Conceptual model of the seasonal inlet closure in the Da Dien estuary

Bachelor thesis – Civil Engineering

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CONCEPTUAL MODELING IS NOT A SCIENCE, BUT AN ART

Stewart Robinson

Abstract

Estuaries are the places where river and sea interfere. Some estuaries are separated from the sea by a sand spit, so the water can only flow through a narrow inlet from the estuary to the sea and back. Along the Vietnamese coast, there are many estuaries with a sand spit. The river mouth of the Ba River is one of them; the Da Dien estuary. Among the several problems identified for this estuary, the seasonal inlet closure is studied in this thesis. Due to this closure, fishing boats cannot pass the inlet for harvesting trips. The goal of this study is to develop a conceptual model that describes the seasonal inlet closure in the Da Dien estuary. The conceptual model will form the basis of a simulation model, in which solutions for the closure can be implemented and evaluated. To reach this goal, the seasonal inlet closure is studied in detail and the factors that affect the closure are reviewed. Based on that knowledge, a conceptual model is developed. Next, the model is validated with collected data.

A literature study of the factors that affect the seasonal inlet closure shows that the closure mainly depends on the river discharge. When the river discharge drops and only a small amount of water is flowing through the inlet channel, deposition occurs and the inlet gets filled up with sediment. Due to the large variation in river discharge in the Ba River, the closure can occur during the dry season. The sediment that is transported by large river discharges during the flood season (September-December), flows through the inlet channel and is deposited in front of the inlet. The sediment is transported back to the inlet during the dry season (January-August). Wind and waves play an important role in this process. They are influenced by the northeast monsoon from September till March and the southwest monsoon from April till August. Because the coastline of the area around the Da Dien estuary is oriented from the northwest to the southeast, the monsoon seasons cause both onshore and longshore currents. After the flood season, onshore currents are dominant from January till March, driven by wind and waves from the northeast. The sediment that is dropped in front of the inlet, is transported back to the inlet, so the inlet fills up. The longshore currents transport sediment along the shoreline. When they are interrupted by tidal currents in front of the inlet, the longshore current velocity drops and the sediment deposes. This process mainly occurs during the southwest monsoon. Other factors that affect the seasonal inlet closure are human activities and climate change.

Since the conceptual model is the basis for further research, the model should be valid, credible, feasible and useful. In the conceptual model, boxes, lines and arrows show direct, indirect and interactive relations between the variables. The first sketch of the conceptual model includes all studied factors. However, the model is too complicated to use in a simulation and needs simplification. Based on the literature study and the first sketch of the model, the monsoon, wind, human activities and climate change are excluded from the model. This leaves a conceptual model in which the seasonal inlet closure is driven by river discharge, waves and tide.

Satellite images and data of river discharge, wind, wave and bed topography have been collected to validate the model with a correlation analysis. Unfortunately, there is a great lack of data (and the data available are not always reliable). The validation shows that there is a direct relation between the river discharge and the seasonal inlet closure, whereby the correlation is stronger when the maximum discharge in each month is used instead of the average discharge. However, the validation also shows that the waves have less than expected influence on the inlet closure. Therefore, the model is adjusted. In the improved model, the seasonal inlet closure still depends on the river discharge, but the other variables in the model also depend on these discharges. This does not indicate that they do not affect the seasonal inlet closure, but their influence depends on the amount of river discharge. To conclude, a conceptual model has been developed that describes the seasonal inlet closure. Further improvements require more and reliable data, after which it can be used to make a simulation model.

SAMENVATTING

Estuaria zijn de gebieden waar interactie tussen de rivier en de zee plaats vindt. Sommige estuaria worden door een zandbank van de zee gescheiden, zodat het water alleen via een smalle inlaat van het estuarium naar de zee en terug kan stromen. Langs de Vietnamese kust bevinden zich vele van deze estuaria. De riviermonding van de Ba Rivier is één van hen: het Da Dien estuarium. In het estuarium spelen een aantal problemen, waarvan de seizoengebonden inlaatsluiting in deze studie nader wordt onderzocht. Door de sluiting kunnen vissersboten de inlaat niet passeren. Het doel van de studie is het ontwikkelen van een conceptueel model dat de seizoensgebonden inlaatsluiting in het Da Dien estuarium beschrijft. Het conceptuele model zal als basis dienen voor een simulatiemodel waar oplossingen voor de sluiting in geïmplementeerd en vervolgens geanalyseerd kunnen worden. Om dit doel te bereiken wordt de seizoensgebonden inlaatsluiting eerst bestudeerd en worden de factoren die de sluiting beïnvloeden in kaart gebracht. Op basis daarvan kan een conceptueel model worden ontwikkeld, welke daarna door middel van een analyse met verzamelde data gevalideerd kan worden.

Een literatuurstudie van de factoren die de seizoensgebonden inlaatsluiting beïnvloeden laat zien dat de sluiting vooral afhankelijk is van de rivierafvoer. Wanneer de er te weinig water door de inlaat stroomt, vindt er afzetting plaats en vult de inlaat zich met sediment. Door de grote variatie in de rivierafvoer van de Ba Rivier kan dit proces tijdens het droge seizoen plaatsvinden. Het sediment dat tijdens het regenseizoen (van september tot december) met de grote afvoeren door de inlaat stroomt en zich afzet vlak voor de inlaat in de zee, wordt tijdens het droge seizoen (van januari tot augustus) weer teruggebracht naar de inlaat. Hierbij spelen wind en golven een belangrijke rol. Zij worden gestuurd door de twee verschillende moessons, uit het noordoosten van september tot maart en uit het zuidwesten van april tot augustus. Doordat de kustlijn rond het estuarium van het noordwesten naar het zuidoosten loopt, veroorzaken de moessonseizoenen zowel landwaartse als kustwaartse zeestromen. Na het regenseizoen zijn de landwaartse zeestromen van januari tot maart dominant, vanwege de wind en golven uit het noordoosten. Het sediment dat door de rivier is afgezet voor de inlaat, wordt naar de inlaat getransporteerd, zodat de inlaat zich opvult. De kustwaartse zeestromen transporteren ook sediment. Als deze stromen worden onderbroken door getijdenstromen voor de inlaat, neemt de stroomsnelheid af en kan het sediment zich afzetten. Andere factoren die de seizoensgebonden sluiting beïnvloeden zijn menselijke activiteiten en klimaatverandering.

Aangezien het conceptuele model als basis dient voor verder onderzoek, moet het model aan een aantal voorwaarden voldoen. Het conceptuele model moet geldig, geloofwaardig, uitvoerbaar en nuttig zijn. In het conceptuele model laten blokken, pijlen en lijnen directe, indirecte en interactieve relaties tussen de variabelen zien. Het eerste ontwerp van het conceptuele model bevat alle bestudeerde factoren. Het model is echter te ingewikkeld en moet versimpeld worden om bruikbaar te kunnen zijn voor een simulatie. Op basis van het literatuuronderzoek en het eerste model wordt besloten de moessons, wind, menselijke activiteiten en klimaatverandering uit het model te laten. Zo blijft er een model over waarbij de seizoensgebonden inlaatsluiting afhankelijk is van de rivierafvoer, golven en getijden.

Vervolgens zijn er satellietbeelden en data van de rivier afvoer, wind, golven en de bedding verzameld om het model te kunnen valideren. Helaas is er niet veel data beschikbaar en is de beschikbare data niet altijd even betrouwbaar. De validatie laat zien dat er een directe relatie is tussen de rivierafvoer en de seizoensgebonden inlaatsluiting, waarbij de relatie groter is wanneer de maximale afvoer per maand in de analyse wordt gebruikt. De validatie laat echter ook zien dat de golven veel minder invloed hebben op de inlaatsluiting dan verwacht. Daarom is besloten het model aan te passen. In het nieuwe

model is de inlaatsluiting nog steeds afhankelijk van de rivierafvoer, maar zijn ook de andere factoren afhankelijk van deze afvoer. Dit betekent echter niet dat zij geen invloed op de sluiting hebben, alleen dat hun invloed afhankelijk is van de rivierafvoer. Er kan dus geconcludeerd worden dat het mogelijk is een conceptueel model van de seizoensgebonden inlaatsluiting te maken. Verdere verbeteringen vereisen meer en betrouwbare data, waarna het model kan worden gebruikt om een simulatie te maken.

PREFACE

Hanoi, 6 July 2015

A new project was recently started recently at the Hanoi University of Science, a faculty of the Vietnam National University in Hanoi. The project investigates two estuaries at the central coast of Vietnam and is led by Professor N.T. Giang. I was asked to assist Mr. Giang in this project. Because the project was in a starting phase, I had some troubles to determine my research area. After some time, I was able to pass that phase and had enough time to study the seasonal inlet closure in the Da Dien estuary.

I would like to thank Mr. Giang for his qualitative feedback on my study. Sometimes it was difficult to have a good perspective on the whole problem, but Mr. Giang helped me in gaining overall understanding. I also want to thank Vinh, the only person in the office I worked who could speak English. He helped me a lot in the first weeks after I came to Vietnam with almost everything I asked him for. We enjoyed lunch together several times a week during the whole period. Had he not wanted contact with me, I would have been quite lonely. Furthermore, I want to thank is Ms. Lieu. I could rent a room in her house, which was only a 5-minute walk from the university. Due to the busy, chaotic and dangerous traffic in Hanoi, having a room close to the university was a nice place to stay.

I also want to thank some people from the Netherlands. First, Mr. Roos, my supervisor from Enschede. He helped me a lot in the difficult start of the research. Also during the rest of my internship, I could ask him a lot of questions and he always gave me useful feedback. I also want to thank my family and friends, who did not forget me when I went abroad. Sometimes I felt lonely, but my family and friends helped me to stay positive. A special thanks to Chris and Diederick, two friends from the Netherlands who traveled through Vietnam in the first weeks of my internship. They visited me in Hanoi and we did some tourist trips together. It was really nice to spend some time with friends at the other side of the world. Finally, I want to thank Matthijs, Judith and Chris for checking my thesis on English grammar and spelling mistakes. I tried to improve my writing skills, but I still need help to get it at a sufficient level.

TABLE OF CONTENTS

1. INTRODUCTION

The first chapter starts with an introduction of the university's project about the Da Nong and the Da Dien estuary. The relevance of this study for the whole project is further explained. This is followed up by some basic information about estuaries in general and the Da Dien estuary is given. It is useful to have that knowledge, before the phenomenon of seasonal inlet closure in estuaries is studied in detail. After that the research questions, goals and methods are defined. Finally, this chapter gives an overview of the thesis by means of a reading guide.

1.1. PROJECT DESCRIPTION

Vietnam has a coastline of more than 3000 km. Many rivers run through the country and have an estuary at the Vietnamese coast. These estuaries, the places where river and sea interfere, are important for Vietnam, as many people live around them. The estuaries are subject to morphological changes such as deposition and erosion, which causes for example damages to houses built along the coast. The processes of deposition and erosion are complex and need to be analyzed. Based on such an analysis, solutions can be proposed, with the goal to prevent further damage to the infrastructure along the Vietnamese coast (Cong, 2006).

FIGURE 1 - THE DA DIEN ESTUARY IN VIETNAM (GOOGLE, 2015)

The deposition and erosion problems in all Vietnamese estuaries are too extensive for one study. Therefore the research for the Vietnam National University of Science in Hanoi will have its focus on the Da Nong and the Da Dien estuary. These two estuaries are located in central Vietnam, in the Phu Yen province (Figure 1 & Figure 2). The research goals of the university's project are defined as:

- To identify the causes, mechanisms and factors affecting the phenomenon of deposition, erosion in two estuaries (the Da Nong estuary and the Da Dien estuary) in Phu Yen province.
- To propose scientific and technological solutions that prevent deposition and erosion. The solutions will stabilize estuaries which meet the requirements of the ships navigation, flood drainage and protection of ecological environment under the context of climate change and sea level rise.

FIGURE 2 - BA RIVER AND THE DA DIEN ESTUARY (GOOGLE, 2015)

Instead of focusing on both estuaries, the focus of the present project is solely on the Da Dien estuary. This thesis investigates the seasonal inlet closure in this area and describe it with a conceptual

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model. The conceptual model will form the basis for a simulation model, which will be developed by another. The simulation model is used to manipulate the system with possible solutions for the inlet closure and evaluate the effect of the solutions.

1.2. ESTUARIES: DEFINITION AND CLASSIFICATION

As mentioned in the first paragraph, estuaries can be defined as the places where river and sea interfere. Such places have a unique value for both nature and inhabitants. Firstly, an estuary contains both salt and fresh water. The water flowing to the estuary transports different kinds of sediment. Because of this, the estuary with brackish water is a fertile area with a broad variety of wildlife. Secondly, estuaries are of great social, economic and ecological importance. Many people live around estuaries because the areas are suitable for agriculture, fishing and transport over water. This emphasizes the great economic importance of these areas, where people live and money is earned and spent. Thirdly, estuaries are environmentally vulnerable. They are subject to change, caused by flooding, waves, pollution, erosion, sea level rise and sedimentation. In conclusion, estuaries are places of importance, but require attention to protect them from destruction (Phy Yen Newspaper, 2014); (Cong, 2006).

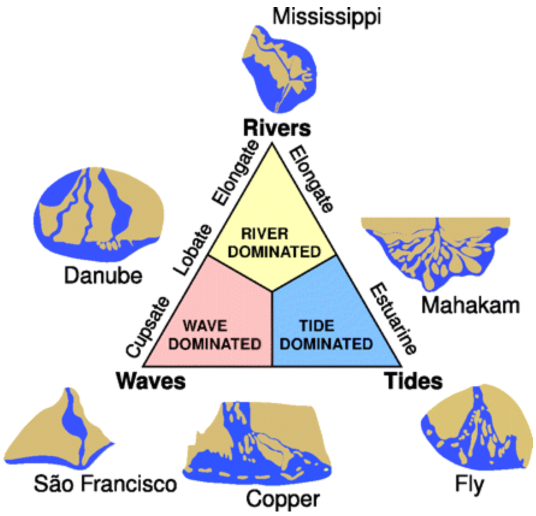

FIGURE 3 - CLASSIFICATION OF ESTUARIES (SEYBOLD, ANDRADE, & HERMANN, 2007)

Estuaries can be classified in many ways, based on different characteristics. Here, three types of classification will be presented. First, a basic classification is based on one of the three dominant factors in an estuary, which are wave, river or tide (Figure 3). If an estuary is classified according to tides, it can be further divided into a micro-tidal (0-2m), meso-tidal (2-4m) or macro-tidal (>4m) estuary. Tide-dominated estuaries have large tidal ranges and strong currents. This creates an estuary with many islands parallel to the tidal flow. On the other hand, estuaries that are river dominated have more river arms in the region and a large river flow. Finally, wave dominated estuaries have regular shorelines and beaches. In reality, more than one primary forcing element could be present and the classification may vary with the seasons, as will be explained in section 1.3 (Guo, 2014).

Another method of classification (based on geology) divides estuaries in five types: coastal plain, bar-built, delta system, tectonic and fjords. Coastal plain estuaries are formed by sea level rise, caused by the melting of glaciers over millions of years. Bar-built estuaries have sandbars or barrier islands built up by the waves in coastal areas. These barriers create a protected area with narrow outlets which are fed by a river. Delta systems are created at the mouths of large rivers from sediment and silt depositing. These type of estuaries occur when the river flow is restricted. Tectonic estuaries are formed through earthquakes, when a large land sinks in the earth. It often has a basin below sea level. Finally, fjords are created by glacial action and could be recognized by a steep slope of adjacent lands and great depth (National Estuarine Research Reserve System, 2011).

A third classification method is based on stratification and circulation. Estuaries are divided into salt-wedge, vertically homogenous and intermediate estuaries. Salt-wedge estuaries are highly stratified. Salt water is moving in the estuary while fresh water flows on top. The velocity of the freshwater is on average larger than the saltwater inflow. The vertically homogenous estuary is well-mixed and characterized by low inflow from fresh water and has large tidal ranges. Salt water and fresh water are vertically mixed and sometimes laterally mixed in these estuaries. Intermediate estuaries are partly mixed. The circulation patterns are between those of salt-wedge and vertically homogenous estuaries. Such an estuary has a moderate inflow of fresh water and a moderate to large tidal range (Oberrecht, 2013).

The three classifications emphasize all different characteristics of an estuary, so they are not related to each other. However, it is plausible that some combinations of classifications are more common than others. For example, the delta systems with restricted river flow, will probably not be a river dominated estuary. The same applies to tectonic estuaries, because they often have a basin below sea level. Vertically homogenous estuaries with large tidal rangers are logically also more often tide dominated estuaries. So the classifications are applied separately, but the characteristics of an estuary can lead automatically to a specific combination of classifications.

1.3. The Da Dien estuary

The Da Dien estuary (Figure 5) is a river mouth of the Ba River (Figure 2), a river which starts at Ngoc Rho High Mountain (1240 m) and finishes after 347 km and a basin area of 13900 km^2 in the Da Dien estuary. It is the third largest river in the southern area of Vietnam. The downstream of the river is also known as Da Rang River, and the estuary as the Da Rang river mouth. The slope of the riverbed changes rapidly along the river, from 0.02 upstream to 0.001 at the river mouth. About 40 km from the river mouth Cung Son Hydrological Station is located. From this point, transport over water is possible.

FIGURE 4 - THE DA DIEN ESTUARY (PHY YEN NEWSPAPER, 2014)

Many years ago, the river mouth was funnel shaped, but due to the interaction between sea and river it became a lagoon type. The Da Dien estuary is located near Tuy Hoa City, the capital of Phu Yen province with about 200,000 inhabitants. The city is located around the estuary, so the estuary has great impact on the city. The northern and southern parts of the city are connected by two bridges. More than 900 ships are moored in the estuary and they are used by the fishermen of Tuy Hoa. Fishing for tuna is of great economic importance for the region. These economic activities should be able to continue, and be protected from natural disasters such as flooding and destruction by waves (Cong, 2006).

The Da Dien estuary can be classified as a river dominated estuary in the flood season and a wave dominated estuary in the dry season, due to the large variation in river discharge between those seasons. Based on the geological classification, it can be classified as a bar-built estuary, because it has a sand spit that separates the estuary basin from the sea and the estuary has a narrow inlet (Figure 4). Finally it can be classified as a salt-wedge estuary during the flood season and as an intermediate estuary in the dry season, because a large difference in river discharge could be noted between these periods (Cong, 2006).

FIGURE 5 - DETAILED MAP OF THE DA DIEN ESTUARY (GOOGLE, 2015)

Various factors are affecting the Da Dien estuary, for example rain, floods, tides, waves, typhoons, urbanization, climate change and sand exploitation. These factors cause morphological changes in the estuary and these changes present Phu Yen province with several problems in social economic development. The three main problems are:

- Sediment deposition in the inlet blocks the estuary, preventing the fishing ships from going to the sea and coming back from the harvesting trips.
- Ocean waves that enter the estuary cause erosion at the northern bank of the river mouth, which threatens the safety of Tuy Hoa inhabitants.
- Serious beach erosion in the southern side of the estuary caused collapsing of dozens of houses and damage to the road along the beach.

