirm this theory. Instead of the expected lower wave height, there will be a higher wave height in the Thuan An inlet, as seen in Figure 78. The reason is that the position of the extended jetty will result in diffraction of the waves directly into the navigational channel of the Thuan An inlet. Due to the limited time for this research, no additional measures are taken. It is advised to analyse the effect of longer jetties in more detail in next studies, to overcome these problems.

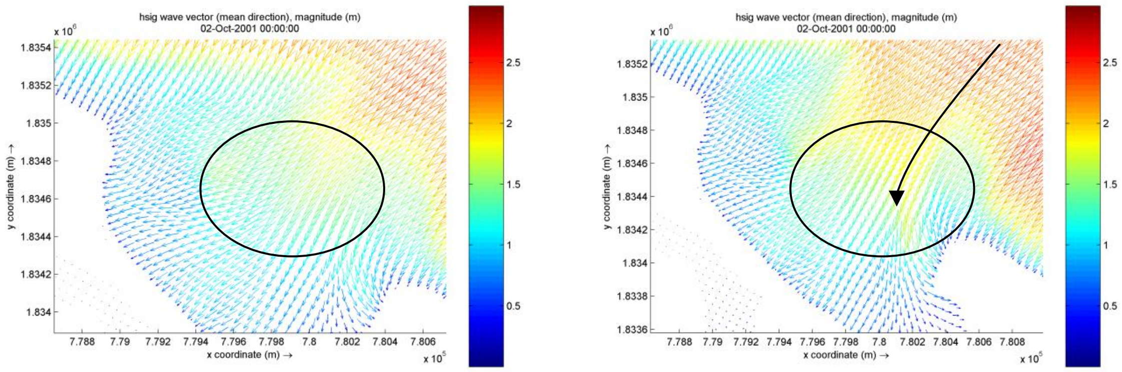


Figure 78: Wave conditions in January for the current situation and option 2.

Effects on the surrounding coast

A major concern of a longer jetty is the fact that the natural system is undermined. Along the Thuan An inlet the dominant longshore transport is directed from south to north. When the east jetty is extended with 1000 meters the longshore transport will be largely blocked. This will probably result in erosion at the west barrier and accretion at the east barrier.

In order to analyse this effect two longitudinal cross-sections are taken about 1 kilometre north and 5 kilometres south from the Thuan An inlet. The results are like expected: erosion occurs at the north and accretion occurs at the south, as can been seen in Figure 79.

What the complete impact of a longer jetty will be on the coast of Hue should be analysed in next studies, because the grid is too coarse near the coastline to accurately state something about the erosion. The most likely solution would be to nourish the beach at the northwest of the Thuan An inlet.

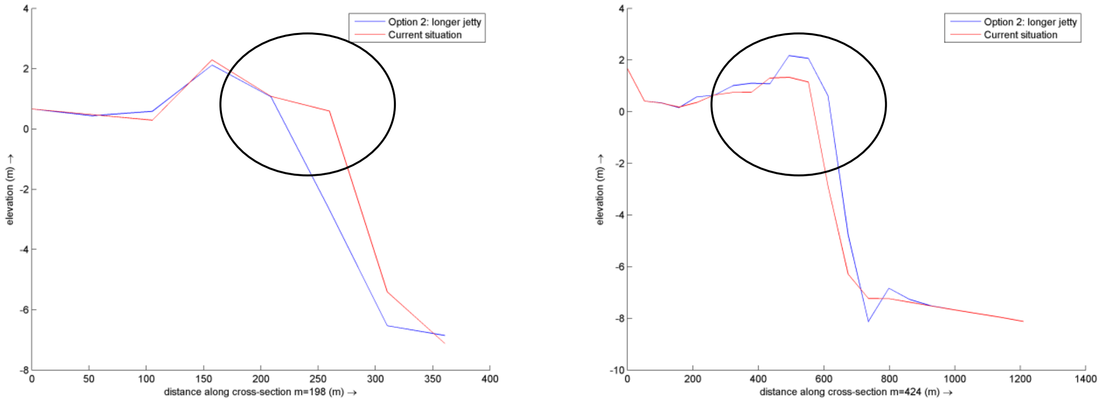


Figure 79: Longitudinal cross section 1 kilometre north (left) and 5 kilometres south (right) of the Thuan An inlet for the extended jetty scenario.

Development of the bed levels of the Thuan An inlet

After the comparison between the current situation and option 2 it is possible to understand the behaviour of the system. The effect of the longer jetty is quite obvious. Accretion behind the longer east jetty will prevent the growing of the spit towards the west.

Most sedimentation occurs at the west side of the inlet. The growing of the spit is slowed down because of the longer jetty, but still some accretion is possible due to the active ebb-tidal delta and the bar-bypassing mechanism. This means that accretion at both banks can still continue. The accretion process occurs at a lower rate compared to the current situation. When one want to counteract the ebb-tidal delta the jetty need to research 1000 meter further into see, as can be seen in Appendix K. This is however not advisable, because the system can not behave naturally and severe erosion will occur northwest of the Thuan An inlet

More interesting is the effect inside the Thuan An inlet. Instead of a growing spit from east towards west, a spit at the east side of the inlet will grow towards the south and will potential limit the navigational width near the lagoon. This is a possible threat for navigation. The effect of this spit is that the navigational channel near the lagoon deepens. The reason for this spit formation are waves that now propagate completely inside the inlet. At the point where the waves hit the spit, the significant wave height is almost 2 meters in the rainy season, as can be seen in Appendix K.

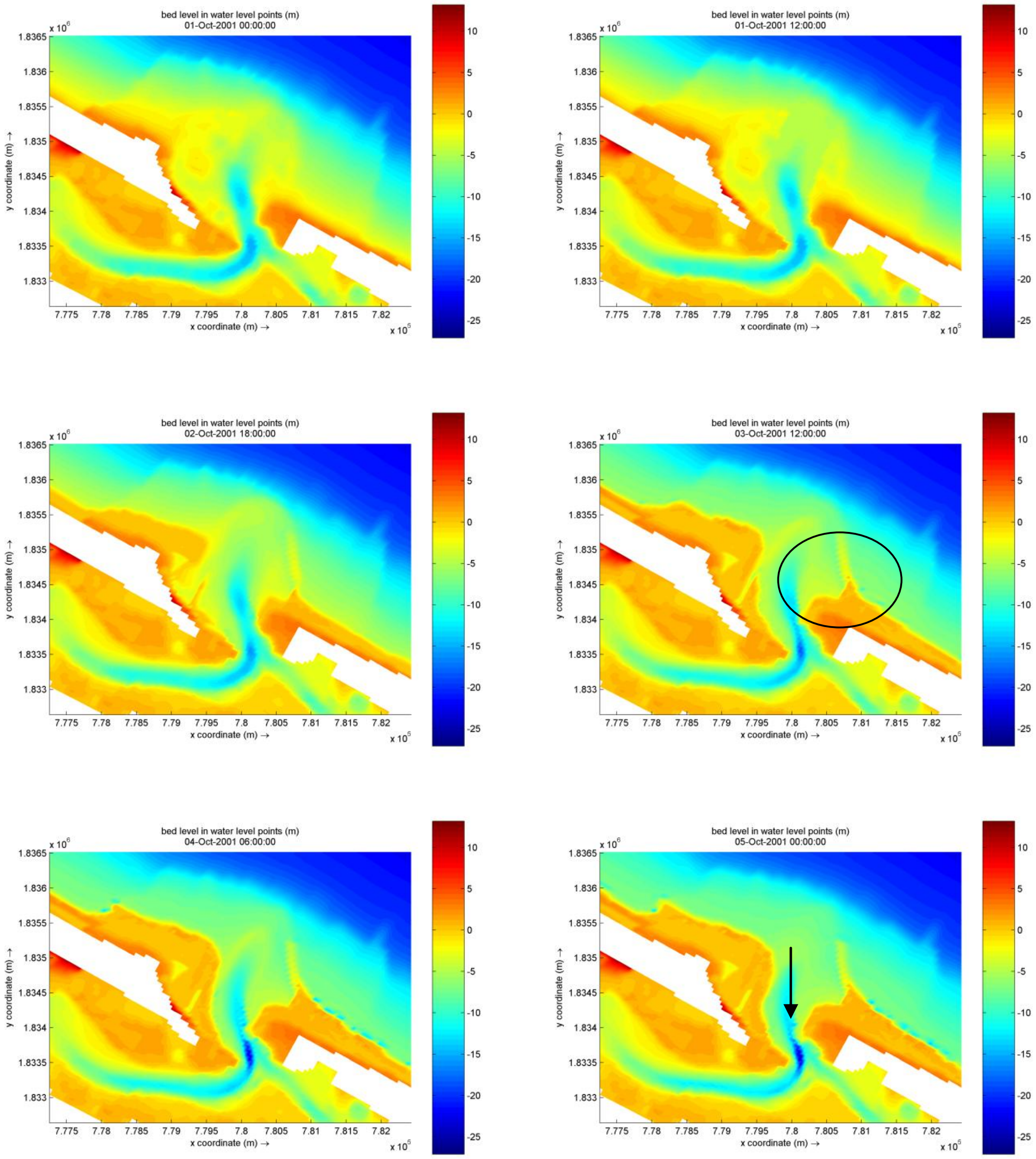


Figure 80: Comparison of the bed level at the start (top left), after the first dredging operation (top right), after 9 months (middle left), 18 months (middle right), 27 months (bottom left) and 36 months (bottom right) for option 2.

Development of the cross-section of the navigational channel

The cross-section of the navigation channel will tend to deepen at the south side of the inlet, because of the formation of a new spit that grows at the east bank in southward direction. The spit accretes each year with 20 meters. The longitudinal cross section shows that offshore no measures are required after the first dredging operation to make the approach channel. This can be found in the Appendix K.

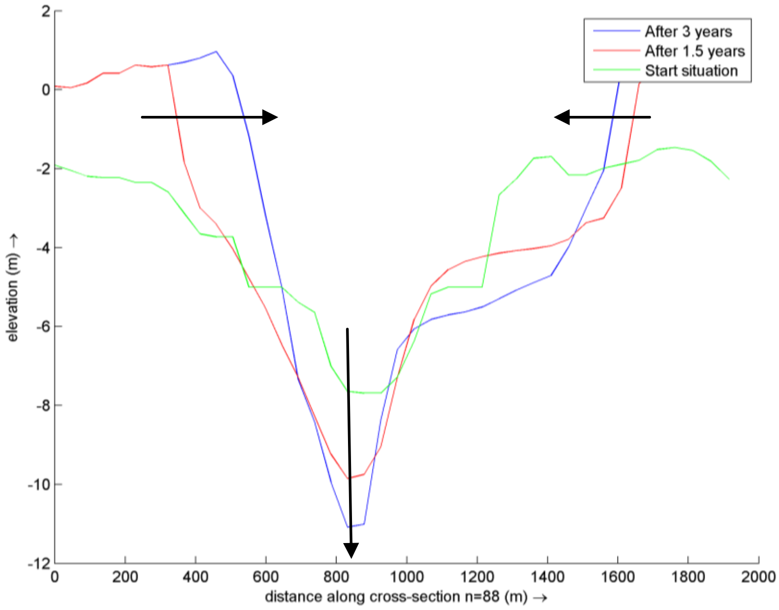


Figure 81: Development of the cross section of the navigation channel for option 2.

Conclusion

Constructing a longer jetty at the east side of the Thuan An inlet is possible way of stabilizing the inlet. Concluding this chapter the following observations can be made:

- Growing of the spit almost stops, but continues with a rate of 20 meters each year due the active ebb-tidal delta;
  - This effect can excluded to build an even longer jetty, but this is not advised;
- Severe erosion at the northwest of the Thuan An inlet expected;
  - In order to state quantitative additional research is needed;
  - Probably beach nourishments will be needed to stabilise some parts of the coast;
- Potential threat because of the growth of a southward directed spit at the east bank.
  - Results in narrowing and deepening of the channel;
  - Additional research needed;
- Wave heights in the inlet increase due to the bad location of the nod in the jetty;
  - Additional research needed for better location and/or length;
- When a solution is chosen that is based on the current jetties, these constructions first need to be improved and/or stabilized before the new tip can be constructed. This is a major downside of this solution, because currently the constructions are failing.

5.5 Option 3: Combination

Introduction

A simulation of three years performed for option 3. The idea on forehand was that 'hard' and 'soft' solutions combined will probably result in a more optimal scenario. In this scenario complete clean material in front of the longer east jetty will be dredged. On top of that the navigational channel will be dredged to fulfil the requirements for class CEMT III. Based on the analytical approximation of accretion at breakwaters it is chosen to simulate this option with a 300 meter longer jetty.

At first a comparison for the bed levels of the Thuan An inlet and the cross-section of the navigational channel is made between the current situation and option 3. After this an analysis is carried out on the surrounding coasts in order to look if the coast is eroding / accreting. The last parts will contain the development figures of the bed level and the cross-section.

Comparison of the bed levels of the Thuan An inlet

The effect of the dredging operation at the start of the simulation is a channel that is suitable for navigational use. The width, depth and manoeuvrability are CEMT III proof. In Figure 82 the bed level after three years is presented for the current situation and option 3. Accretion at the longer east jetty occurs. This was expected because the east jetty is extended with 300 meter. The effect on the navigational channel is that it is less deepened and moved less towards the northwest.

The depth averaged velocity is lower for option 3 compared to the current situation. For the current situation the velocity will increase, because of sedimentation in the inlet, to a value of 0.9 m/s. For the option 3 depth-averaged velocity has a maximum of around 0.7 – 0.8 m/s. This is comparable with option 2. In Appendix L the time series are presented. Also the shoreline profiles of the inlet are compared to the current situation, presented in Appendix L. When the smaller jetty is combined with dredging the solution can be applied for a longer active period. The effect is that a total of 23.7 Mm^3 sediment should be dredged for 30 years.

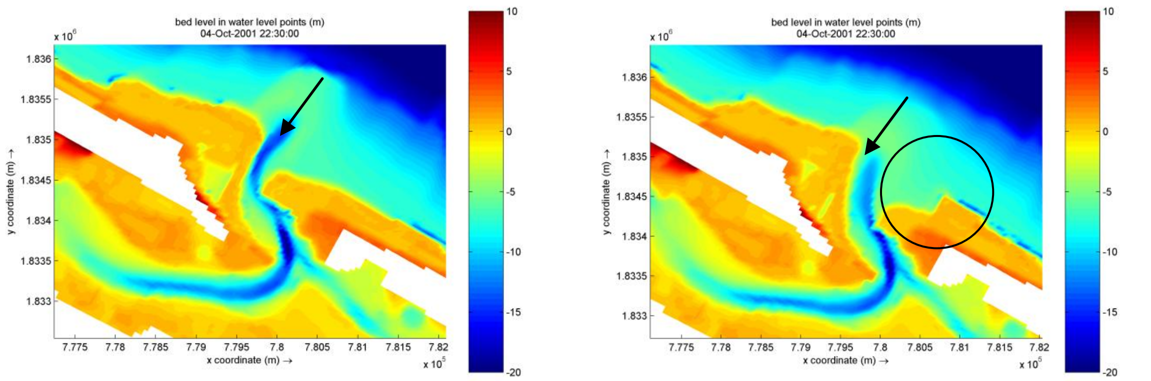


Figure 82: Comparison of the bed level for the current situation (left) and the combination of dredging and a 300 meter longer jetty (right) for a simulation of 3 years.

Comparison of the cross-section of the navigational channel

The effect of option 3 can be shown in more detail when looking at the cross-section of the navigation channel, as seen in Figure 83. The effect of the 300 meter longer jetty will be to partly stop the longshore transport from south to north. The material will be accreted at the east jetty. This means that the spit grows much slower. The reason still some accretion can occur is the fact that sediment is provided from upstream regions, but also due to the effect of bypassing. Most bypassing occurs after 2 years, when the jetty is completely accreted. The magnitude of this transport is 6 times smaller compared to the current situation, but is 40% larger when compared to option 2, with an extended jetty of 1000 meter. An additional effect of slowing down the growing of the spit is the navigation channel that does not propagate towards the northwest and does not deepen as much as in the current situation (see Figure 82 and Figure 83). This means that the channel is in a more stable position for navigational use. The longitudinal cross-section confirms these findings and can be found in Appendix L. However, the depth of the ebb-tidal delta is somewhat smaller compared to the other options and propagates towards 5 meters. This is a potential risk for the navigational use of the inlet and should be analysed in next studies.

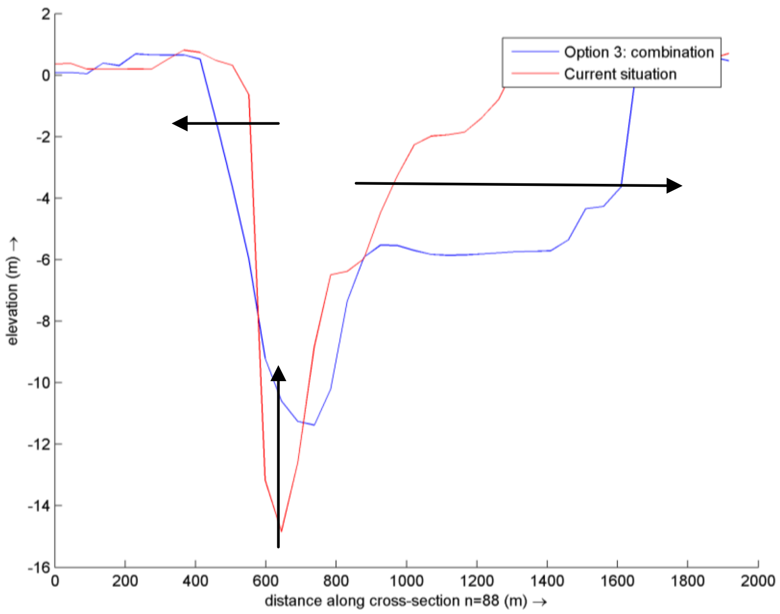


Figure 83: Cross-section of the navigation channel for the current situation (red) and the combination of dredging and a 300 meter longer jetty (blue) for a simulation period of 3 years.

Effects on the surrounding coast

A major concern of a longer jetty is the fact that the natural system is undermined. Along the Thuan An inlet the dominant longshore transport direction is from south to north. When the east jetty is extended with 300 meter the longshore transport will be partly blocked. This will probably result in erosion at the west barrier and accretion at the east barrier.

In order to analyse this effect two longitudinal cross-sections are taken about 1 kilometre north and 5 kilometres south from the Thuan An inlet. The results are like expected: Erosion occurs at the north, but the accretion could not be noticed 5 kilometres south of the inlet, which was possible for option 2. The reason is the fact that the jetty is extended less, which results in less accretion.

What the complete effect will be on the coast of Hue should be analysed in next studies, because the grid is too coarse near the coastline to accurately say something about the erosion pattern. The most likely solution would be to nourish the beach at the northwest of the Thuan An inlet.

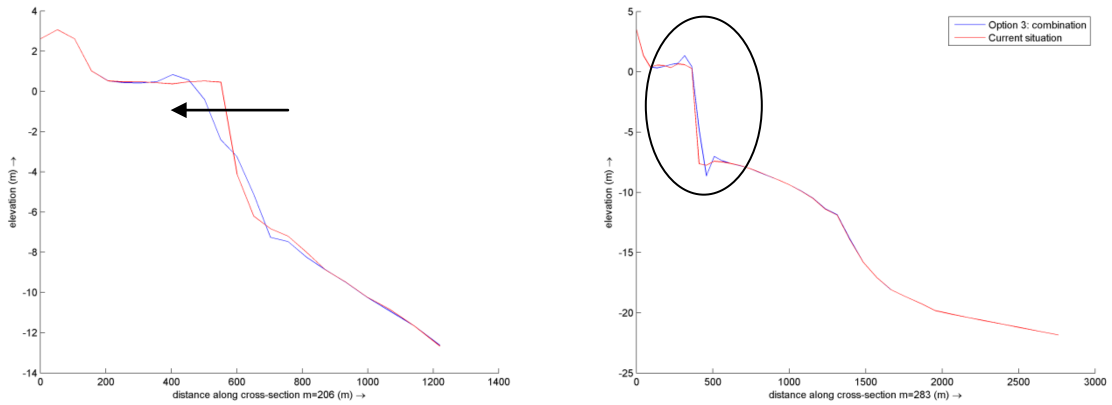
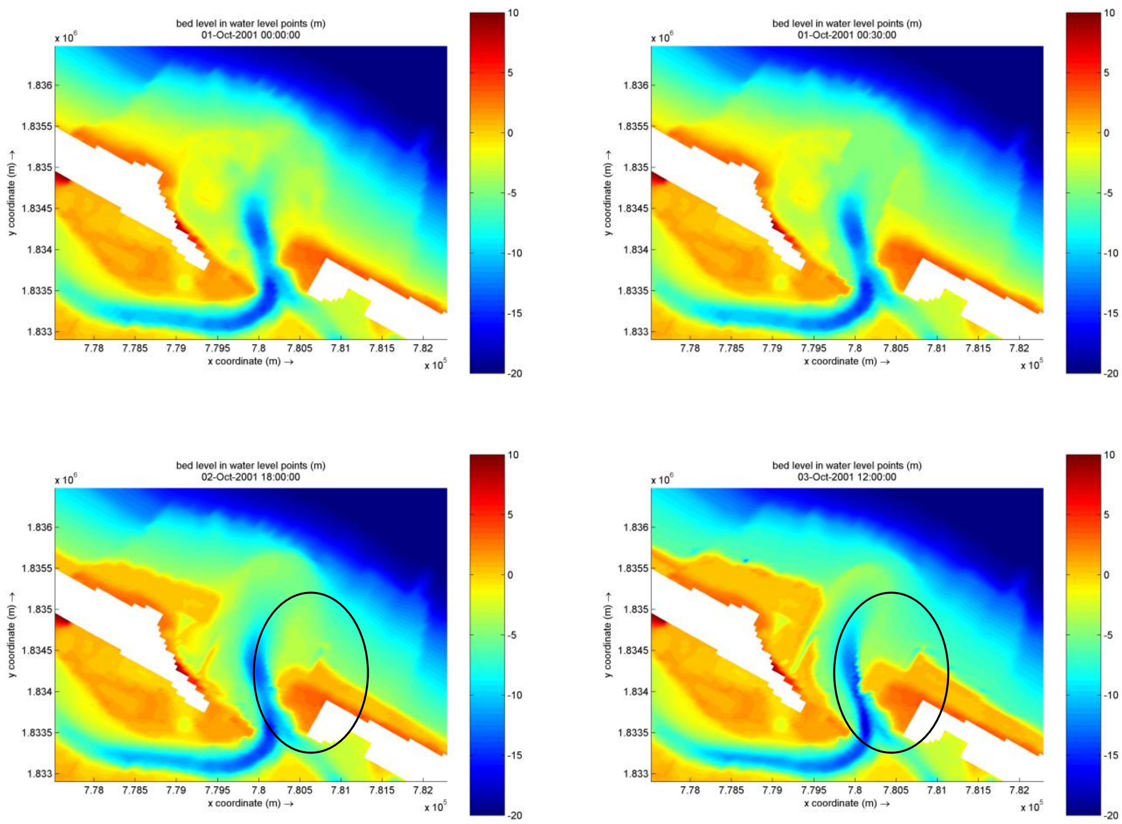


Figure 84: Longitudinal cross section 1 kilometre north (left) and 5 kilometres south (right) of the Thuan An inlet for the combined scenario.

