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MASTERTHESIS

Development of sustainable coastal protection concept for Ca Mau/ Vietnam

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Abstract

The Mekong Delta in the South of Vietnam is the third largest economic region of the country. Enabled through a flourishing agri- and aquaculture, this region is subjected to constant economic development and growth. However, in near future the area faces serious problems. Environmental and climatic changes combined with the pressure on natural resources and biospheres have a high negative impact on the actual flourishing region. For coastal regions flooding and saltwater intrusion are next to erosion processes the main threads. Measures done in the past have not shown any significant impact on these problems, partly due to the poor local realization. The Integrated Coastal Management Program of GIZ Vietnam in collaboration with the Vietnamese Ministry for Agriculture and Rural Development tries to develop a cross-provincial coastal protection strategy for the entire Mekong Delta. This research study aims to contribute at this central issue to the program. In a small-scaled frame the study examines cross-provincial aspects, which will then provide the basis for a large-scale solution and implemented strategy. The studied geographical area is restricted to the West Coast of the Mekong Delta. The various coastal protection strategies are clarified followed by a local inventory of the considered area. The local inventory focusses on existing coastal protection structures, in particular on the existing dike system and the mangrove forest. A morphological analysis of the coast line development is undertaken in order to estimate future development trends of the coast line and to identify potential critical hot-spots in the near future. The findings from these analyses are then implemented into the case study, which aims to estimates the effect of different trends of the coastal area on the dimensioning of a dike system. Different coastal protection strategies are discussed on the basis of the results and the protection strategy has been identifies as the most sustainable solution. Additionally, a staggered arrangement of soft and hard coastal protection structures was found to complement the given needs. The extension of existing data sets regarding wind and swell parameters, as well as substantiated information on topographical and bathymetrical conditions are required for a more specific and detailed analysis in the future. Further, the coastal protection function of mangrove forest has to be explored in a wider context taking into account the damping effects during storm events and the change of the wave period caused by floating through the forest.

Zusammenfassung

Das Mekong Delta im Süden Vietnams stellt den drittgrößten Wirtschaftssektor des Landes dar. Als wichtiger Landwirtschaftssektor und sowie die immer größere Nutzung des Gebiets durch Aquakulturen erlebt die Region derzeit einen enormen Wirtschaftswachstum. Trotzdem ist das Gebiet erhebliche Problemen und Herausforderungen gegenüber Gestellt. Der weltweit zu verzeichnende Klimawandel sowie Umweltveränderungen wirken sich zusammen mit dem Rückgang der natürlichen Ressourcen und der Biosphäre negativ auf den derzeitigen Fortschritt aus. Für die Küstengebiete bedeutet dies, Erosionsprozesse der Küstenlinie, Zunahme an Überschwemmungen und eine ansteigende Versalzung des Bodens. Bislang durchgeführte Maßnahme, diesen Problemen effektiv entgegen zu wirken haben noch keine signifikanten Erfolge erzielt. Ein Grund kann die auf eine Verwaltungsgrenze beschränkte Umsetzung der Maßnahme sein. Das„Integrated Coastal Management Program“ (ICMP) der GIZ Vietnam, in Kooperation mit dem vietnamesischen Ministerium für Agrarwirtschaft und ländliche Entwicklung (MARD) sieht aus diesem Grund die Entwicklung einer Grenzen überschreitenden Küstenschutzstrategie für das gesamte Mekong Delta als zielführend an. Mit der Entwicklung eines nachhaltigen Küstenschutzprojektes im Rahmen eines gegebenen Untersuchungsgebiets trägt die vorliegende Arbeit als Basis für eine großflächige Umsetzung dazu bei.

Das Untersuchungsgebiet ist auf die Westküste des Mekong Deltas begrenzt und wurde im Frühjahr 2015 einer Bestandsaufnahme bzgl. der derzeit vorhandenen Küstenschutzstrukturen, insbesondere des Deichsystems und des Mangrovenwaldes, unterzogen. Nach der näheren Erläuterung der allgemein gültigen Küstenschutzstrategien wird eine morphologische Analyse der Küstenlinie vorgenommen, um zukünftige Entwicklungstendenzen herauszustellen. Die dadurch potentiell ermittelten kritischer Gefahrenpunkte werden in einer Fallstudie auf ihre Auswirkungen auf die Dimensionierung eines Deichsystems untersucht. Aus der Diskussion über die infrage kommenden Küstenschutzstrategien hat sich die Verteidigungsstrategie als nachhaltigste Küstenschutzstrategie erwiesen. Zusätzlich wird empfohlen, die Verteidigungsstrategie durch eine Staffelung verschiedener Schutzsysteme bei ihrer Umsetzung zu verstärken.