20-06-2009 | 31-01-2010 | 03-04-2012

06-02-2013 | 09-04-2014 | 03-07-2014

FIGURE 6 – TOPOGRAPHIC CHANGE OF THE INLET IN SEVERAL YEARS (PHU YEN, VIETNAM, 2015)

Some scientists have proposed to take measures to solve the problems (e.g. dredging), further research is necessary to learn more about the evolution of the problems (Phy Yen Newspaper, 2014). With the outcomes of further research, solutions have to be found for the fore mentioned problems. Not all problems can be analyzed in one study, therefore this study focuses only on the first problem: the seasonal inlet closure (Figure 6). With the outcomes of this study, the phenomenon of seasonal inlet closure in the Da Dien can be better understood, which will hopefully result in solutions to prevent the Da Dien estuary from inlet closure in the future.

1.4. GOAL AND RESEARCH QUESTIONS

As mentioned in section 1.3, the research focuses on the seasonal inlet closure in the Da Dien estuary. The goal of the research is defined as:

"To develop a conceptual model that describes the seasonal inlet closure in the Da Dien estuary."

The final goal of the university's project is to find solutions for the seasonal inlet closure. To evaluate the solutions, a simulation of the seasonal inlet closure is used. However, before such a simulation model can be developed, the problem should be studied in detail and a conceptual model should be developed to determine which parts have to be included in the simulation. So the study holds the first part of an extensive research. It is very important to do this part correctly, otherwise the simulation will not be successful and there will be need to develop it again. A conceptual model can be defined as a 'non-software specific description of the computer simulation model (that will be, is or has been developed), describing the objectives, inputs, outputs, content, assumptions and simplifications of the model' (Robinson, 2008). In the conceptual model about the Da Dien estuary, the factors and processes which contributes to the seasonal inlet closure will be presented graphically with boxes, lines and arrows. A conceptual model can show both individual influence of and interaction between the factors. Precisely this interaction is important in a complex phenomenon like seasonal inlet closure, so a conceptual model is an appropriate means to describe the problem.

To reach the research goal, three subjects have to be studied. First, the focus is on seasonal inlet closure in estuaries. Both about estuaries in general and the Da Dien estuary. The factors which may affect inlet closure in the Da Dien estuary and how this phenomenon develops have to be determined. Second, a conceptual model of the seasonal inlet closure will be built, with use of the factors affecting the closure and general information about conceptual models. Third, data of the factors in the model will be used to validate the model. If the validation shows that the model has some limitations, the model needs to be improved.

The research is divided into three main questions, each divided into multiple sub-questions:

1. How can the seasonal inlet closure in the Da Dien estuary be described?
   1.1. What is seasonal inlet closure of estuaries?
   1.2. How is the seasonal inlet closure developing in the Da Dien estuary and affecting the area?
   1.3. What factors affect the seasonal inlet closure in the Da Dien estuary?
2. How can the seasonal inlet closure be included in a conceptual model?
   2.1. What is a conceptual model?
   2.2. What are the characteristics of a graphic conceptual model?
   2.3. How can a conceptual model of the seasonal inlet closure in the Da Dien estuary be developed?
3. How can the conceptual model be validated with data?
   3.1. What data is available for validating the conceptual model?

3.2. How can the data be used to validate the conceptual model?
3.3. How can the conceptual model be validated with the data?
3.4. What parts of the model, based on the validation, need to be improved?
3.5. How can the conceptual model be improved?

1.5. METHODOLOGY

To reach the research goal of the study, a conceptual model must be developed. Firstly, general information about conceptual models should be studied, to determine a way for developing such a model. Secondly, the factors that affect the seasonal inlet closure need to be included in the conceptual model. The factors and the extent to which they affect the seasonal inlet closure should be identified. Thirdly, the collecting of data can be done by searching on the internet, people from the university or asking for data in companies or the government. Lastly, the data will be linked to the processes in the model by calculating the correlation between the data, to determine if the processes are acceptable. The methods are also listed below, based on the sub-questions:

1. How can the seasonal inlet closure in the Da Dien estuary be described?
   1.1. Search in literature and reports for information about seasonal inlet closure.
   1.2. Search in literature, reports and newspapers for information about the Da Dien estuary.
   1.3. Search in literature and reports for information about factors affecting seasonal inlet closure.
2. How can the seasonal inlet closure be included in a conceptual model?
   2.1. Search in literature and reports for information about conceptual models.
   2.2. Search in literature and reports for information about graphic conceptual models.
   2.3. Use the studied subjects to develop a graphic conceptual model.
3. How can the conceptual model be validated with data?
   3.1. Collect data of the factors in the conceptual model.
   3.2. Define how the data will be used for the validation.
   3.3. Validate the conceptual model by investigating the correlation between the data.
   3.4. Conclude, based on the validation, which parts of the model should be improved.
   3.5. Propose a new improved conceptual model.

1.6. READING GUIDE

After the introduction, the thesis continues in chapter 2 with some basic information about seasonal inlet closure in general and the same phenomenon in the Da Dien estuary. Then, the factors that affect the seasonal inlet closure in the Da Dien estuary are identified and explained in chapter 3. Based on this information a conceptual model is developed and presented in chapter 4. The collected data is presented in chapter 5, which also includes a validation of the conceptual model with these data. Finally, chapter 6 gives the conclusions of the study, discuss the results and give some recommendations for further research.

2. SEASONAL INLET CLOSURE

Chapter 2 focuses on seasonal inlet closure. First the processes that causes the closure are described in general. Then the focus changes to the Da Dien estuary. A basic view of the inlet closure in that estuary is given, without reviewing the characteristics of the factors that affect the inlet closure in detail. These factors are addressed in chapter 3.

2.1. GENERAL CHARACTERISTICS

An inlet is in dynamic equilibrium when there is a balance between sediment import by waves to the inlet and sediment export by tides and river flow from the inlet. Then the morphology of the inlet is not changing and the inlet remains open. If such an equilibrium is not present, inlet closure could occur (Behrens et al., 2013). Inlet closure is the phenomenon whereby a (sand) bar/spit between a sea and an estuary or lagoon closes. Inlet closure can be definite, when the flow through the inlet channel stops or a new inlet is formed. Another form of inlet closure is a seasonal variant, when the inlet closure occurs in a seasonal cycle. This study focuses on that kind of inlet closure.

The seasonal inlet closure arises usually in micro-tidal or wave-dominated areas, with large variations in seasonal flow, wind and waves (Ranasinghe & Pattiaratchi, 2003). The inlet can be closed for several months, some weeks or only some days, depending on the characteristics of the inlet. There is a simple cause of seasonal inlet closure: a river has insufficient flow to prevent deposition in the inlet (Tung, 2011). Many factors such as storms, sediment transport, tides and waves influence the deposition of sediment and other materials in the inlet channel. The extent in which the factors cause a closure of the inlet depends on the characteristics of the inlet. Bruun and Gerritsen (1960) classified the causes of inlet closure as follows:

- Extension of the inlet channel caused by the elongation of the sand spit in one direction
- Large deposition of littoral drift material during storms
- Splitting of the main inlet in two or more inlets
- Opening of a new inlet
- Change in the lagoon, river mouth or estuary (Bruun & Gerritsen, 1960).

Two mechanisms to describe inlet closure are proposed by Ranasinghe and Pattiaratchi (2003). In the first mechanism, inlet closure is caused by the interaction between inlet flows and longshore currents. Due to the interruption of the current at the inlet, a shoal may form in front of the inlet. If the river flow from the inlet is not strong enough to erode the shoal, the shoal continues to grow and finally closes the inlet. This mechanism mainly occurs in coastal zones with large longshore currents. The second mechanism of inlet closure is caused by onshore sediment transport, which occurs mainly in micro-tidal areas. The influence of longshore sediment transport is small, compared with the onshore transport. The onshore sediment transport is caused by a weak ebb flow and strong waves. The sediment in front of the inlet is transported to the inlet channel and closes the inlet (Ranasinghe & Pattiaratchi, 2003). However, the natural processes are irregular and will not fit in such an idealized description, just because every region and inlet closure has its own characteristics.

In Vietnam, many inlets are formed in wave dominated, micro tidal estuaries. These estuaries have a bar that is formed by both material (sand, mud, etc.) from the river and from the sea. Waves and river flow runoff are the main forces that create the inlet channels. The inlet may develop through existing morphological constraints or may have formed due to the developing of sand spits, which also cause narrowing of the inlet. Littoral transport develops at the river mouth and cause a barrier that partially closes the inlet (Dalrymple et al., 1992). In such an estuary, the influence of the tide is small compared to that of wave energy, which is the dominant factor during the dry season. The river flow is dominant in the flood season, when the river flow is much larger than in the dry season and large amounts of fluvial sediment are dropped in front of the inlet. When the flow drops in the dry season, the sediment is transported by waves to the river mouth and the inlet closes (Tung, 2011).

2.2. INLET CLOSURE IN THE DA DIEN ESTUARY

As mentioned in chapter 1, there are several problems in the Da Dien estuary. Erosion on the southern beach caused collapsing of many houses and storms have destroyed the northern river bank in the estuary. The third problem is the seasonal inlet closure of the inlet between the Da Dien estuary and the East Sea. The inlet fills up with sediment and other materials, the water level in the inlet drops below 1 meter and therefore, fishermen are not able to sail into or out of the estuary. In 2015, the government decided to create a new inlet 80 meters in the north of the closed inlet. Earlier, dredging was used as a conventional solution to solve the inlet closure. However, these solutions are only temporally and are not sufficient for the future, because the dredged sand is transported back to the inlet (Tuy, 2015) (Viet Nam News, 2015). Figure 7 shows the change of the inlet in the Da Dien estuary during a year. It is clear that the inlet is subject to topographical changes which can cause the inlet closure.

March 2014 *July 2014* *September 2014*

November 2014 *January 2015* *March 2015*

FIGURE 7 - SEASONAL INLET CLOSURE IN THE DA DIEN ESTUARY (LANDSATLOOK VIEWER, 2015)

The fact that inlet closure occurs in the Da Dien estuary is quite exceptional. Inlet closure arises in general only in river mouths with a small basin and a small annual runoff, but the basin of the Ba River is big and the annual runoff is large. However, the phenomenon of inlet closure is also occurring in the Da Dien estuary. The reason for this exception is the large seasonal variation in the river discharge, which is characterized by a short flood season with large discharge and a long dry season with small discharge (Tung, 2011). About 70% of the annual flow is discharged during the flood season (September to December) and only 30% in the dry season (January to August). In section 2.1 it is stated that an insufficient river flow is causing inlet closure. The river flow in the dry season is so small, that the inlet has great potential for inlet closure, even without observing the factors affecting the closure (Cong, 2006).

The inlet of the Da Dien estuary is open for 3 to 4 months on average in the flood season, and closes during 6 to 7 months in the dry season. The strength of the factors affecting seasonal inlet closure, which is discussed in chapter 3, controls whether the inlet is entirely closed at in the dry season. The Da Dien estuary can be classified as a micro-tidal, wave dominated estuary (Huong, Quy, & Thanh, 2014). According to Ranasinghe and Pattiaratchi (2003), this means that the inlet closure is caused by onshore sediment transport. The conceptual model shows if that hypothesis is true for the Da Dien estuary. Le van Cong (2006) studied the inlet closure of the Da Dien estuary and calculated the topographical change, but separated the sediment transport from the river and the onshore/longshore sediment transport. The conclusion was that an integrated model, which includes river discharge, tidal currents, longshore and onshore sediment transport, is needed to understand the inlet closure in the Da Dien estuary.

3. FACTORS AFFECTING SEASONAL INLET CLOSURE

The seasonal closure of the inlet in the Da Dien estuary is caused by various factors, which is discussed in this chapter. The factors contribute to the transport to and deposition in the inlet channel. All the factors have their own influence on the inlet closure, but they cannot be reviewed without observing their interaction. Without the interaction the inlet would definitely be closed, or remain open during the whole year. So evaluating the interaction is essential, but makes inlet closure also a complex phenomenon. This chapter mentions both the independent influence on the inlet closure and the influence which is caused by the interaction between the factors.

3.1. RIVER FLOW

As mentioned in chapter 2, river flow (or actually the absence of river flow) is the main factor related to seasonal inlet closure. If the river has not enough flow to prevent deposition in the inlet, the inlet closes. A lack of river flow in the Ba River occurs during the dry season, which lasts from January till August. In the dry season the river discharge is only 119 m^3/s, compared to 563 m^3/s in the flood season and an annual average of 283 m^3/s (Hydrology Station, 2000-2014). The lack of discharge is mainly due to the rainfall. In this period only 30% of the annual rainfall in the basin is reached, which results in about the same percentage of river flow in that period. In February and March, the rainfall drops even till only 20 mm per month. The flood season holds 70% of the annual rainfall and lasts from September till December (Cong, 2006). The flood season is influenced by the northeast monsoon rains. The peak in rainfall mainly occurs in October and November, when an amount of 600 mm per month can be reached. Logically, the peak in river discharge also occurs during these months. This discharge holds about 95% of the total flood discharge. However, the peak is not the same every year. A large range in annual peak discharge is observed during the last decades. In 1982 the peak reached only 955 m^3/s, in 1993 even 20700 m^3/s. The average peak lies around 5000 m^3/s (Huong et al., 2014). The difference influences the seasonal inlet closure. A large peak causes a wider opening in the inlet, which closes more slowly during the dry season.

The seasonal variation in river discharge has great influence on both the river, estuarine and inlet morphodynamics. In the flood season, the river floods a several times per year, during the dry season the river returns shallow and almost dry. The flow velocities in the estuary also show a variation between the seasons, small velocities can cause the development of plains in the estuary, which prevents the water to flow directly to the inlet. The river flow in the dry season through the inlet of the Da Dien estuary is in average large enough to keep the inlet open. However, the discharge is too small to prevent a significant drop of the water depth in the inlet, which does not cause not a complete closure, but hinders ships to pass the inlet channel (Cong, 2006); (Tung, 2011).

The river flow transports sediment to the estuary. The amount of transport depends on the amount of the river flow. During the flood season, with large river flow, the sediment transport is also large. About 90% of the annual sediment supply, is transported during the flood season. In average, about 400,000 m^3/year sediment is transported to the river mouth (Cong, 2006). The sediment is eroded upstream, caused by large flow velocities. In the flood season the river discharge is large, which causes a considerable flood current in the estuary. Therefore, the sediment is not deposited in the estuary, but transported through the inlet channel to the open sea. Due to large flow velocities, the sediment is longer in suspension and will not trap in the estuary. Also the sediment that was deposited in the estuary during the dry season, is transported to the sea. In front of the inlet, the flow velocity drops significantly, due to the northeast waves perpendicular to the inlet, and so the sediment deposits in front of the inlet. The northeast waves also prevent offshore sediment transport to the ocean, so the sediment remains in front of the inlet (Ralston et al., 2012); (Tomczak, 2000).

3.2. WIND AND WAVES

In relation to seasonal inlet closure, wind and waves cannot be treated independently. The waves that cause sediment transport to the inlet, are mainly driven by the wind. Wind around the Da Dien estuary is influenced by the monsoon seasons. The Southeast Asia region has two monsoon seasons. The northeast monsoon, which occurs from September till March and the southwest monsoon, from April till August. The northeast monsoon causes the flood season in the Ba River from September to December. The peak in wind speed during the winter is observed from November to January, and from July to August in the summer (Cong, 2006). The dominant wind directions correspond with the seasonal monsoon direction. The wind speed in the southwest monsoon is lower than in the northeast monsoon. The average magnitude is 6 m/s in the summer and 9 m/s in the winter (Huong et al., 2014). Storms and typhoons are normal phenomena in Vietnam. These storms and typhoons cause flooding of rivers and therefore large river discharges through the inlet. Although typhoons generally do not occur in the area of Tuy Hoa, the effect of typhoons in the upstream river basin can be seen in the amount of river discharge (Tung et al., 2006); (Dippner et al., 2007); (Chang, 2013).

When the process of inlet closure has already started, wind can play a role in accelerating this process. The onshore, longshore and offshore currents can be supported by storm conditions, when they are in the same direction. Storms cause high, steep waves and often a rise in water level. The smaller the inlet, the greater the influence of storms on the inlet closure. If such a storm occurs when the inlet is already small, it can contribute to the complete closure. However, storms can also accelerate the process of opening the inlet again when it is closed. The storms cause a rapid transport of deposited sediment from the inlet to the sea and can terminate the closure period in a few days. Finally, storms can prevent the inlet from closure and they may extend the time when the inlet is still open. The storms cause more intense river flow, which prevents the sediment deposition for a while. It depends on the direction of the winds and the morphologic status of the inlet, if such events can occur (Tung, 2011); (Behrens et al., 2009); (Ranashinge & Pattiaratchi, 2003); (Eriksson & Persson, 2014).

Ocean waves in front of the inlet affect the morphology of the inlet by eroding the inlet channel, or contribute to the sediment transport to the inlet when the waves break. The direction and power of the waves in front of the Da Dien estuary are influenced by monsoon winds, both northeast and southwest monsoon. The shoreline around Tuy Hoa runs in the northwest-southeast direction, so the dominant waves during the northeast monsoon (September-March) are onshore. However, during the flood season (September-December) the river discharge is too large, so the waves cannot contribute to the seasonal inlet closure. The onshore currents transport sediment to the inlet only from January till March. In both monsoon seasons, longshore waves cause longshore currents. They are from the northwest in the winter and from the southeast in the summer. However, the longshore currents are overwhelmed by the onshore currents in the winter, so they are only dominant during the summer, when the wind direction changes to the southwest.

From January till March the northeast breaking waves, perpendicular to the shoreline, cause variations in the onshore velocity, which leads to large amounts of sediment transport to and deposition in the inlet. Because the inlet is widened in the flood season, waves can freely enter the inlet channel and drop the sediment. Due to the wind power, which is stronger during the northeast monsoon, the waves in the winter are a bit higher. Without observing the other factors like available sediment, onshore sediment transport has greater potential in the Da Dien inlet, than longshore transport (Cong, 2006); (Dean et al., 2002); (Cartier & Hequette, 2011).

However, longshore transport cannot be neglected. Longshore sediment transport can both contribute to the closure and the opening of the inlet. When the longshore currents pass the inlet and tidal currents, river discharge or offshore wind waves interrupt them, the sediment drops in front of the inlet. When there are no tidal currents and both river discharge and offshore winds are low, the longshore current is not interrupted and can flow to the northwest. When sediment is stored in front of the inlet, the longshore currents can take the sediment and transport it away from the inlet. In this situation the longshore currents contribute to the re-opening of the inlet. Another effect of the longshore currents is the slight migration of the inlet northwards during the summer. The migration is compensated by currents from the northwest from January till April. So the inlet has a slightly seasonal migration, due to wave direction.

The amount of the sediment transport and so the time it takes to re-open the inlet, depends on the wave power. The power of the waves can be measured by wave height, wave period and water depth. First, the higher the waves break, the more sediment is transported. Second, the longer the wave period, the less power the onshore currents have. However, an increase in wave period of 10% to 20% leads to a doubling of the longshore sediment transport (Ranasinghe et al., 1999). So the wave period influences the balance between onshore and longshore transport. Finally, the deeper the water, the higher the wave power that is produced when the waves break, which causes larger amounts of sediment transport. So it is important to also observe the topography around the inlet, to evaluate the rapidly decreasing water depth in the nearshore area. (Cong, 2006); (Cartier & Hequette, 2011); (Rijn, 2013); (Eriksson & Persson, 2014); (Behrens et al., 2009); (Tung, 2011); (Thanka, 1994).