Development of the bed levels of the Thuan An inlet

After the comparison between the current situation and option 3 it is possible to understand the behaviour of the system. The effect of the longer jetty is quite logical. Accretion behind the longer east jetty will prevent the growing of the spit towards the west. However, bypassing is already occurring within 2 years. This means that this option will only limit the growing of the spit with about 70%. This is still a good option, because it will stop the narrowing and deepening of the channel, which is a potential threat for navigation.



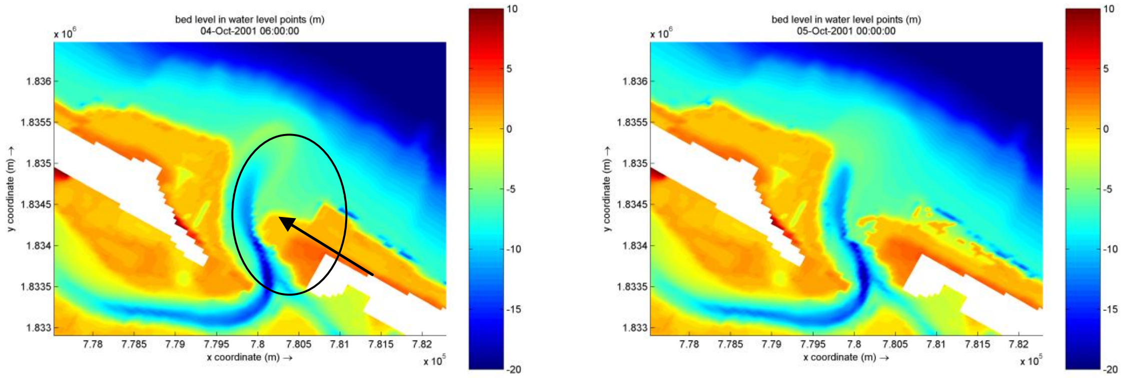


Figure 85: Comparison of the bed level at the start (top left), after the first dredging operation (top right), after 9 months (middle left), 18 months (middle right), 27 months (bottom left) and 36 months (bottom right) for option 3 with the 300 meter longer jetty and dredging.

Development of the cross-section of the navigational channel

Most sedimentation occurs at the east side of the inlet. The growing of the spit is slowed down because of the longer jetty, but still some accretion occurs due the bypassing and the active ebb-tidal delta. Bypassing at the jetty occurs after 2 years. This means that accretion at both banks can still continue. The accretion process occurs at a much lower speed compared to the current situation.

The cross-section of the navigation channel will tend to deepen at the south side of the inlet, due to a formation of a new spit that grows at the east bank in southward direction. The longitudinal cross section shows that offshore no measurements are required after the first dredging operation to make the approach channel. This can be seen in Appendix L.

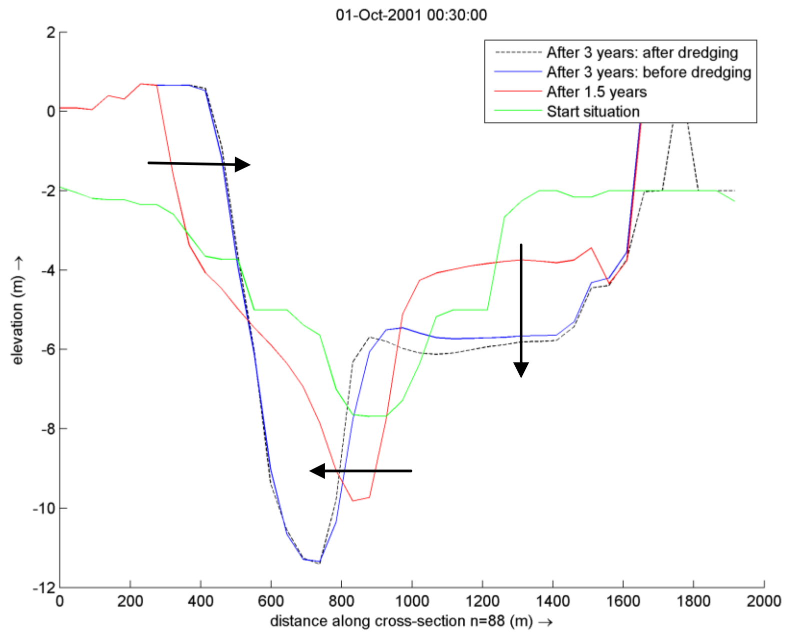


Figure 86: Development of the cross section of the navigation channel for option 3.

Conclusion

Constructing a 300 meter jetty at the east side of the Thuan An inlet in combination with dredging is a possible way of stabilizing the inlet. Concluding this chapter the following observations can be made:

- Growing of the spit slows down, but continues with a rate of 100 meters each year due the active ebb-tidal delta and bypassing at the jetty tip;
- Some erosion at the northwest of the Thuan An inlet expected:
  - In order to state quantitative additional research is needed;
  - Probably beach nourishments will be needed to stabilise some parts of the coast;
- Dredging a total of 23.7 Mm^3;
- Potential threat because of the growth of a southward directed spit at the east bank:
  - Results in narrowing and deepening of the channel;
  - Additional research needed;
- When a solution is chosen that is based on the current jetties, these constructions first need to be improved and/or stabilized before the new tip can be constructed. This is a major downside of this solution, because currently the constructions are failing.

5.6 Multi-criteria analysis

In this chapter the scenarios will be assessed with the help of a multi-criteria analysis. Three scenarios are implemented that provide sufficient spacing for the navigational purposes of the Thuan An inlet for the coming 30 years. The scenarios are:

1. Dredge a channel to maintain enough water depth, width and manoeuvrability;
2. A 1000 meter longer jetty at the east bank;
3. Combine a 1000 meter longer jetty at the east bank with dredging.

The numbers for each solution are presented in Table 28.

Table 28: Hard numbers concerning the different scenarios.

Scenario's	Jetty length [m]	Dredged material*
Option 1a: dredge each year	Current	17.7
Option 1b: dredge each three years	Current	13.8
Option 2: Build 1000 meter longer jetty	+ 1000	0.1
Option 3: Combine longer a jetty with dredging	+ 300	23.7

** for a period of 30 years in* Mm^3

A multi-criteria analysis will be used on order to rank to different scenarios. The idea is that the best scenario for a specific point will get a value of 4. The worst scenario will get a value of 1. The categories considered as most relevant for this situation are construction costs, maintenance costs and side effects like impact on the near coastal zone and/or flexibility of the scenario.

Construction costs

Option 1: dredging:

1. No construction costs at all.

Option 2: build a 1000 meter longer jetty:

2. Highest construction costs, because of the extension of 1000 meter.
3. Also take into account the costs of improving the current system.

Option 3: build a 300 meter longer jetty and apply dredging:

4. Moderate construction costs, because of the extension of 300 meter.
5. Also take into account the costs of improving the current system.

Maintenance costs

Option 1: dredging:

6. Increasing the number of dredging operations will increase the amount of dredged material and thus the maintenance costs. Therefore, dredging each three years is cheaper.

Option 2: build a 1000 meter longer jetty:

7. Lowest maintenance costs, because a well-designed and well-constructed jetty will hardly need any maintenance at all.

Option 3: build a 300 meter longer jetty and apply dredging:

8. Moderate maintenance costs, because of emptying the accretion basin in front of the east jetty.

Side effects

Option 1a: dredge each year:

9. Channel is the smoothest and effects on the near coastline are limited.
10. Flexibility of the dredging operation can be used to counteract the variability of typhoons.

Option 1b: dredge each three years:

11. The new spit on the east bank grows in southward direction. This is a potential threat for the navigational purposes of the inlet.
12. Variability of the weather during the rainy season cannot be counteracted.

Option 2: build a 1000 meter longer jetty:

13. This solution will influence the natural system the most, because the longshore transport is largely affected. The result will be severe coastal erosion northwest of the inlet.

Option 3: build a 300 meter longer jetty and apply dredging:

14. Some erosion on the northeast side is expected, but this can be counteracted with the help of dredging the accretion basin and dumping this at eroding parts of the inlet/coast.

The comments above result in the following table:

Table 29: Multi-criteria analysis of the different scenarios.

Scenario's	Construction costs	Maintenance costs	Side effects	Result
Option 1a: dredge each year	4	2	4	10
Option 1b: dredge each three years	4	3	2	9
Option 2: Build 1000 meter longer jetty	1	4	1	6
Option 3: Combine longer a jetty with dredging	2	1	3	7

Conclusion

From Table 29 it can be concluded that option 1a, dredging each year, is the most preferable solution.

The main reason for this conclusion is the fact that no construction costs are needed. The structural integrity of the recent build jetties and breakwaters is not good enough, so when a solution with the use of the current structures is chosen, first the recently build constructions need to be improved. After this improvement possible extensions can be constructed.
Another reason is the statement that the dredging operation will have the least influence on the tidal inlet. Some coastal erosion is expected, but this will be much less compared to an extension of the east jetty. On the places were erosion is expected, beach nourishments could be applied. An advantage of dredging each year is the flexibility to counteract the variability of typhoons and thus variability of accretion in the navigation channel each year.

This conclusion is stated under the assumption that the total maintenance costs of dredging will not exceed the initial construction costs of the jetty. This seems a quite acceptable assumption, since dredged the amount of dredged material is limited (so no large dredging vessels are needed) and that the dredged material can be sold, which provides some reduction on the net cost of the operation.

6. Conclusion and recommendations

6.1 Conclusion

The objective for this research was to optimize the current infrastructure, or to develop a new solution, that will provide sufficient depth and width for navigational purposes of the Thuan An inlet for the coming 30 years.

At first the morphological response and empirical relations from Chapter 3 could be represented with the Delft3D model. When looking to the current situation, it is clear that the breakwater and jetties that have been constructed last year are not designed in a decent way. The longshore transport is larger than the east jetty can block, because bypassing is already occurring. In addition it can be questioned if the other breakwater and jetties have any added value. The west jetty was probably constructed to protect the area during typhoon events and to limit the cross sectional area of the inlet, but the effect is rather limited. The breakwater will limit the amount of sedimentated material behind it. After nine years the current situation will not be able to accommodate class CEMT III.

Three scenarios are implemented that provide sufficient spacing for the navigational purposes of the Thuan An inlet for the coming 30 years. The scenarios are:

1. Dredge a channel to maintain enough water depth, width and manoeuvrability;
    - This solution can be applied each year or each three years;
2. A 1000 meter longer jetty at the east bank;
3. Combine a 300 meter longer jetty at the east bank with dredging.

Al the scenarios were able to provide sufficient surroundings for navigational purposes. With the help of a multi-criteria analysis the different scenario were rated. A short summary is presented below:

1. Dredge a channel to maintain enough water depth, width and manoeuvrability;
    - Pro: flexibility of the dredging operation to compensate the variability of the extreme events and thus variability of the navigational channel;
    - Contra: 'hard' solutions are preferred in Vietnam;
2. A 1000 meter longer jetty at the east bank;
    - Pro: 'hard' solution is preferred in Vietnam;
    - Contra: effects on the surroundings of the inlet with for example severe coastal erosion northwest due impact on the longshore transport;
3. Combine a 300 meter longer jetty at the east bank with dredging;
    - Pro: combination between preferred solution and dredging;
    - Contra: large amounts of dredged material and erosion on the surroundings of the inlet.

From the MCA it can be concluded that the scenario with a dredging operation each year is the best solution towards the stated problem description. The advantage of dredging each year instead of each three years is the fact that the flexibility of the dredging operation can be used to counteract the variability of typhoons and thus variability in accretion of the navigation channel.

6.2 Recommendations

Applied model

The origin of the data used is all based on the research of Lam just after the flooding of 1999. This means that the bathymetry is not completely up-to-date. On top of that, the model itself is not calibrated on any measurements. In order to get a better insight in the dynamics of the inlet on a yearly basis it is recommended to measure water levels, currents, discharges from all the rivers and transport rates during at least a year.

Due the lack of computational power severe input reduction was applied to be able to make an overnight computation. Therefore the morphological factor in combination with one wave height, direction and wind per relevant period is applied. In order to reproduce a more accurate and realistic situation one should impose multiple conditions per period and calibrate and validate this with measurements in the field.

A depth-averaged model is applied on the region around the Thuan An inlet in order to reduce computational effort. To be able to investigate the morphodynamics in a qualitative manner a 3D sediment transport calculation should be carried out.

Relations to other aspects / cases

All the interventions impact the longshore transport along the coast of Hue. One has to understand the dynamics of important processes well, before an intervention is carried out. Due to lack of knowledge important processes can be underestimated. In Part 1 of this report the case relations have been presented.

All the measures will influence the sediment balance of the coast and the lagoon. Therefore the grid size near the coast should be decreased in order to reproduce a more accurate model. This must be done in order to ensure the relation between the (structural) dune erosion, the sediment balance of the lagoon and the stability of the Thuan An inlet.

A research for impact of the extreme events is also necessary. The main reason is the impact at the tidal inlet itself, but also the water levels and potential breaches could be indentified in this way. This is important for the stability of the Thuan An inlet. In addition, the effects of climate change also can be taken into account to ensure that changes in the environment in the coming 30 years are weighted.

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Appendix A: List of Meetings, Figures & Tables

Table 30: List of consulted experts.

Person	Profession
Prof.dr.ir Quang Tuan	Hue expert, Ocean and Coastal Engineering
Dr.ir. Nghiem Tien Lam	Hue expert, Ocean and Coastal Engineering
Dr.ir. Ngo van Quan	Water Resources expert
Dr.ir. Pham Thanh Hai	Disaster Management expert
Dr.ir. Tran Thanh Tung	Vice Dean, Marine and Coastal Engineering
Dr. Le van Thang	Hue University institute of recourses and environment
Ir. Theo Sturm	Hue expert, Coastal Engineering
Ir. Nguyen Dinh	Hue institute of Natural Resources, Environment and Sustainable development
Tom Kompier M.a. M.phil.	First Secretary Water Sector Dutch Embassy
Lam Thi Thu Suu	Vietnam Rivers Network coordinator

Table 31: List of meetings with experts.

Date	Oral/Email	Who?	Subject(s)
03-Sep	Personal	Lam, Tuan, Tung	Finetuning of the assignment, including a first impression of the problems in the Hue area.
04-Sep	Personal	Hai	Subjects/problems concerning the Hue area, with the main focus on the Disaster Management Cases.
10-Sep	Personal	Sturm	General information of the Hue surroundings, governmental structure and some examples concerning past measures.
11-Sep	Personal	Hai	Discussing of different subjects, with more detailed information.
16-Sep	Personal	Lam	Discussing of different subjects, with more detailed information.
17-Sep	Personal	Tuan	Discussing of different subjects concerning Coastal Engineering.
27-Sep	Personal	Niche Students	Discussing the water management cases, developing new cases.
27-Sep	Personal	Lam, Tuan	Short discussion concerning climate change.
03-Oct	Personal	Quan	Short meeting related to water resources.
08-Oct	Personal	Dinh	Presentation about the general problems in the Hue area.
08-Oct	Personal	Thang	Presentation and short discussion about the water quality and allocation in Hue.
08-Oct	Personal	Suu	Presentation about the environmental impact of reservoirs.
14-Oct	Personal	Lam	Discussing the outcomes of the Delft3D runs.
14-Oct	Personal	Kompier	Discussing the approach of the combined Dutch and Vietnamese government towards water related problems.

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Appendix B: Flood wave volumes

For each month the highest consecutive rainfall has been multiplied with the catchment area, arriving at an estimate for the highest discharge into the reservoir. Subsequently the highest discharges from 1979 till 1999 for each month have been ordered from high to low, with the associated return period, and plotted on a logarithmic scale. See Table 32 and Figure 87 for the calculation for January at the Binh Dien dam.

By drawing a best fit line through the points in Figure 87: Flood volume per year with the return period., the flood volumes with a certain return period can be obtained. The same has been done for all months and for both dams, see Table 33 and Table 34 for the results.

Table 32: Flood volume per year with the return period.

# (n ... N)	Year	Flood volume [m^3]	Return period [years] (N / n)
1	1999	115308500	20
2	1981	55774500	10
3	1997	55362500	7
4	1992	28943000	5
5	1983	27964500	4
6	1990	26162000	3
7	1982	25904500	3
8	1980	25853000	3
9	1995	24308000	2
10	1985	23999000	2
11	1989	23329500	2
12	1994	19776000	2
13	1998	19724500	2
14	1987	19209500	1
15	1993	19209500	1
16	1984	17561500	1
17	1979	14214000	1
18	1986	12772000	1
19	1996	6901000	1
20	1988	5356000	1

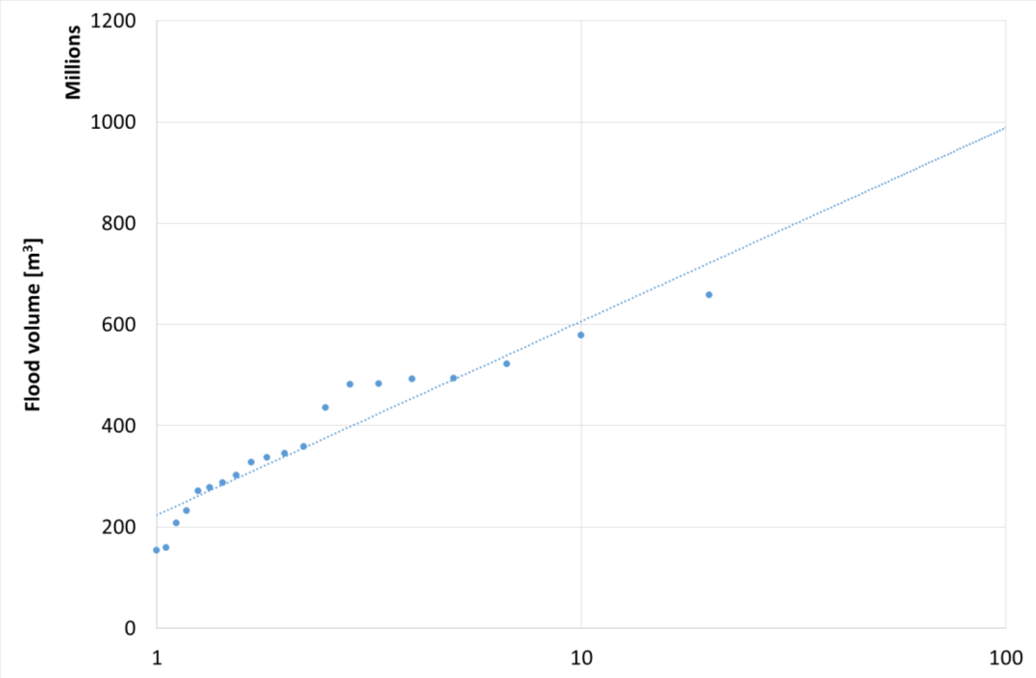

Figure 87: Flood volume per year with the return period.

Table 33: Design flood for the Binh Dien dam, in Mm^3.

Return period [years]	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	5	0	0	3	0	0	0	5	14	89	223	13
3	34	22	11	20	68	65	40	71	156	288	326	134
5	48	35	16	28	105	96	60	102	222	380	373	190

Table 34: Design flood for the Ta Trach dam, in Mm^3.