3.3. TIDES

Tidal ranges in an area are caused by the relative position to the moon and sun. Due to the tide, the sea level in the ocean, inlet and estuary changes in a daily cycle. In the sea near the Da Dien estuary a diurnal tide from the Tonking gulf is observed, with about 20 days of diurnal tide per month. The range of the tide decreases slightly when it enters the channel. The mean tidal range is 1.6 meter, the neap tidal range is 0.7 meter and the spring tidal range 2.5 meter (Huong et al., 2014). The maximum velocity of the tidal currents is between 20 and 30 cm/s (Cong, 2006). Tidal currents through the inlet are caused by the change in sea level, which results in a difference between the water level in the sea and the estuary. This leads to a flow through the inlet, which can transport sediment. The amplitude of the tide in the sea in front of the Da Dien estuary is small, so the area can be classified as micro-tidal. The direction of the tidal current in the study area is west during the flood tide, and east during the ebb tide. The flood tide is in the opposite direction of the northeast waves during the northeast monsoon. Therefore, the tide reduces the effect of onshore sediment transport caused by these waves. In the summer, when the currents in the sea change to the southeast, the tidal currents interrupt the longshore currents. The longshore current velocity drops and so the sediment that is transported deposits in front of the inlet. Because the area around the Da Dien estuary is micro-tidal, the tides itself do not transport a significant amount of sediment. However, the interruption of the longshore currents by the tidal currents cause sediment deposition in front of the inlet, which is quite important for the seasonal inlet closure (Eriksson & Persson, 2014).

3.4. CLIMATE CHANGE

Just like the rest of the world, Vietnam is subject to climate change. With regard to seasonal inlet closure, climate change will influence the discussed factors. The river discharge will increase due to more rainfall. The waves will have more power due to sea level rise. The sea level rise also causes greater influence of tides in the inlet. Finally, climate change will cause extreme weather conditions, which means more storms that can affect the inlet morphology and dry seasons with less rain and river flow. The combination of sea level rise and extreme storms could cause overtopping of the sand spit, which could result in a new inlet. All those changes affect the sediment transport and deposition in the inlet channel. There will be more sediment dropped in front of the inlet. The sediment will be transported back to the inlet by onshore currents in shorter time, due to larger waves and less river discharge. Therefore, inlet closure will occur likely more frequent. Some measures will probably be taken to protect Tuy Hoa from damaging by flooding and sea level rise. These measures are mostly in the form of dikes or other structures. The influence of such constructions are discussed in section 3.5 (GFDRR, 2011).

TABLE 1 - CLIMATE CHANGE IN VIETNAM (INSTITUTE OF STRATEGY AND POLICY ON NATURAL RESOURCES AND ENVIRONMENT, 2009)

CLIMATE CHANGE	2050	2100
ANNUAL RAINFALL (%)	1,7	3,2
RAINFALL DEC-FEB (%)	-5,4	-10,2
RAINFALL MAR-MAY (%)	-7,4	-14,2
RAINFALL JUNE-JULY (%)	2,1	3,9
RAINFALL SEP-NOV (%)	6,3	12,1
SEA LEVEL RISE (CM)	30	75

Some forecasts have been made to estimate the effect of the climate change. The expected rainfall is shown in Table 1. The decrease of the average annual rainfall is not that large, but the seasonal changes are expected to be significant. The dry season will be more dry and in the flood season there will be much more rainfall. The sea level rise is estimated at 30 cm in 2050 and 75 cm in 2100. The expected effects of the changes are discussed in the previous paragraph (Institute of Strategy and Policy on Natural Resources and Environment, 2009); (Ministry of natural resources and environment, 2009).

3.5. HUMAN ACTIVITIES

Estuaries are important areas for human in respect to both economic and natural aspects. Therefore, humans want to take advantage of as many of the resources that an estuary has as possible. A way to use more of the possibilities in an estuary, is to develop activities in the estuary. Dikes are built to prevent the area from flooding, berths are created for fishing boats, the inlet channel is dredged to ensure the possibility to pass the inlet, sand is extracted from the estuarine bottom, houses are built at the banks and these are only some of the many human activities. The human intervention in the estuary affects the inlet morphology. Constructions and dredging in the estuary prevent the river flow to stream directly to the inlet. It depends on the exact location of the construction, in which way the river flow is deflected. If the river flow is not entering the inlet with a perpendicular flow relative to the sand spit, the flow erodes the inlet channel more in either the northern or southern bank. So the inlet topography changes and the inlet migrates. Dredging of the inlet channel in the winter has only temporary effects on the inlet morphology. Due to river flow, waves and tides, new sediment is transported to the inlet in the summer and autumn, which fills the dredged place again with sediment (Australian Government, 2010); (EPA, 2011).

In the upstream parts of the Ba River, water is retained in reservoirs for drinking and agriculture. In 2006, 41 reservoirs and 53 weirs were observed (Cong, 2006). In years with small rainfall, more water from the river is needed. Because the river flow is mainly influenced by rainfall, the river flow in that years is also small. When then a large amount of water is extracted from the river, the flow drops significantly and can even be equal to zero. This could have disastrous effects at the river mouth. Due to the lack of river flow, the inlet closes much faster and could finally close completely. Even though the extraction in the Ba River basin is small compared to other river basins, the effects are the same, because of the small river flow in the dry season. An inlet closure caused by water kipping upstream occurred at the Da Dien estuary in 1995. Also the damming of the Ba River in 1990 contributes to more frequent shoaling (Tung, 2011); (Cong, 2006).

4. CONCEPTUAL MODEL

The factors that affect the seasonal inlet closure in the Da Dien estuary were presented in chapter 3. Although they were separated in different sections, their interaction is unmistakable. The evaluation of this interaction is important to understand the mechanism of seasonal inlet closure. A tool for understanding such complex problems is a process based conceptual model. Chapter 4 presents a conceptual model of the seasonal inlet closure in the Da Dien estuary. Before that, a general introduction about conceptual models is given.

4.1. WHAT IS A CONCEPTUAL MODEL?

The aim of the whole project about the seasonal inlet closure in the Da Dien estuary, is to develop a simulation model that can be used to evaluate manipulations in the system. Before a simulation model can be developed, a conceptual one should be defined. A conceptual model is the result of a (literature) study of the mechanisms that occur in the real world. The model shows a simplification of the real processes and is the basis for the simulation model (Figure 8). If some processes are missing in a conceptual or the model does not have a good level of simplification, the simulation model will probably fail. That is why a conceptual model is so important.

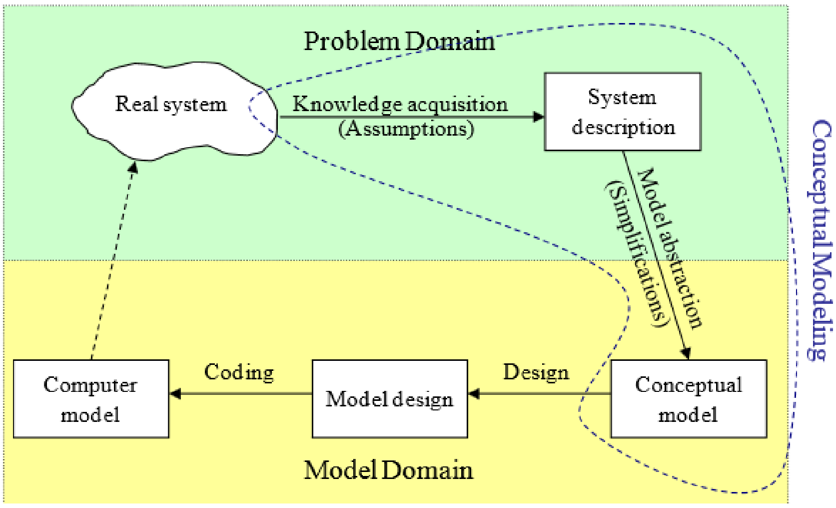

FIGURE 8 - ARTEFACTS OF CONCEPTUAL MODELING (ROBINSON, 2011)

Robinson (2008) defined a conceptual model as 'a non-software specific description of the computer simulation model (that will be, is or has been developed), describing the objectives, inputs, outputs, content, assumptions and simplifications of the model.' The part of the definition in parentheses shows that conceptual modelling is an iterative process. If the simulation model (which is based on the conceptual model) fails, first the conceptual model needs to be improved, before a new simulation could be developed. Then, the definition gives a list of what a conceptual model describes.

Objectives should be known before the modelling part starts, as it is difficult to model if the purpose of the model is not known. A lack of understanding of the objectives often results in a poor simplification level. The inputs are factors that try to reach the modelling objectives and the outputs are the statistics that show if the objective is reached. In case of the model of the seasonal inlet closure, both input and output factors are data. The input data are measured data for the factors that contribute to the inlet closure and the output is the data of the calculations made, based on the processes in the model. The content of the model is about the model scope and the level of detail. The model should be able to receive input and provide output. If, for example, data of the river flow is available, the conceptual model should show how the river flow affects the seasonal inlet closure, which can result in calculations with the data. Finally, the conceptual model describes assumptions and simplifications. Assumptions are made when there are uncertainties or beliefs about the real world. Simplifications are applied to enable a more rapid model development and use, and to improve the transparency of the model. Both assumptions and simplifications are unavoidable and cause limitations in simulating, so it is very important to know and understand these factors.

A good conceptual model is valid (enough results for the purpose), credible (believed by the clients), feasible (built within the constraints of available data and time) and useful (easy, flexible, visual) (Robinson, 2008). In case of the model about the seasonal inlet closure, it means that the conceptual model should:

- contain enough factors that affect the inlet closure (valid)
- not exclude a clearly visible factor like river flow, even when its impact is limited (credible)
- include only factors from which data is available or could be measured (feasible)
- be simple, so it can easily be translated into a simulation model (useful)

It is difficult to get the right level of simplification. Many factors play a role in the seasonal inlet closure and their interaction is the key factor for the closure. So it seems important to include all those factors in the conceptual model. However, it makes the conceptual model quite complicated and a complicated model is exactly the model that is not useful for a simulation. According to Thomas and Charpentier (2005) a simple model is preferred because it can be developed faster, it is more flexible, it requires less data, it runs faster and the results are easier to interpret since the structure of the model is better understood. Complex models can, of course, also be developed, but only when that is required to meet the objectives of the model. So by developing the model, some factors should be excluded, even if they have (limited) impact on the inlet closure. The study of de factors in chapter 3 should be used to choose which factors are in- or excluded in/from the model (Robinson, 2011).

4.2. Characteristics of a graphic conceptual model

The conceptual model of the inlet closure in the Da Dien estuary will be presented graphically in section 4.3. The figure shows boxes, lines and arrows that simulate the processes that are observed in the area of Tuy Hoa. To understand the conceptual model, it is necessary to have a basic knowledge of the characteristics of such a graphic presentation. To explain the relations in a conceptual model, a simple example is given about the factors that affect the performance of an athlete, who participates in an individual discipline. The factors are defined as training, doping and teammates. The performance of the athlete is the dependent variable, the other factors are independent variables, because we want to know what the influence is of the training, doping and teammates at the performance. An arrow from the factors to the performance means that the characteristics of the factors affect the characteristics of the performance (Figure 9). If a line is drawn instead of an arrow, there is only correlation between the boxes and no causality.

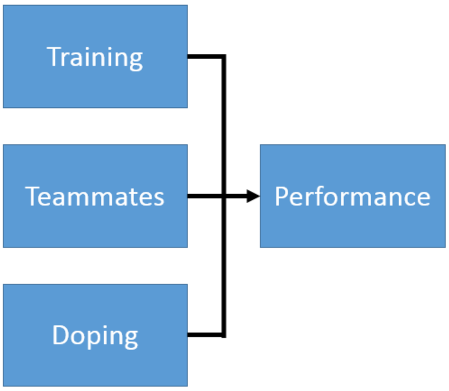

FIGURE 9 - DIRECT RELATION

Three different relations between dependent and independent variables can be observed. The first relation is a direct relation between the factors and the research subject, which is showed in Figure 9. In this model, there is no relation between the factors mutually, they have an independent impact at the performance. It is possible that the literature study shows that some of the relations are not entirely direct. A factor could have an indirect influence on the research subject. In the example of the performance of an athlete, it is questionable if the teammates have a direct influence on the performance. It is more likely that they affect the quality of the training. So teammates affect the

FIGURE 10 - INDIRECT RELATION

performance, but only in an indirect way. This second type of a relation in a conceptual model is shown in Figure 10. Finally, a factor can affect the dependent variable in an interacting way. It means that one factor is affecting the amount of influence that another factor has on the research subject. In our example, this influence can be observed when an athlete uses doping. The doping has a direct influence on the performance, but training can influence the effect of doping on the performance. When an athlete uses doping for his stamina, but he has just improved that part with training, the influence of the doping is limited. The impact of another factor at the direct relation, could be both positive and negative. A graphic presentation of this relation is shown in Figure 11 (Hans Doorewaard - Radboud Universiteit Nijmegen); (Swaen, 2014).

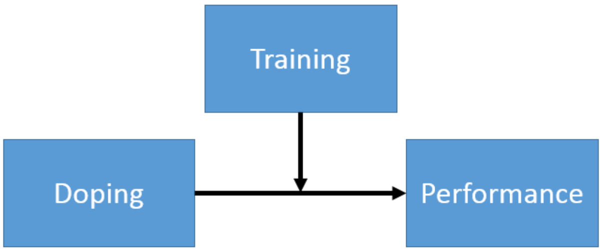

FIGURE 11 - INTERACTIVE RELATION

4.3. Model of the seasonal inlet closure in the Da Dien estuary

A graphic conceptual model of the Da Dien estuary is developed. It is based on the knowledge of the factors affecting the inlet closure, conceptual models in general and the relations in a graphic presentation of a conceptual model. First, a complex model is shown, which includes all the factors affecting the inlet closure. Then some simplifications are proposed, which result in a simpler conceptual model.

4.3.1. Complex model

All of the factors that affect the seasonal inlet closure in the Da Dien estuary are included in the complex conceptual model (Figure 12). The model is developed to show all the relevant processes that are observed in the estuary and to be sure that none of them is forgotten. The dependent variable in the model is of course the seasonal inlet closure and the independent variables are the factors affecting the closure. The dotted arrows have the same meaning as the solid arrows, they are just dotty to ensure the distinct between the arrows is clear. All the processes in the estuary result in many relations in the model. These relations are explained in Table 2.

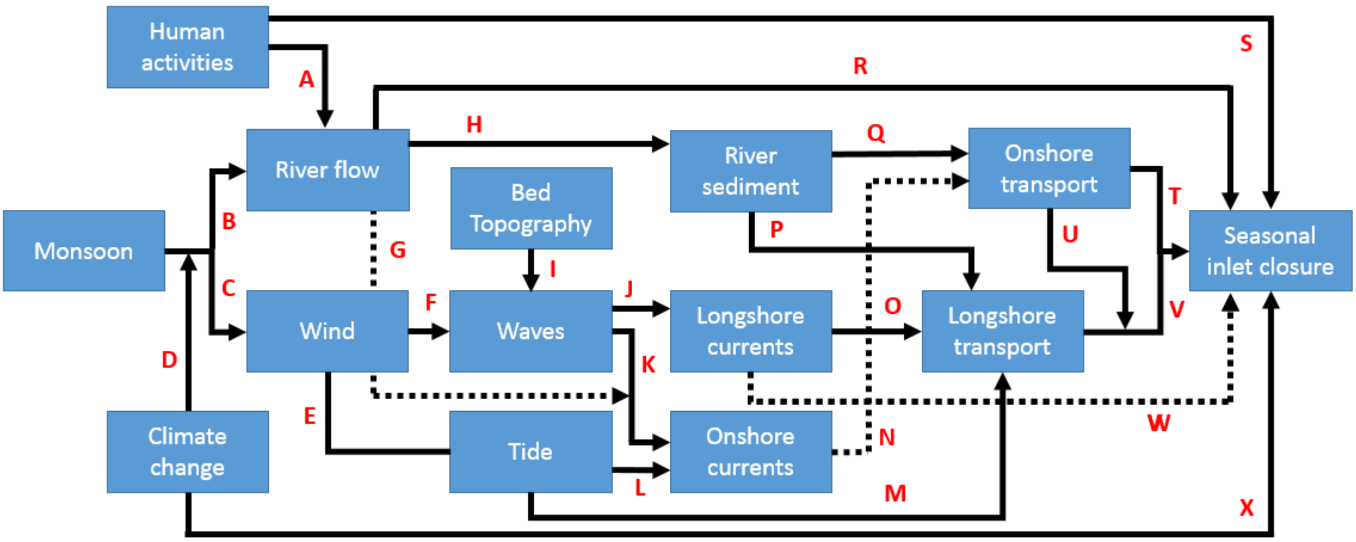

FIGURE 12 – COMPLEX CONCEPTUAL MODEL OF THE SEASONAL INLET CLOSURE IN THE DA DIEN ESTUARY

TABLE 2 - PROCESSES IN THE COMPLEX CONCEPTUAL MODEL

A	Humans who extract water from the river upstream affect the amount of river flow
B	Monsoons cause rain and dry seasons, which leads into large or small river flow
C	Monsoon seasons cause different wind power and directions
D	Climate change has influence on the way in which the monsoon affects river flow and wind
E	Wind is not influencing the tide, but the combination of storm and springtide is dangerous
F	Wind is the driven factor for wave height, direction and power
G	River flow is preventing the waves to produce onshore currents in the flood season
H	The river flow transports sediment to the inlet channel
I	The bed topography is about the water depth, which influences the wave magnitude
J	Waves cause longshore currents along the coast
K	Waves cause onshore currents perpendicular to the coast during the NE monsoon
L	Tidal currents are perpendicular to the coast and cause inter alia onshore currents
M	Tidal currents interrupt the longshore currents, so the sediment drops near the inlet
N	Onshore currents take sediment and cause onshore sediment transport to the inlet
O	Longshore currents take sediment and cause longshore sediment transport to the inlet
P	A small part of the sediment dropped by the river is transported by longshore currents
Q	The sediment dropped in front of the inlet by the river can be used for onshore transport
R	Enough river flow through the inlet channel prevents the inlet from closure
S	Dredging, extracting sand and other activities in the estuary influence the seasonal closure
T	Due to the onshore sediment transport, the inlet fills up with sediment
U	The sediment that is not transported by onshore currents, is transported longshore
V	Longshore sediment transport is smaller than onshore, but contributes to the closure
W	Longshore currents can take sediment away from the inlet, when they are not interrupted
X	Sea level rise can cause overtopping of the sand bar and create another inlet

4.3.2. SIMPLIFICATION

With 24 processes, the first sketch of the conceptual model is too complicated. Such a complex model is not useful for making a simulation, so the model must be simplified. The difficulties with simplification are the level of simplification and which parts should be included or excluded in/from the model. A good understanding of the model objective is necessary to determine the level of simplification. The model should after all reach its objective. In the case of the seasonal inlet closure in the Da Dien estuary, the model objective is to describe the main processes that lead to the seasonal inlet closure. In the complex conceptual model, all of the processes are described, but it is not shown to what extent they affect the inlet closure. That can be determined from the study of the factors that affect the seasonal inlet closure in chapter 3. Based on that information, an informed choice can be made to include or exclude a factor. However, as stated in section 4.1, a conceptual model must not only be useful, but also valid, credible and feasible. The model should contain enough factors, not exclude a clearly visible factor and contain only factors from which data is available or can be measured. Al these criteria should be taken into account when the level of simplification is determined.

Simulation models of other estuaries subject to seasonal inlet closure are already developed. It is useful to observe those models and the choices that are made in case of including or excluding factors that affect the closure. Tung (2011) simulated the seasonal inlet closure with a numerical model. The model does not simulate a specific inlet at the Vietnamese coast, but a fictitious inlet with the characteristics of a general inlet at the Vietnamese coast. The sediment transport in the sea, due to wave and tide characteristics is included in the model. The model successfully reproduces the inlet channel evolution. Ranasinghe et al. (1999) used only wave characteristics to make a numerical model. The model simulates both cross-shore and longshore transport and was implemented successfully. The numerical models are split in a hydronamic and ocean dynamic model by Lam et al. (2008). The results of the river flow simulation in the hydronamic model are used as boundary conditions in the ocean dynamic model. The ocean dynamic model contains wind, wave and tide characteristics and simulates the morphodynamics of the inlet. A simulation of the Thuan An inlet is developed by Nghiem (2009). The simulation contains five elements: the whole ebb tidal delta, the total inter-tidal flat area of the lagoon, the total channel volume in the lagoon, the adjacent southern coast and the adjacent northern coast. The sediment transport between the elements is simulated to evaluate the seasonal inlet closure.

The earlier developed numerical models show two important things: factors that affect inlet closure are inherently complex and so only a few factors can be included in one model, and river flow is either not simulated or only in a separate model. However, the interaction between river and sea seems very important in the Da Dien estuary, so both parts should be included in one simulation model. In addition, it is now sure that not all of the factors affecting seasonal inlet closure can be included in the simulation model. So the model must be simple and include both river and sea dynamics. Based on this condition, the complex model and the knowledge about the extent in which the factors affect the inlet closure, a decision is made to include or exclude factors in/from the conceptual model (Table 3). This simplification results in a valid, credible, feasible and useful model.

TABLE 3 - SIMPLIFICATION OF THE COMPLEX CONCEPTUAL MODEL

FACTOR	IN-/EXCLUDE	JUSTIFICATION
Bed topography	Include	The bed topography has direct influence on the wave power in the nearshore area. Differences in topography can change the amount of sediment transport.
Climate change	Exclude	The climate is changing, but it is still uncertain to which extent. If climate change should be included in the model, different scenarios (for sea level rise and change in river flow/wind/waves) should be simulated, which makes the simulation large and complicated.
Human activities	Exclude	The difficulty with human activities is the available data. The extraction of water from the river is already included in the river flow, but activities in the estuary are difficult to measure and do not occur regularly. However, knowledge about when human activities have taken place can be used to refute failures in the model.

Longshore currents	Include	Longshore currents prevent the inlet from complete closure and transport sediment along the shoreline. Without the longshore currents during the summer, the inlet closes complete.
Longshore transport	Include	Although longshore sediment transport is much smaller than onshore sediment transport, it cannot be neglected. Especially because longshore transport is both into and out of the inlet.
Monsoon	Exclude	Monsoons seasons cause change in river flow and wind direction, but the monsoon itself does not affect the seasonal inlet closure and also no data about the monsoon can be used in the simulation, so it is excluded.
Onshore currents	Include	Onshore currents are caused by onshore waves and make onshore sediment transport possible, which brings most of the dropped sediment back to the inlet.
Onshore transport	Include	The onshore currents take sediment to the inlet and drop it in the channel, which causes a narrow and shallow channel.
River flow	Include	The discharge of the river has great seasonal variation. In the flood season the large river flow widens the inlet and the lack of river flow in the dry season makes the inlet closure possible.
River sediment	Include	The river flow drops sediment in front of the inlet, which is transported back to the inlet by onshore currents. Without the river sediment, there is not enough material for inlet closure.
Tide	Include	The Da Dien estuary is a micro-tidal area, so tides do not have a large impact on the inlet closure. The only importance of tide is observed when it interrupts the longshore currents. So tides are included, but only the effect on longshore currents.
Waves	Include	Wave direction and power have great influence on the currents and sediment transport in the ocean in front of the inlet.
Wind	Exclude	Wind is the driven factor for waves, but when wave data is used in the simulation, the influence of wind is already taken into account. The impact of storms is neglected when wind is excluded from the model. Storms can speed up the process of closing or opening of the inlet in some years, so the simulation does not have that extreme values.

4.3.3. Simplified model

The excluding of some factors results in a simplification of the conceptual model. The simple model showed in Figure 13 can be used as a basis for a numerical model. The model shows that the seasonal inlet closure is caused by three main factors. The three factors all represent a part of the year. First, in the flood season (September-December) the large river flow creates a broad and deep inlet channel (A). The river flow transports sediment transport through the inlet channel and drops it in front of the inlet (B). Then in the first part of the dry season (January-March), sediment transport to the inlet fills up the channel, which results in a narrow and shallow inlet. In this part of the year, sediment transport is mainly onshore (C) and transports the sediment that is dropped by the river in the flood season (D). A small part of the sediment in front of the inlet is left for longshore transport (E), the larger the onshore transport, the smaller amount can be transported longshore (F). The onshore transport is caused by onshore currents (G), driven by waves from the northeast (H), which are dominant from September till March. Due to the large river flow in the flood season, only from January till March these waves can produce onshore currents in front of inlet channel (I). Finally, in the second part of the dry season (April-August), longshore currents flow along the coast and in front of the inlet. These currents take the sediment that is dropped in the inlet northwards and so the inlet is open again (J). In the same time, longshore sediment transport to the inlet channel is observed (K). The longshore currents, which take the sediment along the coastline (L), are driven by the waves from the southeast (M). When the longshore currents are interrupted by tidal currents (N), the sediment drops in front of the inlet. So the longshore currents transports sediment into the inlet from the southeast, but take also sediment away from the inlet to the northwest. The effect of waves on the sediment transport depends on the nearshore bed topography (O). Due to the increase in water depth, the waves break. The distance from the coastline where the waves break affects the amount of sediment that can be transported to the inlet. This seasonal cycle of inlet closure occurs every year, however, Mother Nature has her own rules and other observations are more regular than an exception.

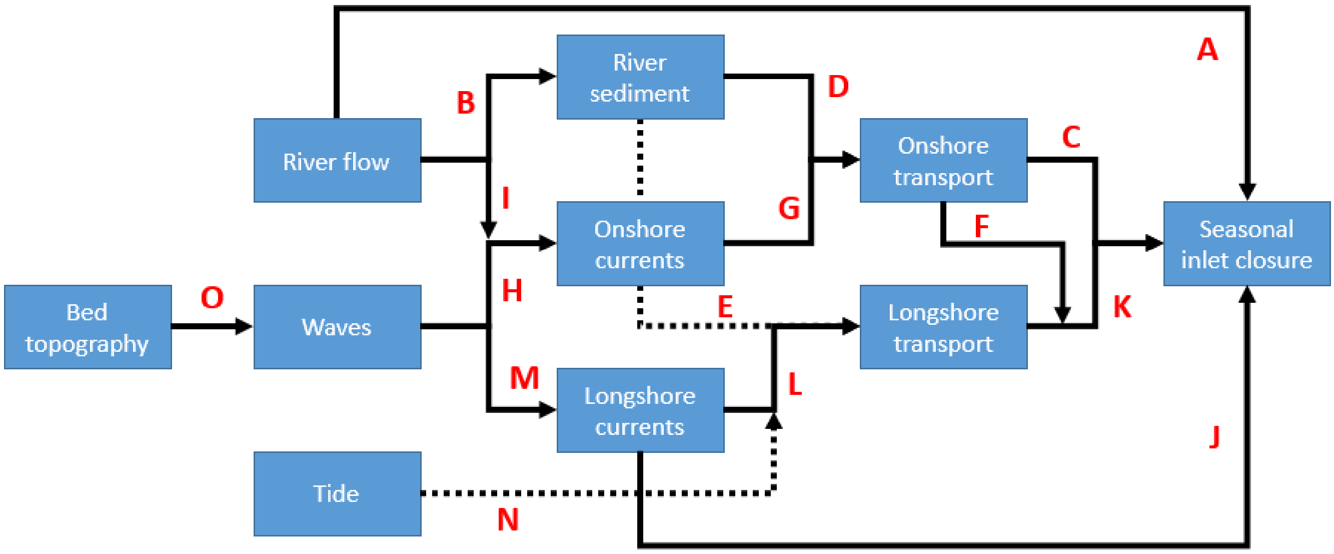

FIGURE 13 - SIMPLE CONCEPTUAL MODEL OF THE SEASONAL INLET CLOSURE IN THE DA DIEN ESTUARY

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5. Validation with collected data

The conceptual model that is developed in chapter 5 is based on assumptions from literature. The assumptions are supported, but it is hard to say if they are also true for the specific area around the Da Dien estuary. In chapter 5, data is used to validate the conceptual model with a correlation analysis. First, the collected data is presented and discussed. Then the data is used to investigate the correlation between the data. The outcomes of the validation make the model more plausible or conclude that the model has to be changed.

5.1. Collected data

Based on the conceptual model, data of the river discharge and wave characteristics are needed to validate the model. Unfortunately, data of the wave direction were not available. However, as stated in section 3.2, the wind is the driven factor for the waves. So the wind characteristics are used to estimate the wave direction. In addition, the satellite images of the inlet, the daily average river discharge, the wave height, wave period and the bed topography are observed. Due to the availability of the data, the reviewed period is determined on 2000-2014. The seasonal averages are presented in chapter 5, the monthly averages can be found in the appendix.

5.1.1. Opening inlet

Satellite images are used to observe the change of the opening of the inlet. Most of the images are found in the LandsatLook Viewer (2015) and a few in Google Earth (2015). The openings were measured by a digital ruler, which was available in both sources. However, as showed in Figure 14, this was much easier in Google Earth, because the inlet could be observed there closer. Because it was hard to measure the opening in LandsatLook, that measurements are a bit unreliable. However, the difference between a narrow and wide inlet is clear, so the data is still useful for the validation.

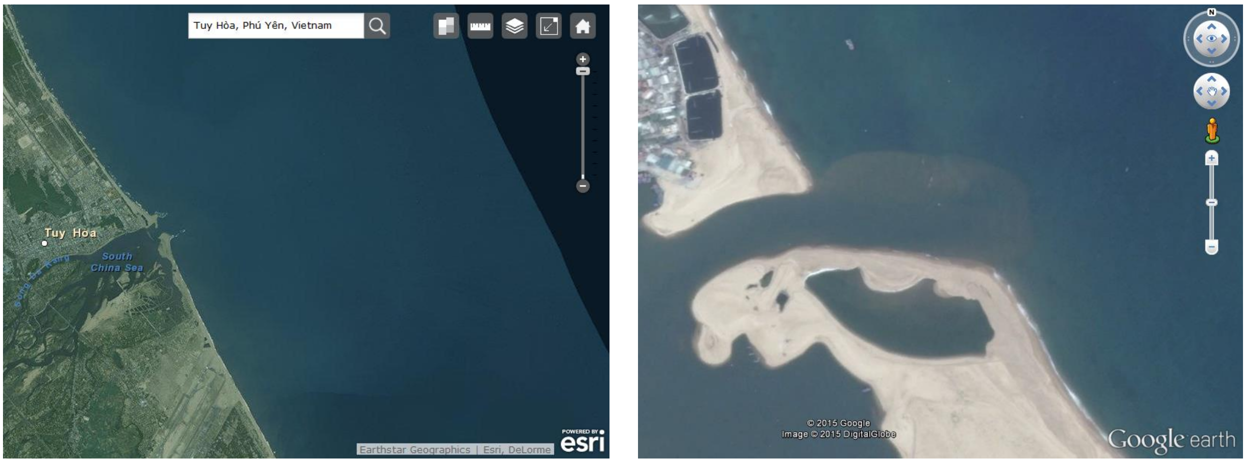

FIGURE 14 - THE DIFFERENCE BETWEEN LANDSATLOOK (2015) (LEFT) AND GOOGLE EARTH (2015) (RIGHT)

Unfortunately, only 175 images were available during a period of 15 years, which means in average one image per month. Moreover, the images were not taken at fixed intervals and so only in 114 of the 180 months in the observed period, a monthly average could be calculated. All the measurements are showed in Figure 16. The difference in the opening between several years is quite large. In 2007 and 2009 openings of more than 400 meter were observed, while the opening was not larger than 200 meter from 2011 till 2014. However, almost all years show a peak at the end of the year. This is confirmed by Figure 15, where the seasonal difference in the opening is showed. The line of the flood season (September - December) is in average above the lines of the dry seasons. However, as mentioned earlier, the difference between the years is quite large, both in the flood and dry season.

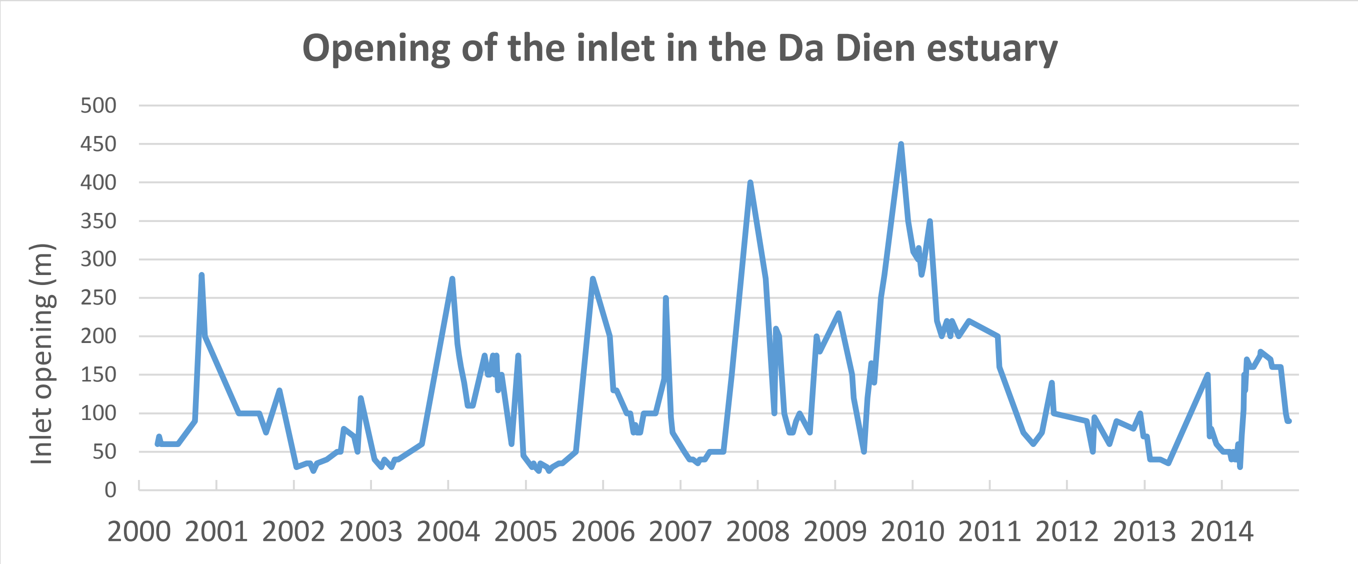

FIGURE 16 – CHANGE OF THE INLET OPENING IN THE DA DIEN ESTUARY FROM 2000-2014 (LANDSATLOOK VIEWER, 2015) (GOOGLE, 2015)

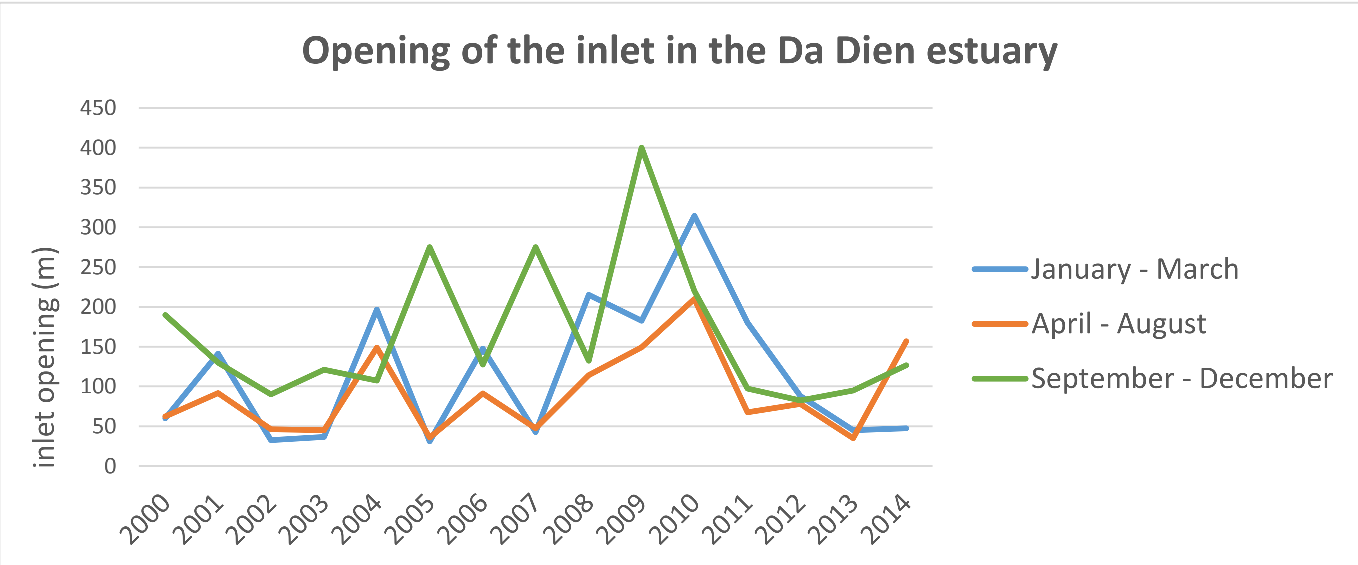

FIGURE 15 – SEASONAL AVERAGES OF THE OPENING OF THE DA DIEN ESTUARY FROM 2000-2014 (LANDSATLOOK VIEWER, 2015) (GOOGLE, 2015)

5.1.2. River discharge

The river discharge is measured at Cung Son Hydrology Station (2000-2014) which lies about 40 km upstream from Tuy Hoa (Figure 17). No measurements of the river discharge were taken at the height of the inlet. However, all the water that passes through Cung Son also passes through the inlet in the Da Dien estuary, so the river discharge in Cung Son gives a reliable view of the river discharge through

FIGURE 17 – DISTANCE BETWEEN CUNG SON AND TUY HOA (GOOGLE, 2015)

the inlet channel. The daily average discharge could be used, which gives enough data for a reliable validation.