Return period [years]	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	9	6	3	13	23	10	22	0	34	146	81	20
3	39	22	18	42	102	129	57	116	203	482	532	143
5	53	30	25	56	138	184	73	178	282	639	742	200

Appendix C: Scenario results

Scenario 1

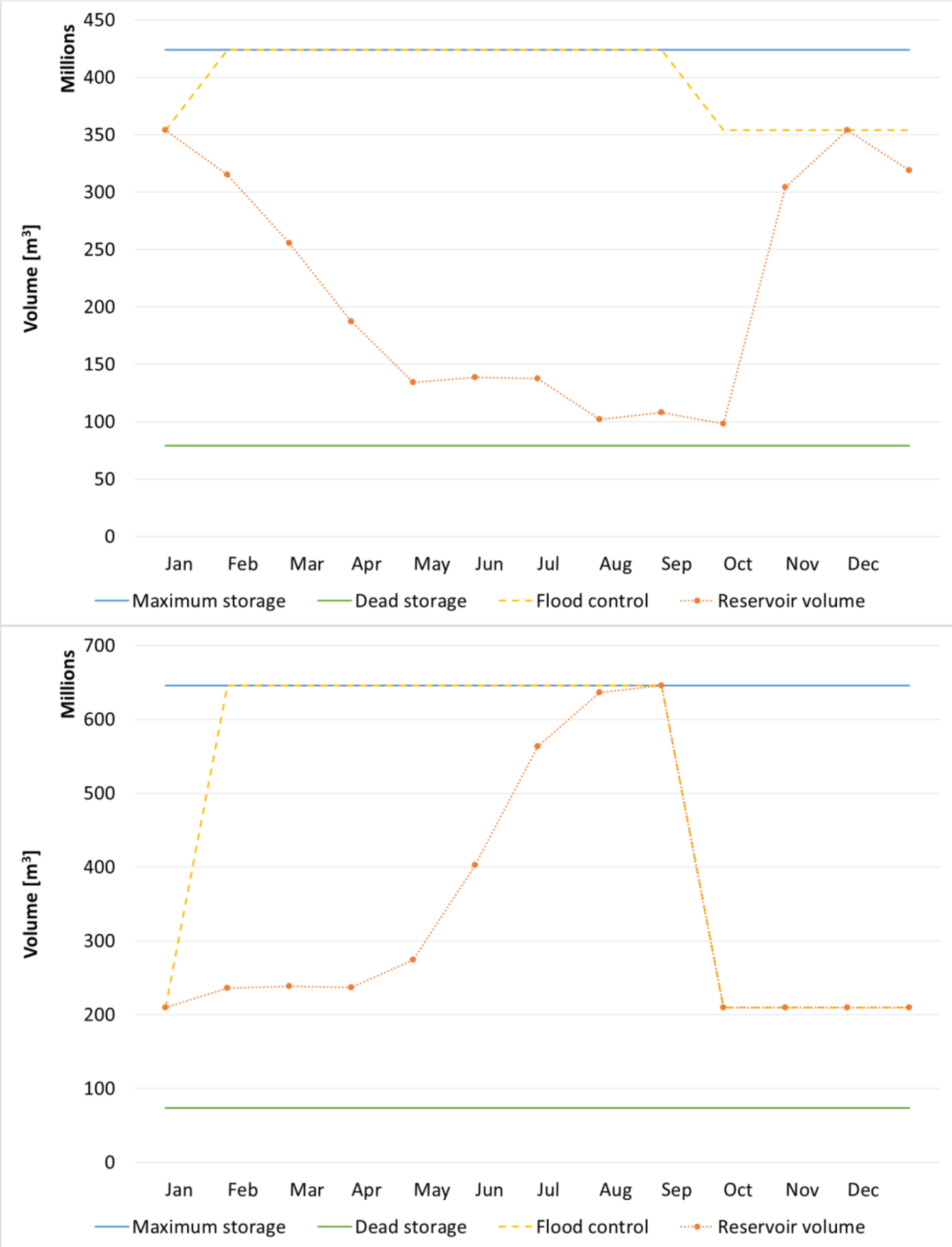

Figure 88: Binh Dien (above) and Ta Trach (below) reservoir storage volumes, scenario 1.

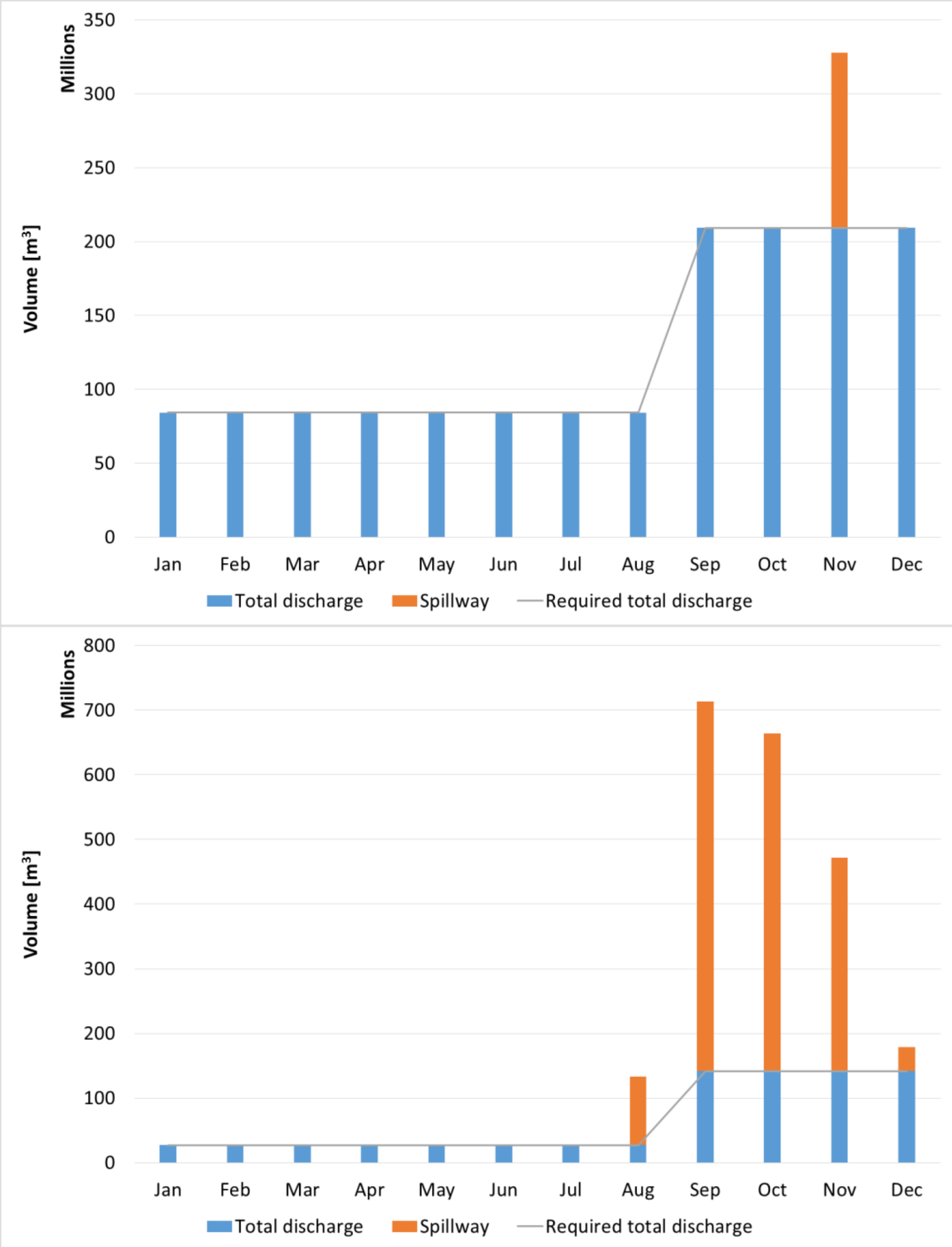

Figure 89: Actual discharge out of the Binh Dien and Ta Trach reservoirs, scenario 1.

Scenario 2

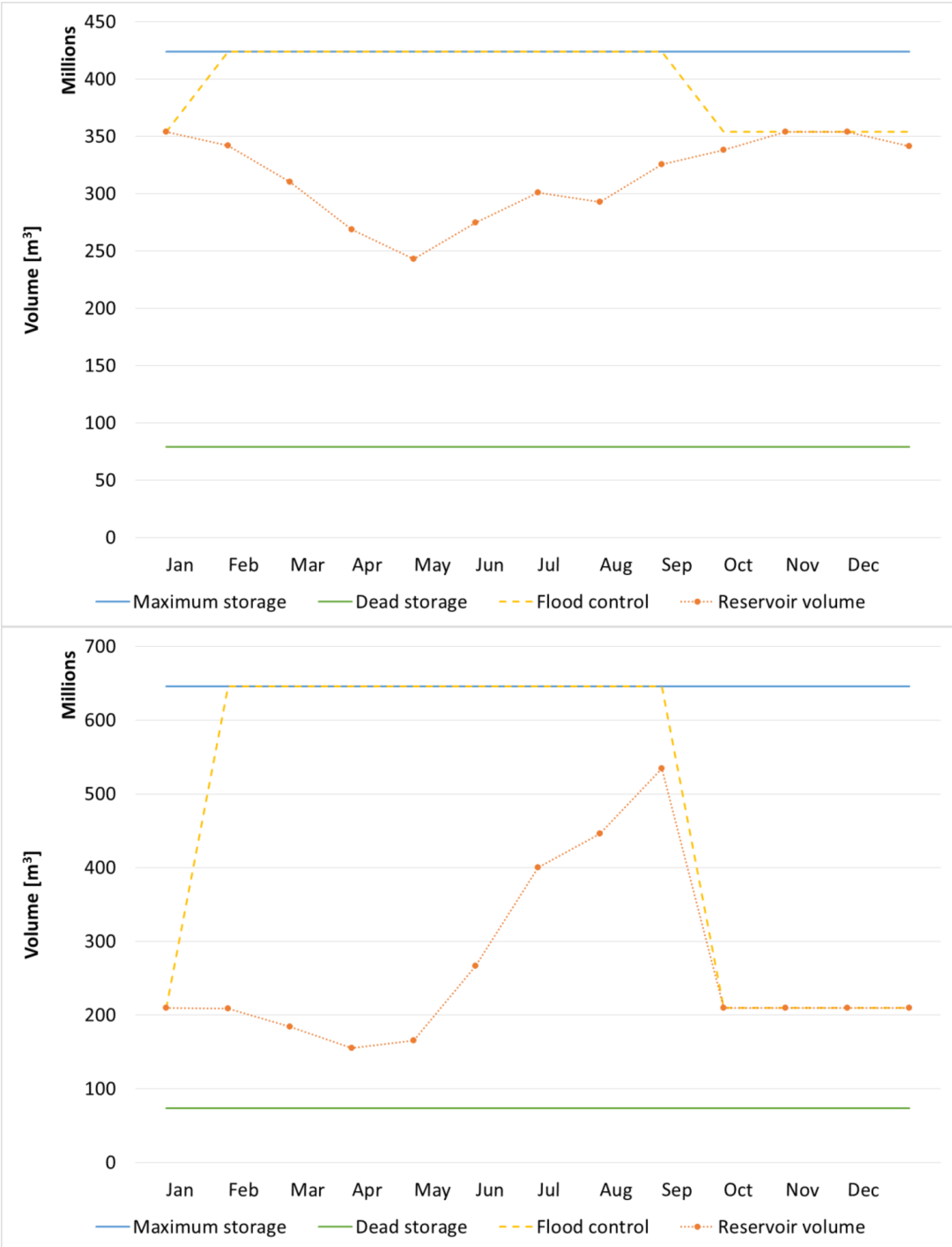

Figure 90: Binh Dien (above) and Ta Trach (below) reservoir storage volumes, scenario 2.

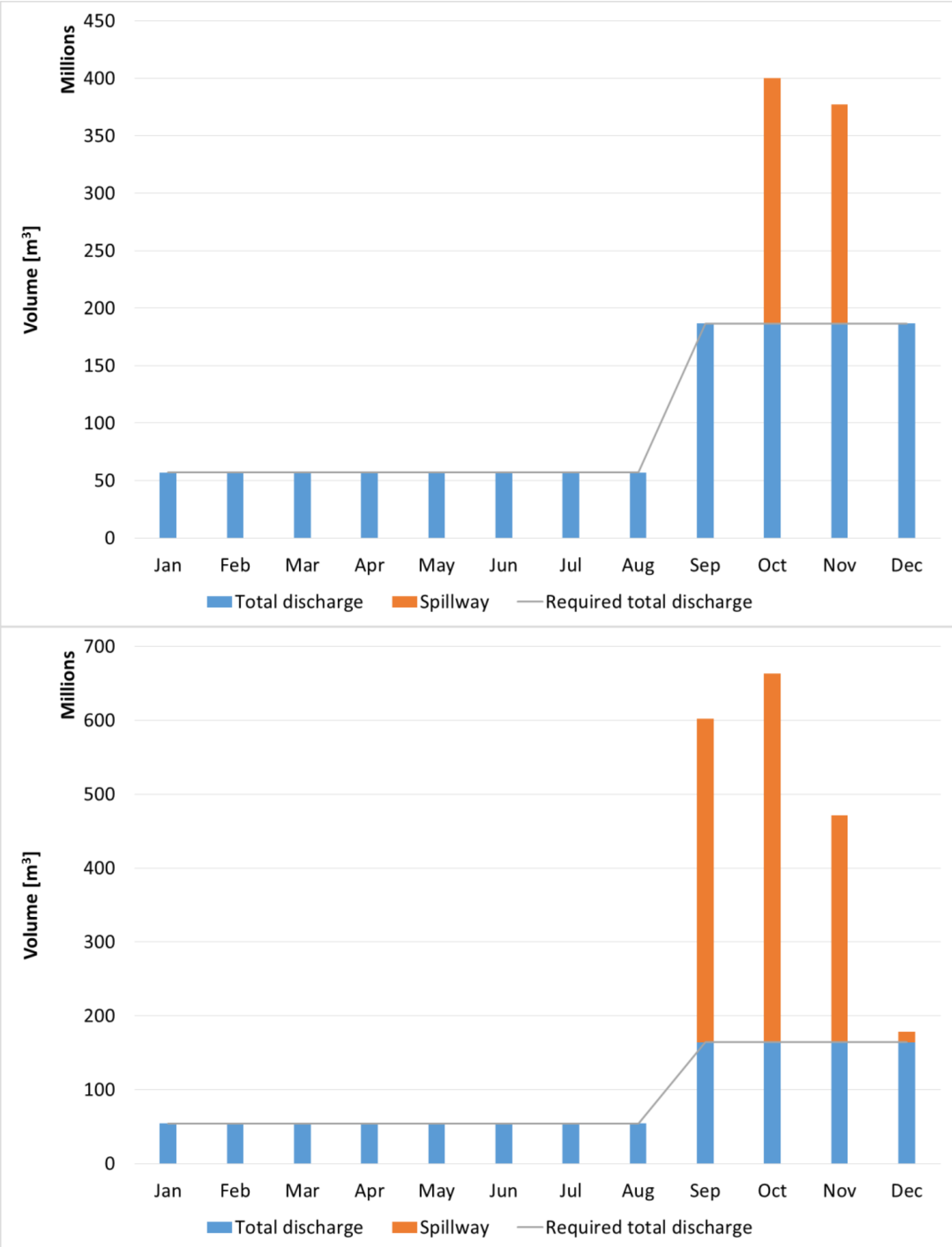

Figure 91: Actual discharge out of the Binh Dien and Ta Trach reservoirs, scenario 2.

Scenario 3

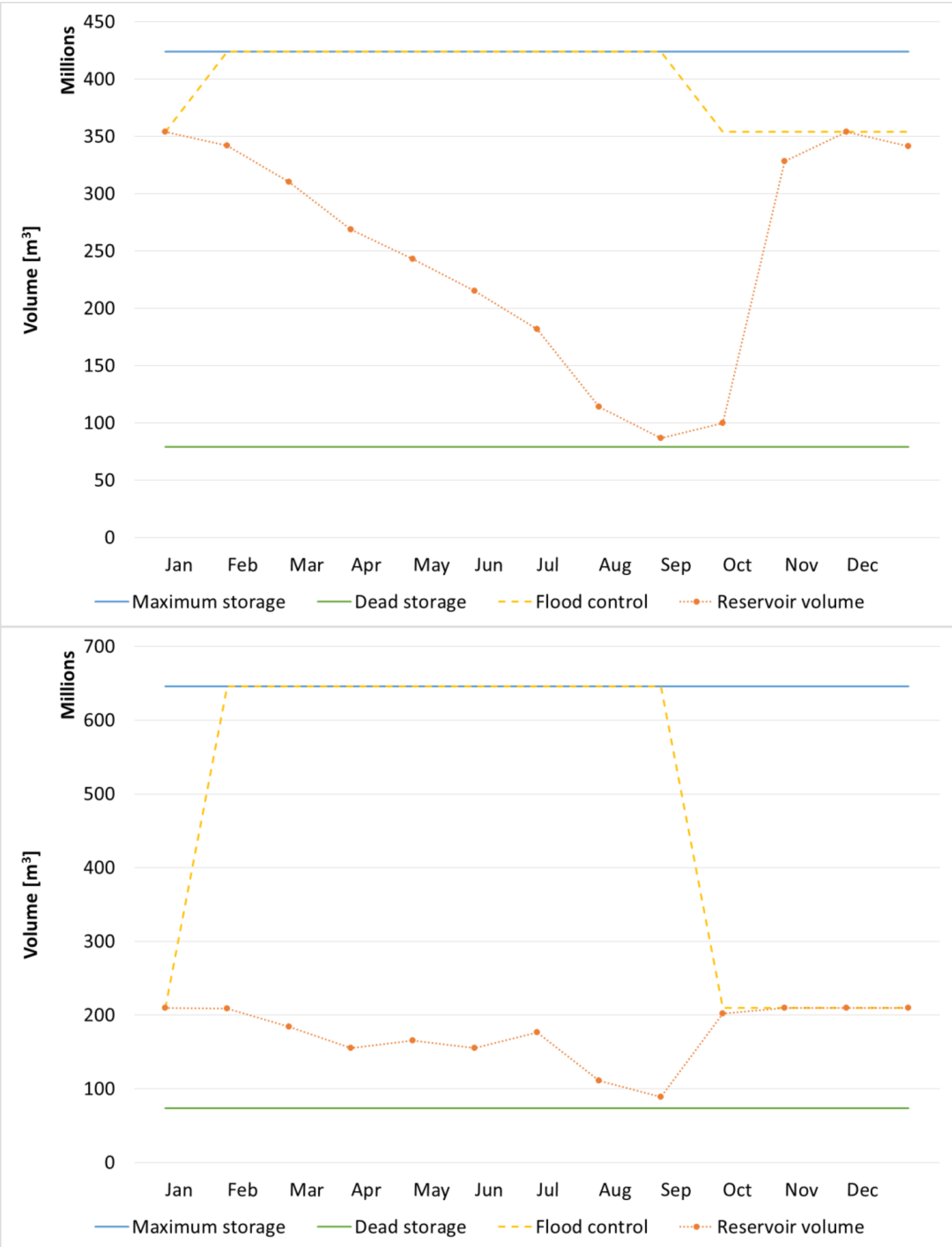

Figure 92: Binh Dien (above) and Ta Trach (below) reservoir storage volumes, scenario 3.

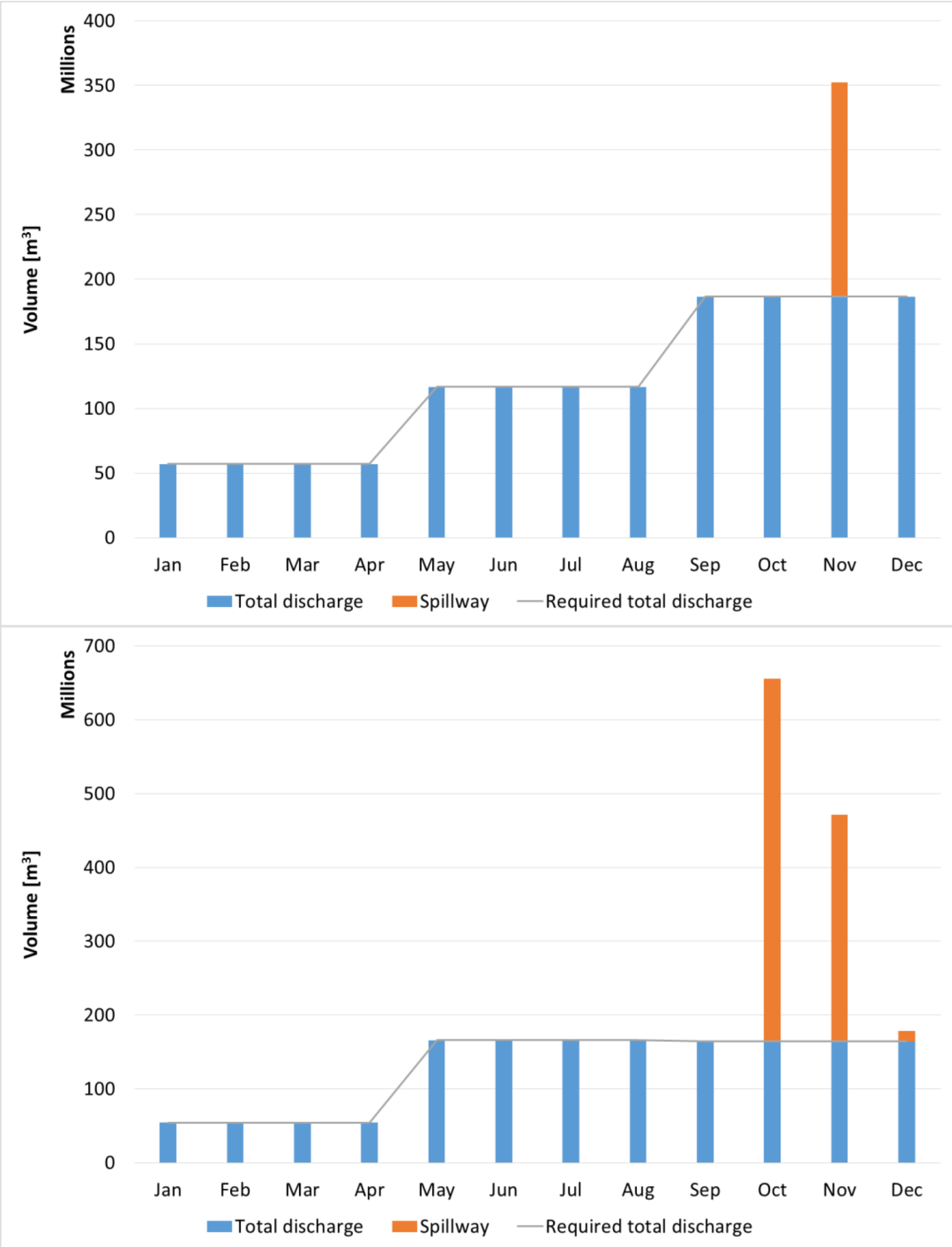

Figure 93: Actual discharge out of the Binh Dien and Ta Trach reservoirs, scenario 3.

Scenario 4

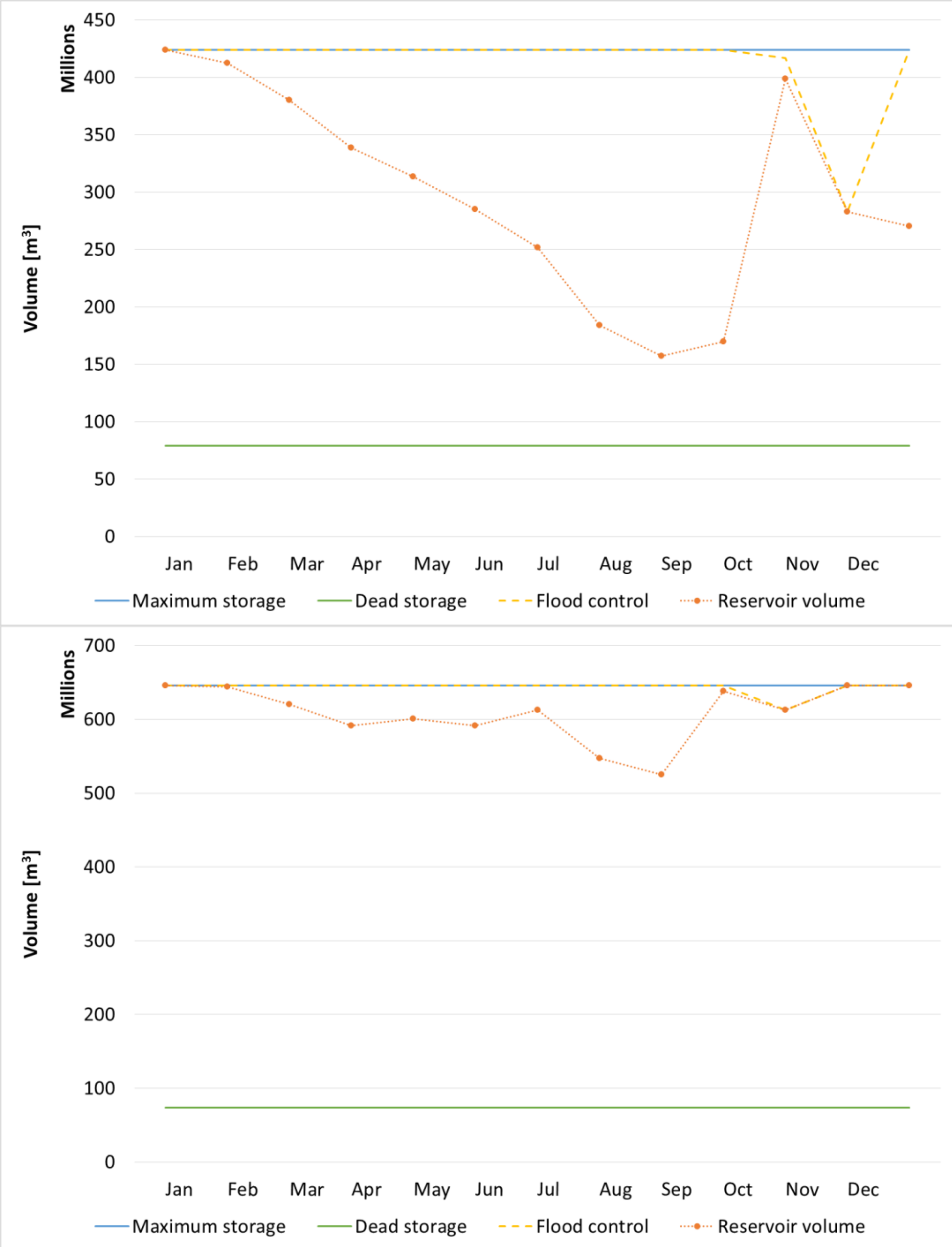

Figure 94: Binh Dien (above) and Ta Trach (below) reservoir storage volumes, scenario 4.

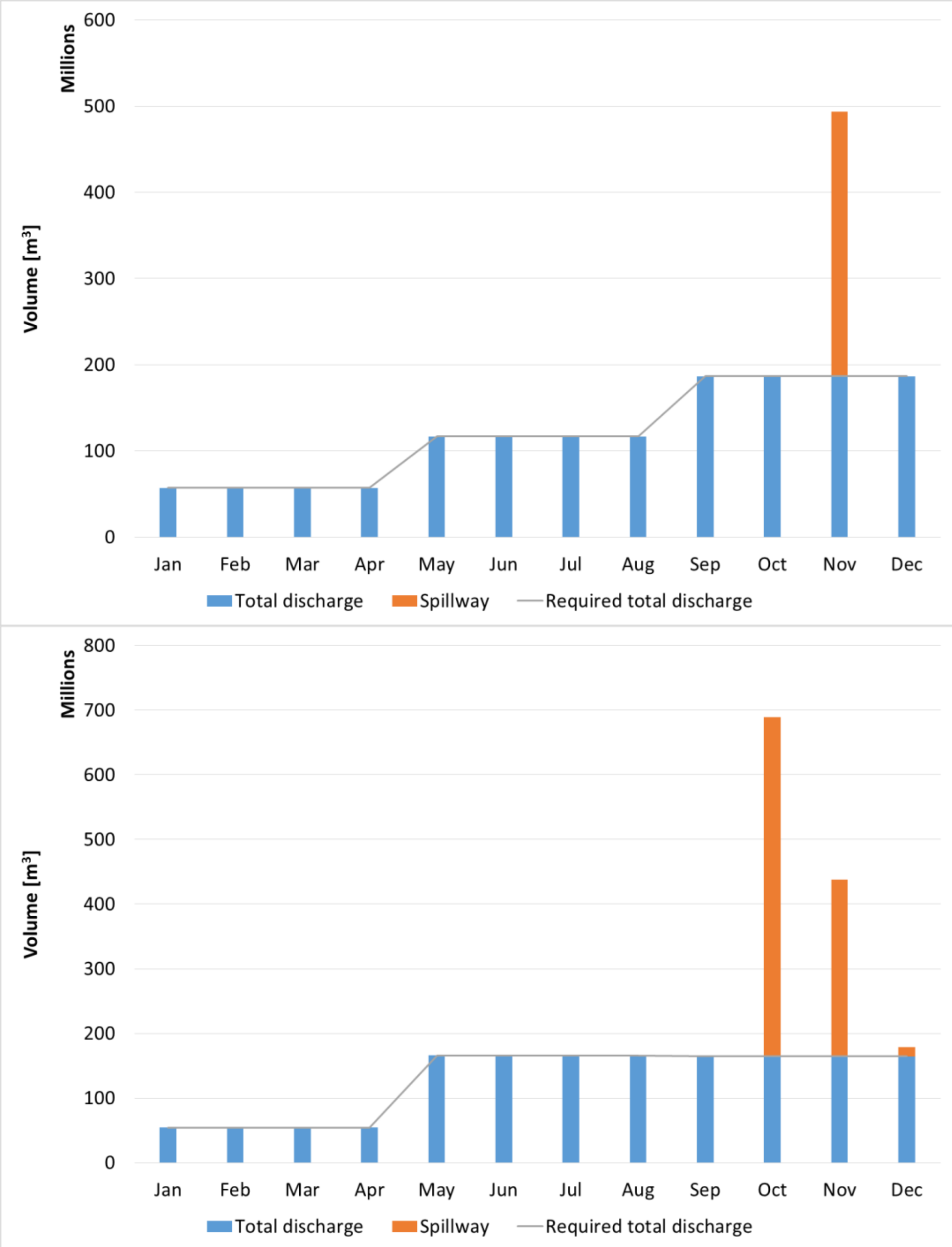

Figure 95: Actual discharge out of the Binh Dien and Ta Trach reservoirs, scenario 4.

Scenario 5

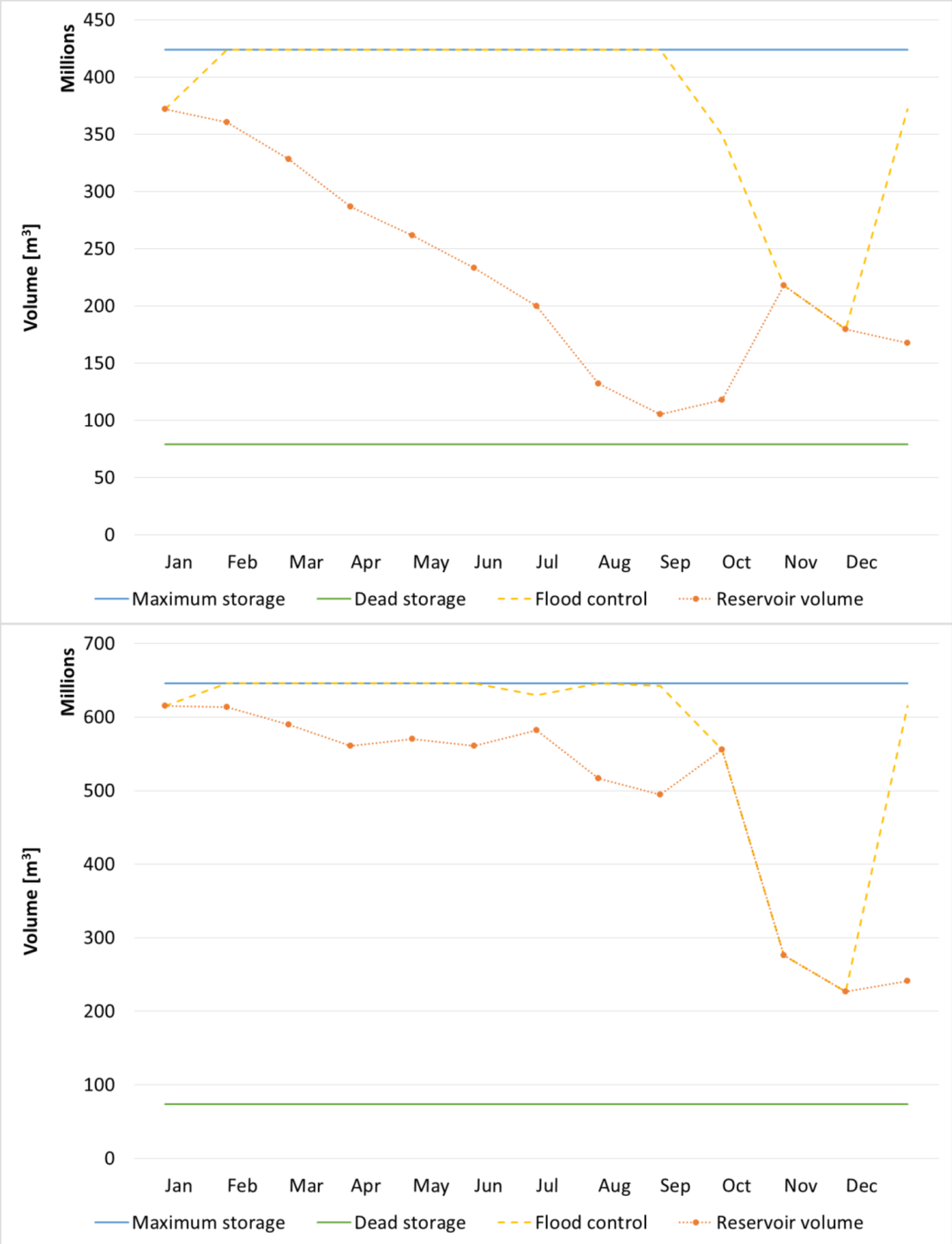

Figure 96: Binh Dien (above) and Ta Trach (below) reservoir storage volumes, scenario 5.

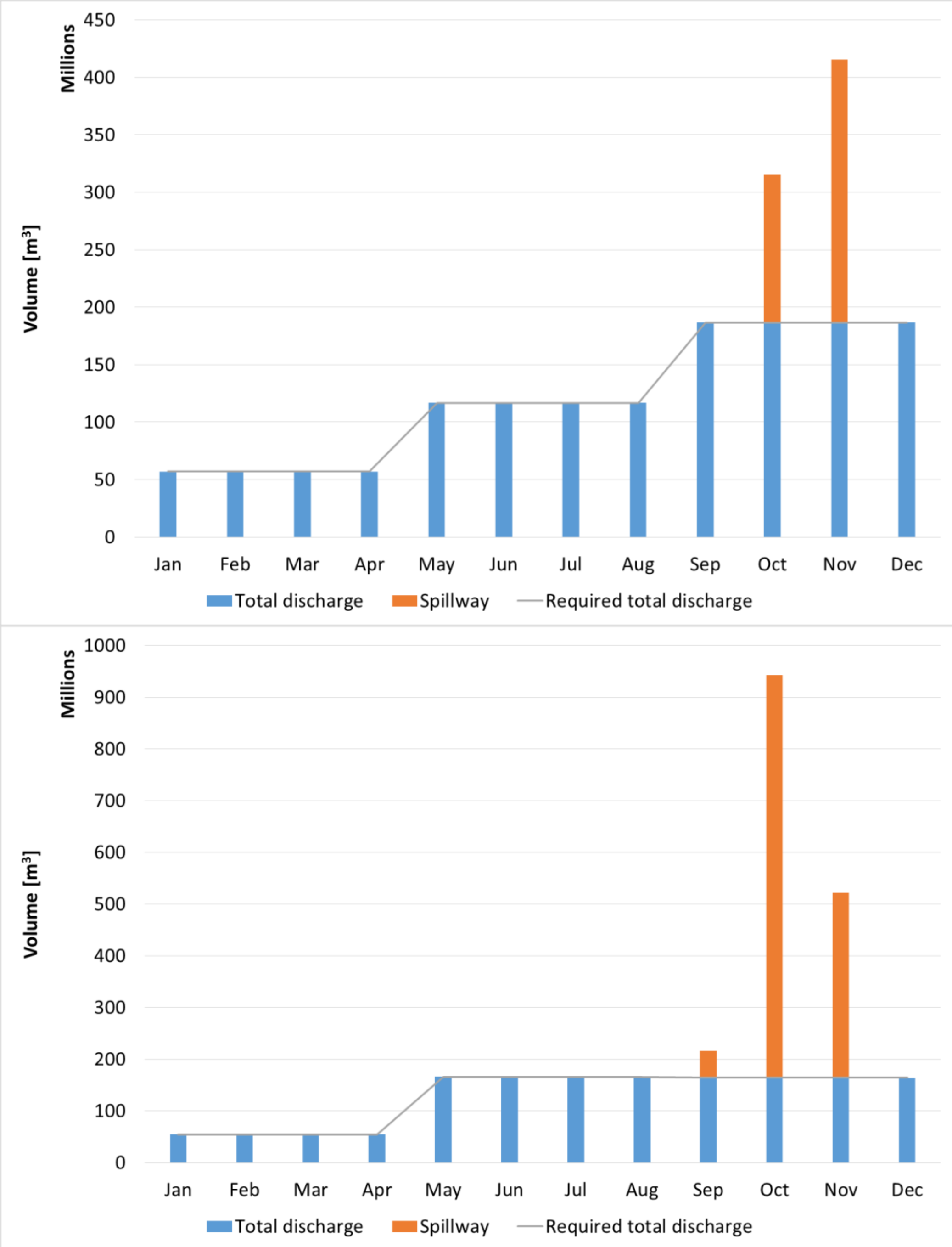

Figure 97: Actual discharge out of the Binh Dien and Ta Trach reservoirs, scenario 5.

Appendix D: Time step restriction

Calculations with different time steps for the water level in the Thuan An inlet

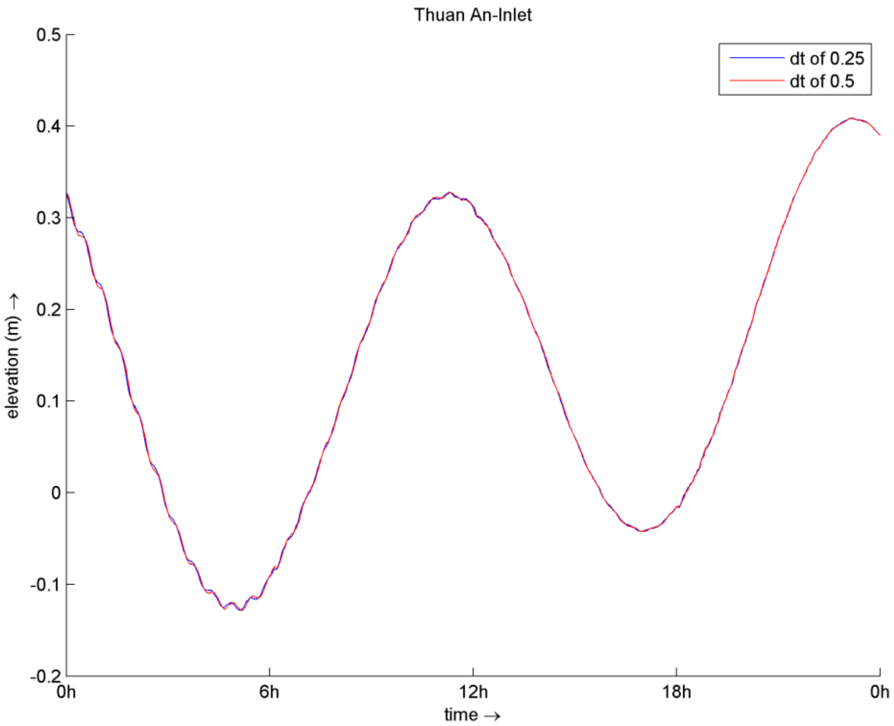

Figure 98: Time step of 0.25 (blue) and 0.5 (red) minutes.

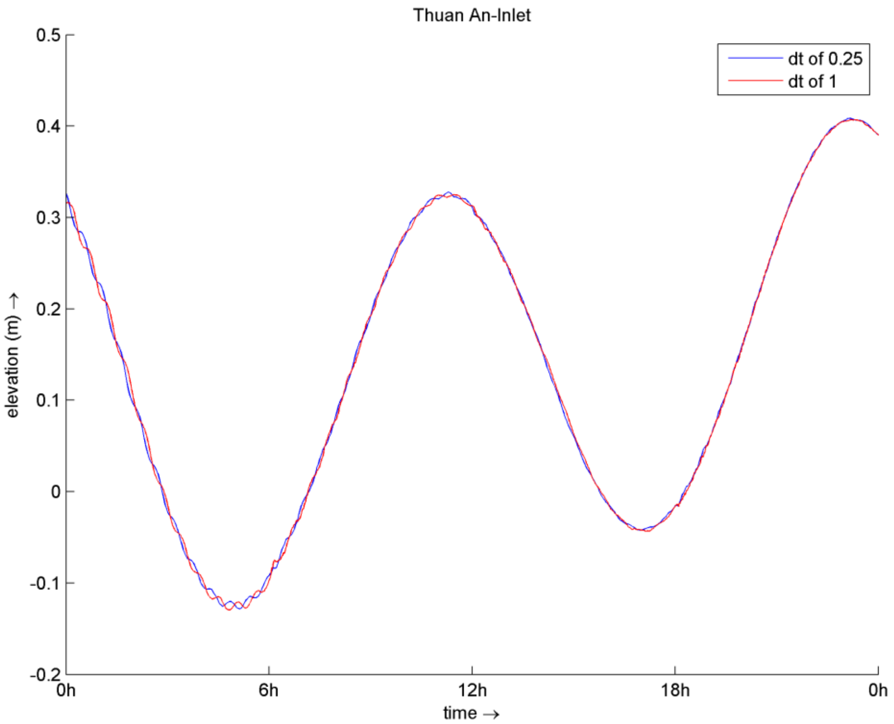

Figure 99: Time step of 0.25 (blue) and 1.0 (red) minutes.

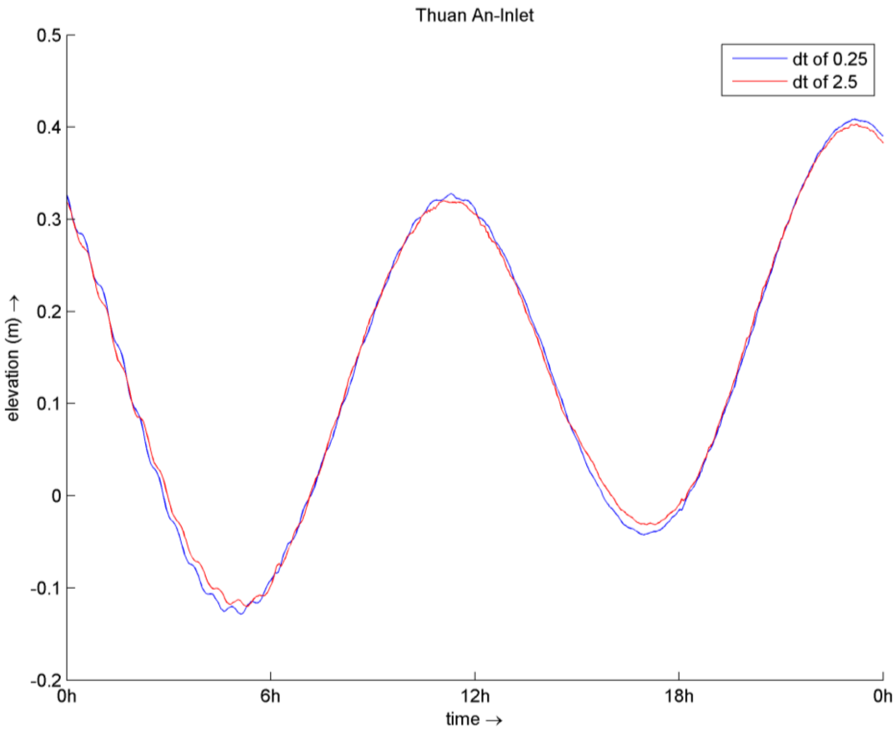

Figure 100: Time step of 0.25 (blue) and 2.5 (red) minutes.