The average river flow per season is showed in Figure 18. It is clear that the flood season takes from September till December. However, the river discharge during the flood seasons has a great variation between the years. On the other hand, the river discharge in the dry seasons is quite stable and stays almost every year below 200 m³/s. In most years, the river discharge in the summer dry season is a bit larger than in the winter dry season. The same is observed when the average of the maximum river flows per month is presented per season in Figure 19. The monthly average river discharge can be found in appendix B.

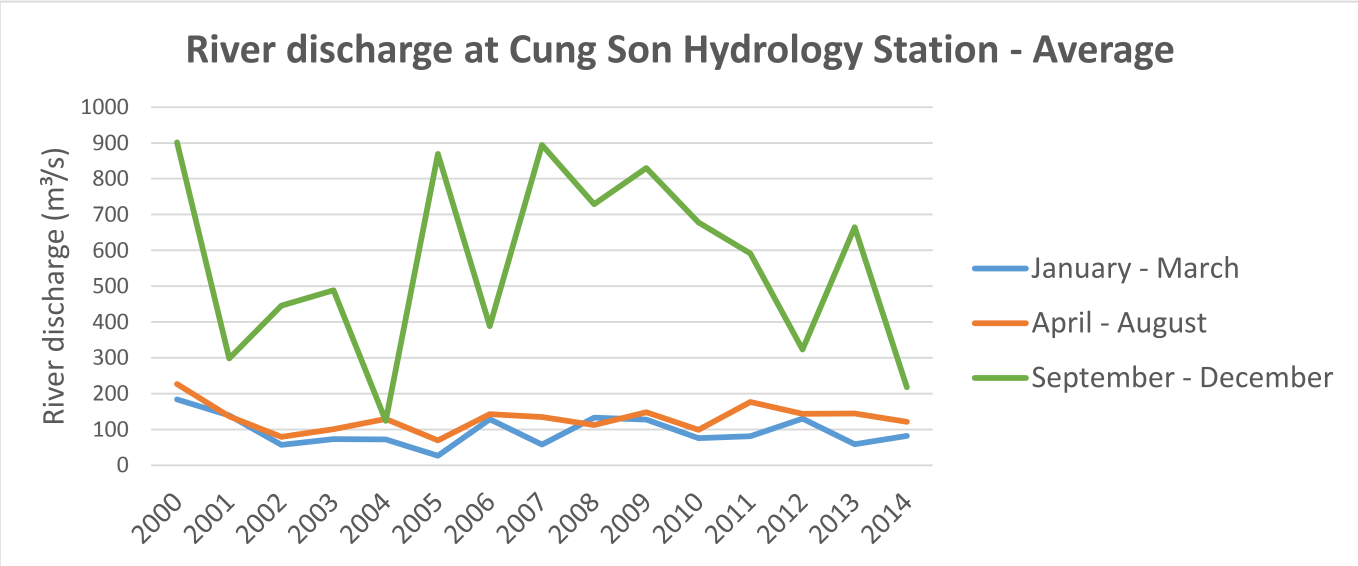

FIGURE 18 - AVERAGE RIVER DISCHARGE PER SEASON FROM 2000-2014 (HYDROLOGY STATION, 2000-2014)

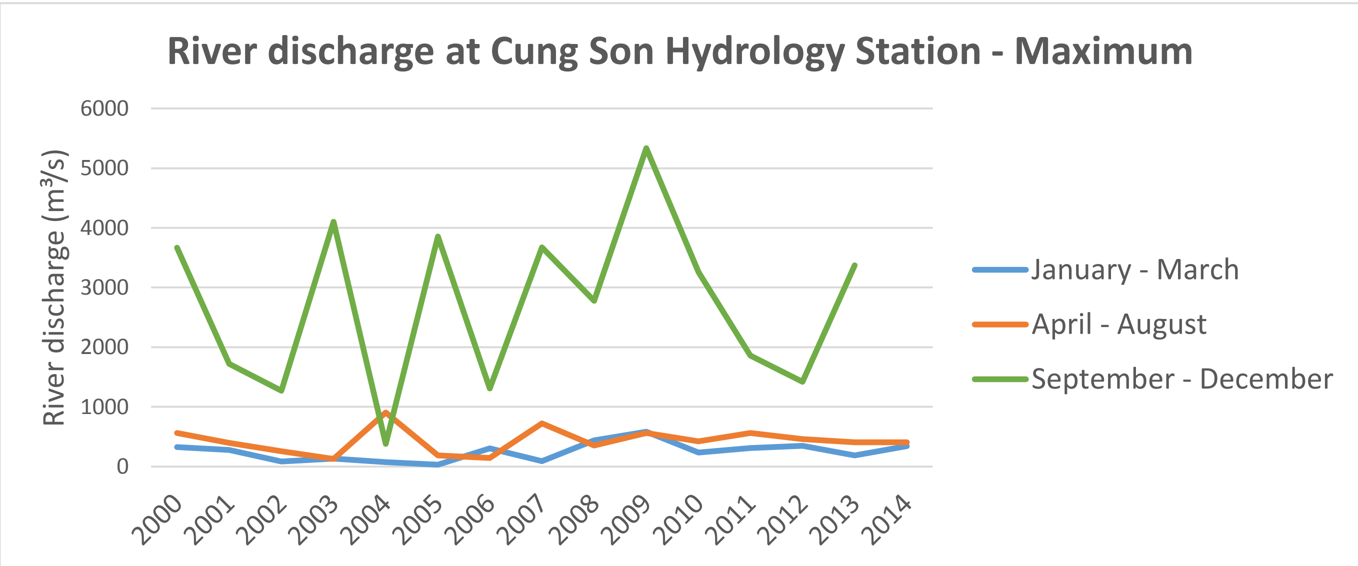

FIGURE 19 – MAXIMUM RIVER DISCHARGE PER SEASON FROM 2000-2014 (HYDROLOGY STATION, 2000-2014)

5.1.3. Wind and waves

Data of the wind and waves are collected from the International Comprehensive Ocean-Atmosphere Data Set (ICOADS, 2015). It is a global ocean marine meteorological and surface ocean dataset. The dataset is formed by merging many data sources that contain measurements and observations from ships, buoys and coastal stations. Many variables are observed, including wind direction, wind speed and wave height. A subset of the global dataset is used for the evaluation of the wind and wave characteristics near Tuy Hoa. Because of the lack of data from the ocean in front of Tuy Hoa, a greater area around the estuary is observed to collect the wind and wave characteristics (Figure 20). In this area, a large amount of data was available to evaluate the wind and waves. However, waves behave different in nearshore areas, so for a reliable simulation, data of wind and waves near Tuy Hoa is needed. The wind direction was given in degrees and needed to be transferred into rhumbs to create seasonal windroses (Figure 21). The windroses contain both wind direction and speed. They are developped with 'Wind Rose Excel' (2015).

FIGURE 20 - OBSERVED AREA TO COLLECT WIND AND WAVE CHARACTERISTICS (ICOADS, 2015)

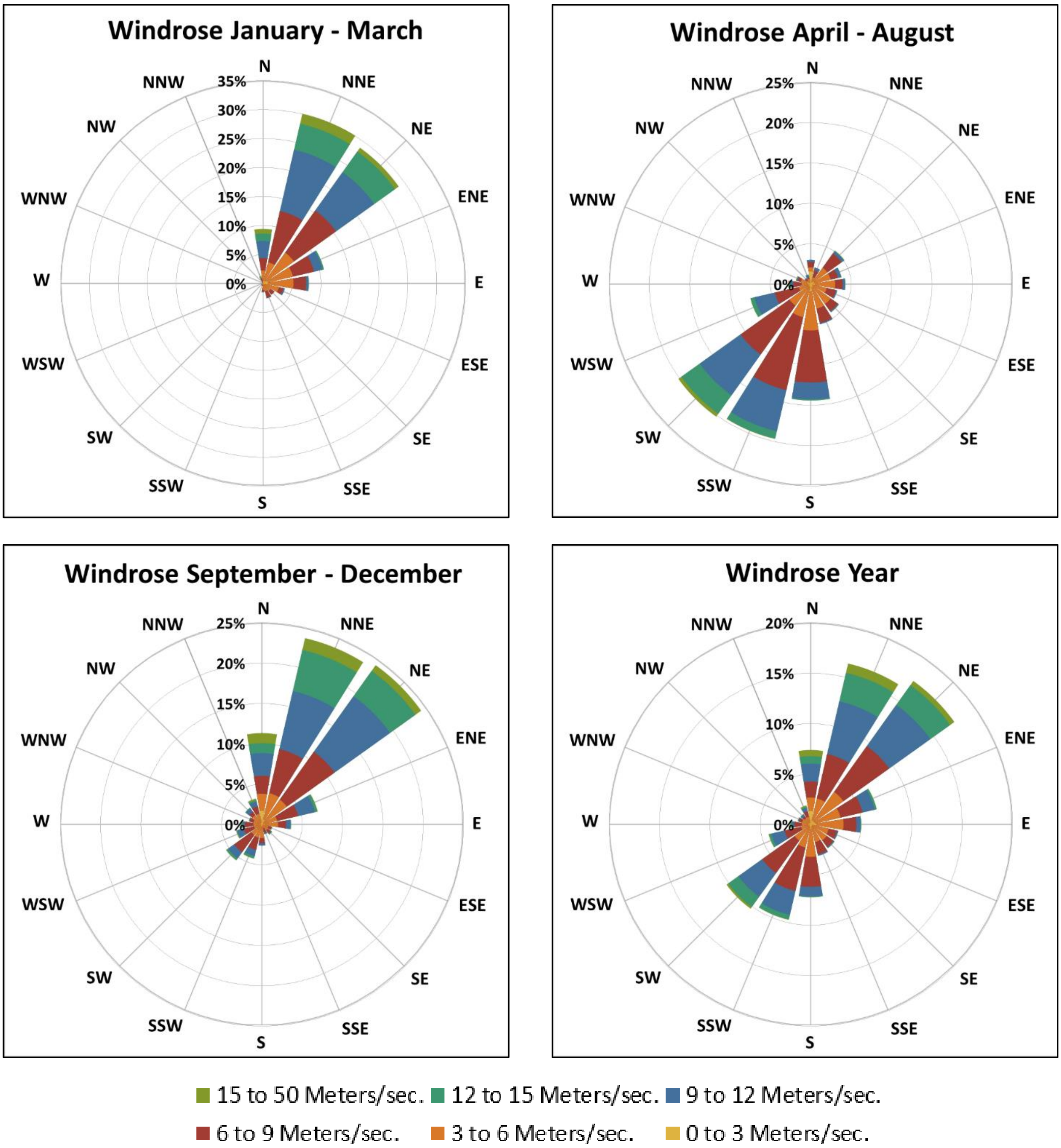

FIGURE 21 - WINDROSES ABOUT THE WIND DIRECTION AND SPEED AT THE CENTRAL COAST OF VIETNAM (ICOADS, 2015)

The windroses show the seasonal difference in wind direction and speed during the seasons. The wind direction is driven by the monsoon seasons, the northeast monsoon from September till March and the southwest monsoon from April till August. The seasons are clearly visible in the windroses. It is important to observe the scale of the windroses, the smaller the scale the more divided the directions are. For example the windrose of January till March has a scale till 35%, while the scale of the yearly windrose only reaches till 20%. The colors in the windroses represent the wind speed, the green and blue colors show high wind speeds, the red and orange colors show low wind speeds. The red and orange part is larger in the April till August windrose, so the wind speeds are lower in the summer. The windroses per month can be found in appendix C.

The wave data in the ocean around Tuy Hoa as collected from the same source as the wind speed and direction. The waves are a bit higher during the northeast monsoon (Figure 22). It is likely that this is caused by the higher wind speed in the same season. The wave period is showed in Figure 23. It is remarkable that the wave period seems to increase during the years. A clear reason for the increase is not observed. The monthly averages of the wave characteristics can be found in appendix D and E.

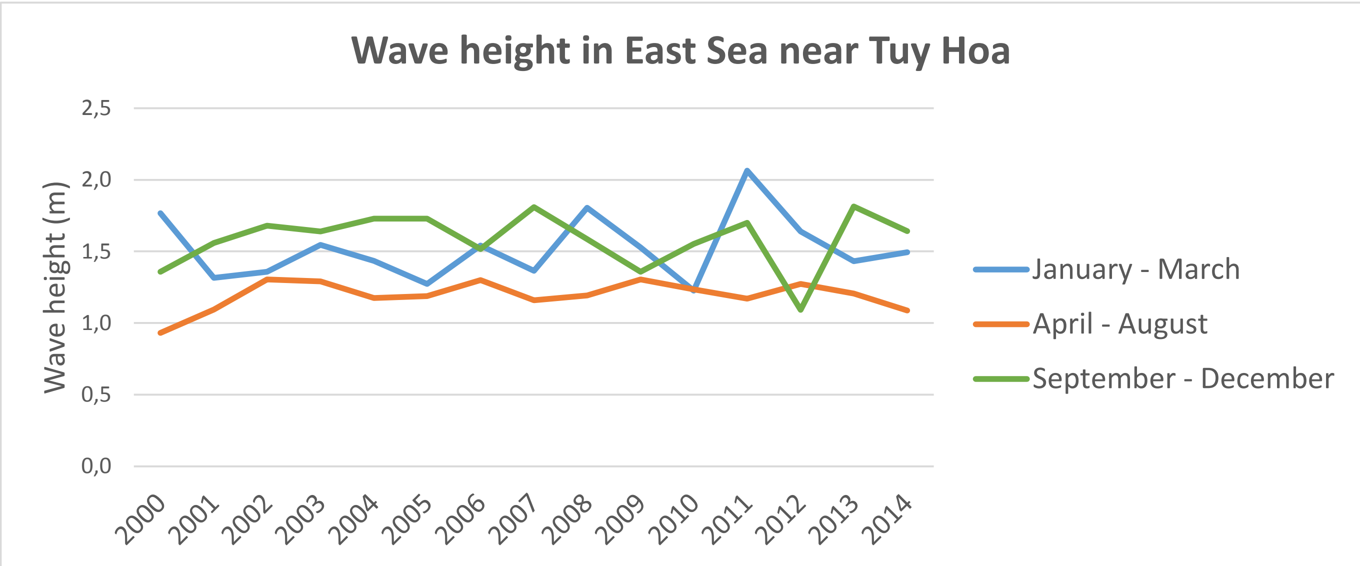

FIGURE 22 - WAVE HEIGHT IN THE EAST SEA NEAR TUY HOA (ICOADS, 2015)

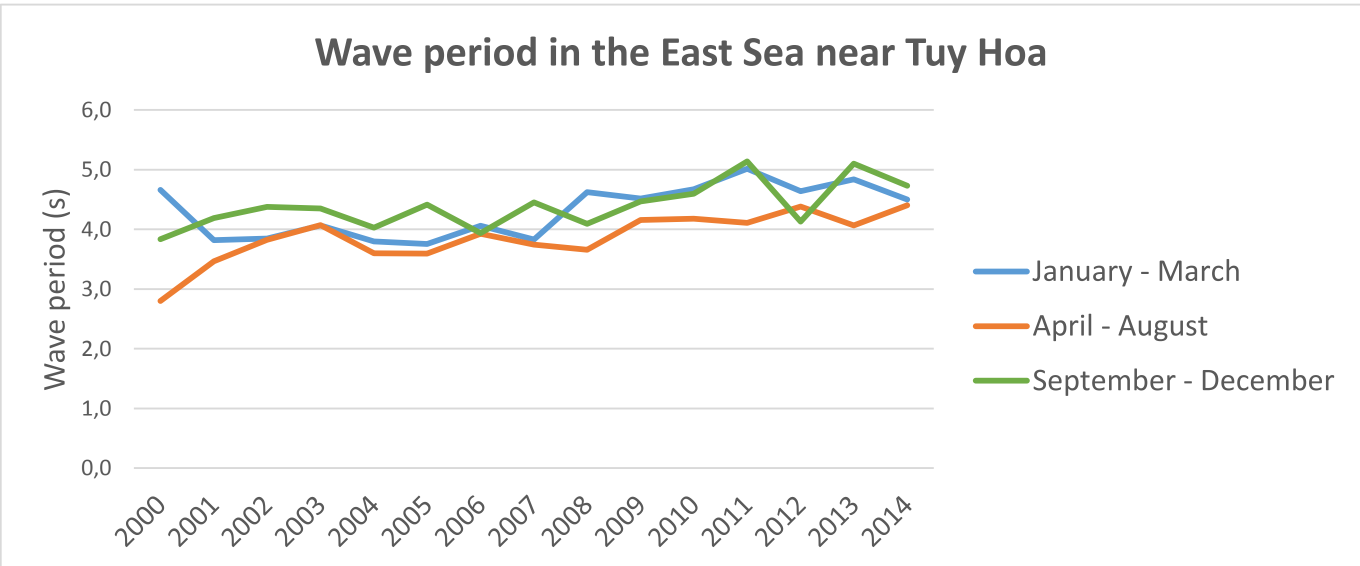

FIGURE 23 - WAVE PERIOD IN THE EAST SEA NEAR TUY HOA (ICOADS, 2015)

5.1.4. Bed topography

The bed topography around the inlet is measured from a map (Figure 24). Unfortunately, only one map was available, which means a fixed water depth. However, in reality, the bed topography changes, and so does the water depth. A negative value means above sea level, a positive value below. Around the inlet a green color is observed, which means a water depth between 0 and 10 meter. The depth in the inlet channel is about 8 meter, and the depth in front of the inlet is between 5 and 9 meter. Waves usually break when the water depth comes below 1.3 times the wave height. The waves are not above 3 meter, so the waves first enters the estuary before they break.

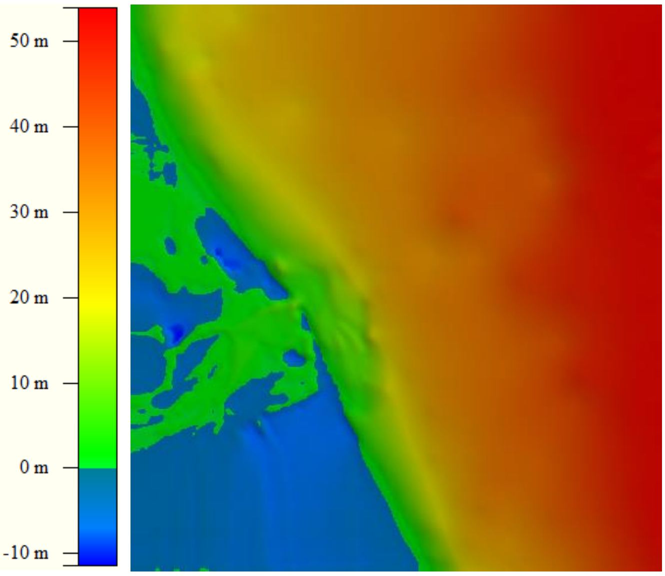

FIGURE 24 - BED TOPOGRAPHY AROUND THE DA DIEN ESTUARY

5.2. Validation by correlation analysis

The collected data is used to validate the conceptual model (Figure 25) by correlation analysis. The validation covers two input variables of the model: river discharge and waves, data of tides was not available for the validation. The influence of the factors on the seasonal inlet closure is shown in this section. The other variables are assumed to be a result of the river discharge or waves, they do not influence the seasonal inlet closure by themselves. The bed topography is an input variable for calculating the wave influence. So observing the river discharge and waves should be sufficient to validate the conceptual model.