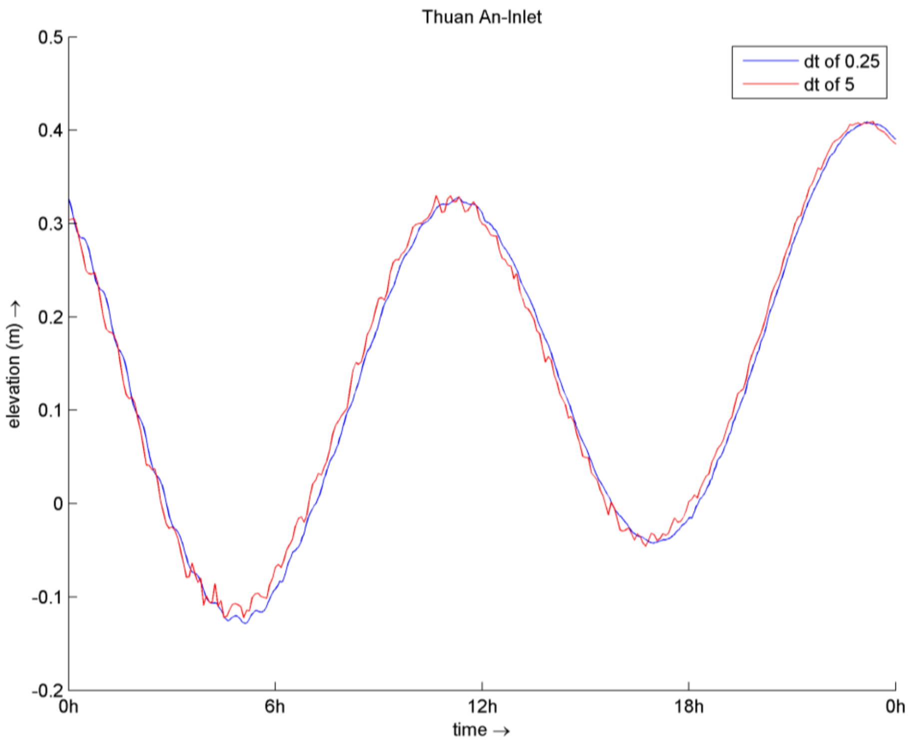

Figure 101: Time step of 0.25 (blue) and 5.0 (red) minutes.

Calculations with different time steps for the cumulative sedimentation or erosion in the Thuan An inlet.

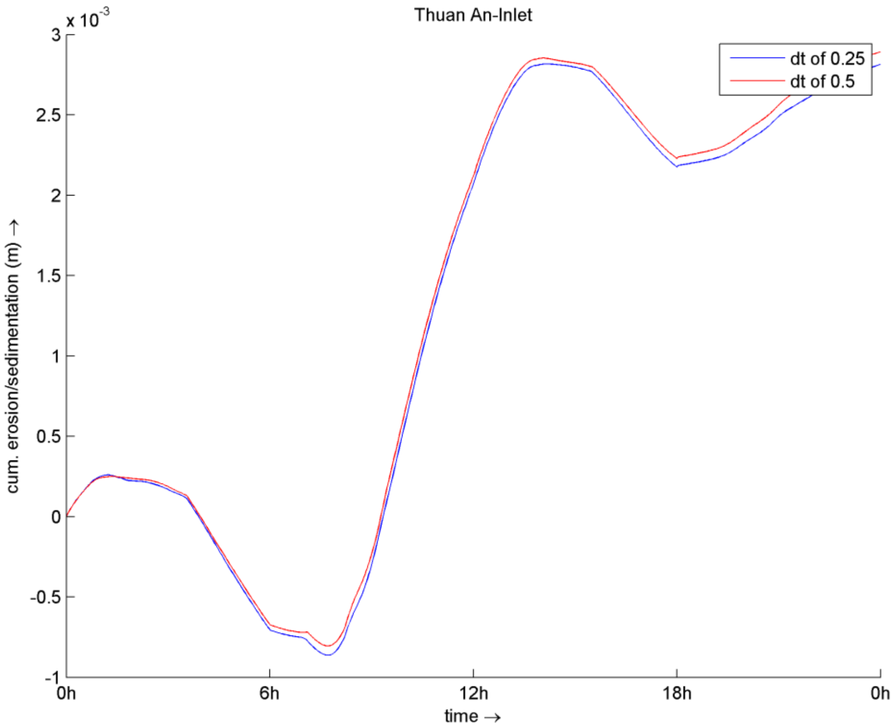

Figure 102: Time step of 0.25 (blue) and 0.5 (red) minutes.

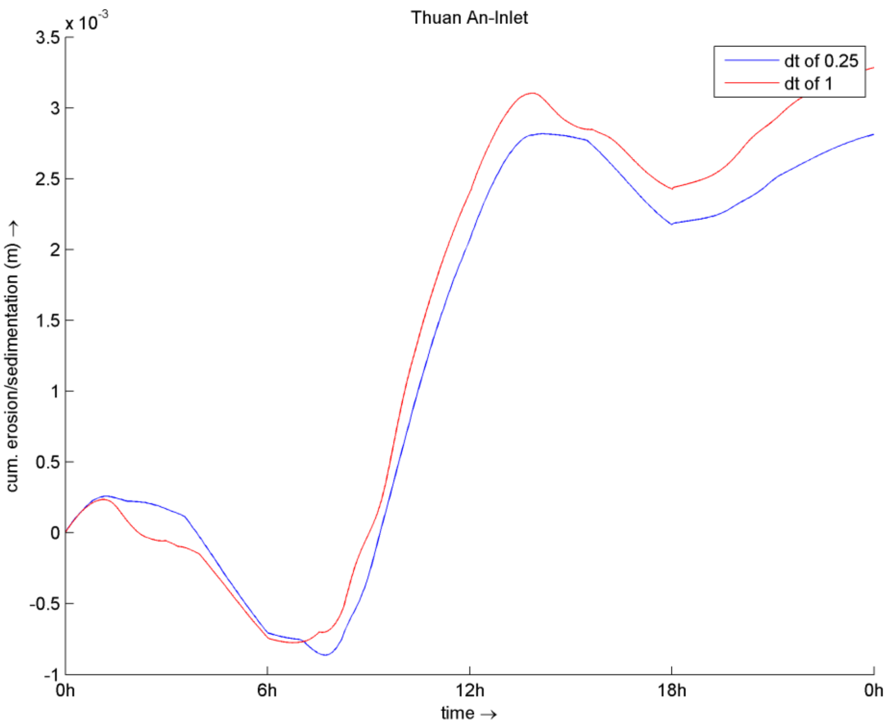

Figure 103: Time step of 0.25 (blue) and 1.0 (red) minutes.

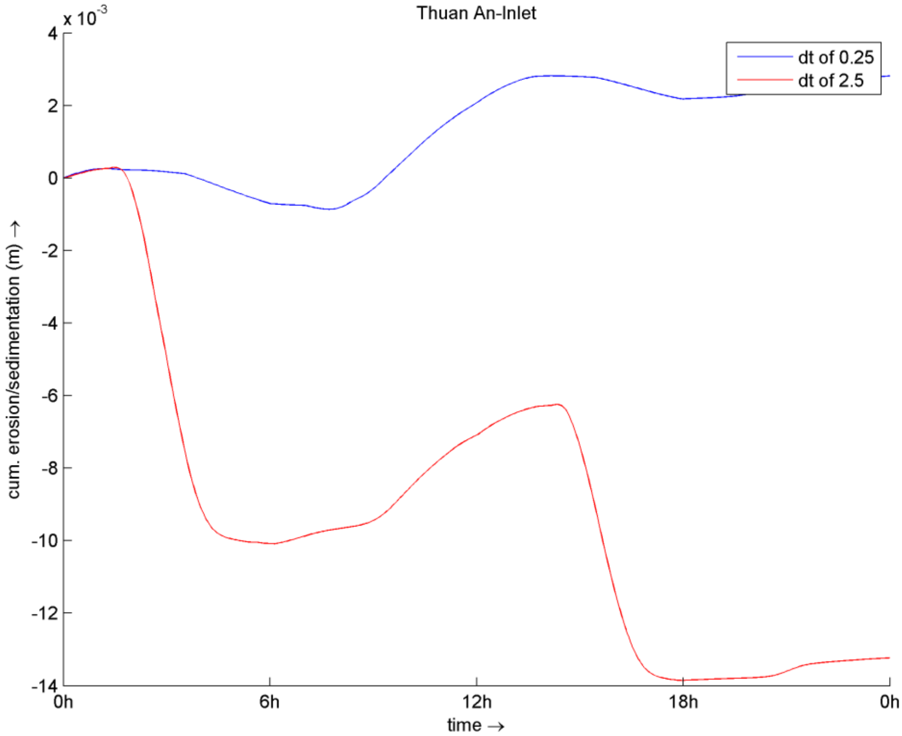

Figure 104: Time step of 0.25 (blue) and 2.5 (red) minutes.

Appendix E: Wave-and wind roses

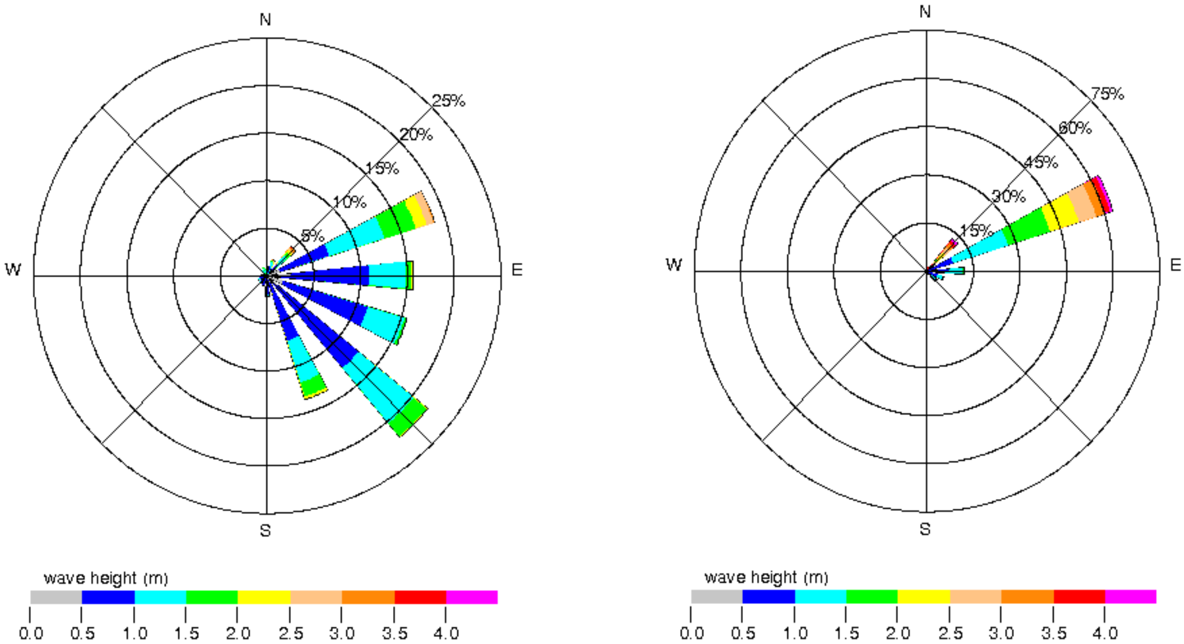

Figure 105: Wave rose for the months January, February and March (left) and for the months April and May (right).

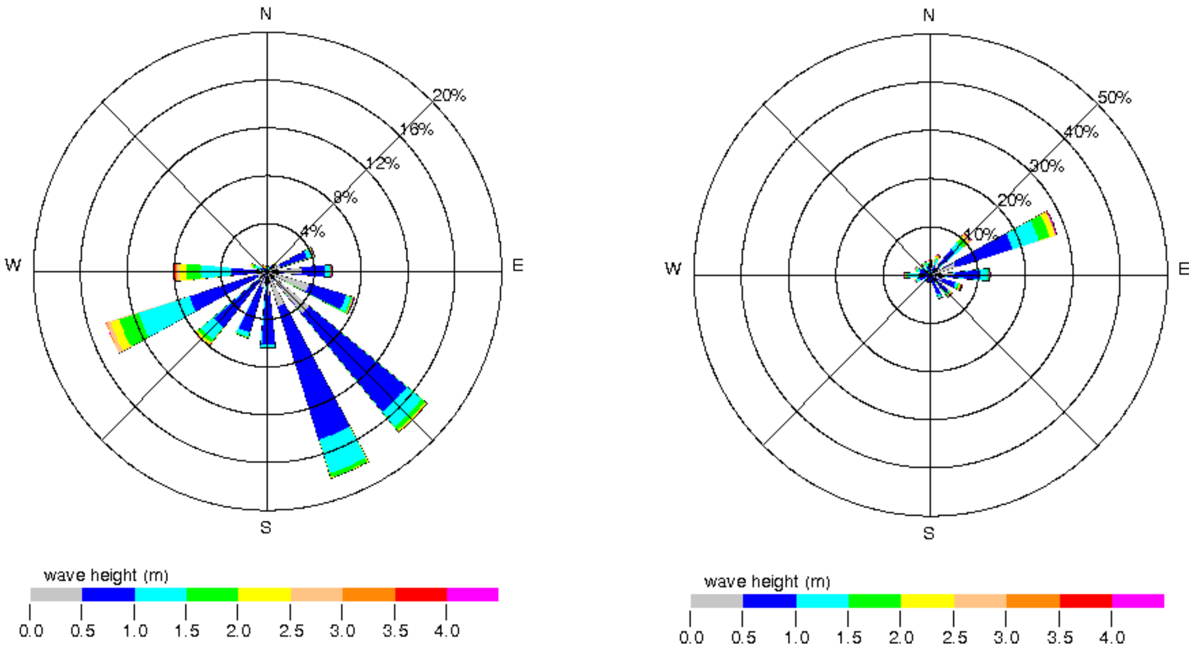

Figure 106: Wave rose for the months June, July and August (left) and for the month September (right).

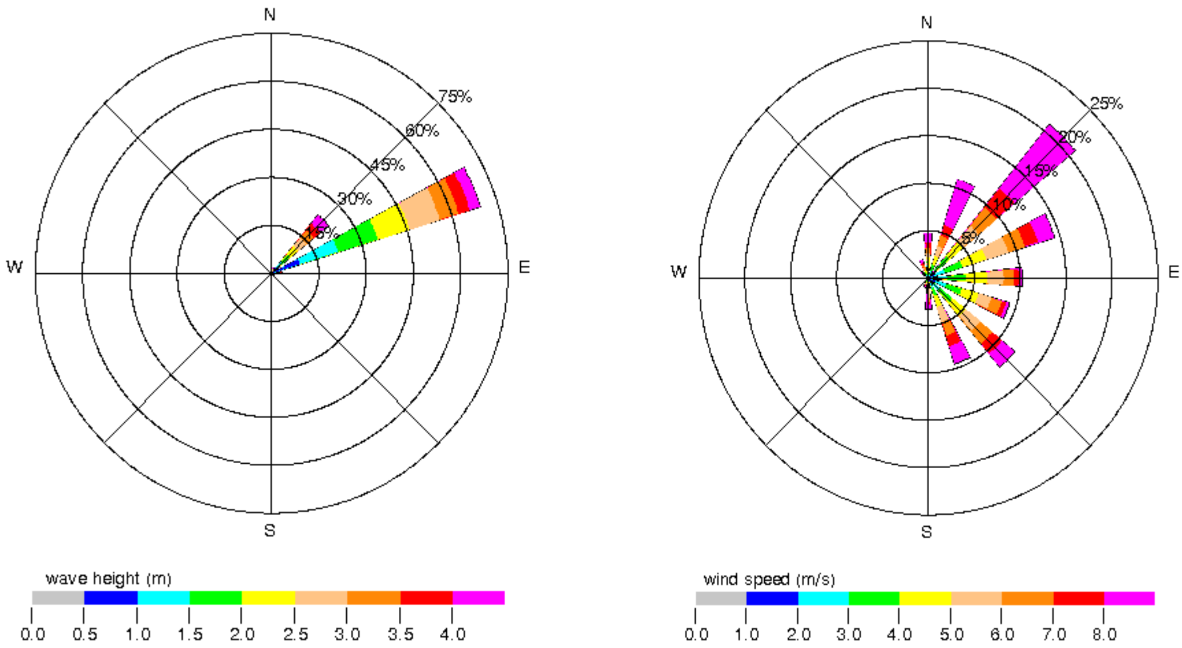

Figure 107: Wave rose for the months October, November and December (left) and a wind rose for the months January, February and March (right).

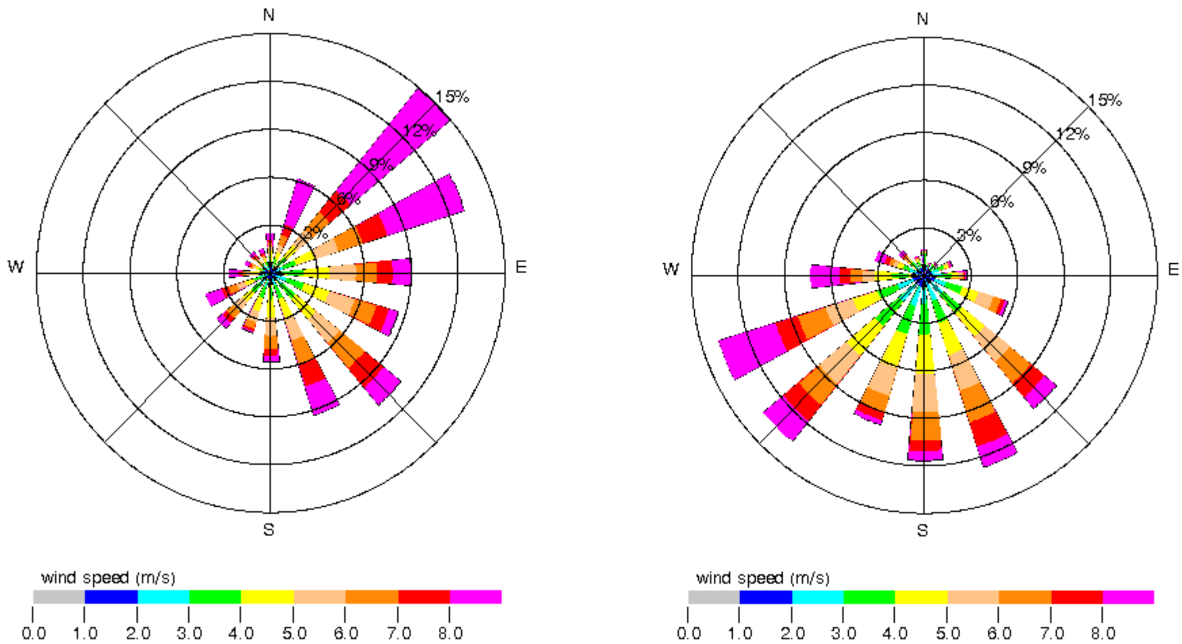

Figure 108: Wind rose for the months April and May (left) and for the months June, July and August (right).

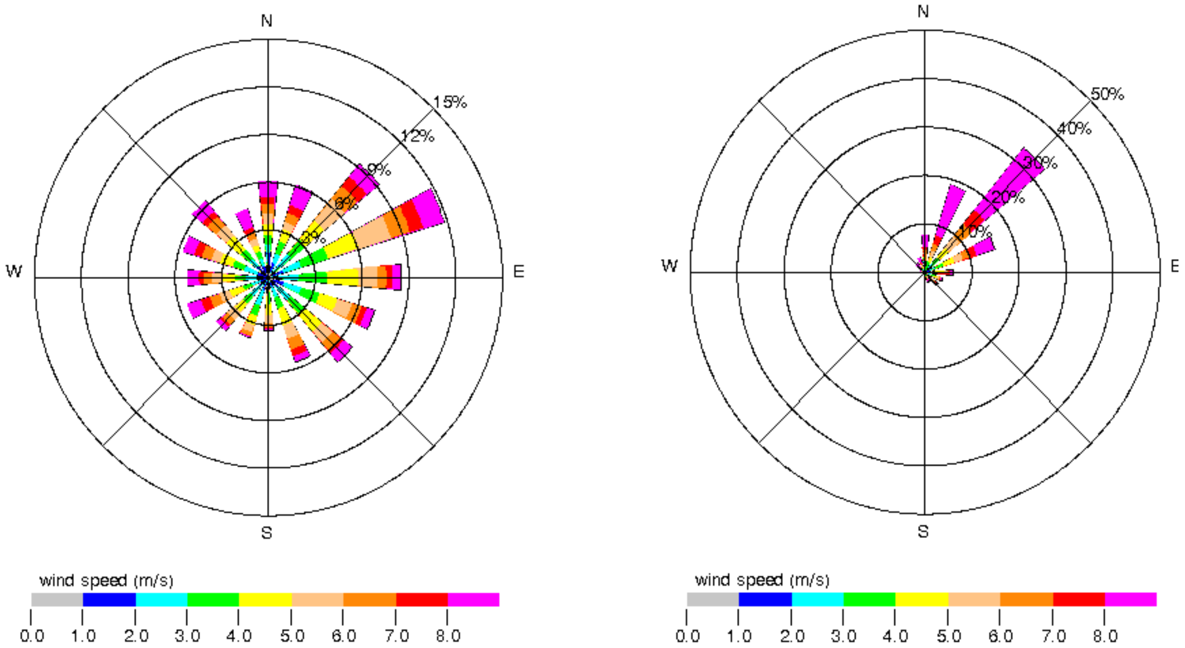

Figure 109: Wind rose for the month September and for the months October, November and December.

Appendix F: Relation wave speed and period

Table 35: Data retrieved from ARGOSS: Model output point is 18° 00'N, 108° 45'E, Season is all year. Based on the years 1992-2012 on 61368 model records with variables wave height (m) and mean wave period (s).

	lower	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**	**11**	**12**	**13**	**14**	
lower	**upper**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**	**11**	**12**	**13**	**14**	**15**	**total**
0.0	**0.5**	0	0.3	3.0	3.2	2.0	0.9	0.4	0.2	0.1	0.0	0.0	0.0	0	10.3
0.5	**1.0**	0	1.0	17.6	12.7	6.9	3.4	0.6	0.2	0.1	0.0	0.0	0	0	42.6
1.0	**1.5**	0	0	4.2	7.9	6.3	5.8	2.3	0.3	0.0	0.0	0.0	0	0	26.8
1.5	**2.0**	0	0	0.1	2.1	3.2	3.6	2.9	0.9	0.1	0.0	0	0	0	12.9
2.0	**2.5**	0	0	0	0.4	1.1	1.5	1.3	0.8	0.1	0.0	0	0	0	5.2
2.5	**3.0**	0	0	0	0.0	0.3	0.7	0.4	0.2	0.0	0.0	0.0	0	0	1.6
3.0	**3.5**	0	0	0	0	0.0	0.2	0.1	0.0	0.0	0	0.0	0	0	0.4
3.5	**4.0**	0	0	0	0	0.0	0.1	0.0	0.0	0	0	0	0	0	0.1
4.0	**4.5**	0	0	0	0	0.0	0.0	0.0	0.0	0	0	0	0	0	0.1
4.5	**5.0**	0	0	0	0	0	0.0	0.0	0.0	0	0	0	0	0	0.0
5.0	**5.5**	0	0	0	0	0	0.0	0.0	0.0	0	0	0	0	0	0.0
5.5	**6.0**	0	0	0	0	0	0	0.0	0.0	0	0	0	0	0	0.0
6.0	**6.5**	0	0	0	0	0	0	0.0	0.0	0	0	0	0	0	0.0
6.5	**7.0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
7.0	**7.5**	0	0	0	0	0	0	0	0.0	0	0	0	0	0	0.0
7.5	**8.0**	0	0	0	0	0	0	0	0.0	0	0	0	0	0	0.0
8.0	**8.5**	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
8.5	**9.0**	0	0	0	0	0	0	0	0	0.0	0	0	0	0	0.0
9.0	**9.5**	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
9.5	**10.0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
10.0	**10.5**	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
10.5	**11.0**	0	0	0	0	0	0	0	0	0	0.0	0	0	0	0.0
11.0	**11.5**	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
11.5	**12.0**	0	0	0	0	0	0	0	0	0	0.0	0	0	0	0.0
12.0	**12.5**	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
total		0.0	1.3	24.9	26.4	19.8	16.2	8.1	2.5	0.6	0.1	0.1	0.0	0.0	100.0

Appendix G: Supporting figures for the zero scenario

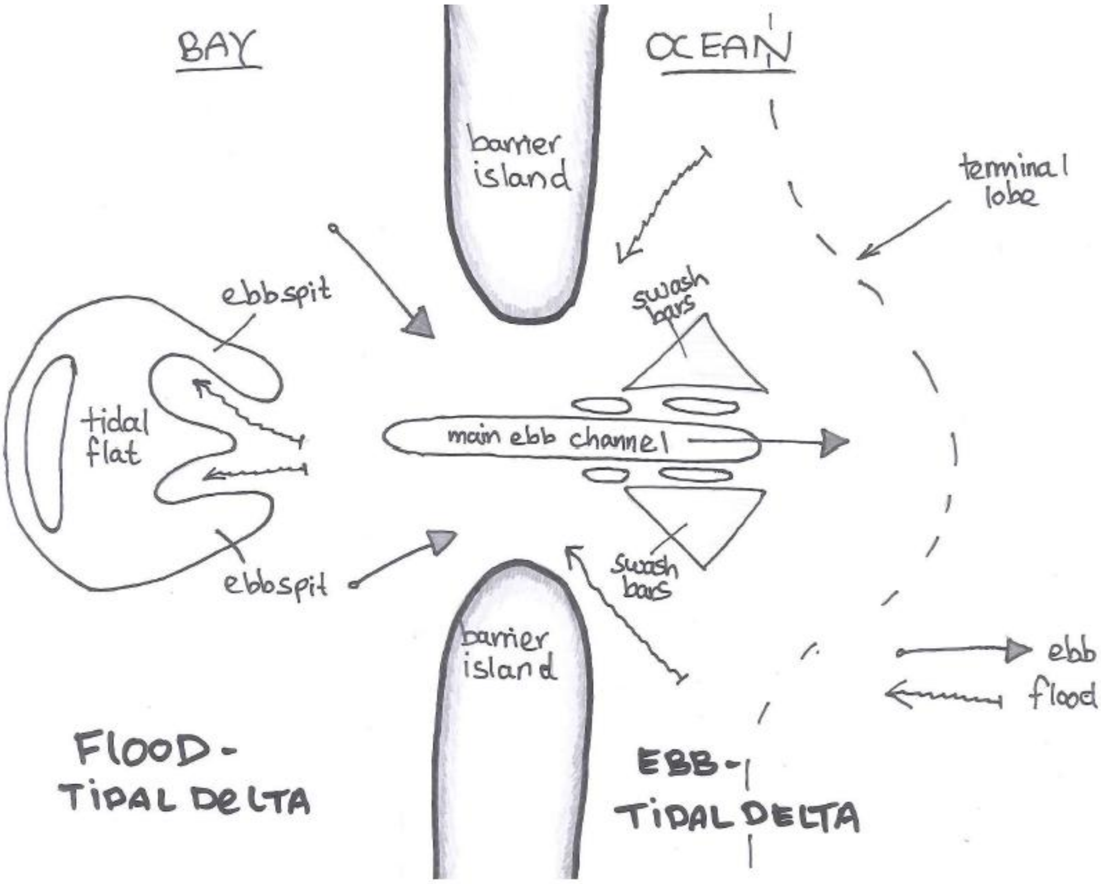

Figure 110: Theory of the ebb-tidal delta and flood tidal delta, based on Bosboom & Stive (2013).

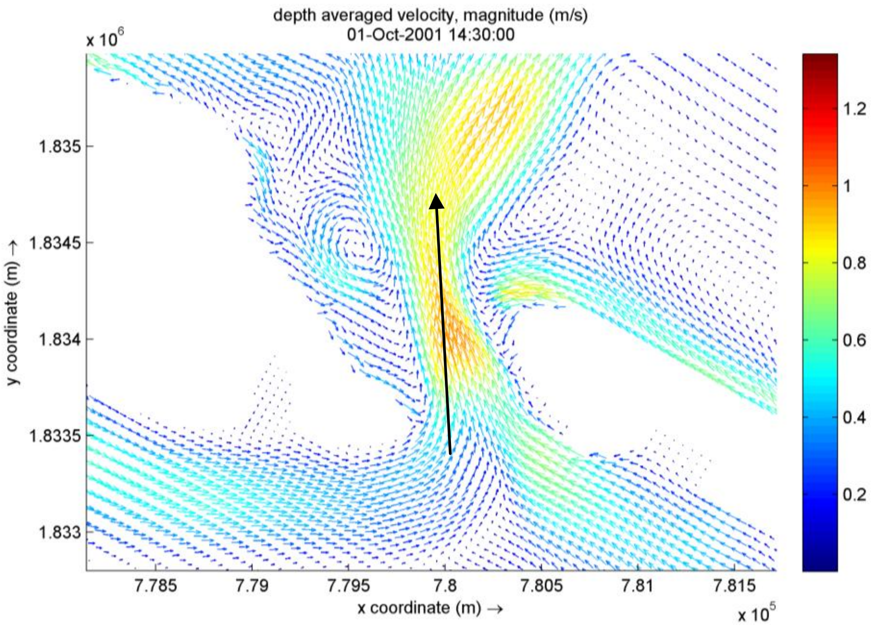

Figure 111: Velocities trough the main ebb channel in the Thuan An inlet during ebb.

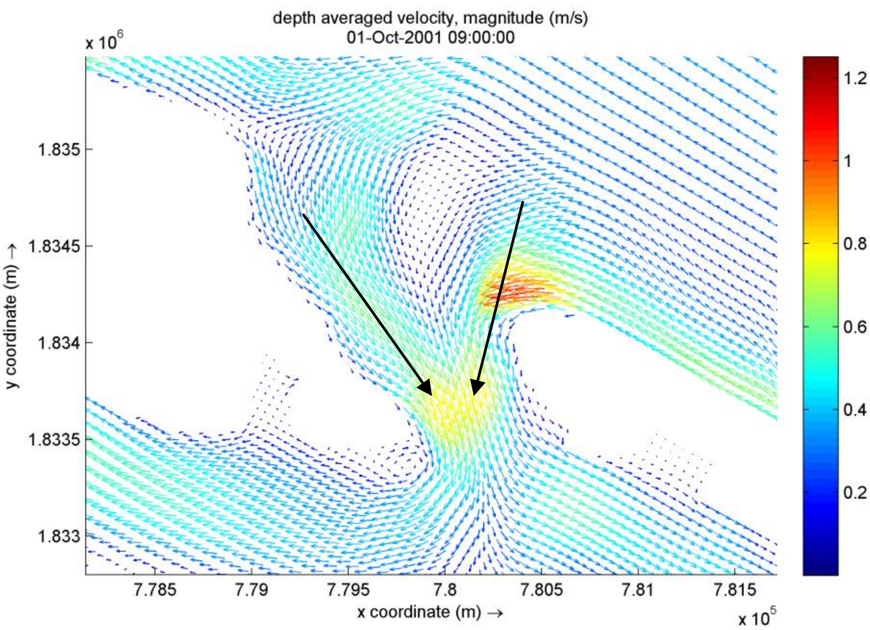

Figure 112: Velocities trough the marginal flood channels in the Thuan An inlet during flood.

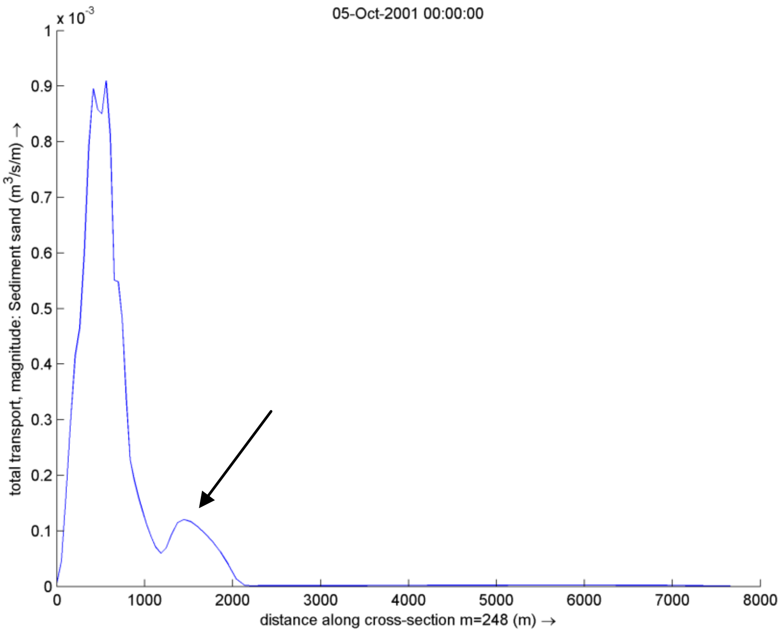

Figure 113: Sediment transport during the winter along a longitudinal cross section in the Thuan An inlet, where the arrow indicates the location of the bar-by-passing.

Appendix H: Supporting figures for the current situation

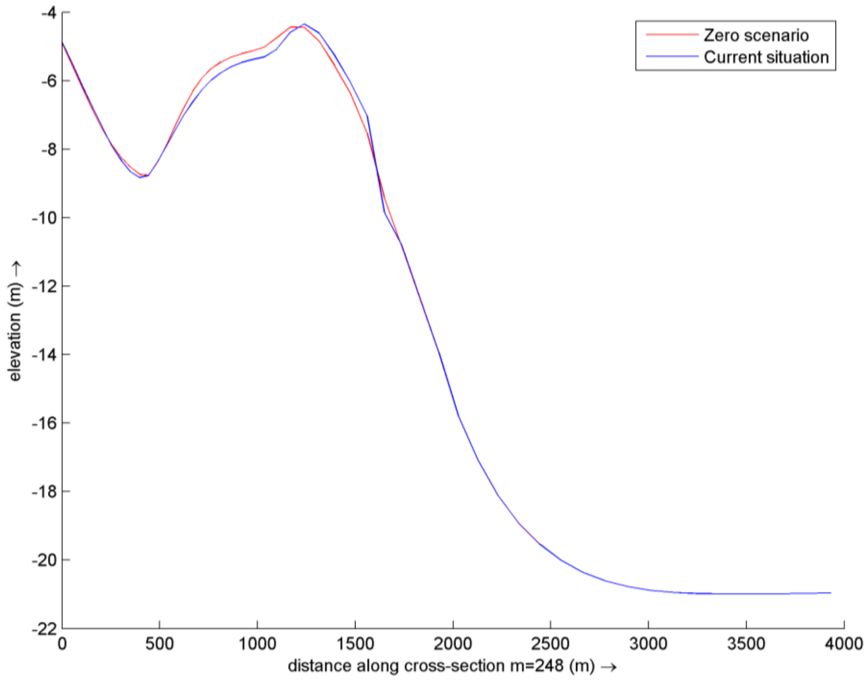

Figure 114: Comparison of the longitudinal cross-section between the zero scenario and current situation for one year simulation.

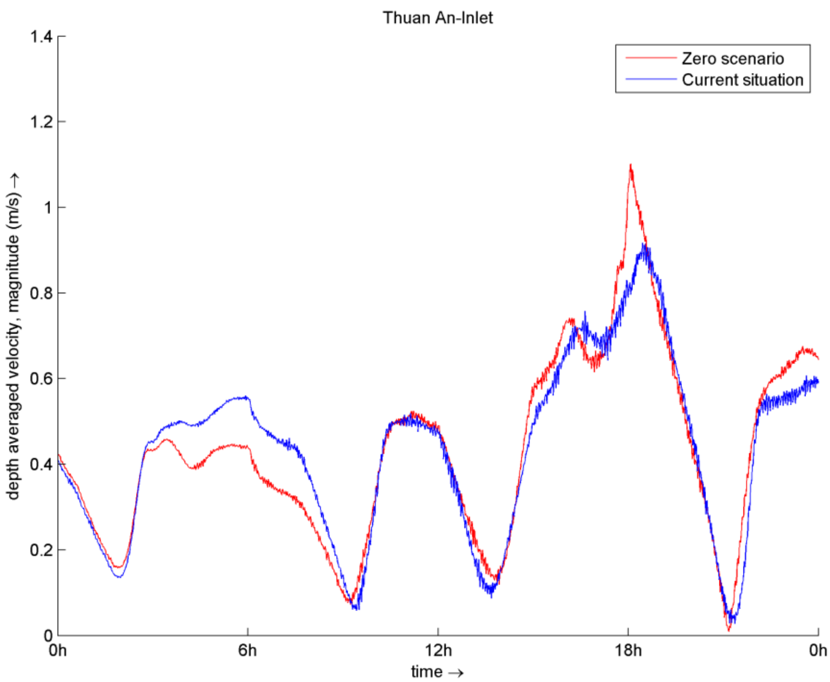

Figure 115: Comparison of the depth-averaged velocities between the zero scenario and current situation for one year simulation.

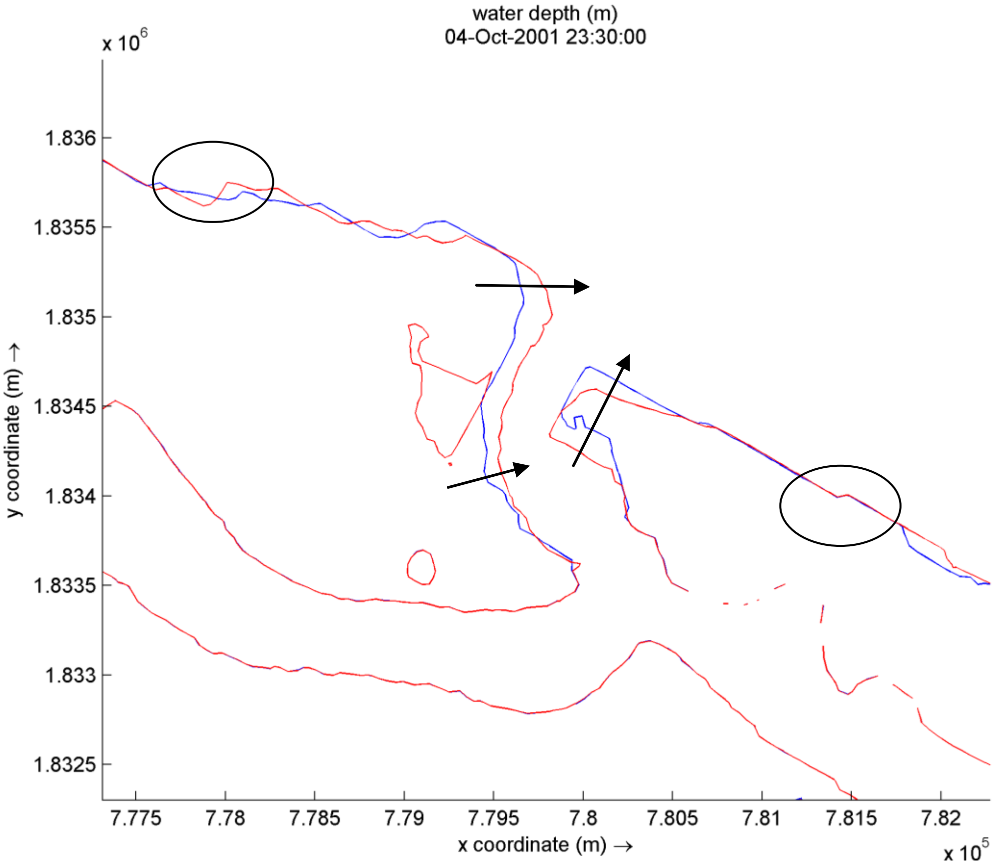

Figure 116: Comparison of the shoreline between the zero scenario (blue) and current situation (red).

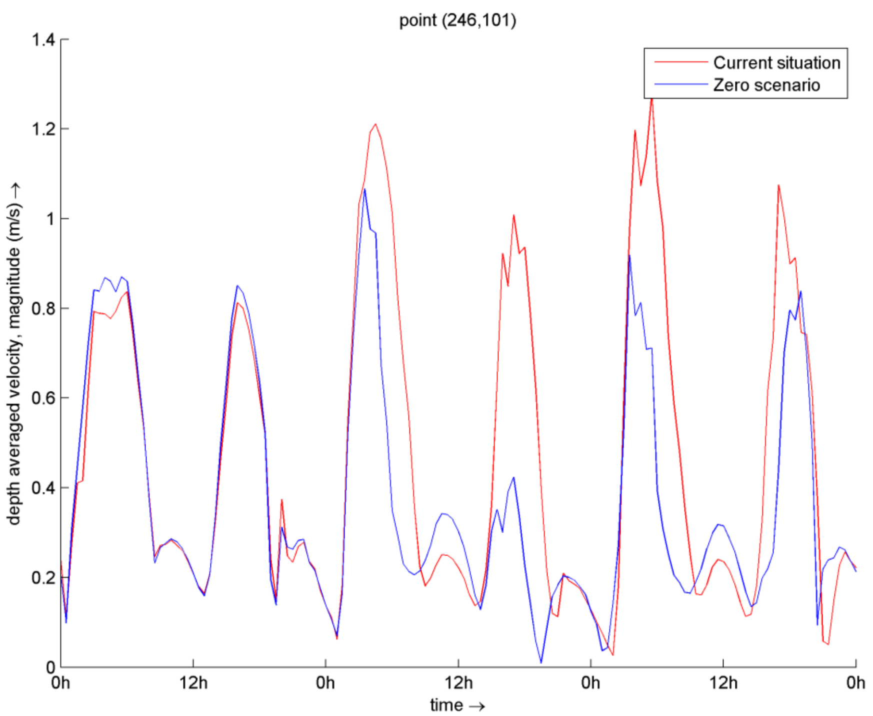

Figure 117: Depth-averaged velocities in the middle of the ebb-tidal delta for the zero scenario (blue) and the current situation (red).

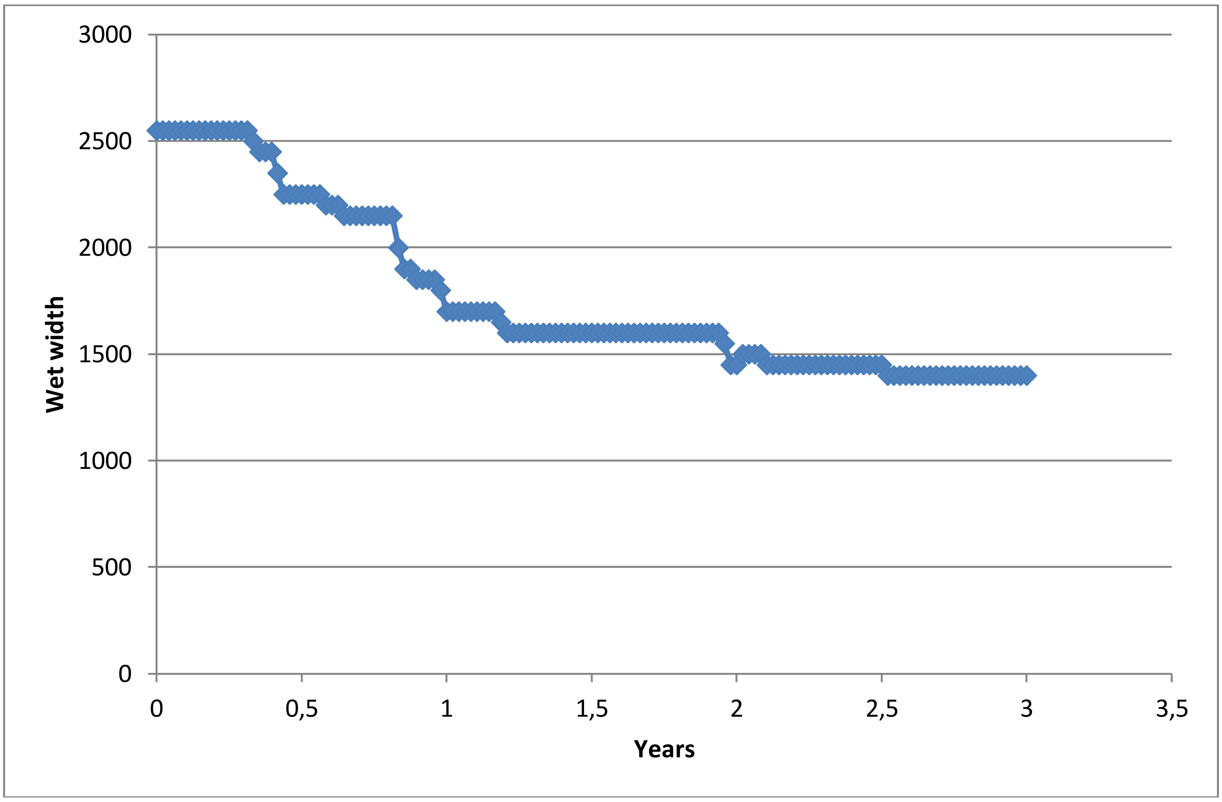

Figure 118: Analysis of the navigational width with a depth of minimal 0.5 meter, for the current situation.