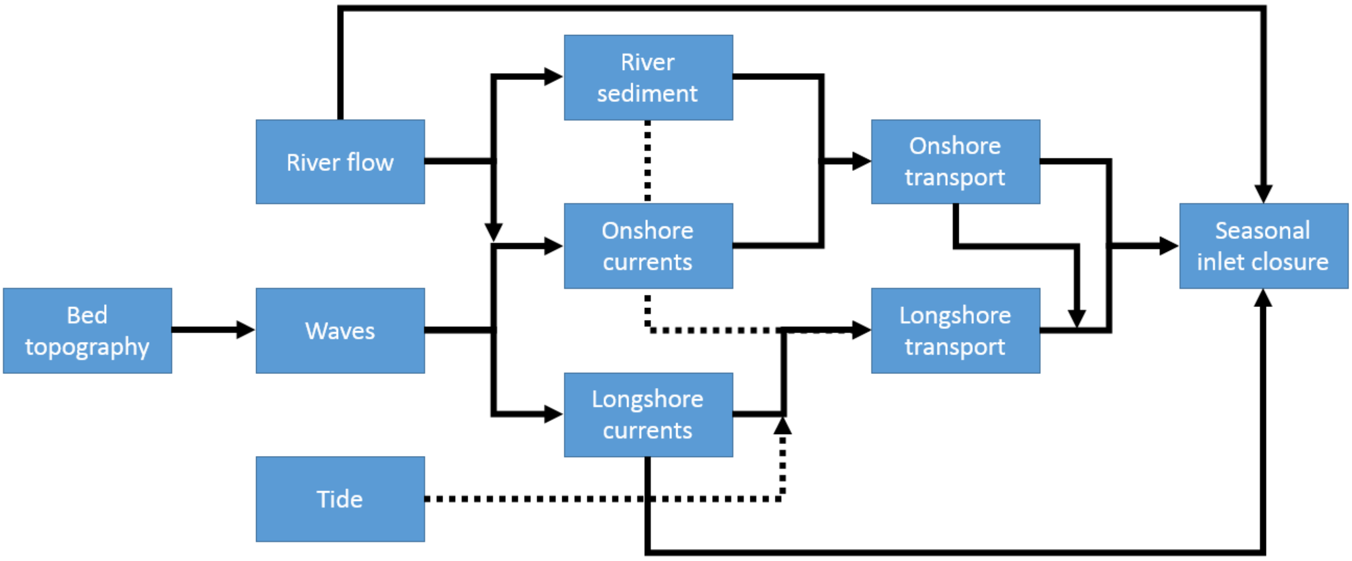

FIGURE 25 - CONCEPTUAL MODEL OF THE SEASONAL INLET CLOSURE IN THE DA DIEN ESTUARY

5.2.1. River discharge

As shown in section 5.1.2, the river discharge has a large seasonal variation. If the river discharge is influencing the seasonal inlet closure, that variation has to be observed in the opening of the inlet. In Figure 26, the seasonal averages of the river discharge and the opening of the inlet are compared.

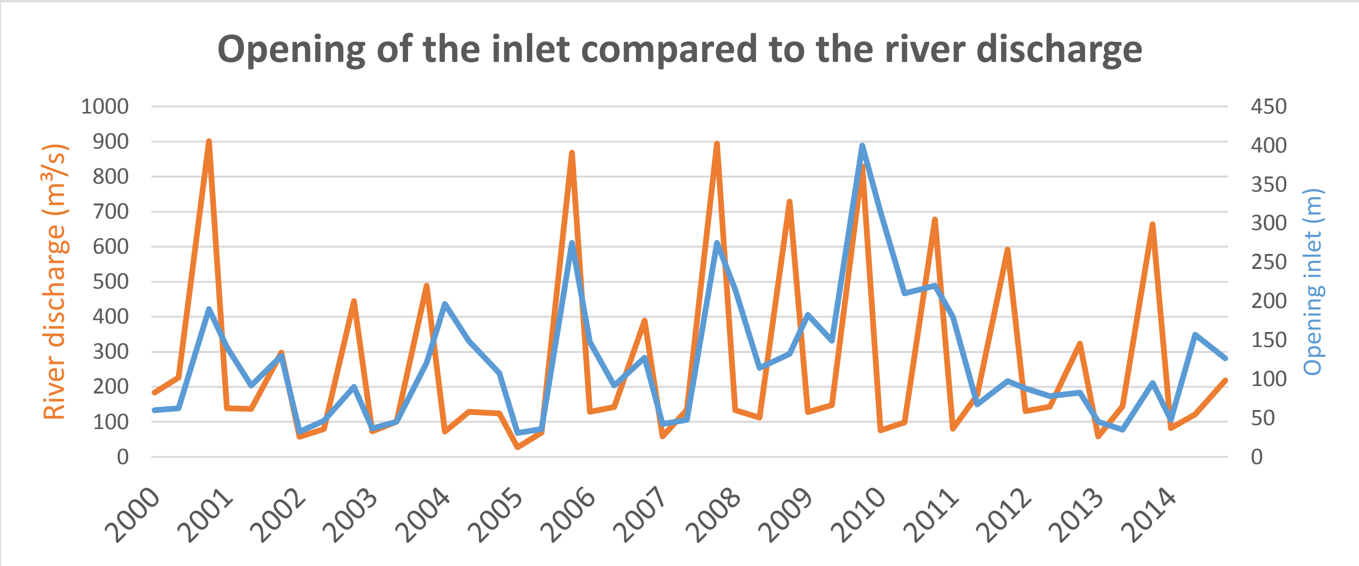

FIGURE 26 - OPENING OF THE INLET COMPARED TO THE AVERAGE RIVER DISCHARGE PER SEASON

The curves of the river discharge and the opening of the inlet seem to have a relation with each other. The seasons in which a peak in river discharge occurs, mostly also have a peak in the opening of the inlet. However, the extent to which the peaks are at the same level differs. In 2001, 2003, 2006, 2007, 2008, 2010 and 2011, the peak in river discharge is around the peak in the opening of the inlet, but the other years show a larger difference. Also the dry season show a comparison. In most years, the lowest level of the river discharge is around the narrowest opening. Only in 2004 and 2010 this difference is quite large. Because the lack of data of the opening of the inlet it is hard to say if the river discharge is really direct related to the seasonal inlet closure, but the figure makes it plausible.

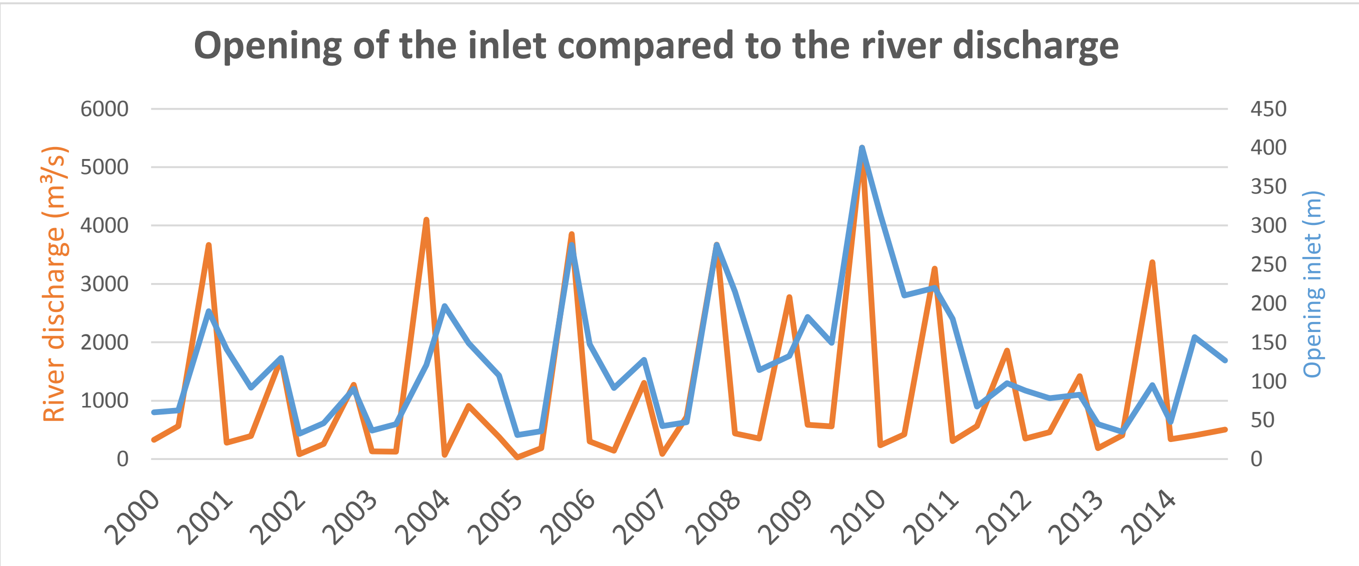

FIGURE 27 - OPENING OF THE INLET COMPARED TO THE AVERAGE OF THE MAXIMUM RIVER DISCHARGE PER MONTH IN A SEASON

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Figure 27 shows the opening of the inlet compared to the average maximum river discharge per season. For each month in a season the maximum river discharge is determined, and that values are used to calculate a seasonal average. The curves in Figure 27 seem to have a larger similarity than in Figure 26. More peaks are at the same level and the differences are smaller. This is confirmed by a calculation of the correlation between the two curves in Figure 28. The correlation with the maximum values per month is 0.325 and with the average discharges 0.2685. The fact that there is a larger similarity with the average maximum dischargers per month shows that the maximum river discharge has more influence on the seasonal inlet closure, than the average river discharges. In other words, the few days a year with huge river discharges and the months without that values contribute the most to the seasonal inlet closure. A huge river discharge has great power and can transport more sediment in one day, than average river flows during a longer period with the same total discharge. When such a huge discharge is not observed in a month, the sediment continues to drop in the inlet. However, the correlation is only 0.3205 and 0.2685, far from an ideal value of 1. So there is a direct relation with the river discharge, but there are also other factors that affect the seasonal inlet closure.

Correlation between the opening of the inlet and the river discharge

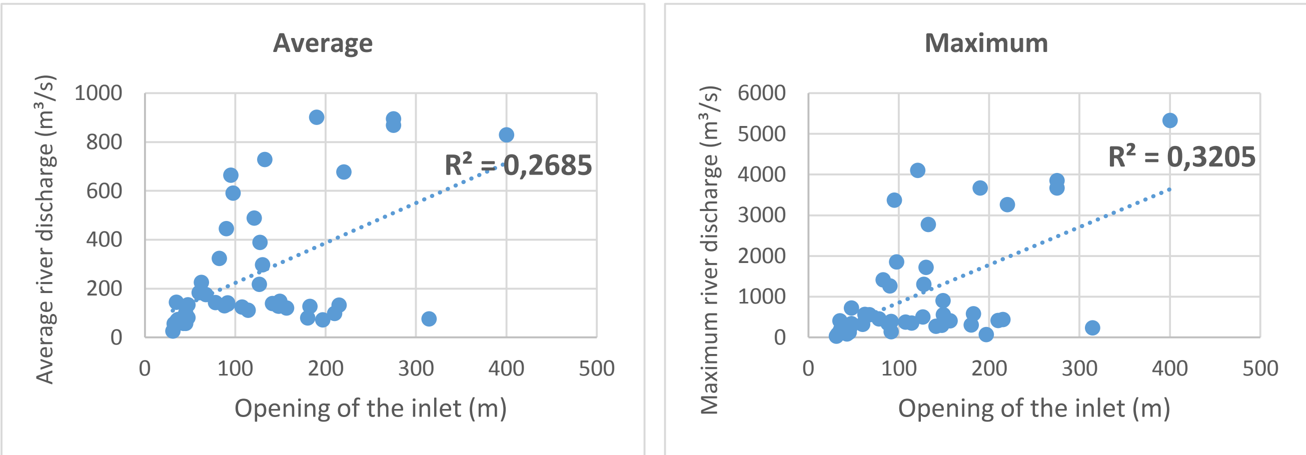

FIGURE 28 - CORRELATION BETWEEN THE OPENING OF THE INLET AND THE RIVER DISCHARGE

5.2.2. WAVES

It is more difficult to determine the influence of waves on the seasonal inlet closure. First the power of the waves should be determined: what is a reasonable assumption about the influence of waves on the inlet closure? In chapter 3 is stated that the waves can only contribute to the closure during the dry seasons, when the river discharge is small. So only the effect of waves on the opening during the dry seasons is validated. The direction of the waves has impact on its influence. Figure 29 shows that waves from the NE and the ENE cause onshore transport, while waves from the NW, NNW, SSE and SE cause longshore transport. Waves from the WSW and the SW are offshore and contribute to making the channel open again. Unfortunately, the data of the wave direction is not available. However, based on section 3.2, where is stated that wind is the driven factor for waves, so it is assumed that the wave direction is the same as the wind direction. Because also the wind data could not be collected in the nearshore area, the data is still unreliable, but no other data are available at this moment.

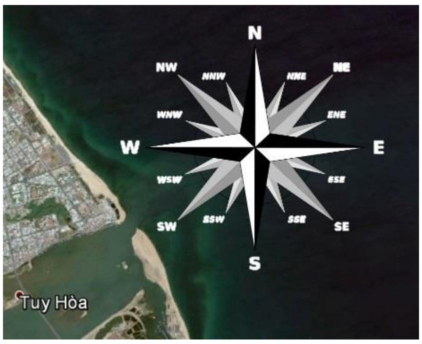

FIGURE 29 - WAVE DIRECTION (GOOGLE, 2015)

The onshore current, driven by the waves, can be calculated with a formula:

$$q = \frac{4h}{\sqrt{3}} \frac{\sqrt{Hh}}{T} \text{ (Thanka, 1994)}$$

In which T is the wave period, H the wave height, h the water depth and q the volume of flow per unit width. The onshore current is calculated for different water depths, because the bed topography also changes in reality. The formula is only about the onshore current, so it can only be used for months with a wind direction of NNE, NE, ENE or E. Because the seasons need to be compared, only the first part of the dry season could be included, because from January-March these directions are dominant. The onshore currents are compared with the change of the opening of the inlet. The values of the inlet are measurements of the inlet change between 1 January and 31 March. Because no measurements for every day is available, measurements of days near the mentioned dates are used. Unfortunately, not for every year a reliable estimation could be made. The results of the calculation are presented in Figure 30.

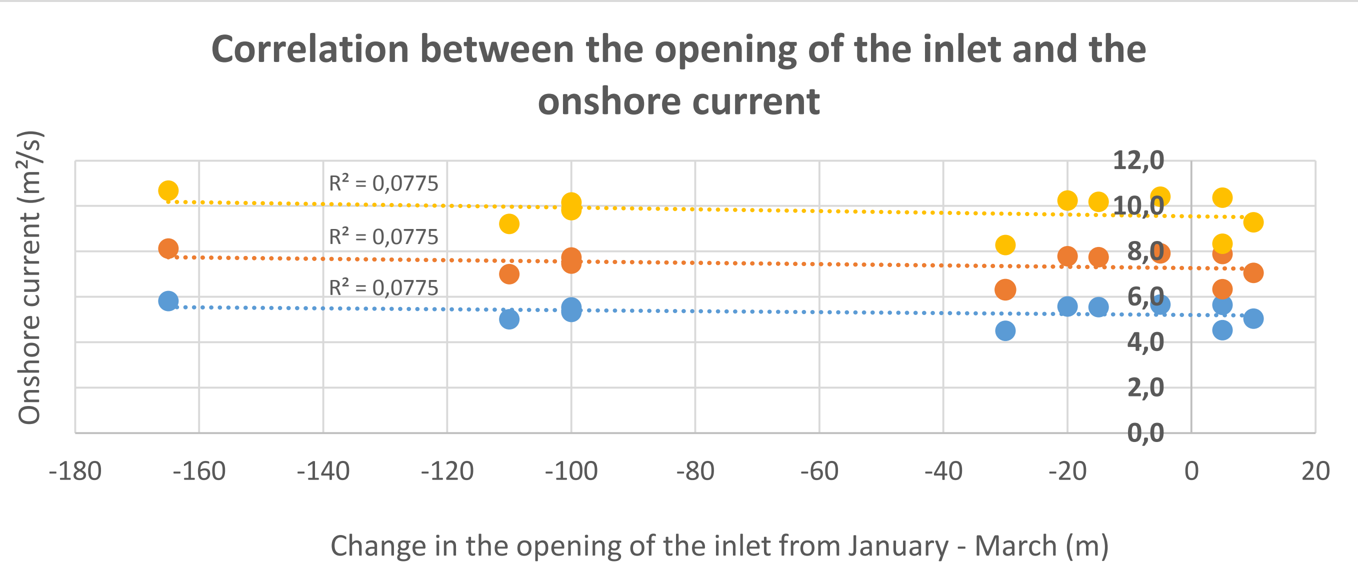

FIGURE 30 - CORRELATION BETWEEN THE OPENING OF THE INLET AND THE ONSHORE CURRENT AT DIFFERENT DEPTHS

The onshore current seems to have no direct relation to the seasonal inlet closure. The correlation between the both variables is near 0. The water depth has no influence on the correlation. For a depth of 4, 5 and 6 meter, the correlation is the same. The points in the graph show only a small variation in onshore currents, but a large variation in the change of the inlet. So the onshore current is a constant factor, which has only a small influence on the change of the inlet topography. The large variation in change of the inlet must be caused by other factors. Based on the results of section 5.2.1, it is likely that the driven factor is the river discharge. Because no formula for the longshore transport was available, the correlation between the opening of the inlet and the longshore current could not be calculated. However, the correlation with the onshore current is so small, that is assumed that also the longshore current has no direct relation with the opening of the inlet. Like the onshore current, the longshore current probably depends on the wave height, wave period and the water depth. These factors show also in the summer period not the great variations that are observed in the opening of the inlet channel. Whatever formula you use, the difference between the calculated longshore currents are small and have therefore no relation with the opening of the inlet.

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5.3. IMPROVEMENT OF THE MODEL

The validation showed that the seasonal inlet closure is mostly depended on the river discharge. However, the conceptual model developed in chapter 4 assumes that the waves are also an important factor. The model is improved and therefore it is more in line with reality (Figure 31).