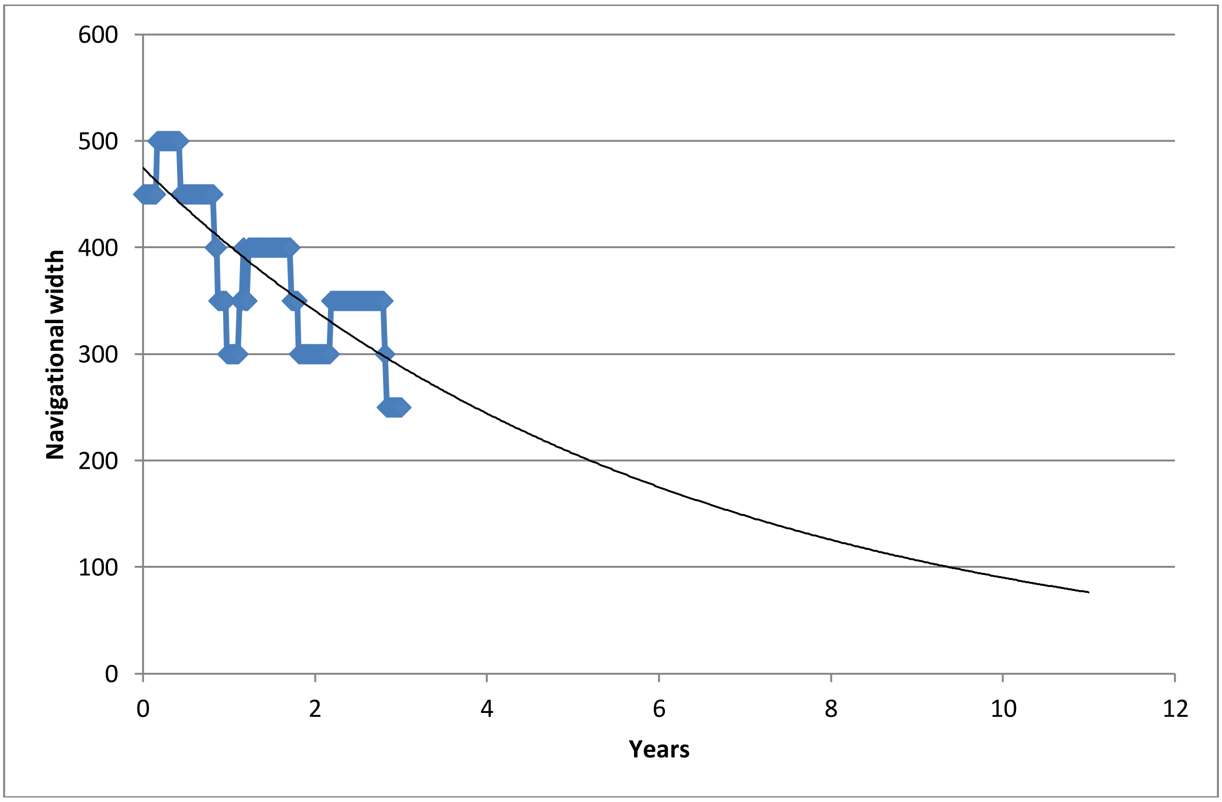

Figure 119: Analysis of the navigational width with a depth of minimal 4.5 meter for the current situation. Trend line is exponential.

Appendix I: Supporting figures for option 1

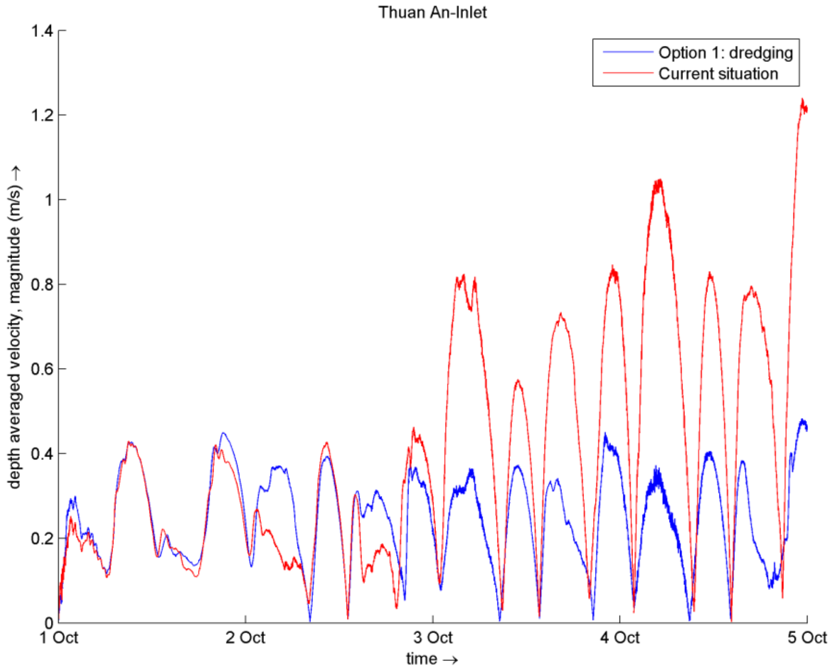

Figure 120: Comparison of the depth-averaged velocities between the current situation and option 1 with continuous dredging.

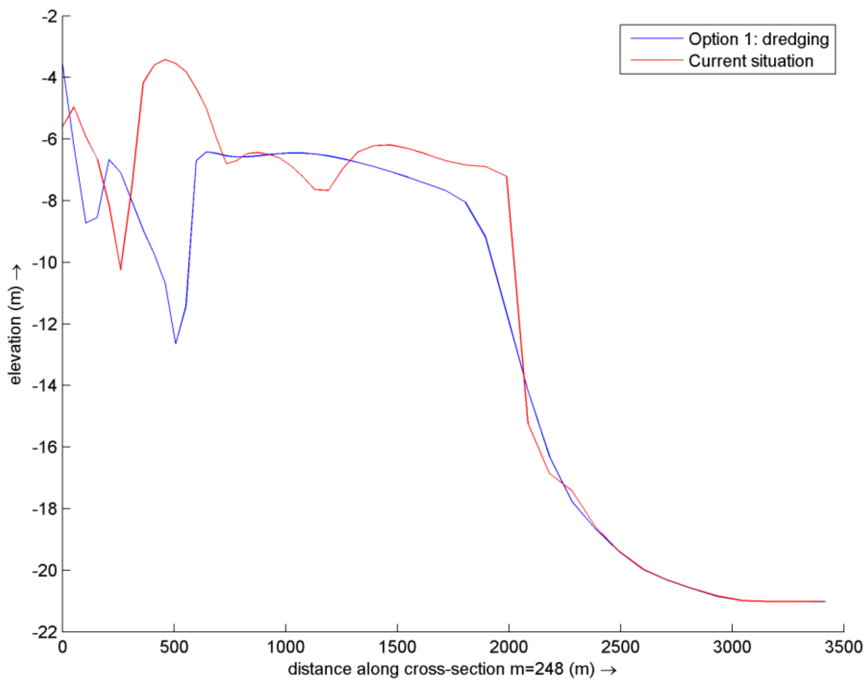

Figure 121: Comparison of the longitudinal cross-section between the current situation and option 1 with continuous dredging.

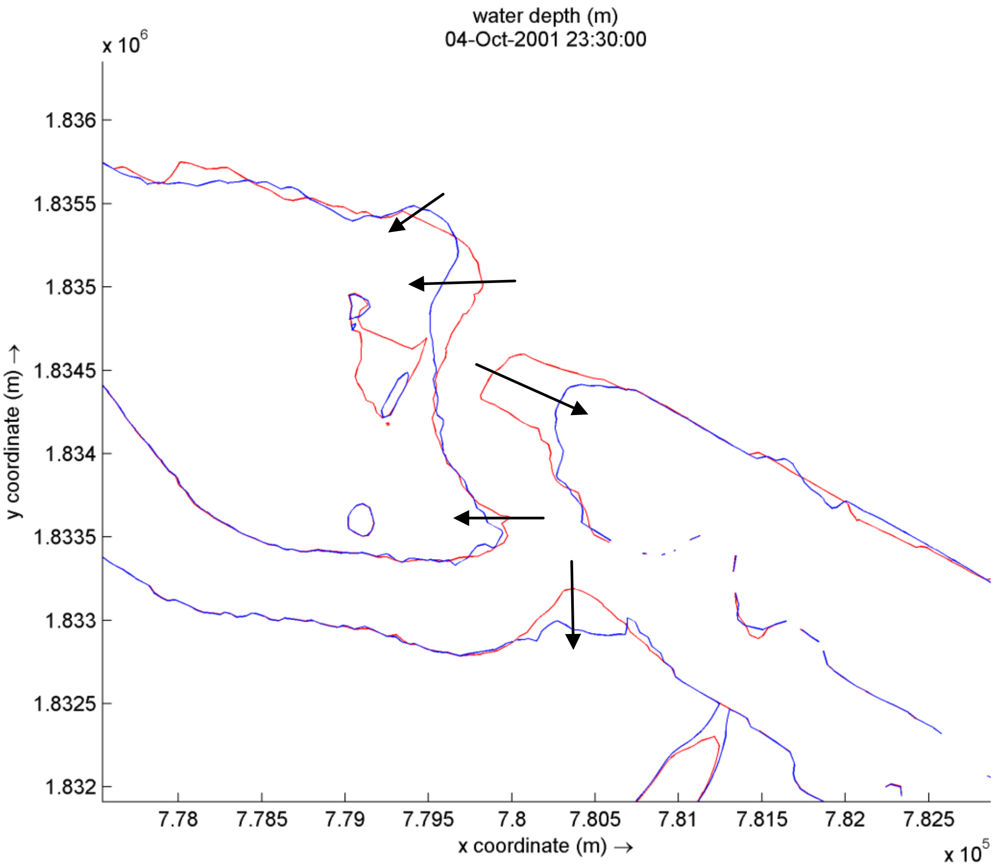

Figure 122: Comparison of the shoreline between current situation (red) and option 1 (blue).

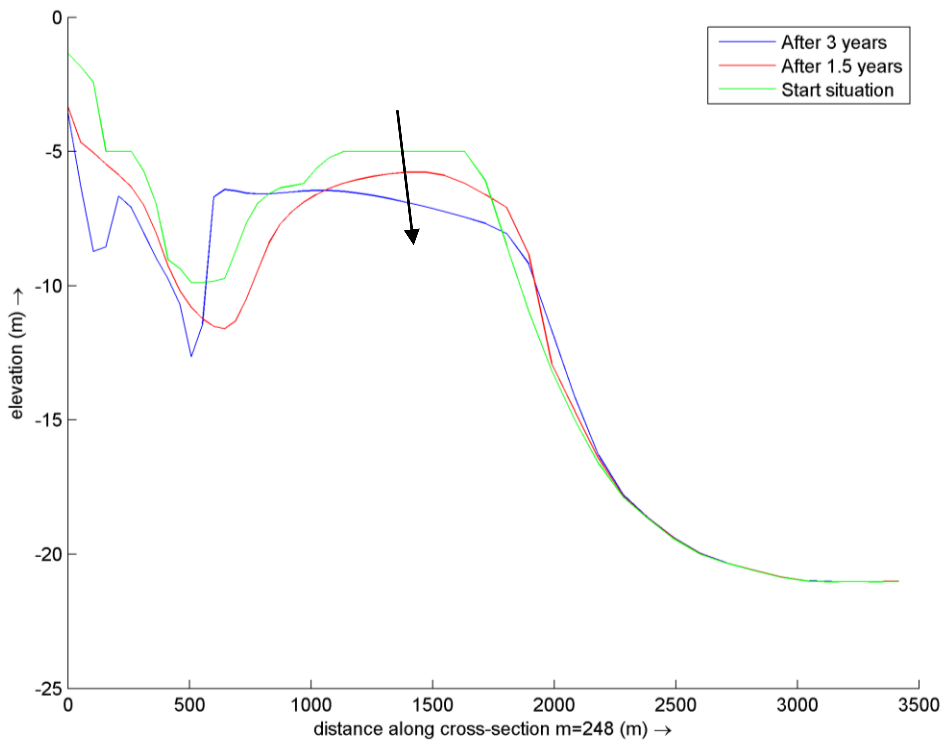

Figure 123: Development of the longitudinal cross section of the navigation channel with option 1 continuous.

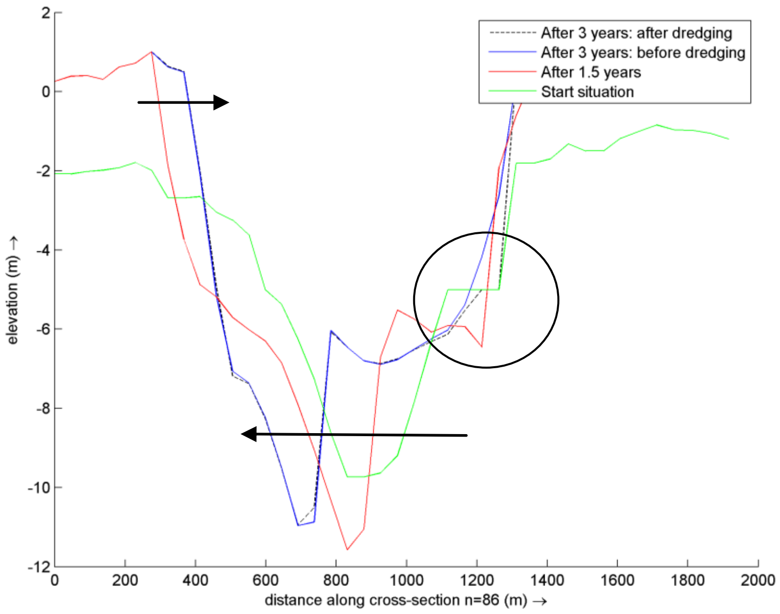

Figure 124: Cross-section for multiple time periods for dredging activity each year.

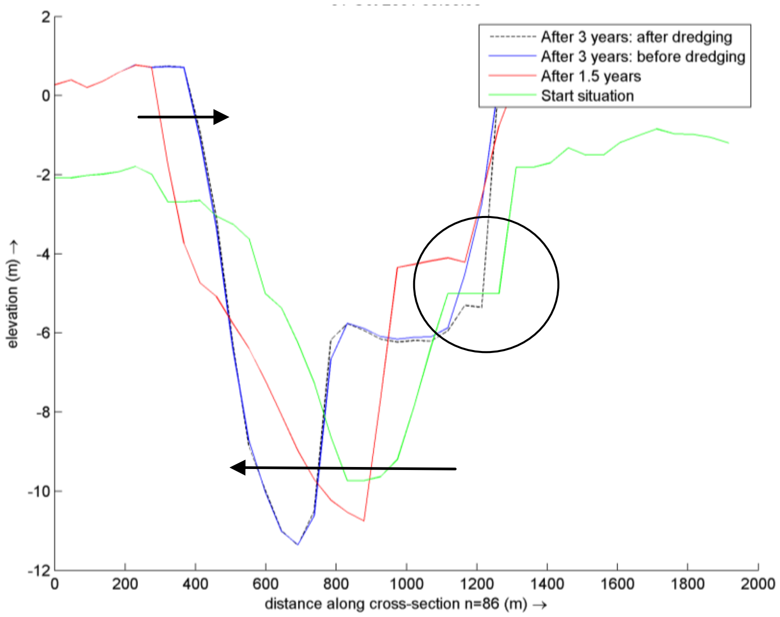

Figure 125: Cross-section for multiple time periods for dredging activity each three year.

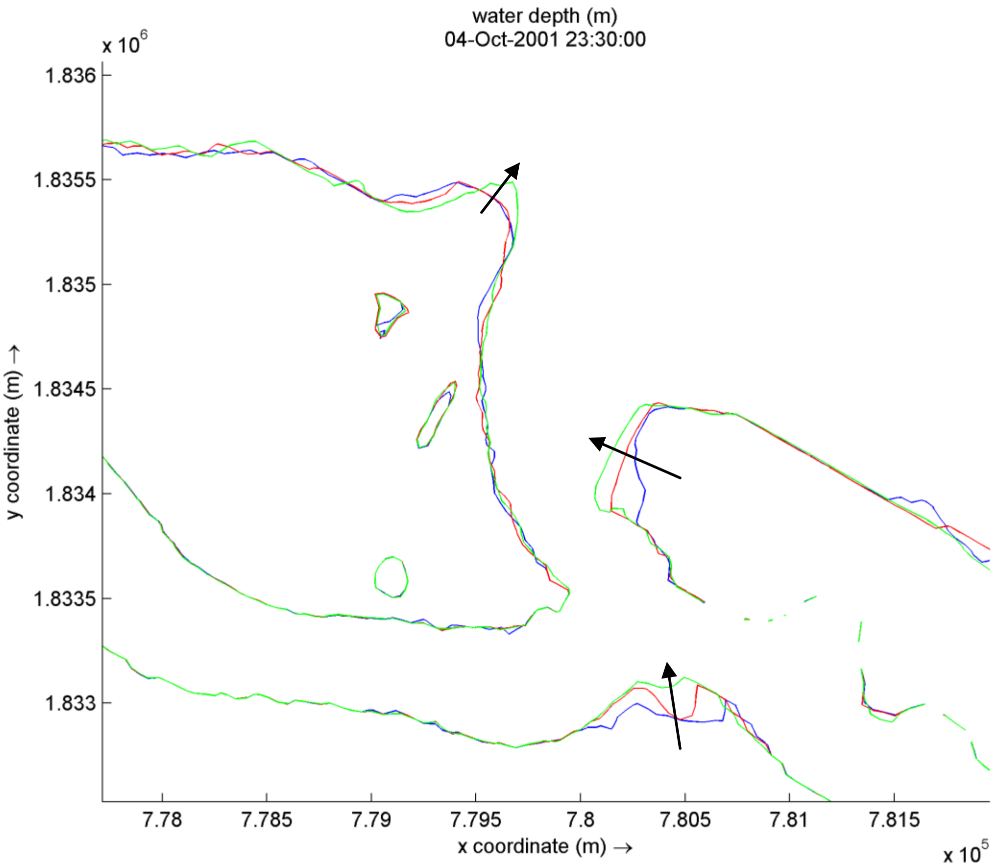

Figure 126: Comparison of the shoreline between continuous dredging (blue), each year (red) and each three years.

Appendix J: Supporting calculations for option 2

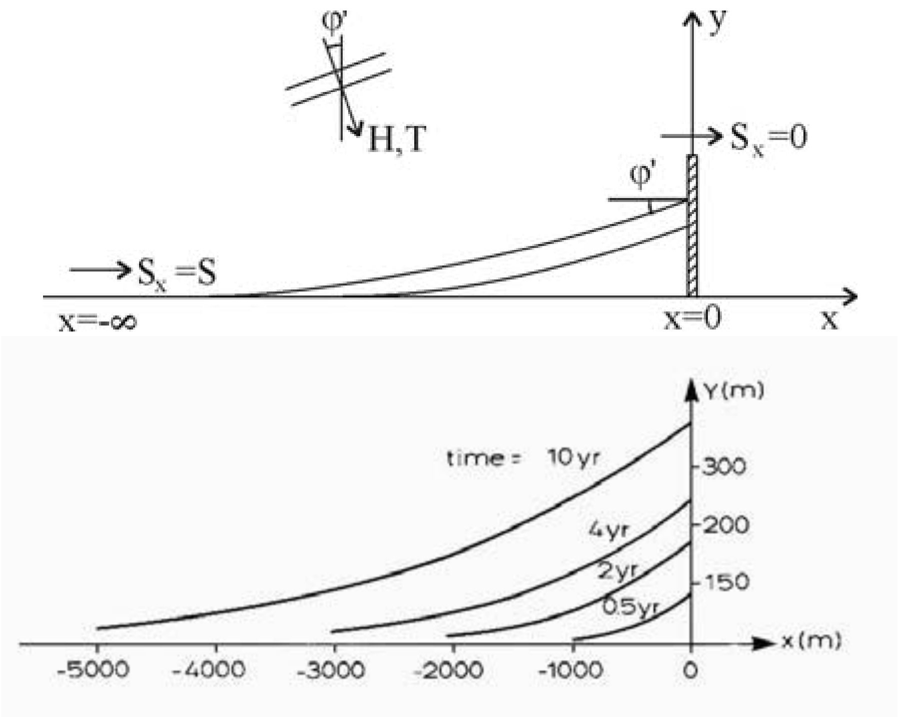

Figure 127: Analytical solutions for accretion of breakwaters, Figures and equations from Bosboom & Stive (2013).

Equation used

$$L^2 = 4\frac{\varphi' S t}{\pi d}$$

$$t = \frac{L^2 \pi d}{4 S \varphi'} = \frac{1000^2.\pi.5}{4.0.249.10^6.0.5} \approx 30\ year$$

In which

t is time in years
d is profile height in meters
S is longshore transport in m^3/year

Appendix K: Supporting figures for option 2

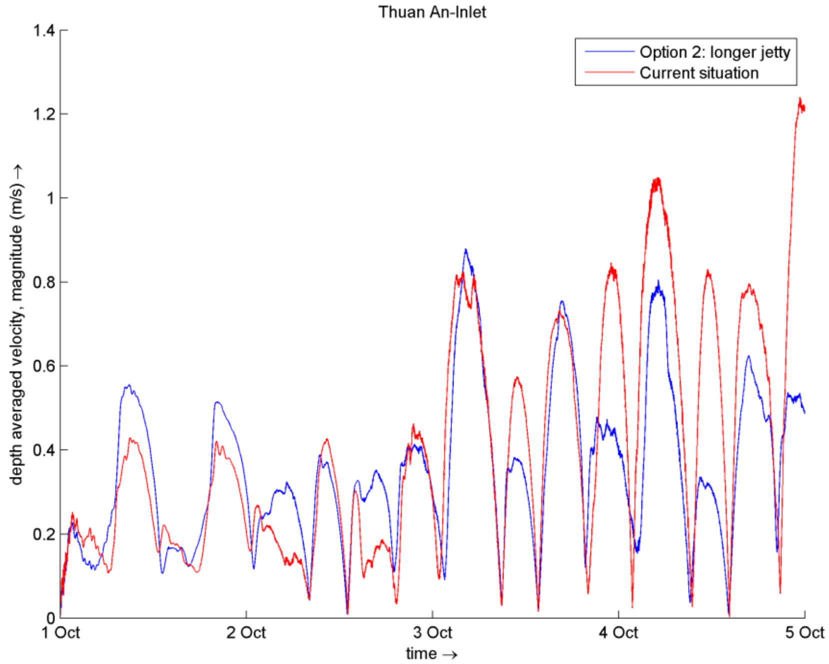

Figure 128: Comparison of the depth-averaged velocities between the current situation and option 2 with a longer jetty.