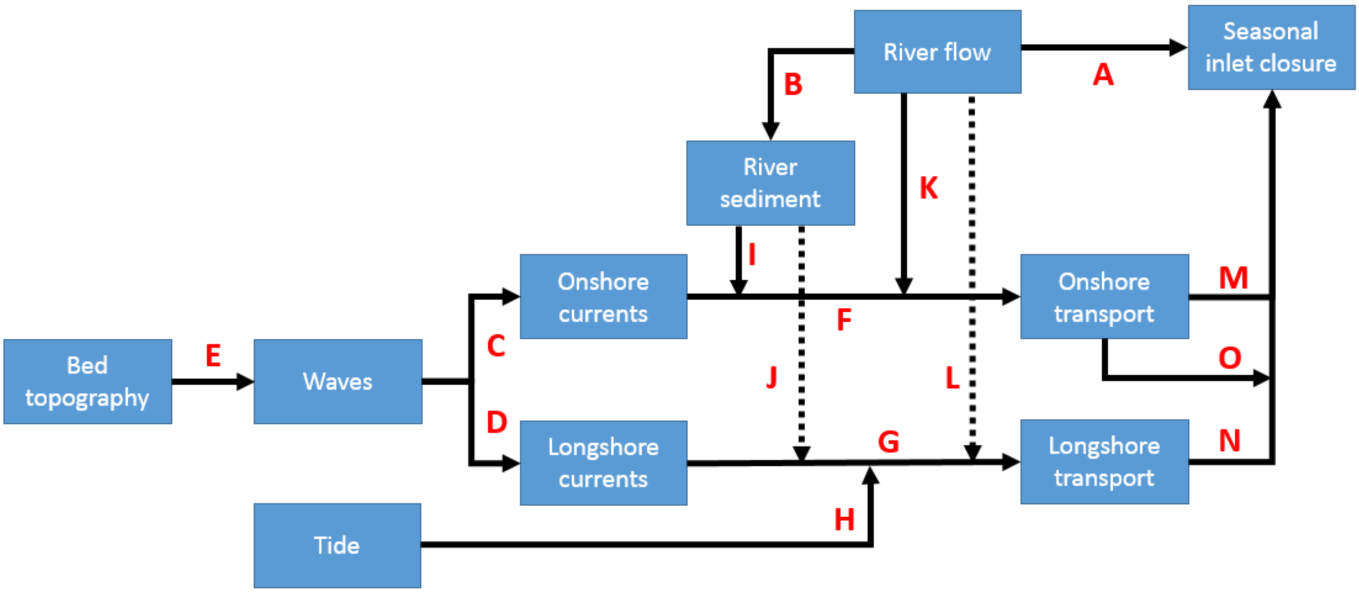

FIGURE 31 - ITERERATED CONCEPTUAL MODEL OF THE SEASONAL INLET CLOSURE IN THE DA DIEN ESTUARY

The river flow affects the opening of the inlet (A), with large flow the inlet widens and if the flow is small, the opening decreases. The river flow transports sediment to the river mouth (B), in the flood season the sediment drops in front of the inlet. Waves cause onshore (C) and longshore (D) currents. The characteristics of the waves depend on the bed topography in the nearshore zone (E). The currents can take sediment, which results in onshore (F) and longshore (G) transport. When the longshore currents are interrupted by tidal currents (H), the sediment drops in front of the inlet. The amount of sediment that can be transported depends on the available sediment (I) (J), and the amount of river flow (K) (L), when the river flow is large, no sediment can be transported to the inlet channel. The onshore (M) and longshore (N) sediment transport to the inlet fills the channel up and can cause a complete closure. The amount of longshore transport depends on the amount of onshore transport (O). Due to NE monsoon from January till March, the dropped sediment in the flood season is transported first onshore. The sediment that is left behind, can be transported by longshore currents.

6. Discussion, conclusions and recommendations

In chapter 6, the results of the study are presented. First the results of the study are discussed. Second, the answers to the research questions are given and interpreted in the conclusions. Final, some recommendations are done for the continuation of the university's project.

6.1. Discussion

Seasonal inlet closure is a complex problem, which gives some limitations in studying the phenomenon. First, it is not sure if the assumptions of the literature study fit the specific area of the Da Dien estuary. All estuaries and inlets at the Vietnamese coast have their own characteristics. A study of general characteristics of the factors that affect the seasonal inlet closure is useful, but the specific characteristics of the Da Dien estuary could be neglected. However, only a few studies have been done before about the Da Dien estuary, so the general information must be used. Second, the simplification of the conceptual model gives some limitations in modelling. Human activities, climate change and storms indeed play a role in the seasonal inlet closure, but are not included in the model, because they could make the model less valid, credible, feasible and useful. For example, dredging of the inlet creates a wider and deeper opening, which is observed by satellite images, but is not caused by one of the factors in the model. When the simulation model shows some failures, the missing factors should be studied more in detail to determine their influence on the model results, before the other factors are improved.

Final, the data collection was subject to huge limitations. Only a few satellite images could be used to determine the opening of the inlet. The wind and wave characteristics had to be observed in a large area around the Da Dien estuary. There was only one map available of the bed topography and data of the tide was not useful to include it in this study. So there is a lack of data and the available data is not reliable, this makes the validation of the conceptual model questionable. The main characteristics could be determined from the data, but a complex process like seasonal inlet closure needs detailed characteristics. Due to the lack of reliable data only a correlation analysis could be done. To get a better understanding of the causes for the seasonal inlet closure a multiple regression analysis is needed. The reliable wind data shows also a remarkable observation. The windroses of April and September (appendix C) show a difference with the assumed monsoon season. The direction in April has large variation, but shows a peak in NE direction and in September the SW winds are dominant, while they are assumed to have another direction. The northeast monsoon was divided in a flood season (September-December) and a dry season (January-March), while the southeast monsoon had only a dry season (April-August). It could be useful to change the division in October-December, January-April and May-September and study the effects of the change on the model results.

6.2. Conclusions

The goal of the study was defined as:

"To develop a conceptual model that describes the seasonal inlet closure in the Da Dien estuary."

To reach this goal, three research questions were defined, with multiple sub-questions. The answers on that questions are discussed separate, after that it can be concluded if the research goal has been reached.

1. How can the seasonal inlet closure in the Da Dien estuary be described?
2. How can the seasonal inlet closure be included in a conceptual model?
3. How can the conceptual model be validated with data?

6.2.1. Seasonal inlet closure

Seasonal inlet closure occurs usual only at river mouths of small river basins. However, the river basin of the Da Dien estuary is large, but seasonal inlet closure is also observed in the inlet channel. The reason why it still occurs in the Da Dien estuary, is the large variation in river discharge during a year. When the river discharge is not large enough to prevent deposition of sediment in the inlet channel, the channel fills up and can close completely in some years. However, many other factors do also contribute to the seasonal inlet closure. The monsoon seasons from the northeast (September-March) and the southwest (April-August) are equal to the wind direction in that periods. The wind is the driven factor for the waves, which cause onshore and longshore currents that transport sediment to the inlet. Due to the large river discharge in the flood season (September-December), the waves cannot transport sediment to the inlet channel. After the flood season, the northeast monsoon is still present till the beginning of April. The waves from the northeast cause onshore sediment transport. From April to August the wind direction changes to the southwest and longshore currents become dominant. If the longshore currents are interrupted by tidal currents they drop their sediment in front of the inlet. Both onshore and longshore currents depend on the bed topography in the nearshore area. The water depth has a great influence on the wave power. Other factors that influence the seasonal inlet closure are climate change and human activities. So many factors are influencing the seasonal inlet closure in the Da Dien estuary. However, their interaction is the most important, but makes seasonal inlet closure also a very complex phenomenon.

6.2.2. A conceptual model

A conceptual model shows the processes and relations between different variables. The model should be valid, credible, feasible and useful. The first sketch of the model was way too complex (Figure 12). After an informed simplification, monsoon, wind, human activities and climate change were excluded from the model. The simple model describes the influence of river discharge, waves and tide on the seasonal inlet closure (Figure 13). The model contains enough factors that affect the inlet closure (valid), does not exclude a clearly visible factor like river discharge (credible), includes only factor from which data is available or could be measured (feasible) and is simple enough for using it as basis for a simulation model (useful).

6.2.3. Validation with collected data

Data of the opening of the inlet, river discharge, wind direction and speed, wave height and period, and bed topography could be collected. Unfortunately, there was a lack of reliable data. The validation shows a correlation between the river discharge and the opening of the inlet, whereby the correlation was greater when the maximum river discharges per month were used to determine the seasonal average river discharge (Figure 28). This assumes that a peak discharge at one day has more power than the sum of average discharges during a longer period. However, the correlation between the river discharge and the opening of the inlet reaches only till 0.3, so other factors like tide, human activities and climate change do also contribute to the seasonal inlet closure. In contrast to the river discharge, the waves do not seem to have a direct relation with the seasonal inlet closure. The correlation between the opening of the inlet and the onshore current was calculated, but is was near 0 (Figure 30). So the seasonal inlet closure is mostly affected by the river discharge, which means that the conceptual model needs to be improved. In the final version of the model, the same variables can be observed, but in contrast to the earlier models, all variables are influenced by the river discharge (Figure 31).

6.3. Recommendations

With the study of the seasonal inlet closure and the developing of a conceptual model, there is a better understanding of the problem. However, before the research could continue with a simulation model, some parts need to be improved. First, a field study in the Da Dien estuary should be done to gather detailed information about the inlet and from people who live around the estuary. That information could be used to determine the characteristics of the seasonal inlet closure and the effect of human activities. Second, more and better data should be collected. More satellite images have to be found, to get a better view of the seasonal inlet closure over the last years. Wind and wave data should be collected from the nearshore area of the Da Dien estuary, to make a more reliable estimation. Data of the bed topography should be collected, preferably over several year or at least over different seasons. These new data can be used together with the data of tides, to improve the quality of the validation. The improved validation holds at least also a multiple regression analysis. When the conceptual model still shows some limitations, the division in seasons could be changed to evaluate that effect on the results.

7. REFERENCES

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8. APPENDIX

A COMMENTS ON THE DATASET

The data of the opening of the inlet, river discharge, wind, waves and swell are gathered in an Excel file. The file contains tabs with graphs of the data, the validation of inlet closure by waves and the input data for the windroses. Besides, there are tabs with multi-year, seasonal, monthly and daily averages. Finally the raw data of the variables is presented. The explanation of the validation of the influence of waves on the inlet closure is given in section 5.2.2.

The periodic averages of the wind direction is split in two values: a normal wind direction and a weighted wind direction. In the weighted wind direction, the wind speed influences the average wind direction. The higher the wind speed for a particular direction, the more it counts. In the raw data, the wind directions are given in degrees. To get the averages, first the sinus and cosines of the directions in radians were calculated. Then, the average of the sinus and cosines values for a specific period were translated again in degrees. Finally the degrees were translated into a rhumb. The same method was used to calculate the swell direction. The swell data was collected to make an assumption about the wave characteristics. Afterwards, the swell data was not useful, because the data could not be used for assumptions about waves. However, the data is still present in the dataset, because it may be useful in the future.

The input data of the windroses contains the number of days in which the wind has particular direction and wind speed. First, all days are counted and divided over the rhumbs. Then, the values are divided in different classes of wind speed. The tables are given for every month, the seasons and for a year. The software 'Windrose Excel' was used to transform the tables into windroses. Because the wind speed is calculated separate, the normal wind direction was used to divide the days over the rhumbs.

MONTH	OPENING INLET	RIVER DISCHARGE	WIND DIRECTION	WIND SPEED	WAVE HEIGHT	WAVE PERIOD
UNITS	m	m^3/s	rhumbs	m/s	m	s
1	120	153	NNE	9.8	1.9	5.0
2	119	77	NE	8.0	1.4	4.2
3	96	55	ENE	7.0	1.2	3.8
4	87	43	E	5.9	0.9	3.4
5	82	102	S	6.5	1.1	3.7
6	98	130	SSW	7.7	1.4	4.1
7	106	128	SSW	7.9	1.3	4.1
8	125	252	SW	8.0	1.3	4.1
9	128	449	SW	6.4	1.1	3.7
10	146	594	NNE	10.5	1.3	4.2
11	195	825	NE	9.0	1.8	4.7
12	135	383	NNE	10.5	2.2	5.0
1-3	112	95	NE	8.3	1.5	4.3
4-8	99	131	SSW	7.2	1.2	3.9
9-12	151	563	NNE	9.1	1.6	4.4

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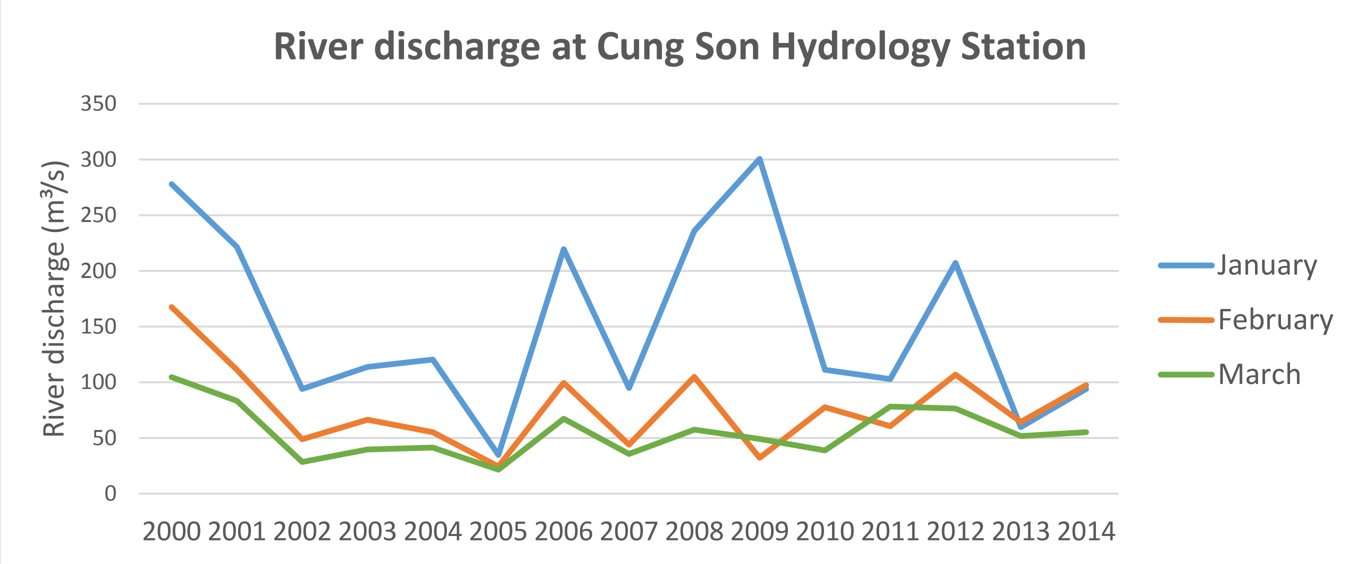
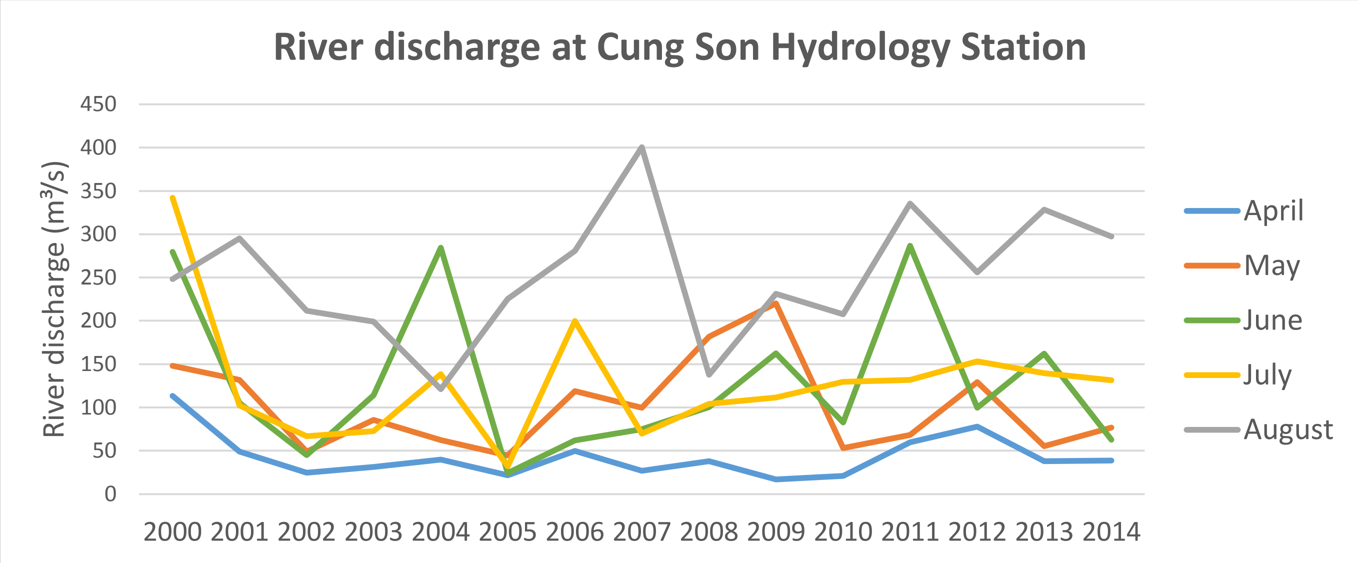
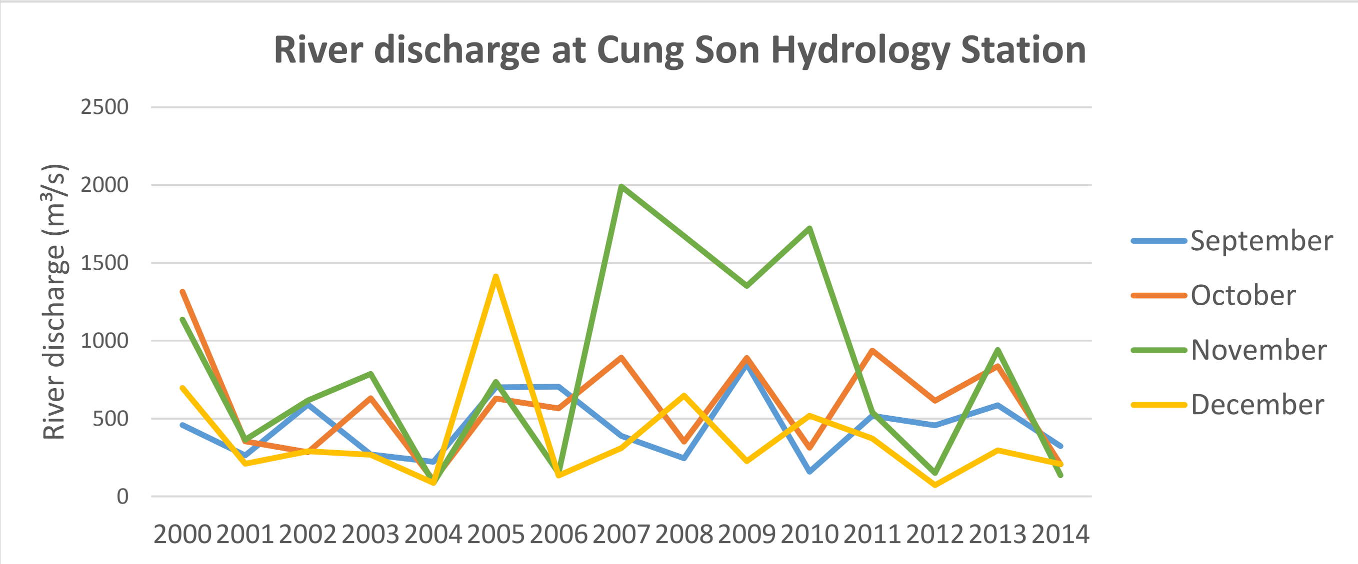
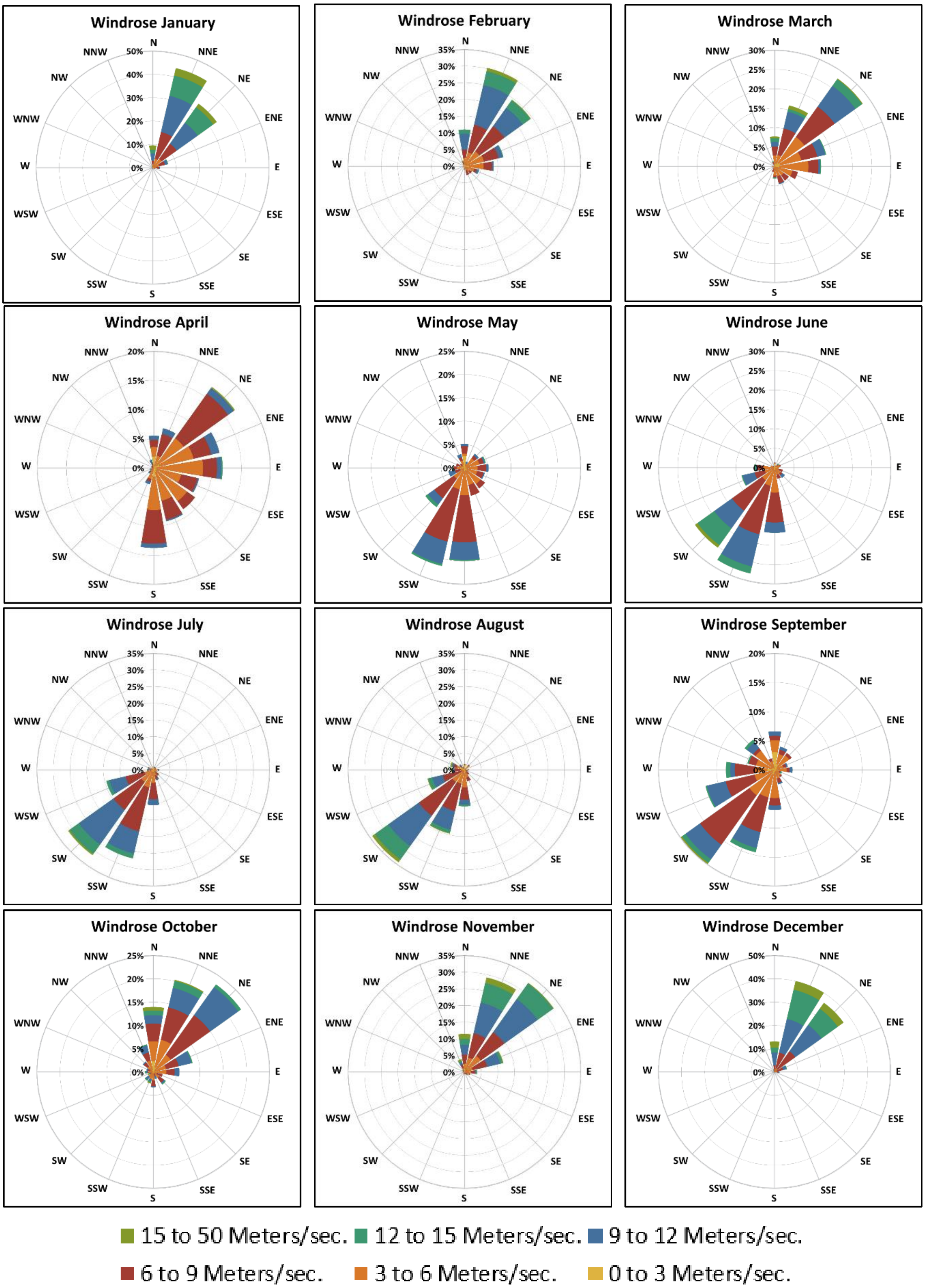
B RIVER DISCHARGE PER MONTH



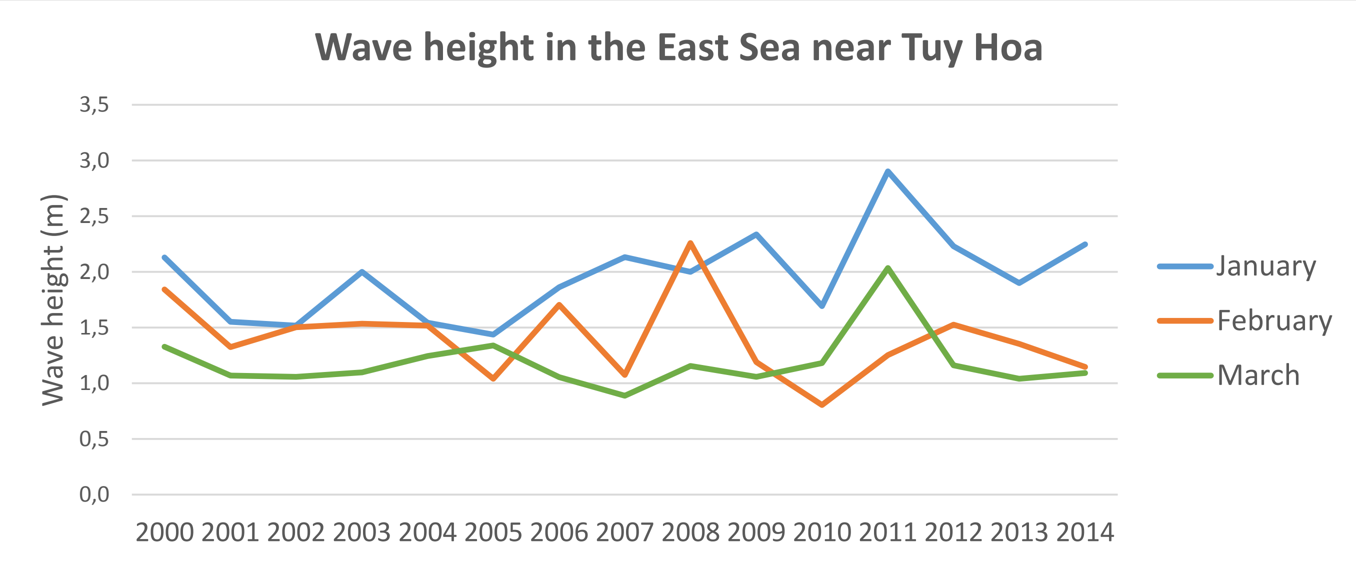


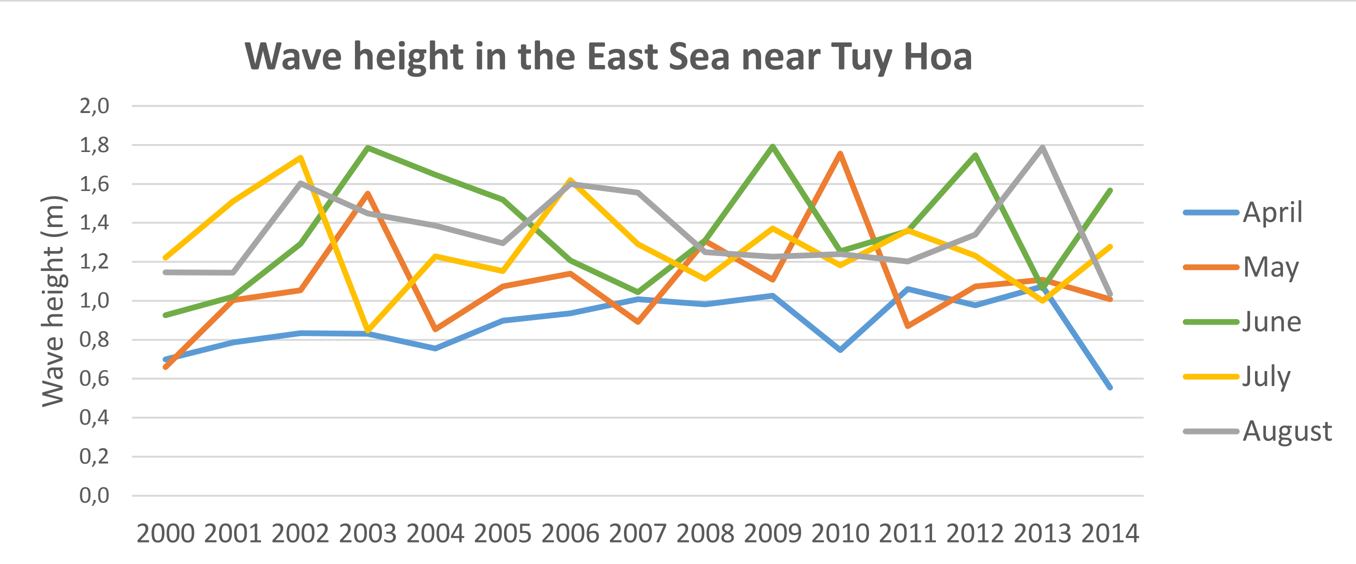


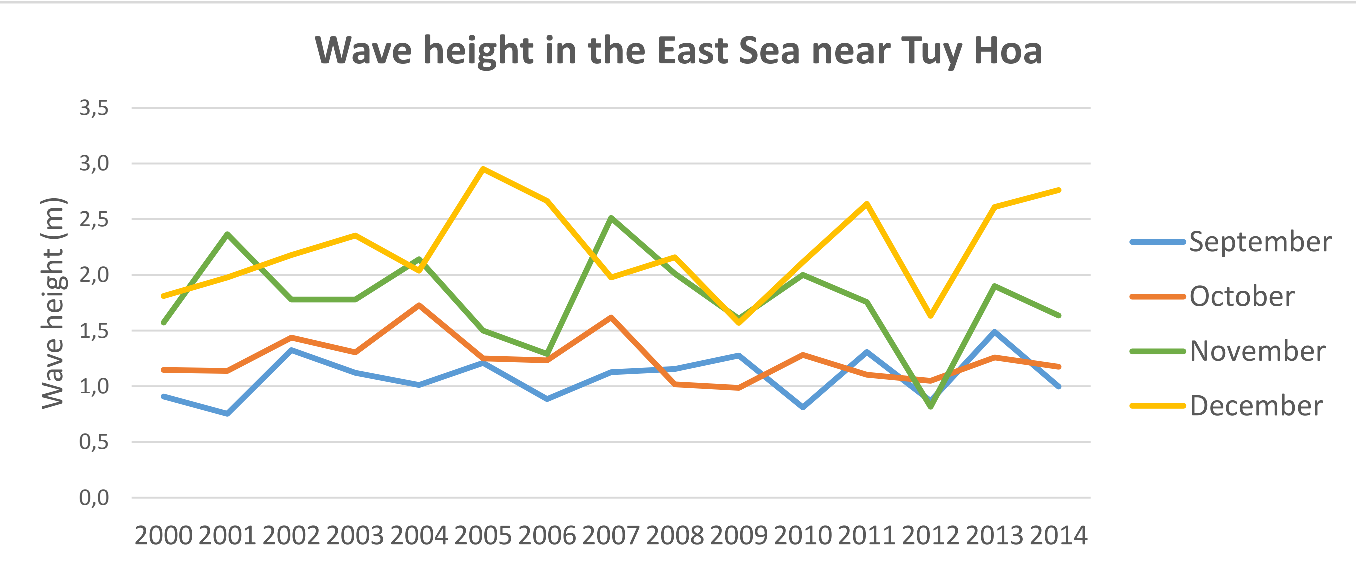
C WIND PER MONTH



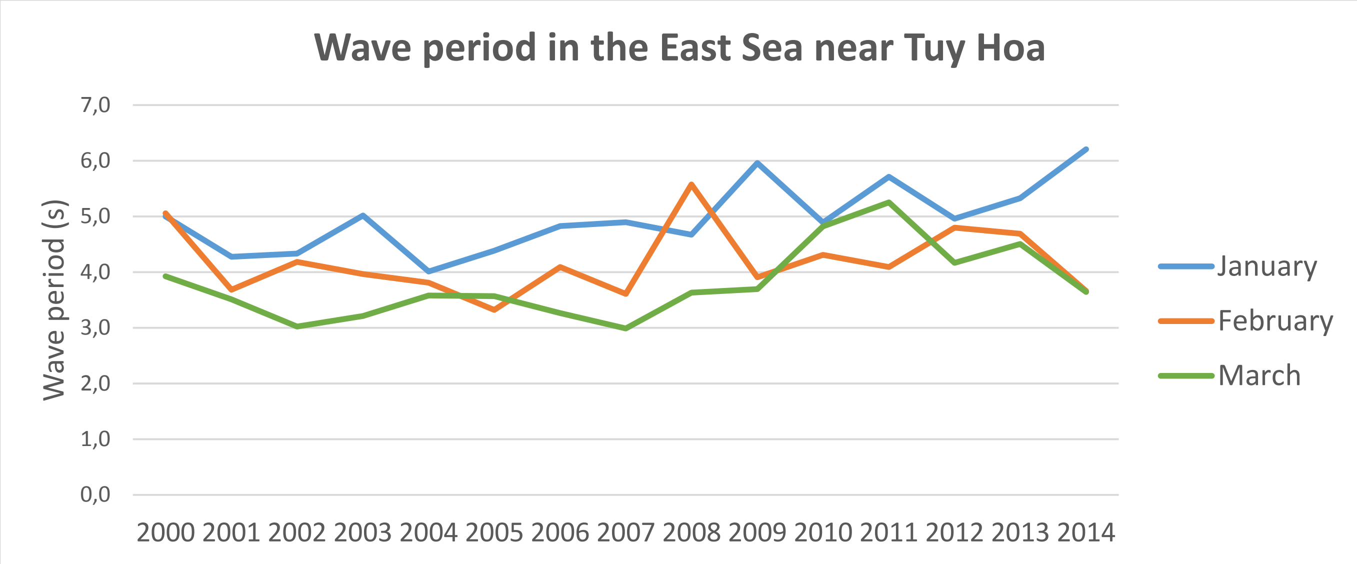
D WAVE HEIGHT PER MONTH

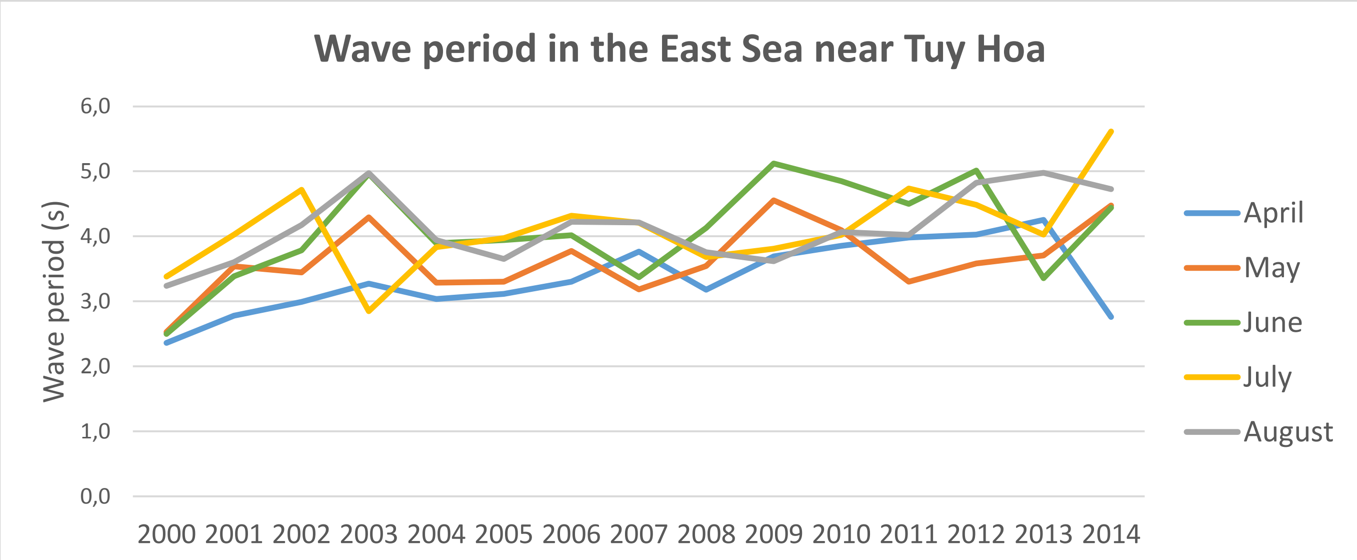


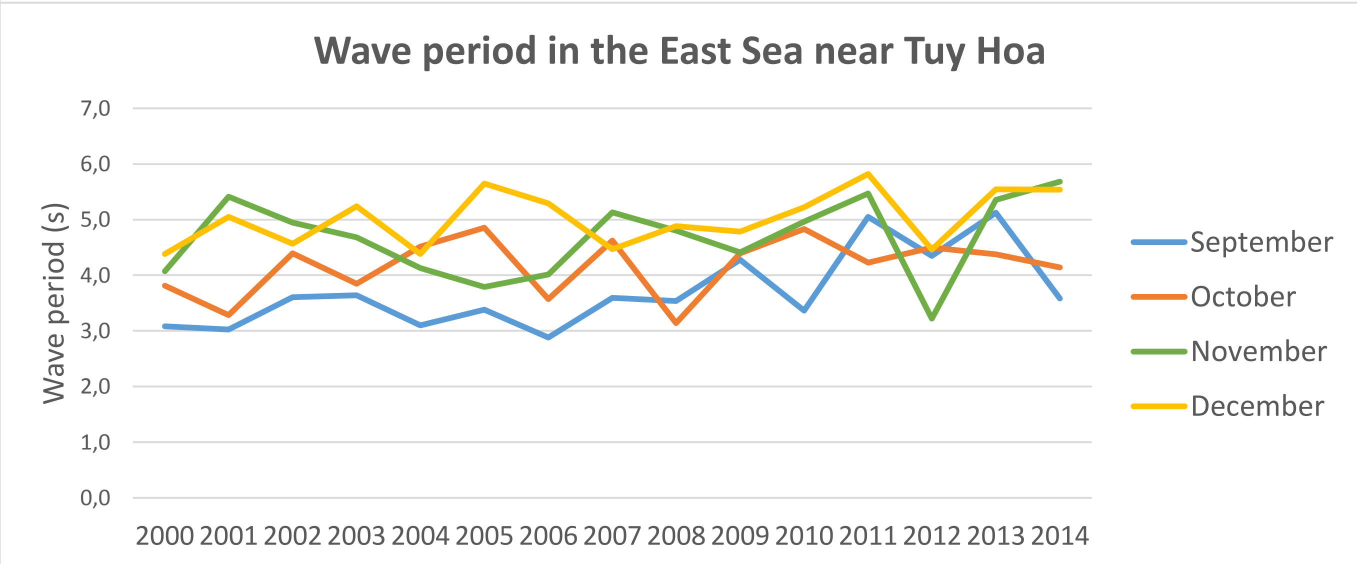




E WAVE PERIOD PER MONTH







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