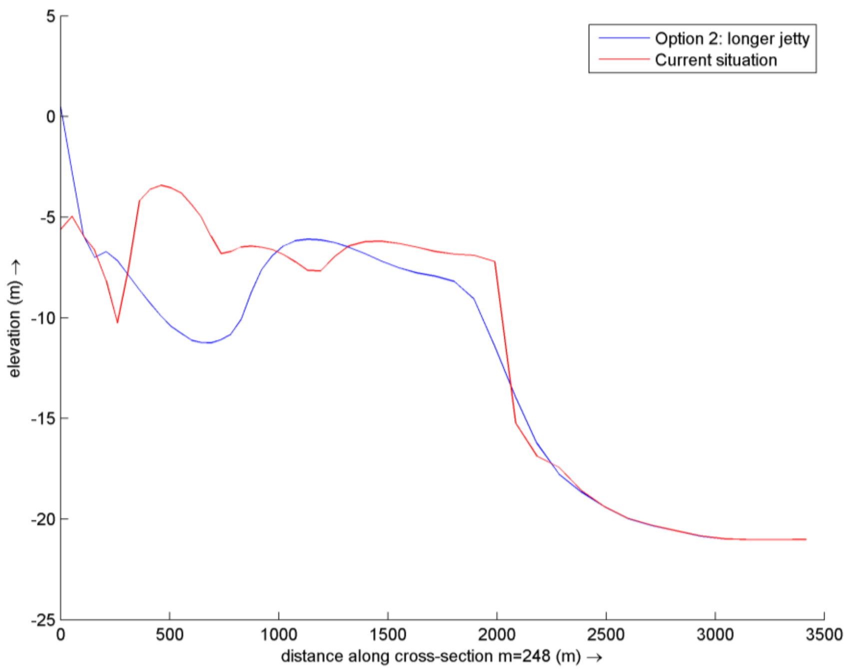

Figure 129: Longitudinal cross-section for three year of simulation for option 2.

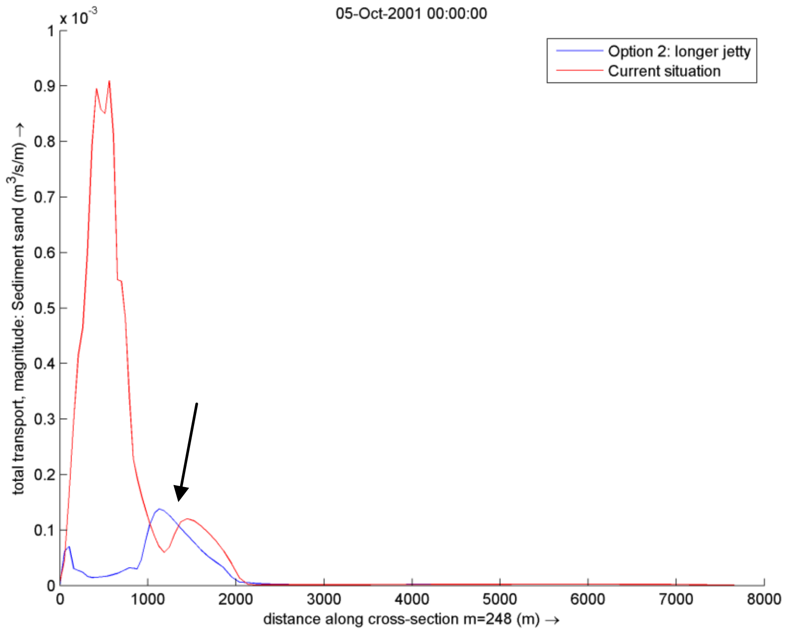

Figure 130: Comparison of the sediment transport during winter time between the current situation and option 2 with a longer jetty.

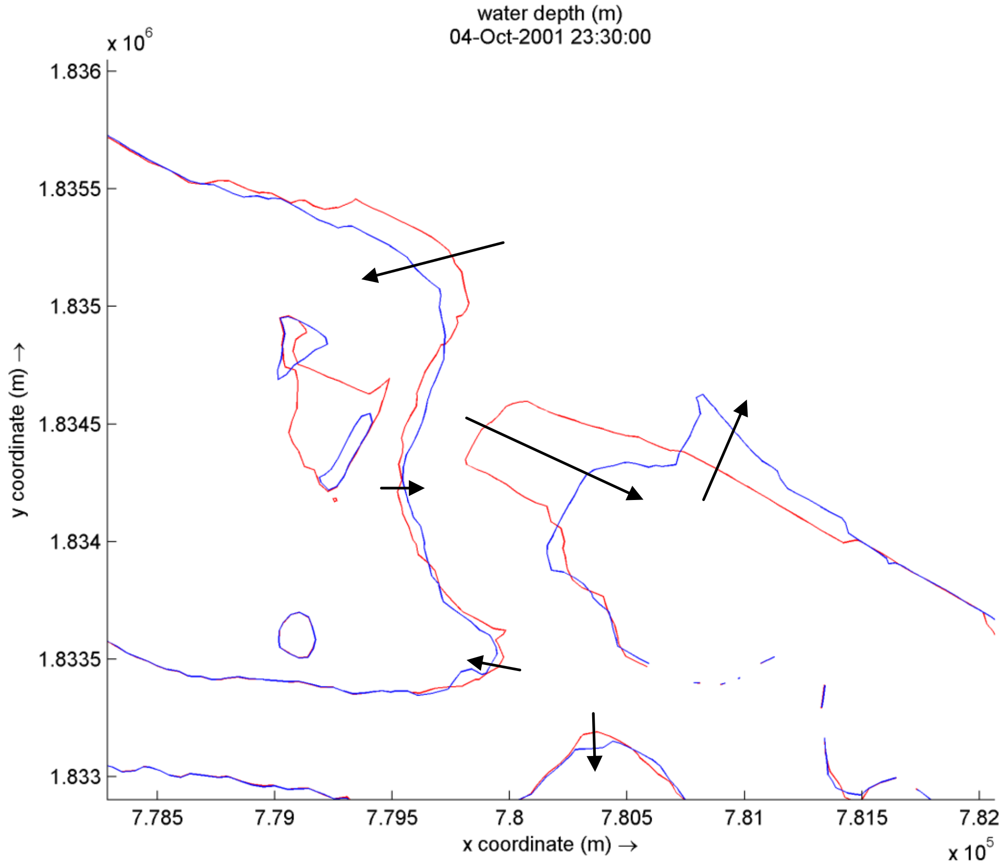

Figure 131: Comparison of the shoreline between current situation (red) and option 2 with a longer jetty (blue).

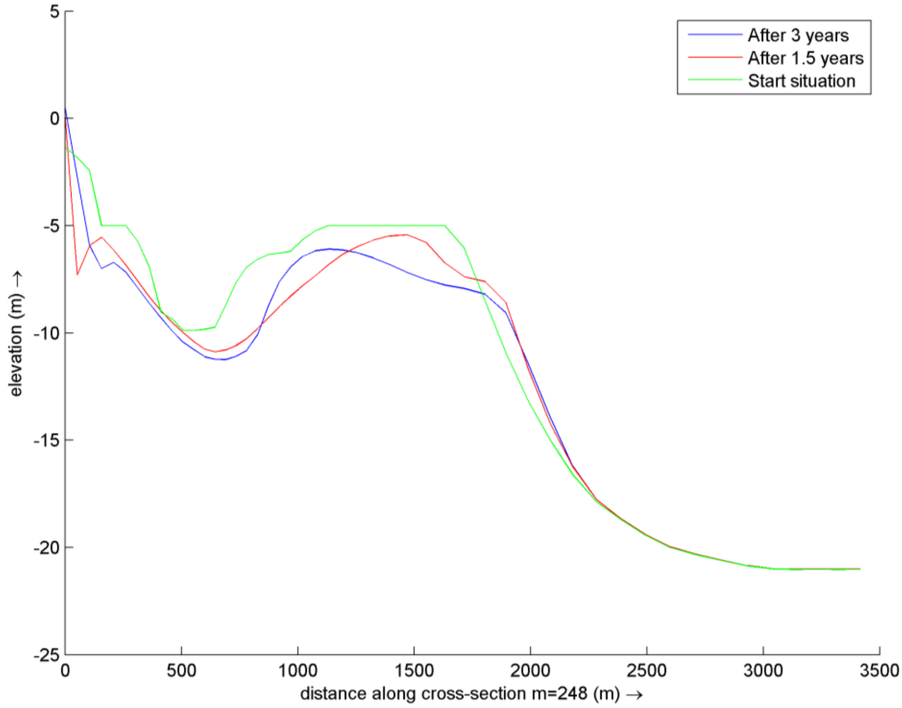

Figure 132: Longitudinal cross-section for multiple years for option 2 at gridpoint 248.

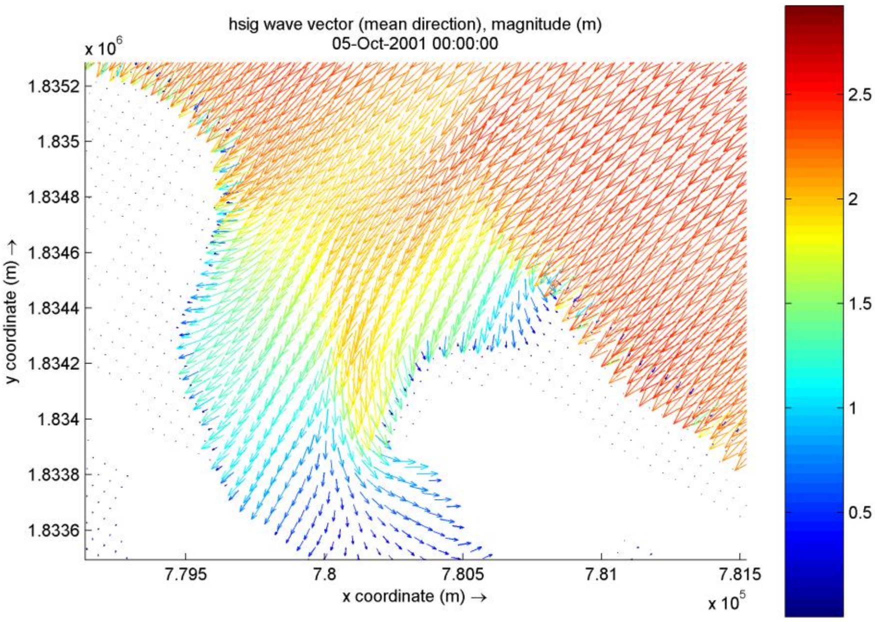

Figure 133: Wave height and direction in winter time for option 2.

Appendix L: Supporting figures for option 3

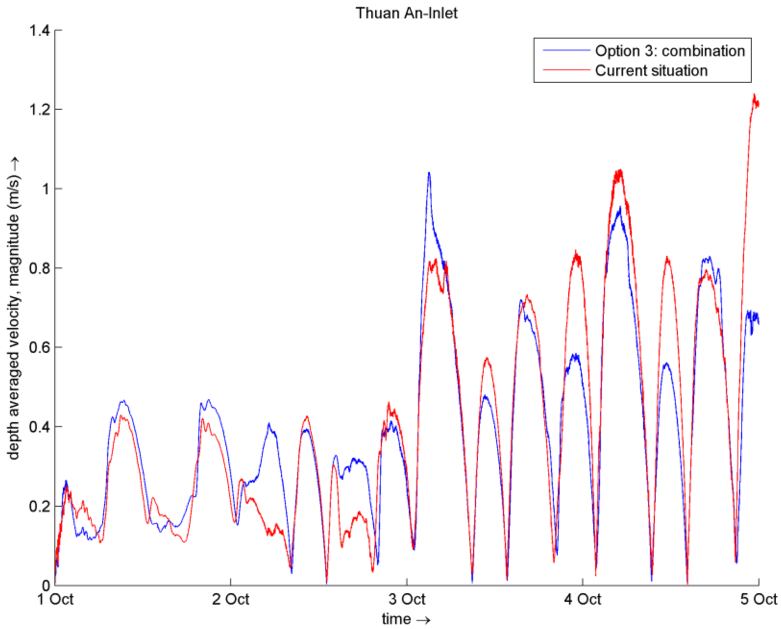

Figure 134: Comparison of the depth-averaged velocities between the current situation and option 2 with a longer jetty.

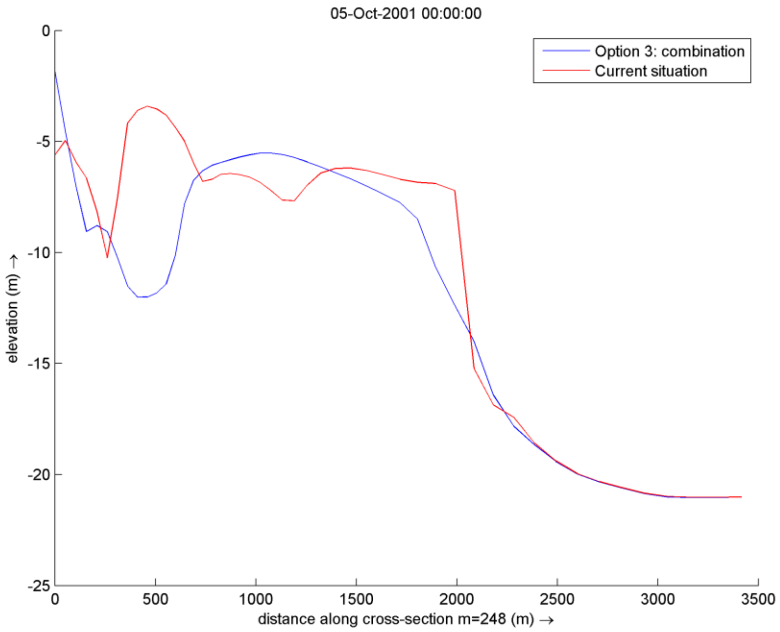

Figure 135: Longitudinal cross-section for three years of simulation for option 3.

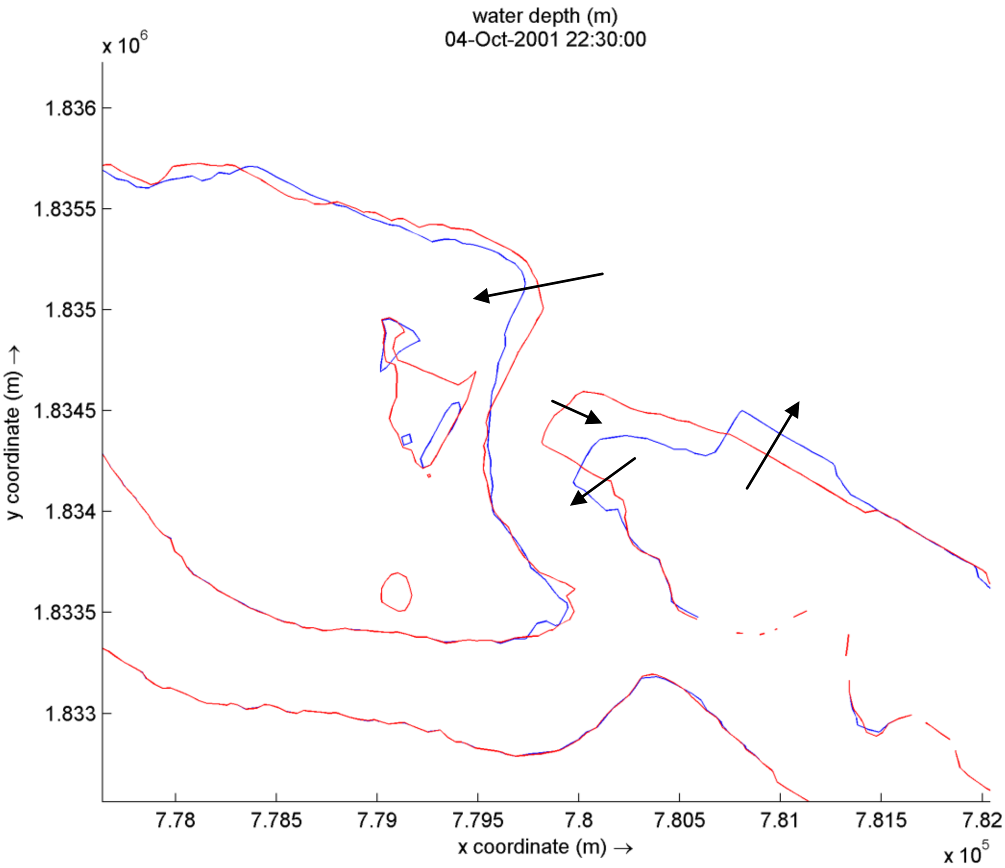

Figure 136: Comparison of the shoreline between current situation (red) and option 3 (blue).

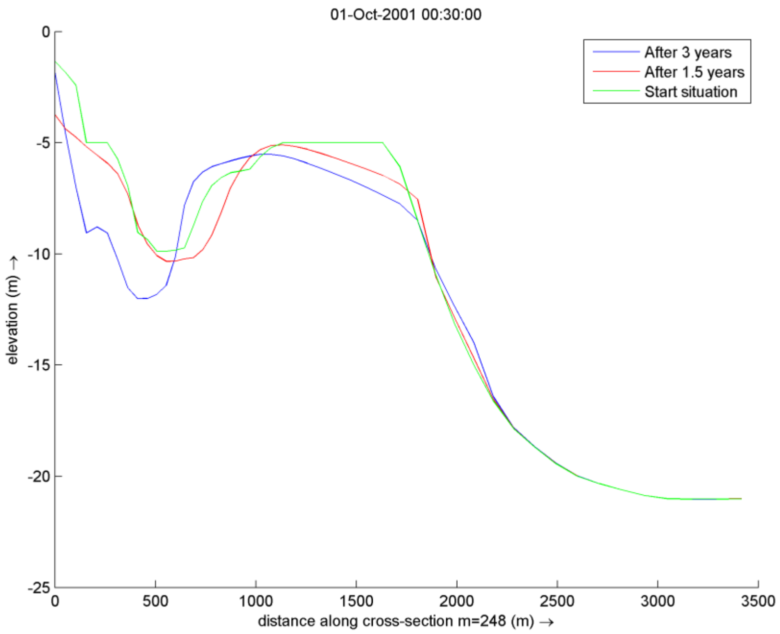

Figure 137: Longitudinal cross-section for multiple years for option 3 at gridpoint 248.

Appendix M: Supporting figures conclusion

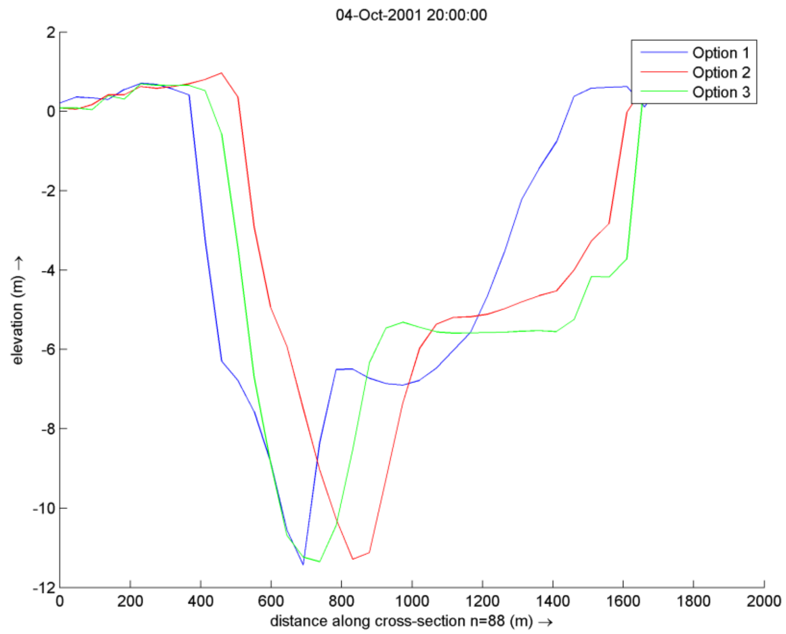

Figure 138: Cross-section for all the options.

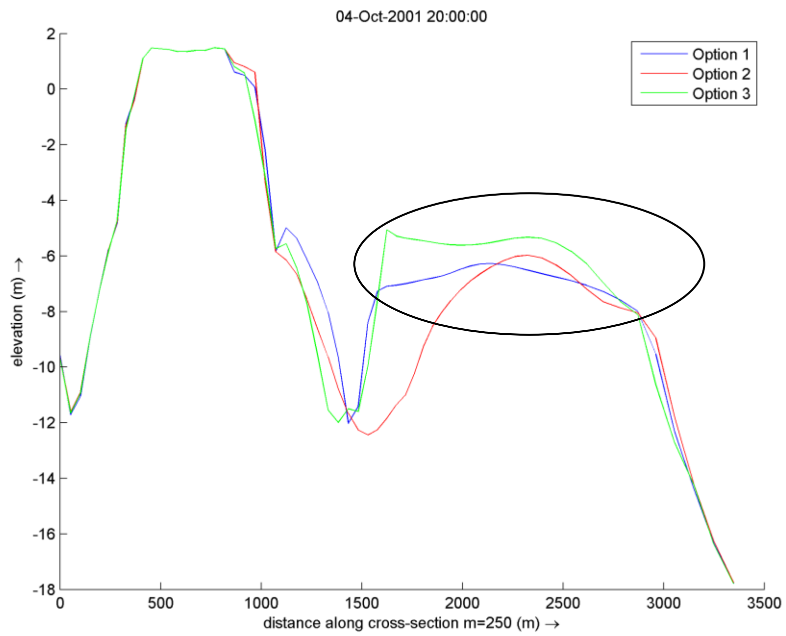

Figure 139: Longitudinal cross-section for all the options after 3 years, at gridpoint 250.

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