Für detailliertere Analysen sind die Erweiterungen des Datenmaterials hinsichtlich Wind- und Seegangseigenschaften, sowie die genaue Kenntnis über die Topographie und Bathymetrie dringend notwendig. Des Weiteren muss die Schutzfunktion von Mangrovenwäldern noch intensiver untersucht werden, sodass Aufschluss über ihre Dämpfungswirkung während Starkregenereignissen und ihren Einfluss auf die Änderung der Wellenperiode beim Durchströmen des Waldes gewährleistet werden. Nur mit der genauen Kenntnis über seine seegangsdämpfende Eigenschaft kann er als Küstenschutzsystem sinnvoll in Küstenschutzstrategien mit einbezogen werden.

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1 Introduction

This research study has been initiated and financed in the context of the live project “Integrated Coastal Management Programme” (ICMP) of the German Society for International Collaboration (Deutsche Gesellschaft für international Zusammenarbeit (GIZ)) in Vietnam. The project is commissioned by the German Federal Ministry for Economic Cooperation and Development (BMZ) with expected termination date in 2017. The national lead executing agency of this project is the Ministry of Agriculture and Rural Development of Vietnam (MARD). The ICMP project was partly co-financed by the Australian Government’s Department of Foreign Affairs and Trade (DFAT) (2010- 2014). This research study is the result of a close collaboration between the GIZ Vietnam, MARD and the RWTH Aachen. The object of the ICMP project is the coastal area of the Mekong Delta in South Vietnam and the interlinked challenges of strengthening this area against environmental and climatic changes (GIZ ICMP 2015). At the time of this study, the project which is set for the period of time between 2010 and 2017 reached its second phase. The main focus of the second phase is to scale up the small-scale solutions developed in the first phase of the project and to integrate solutions into the broader integrated coastal management system of the Mekong Delta. Under this aspect, the present study has been carried out.

The Mekong Delta is the last section the Mekong River (the tenth largest river on earth) has to pass before it reaches the Vietnamese East Sea (South China Sea). Formed by amounts of silt which got carried downstream by the river itself the Mekong Delta of today is a low-laying area in the south of Vietnam. The area measures approximately 39,000 km² with a population of approximately 18 million people; which is almost 20 % of the whole Vietnamese population concentrated only in the southern tip of Vietnam (Alliance 2015). Due to its size, topographic characteristics and population the Mekong Delta is comparable to the Netherlands. Furthermore, the Mekong Delta plays an important role for the national agriculture. Known as the “rice bowl” of Vietnam, approximately 46 % of the total amount of food in Vietnam is produces in this area (Hays 2015) which is therefore one of the strongest economic regions in the country after Ho Chi Minh City and the capital Hanoi. The economic development of this area is still rising. More and more, shrimp farming as a new branch of the aqua culture is spreading in the coastal near areas and developed industrial urban zones are growing continuously resulting into an annual population growth of 1.1 % in this area. However the area faces serious reasons of concern. Environmental and climatic changes may have a high negative impact on the actual flourishing region. One of the main concerns is the pressure on natural resources and biospheres. Another threat comes with the global climate change. The increase of extreme weather events like storm surges and typhoons in combination with sea level rising represent a serious risk of flooding and erosion for this area. Another effect of the rising seawater level is saltwater intrusion. The resulting saline soils have a considerable impact to the future agricultural production. In the scope of this study the problem of flooding and erosion processes in the coastal area has been closely evaluated. Missing effective coastal protection strategies and structures, as well as improper dimensioning caused by missing data sets represent a major vulnerability in the coastal protection of this area.

In line with the current phase of ICMP the objective of this study is the development of sustainable coastal protection concepts for Ca Mau/ Vietnam. During the process of this study, the condition of the study area becomes more specific. Following the main idea of ICMP to create an interprovincial coastal protection strategy, the study area has been extended to the western neighbour province of Ca Mau up o Kien Giang. Due to the wide range of examination aspects, resulting of the problem definition, the width of the study area is restricted by the city Dá Bac, in Trân Van Thói District, Ca Mau up to An Minh District in Kien Giang province. The north border is set in An Minh as the realisation of inventory is time consuming and limited in the scope of this research. The borders of the geographical area are chosen to be in the north: 104.8809 4.7753 in the south: 104.8108 9.1786. This area is characterised by an intensive use of the dike hinterland for agriculture. In the foreland old and still used aquaculture ponds and settlements (for more information see chapter 2) carve up the mangrove forest, which represents a natural barrier between the sea and mainland. Another restriction is given by the available data. The data set of real field data is highly limited which leads to several close-to-nature assumptions in the following chaptures.

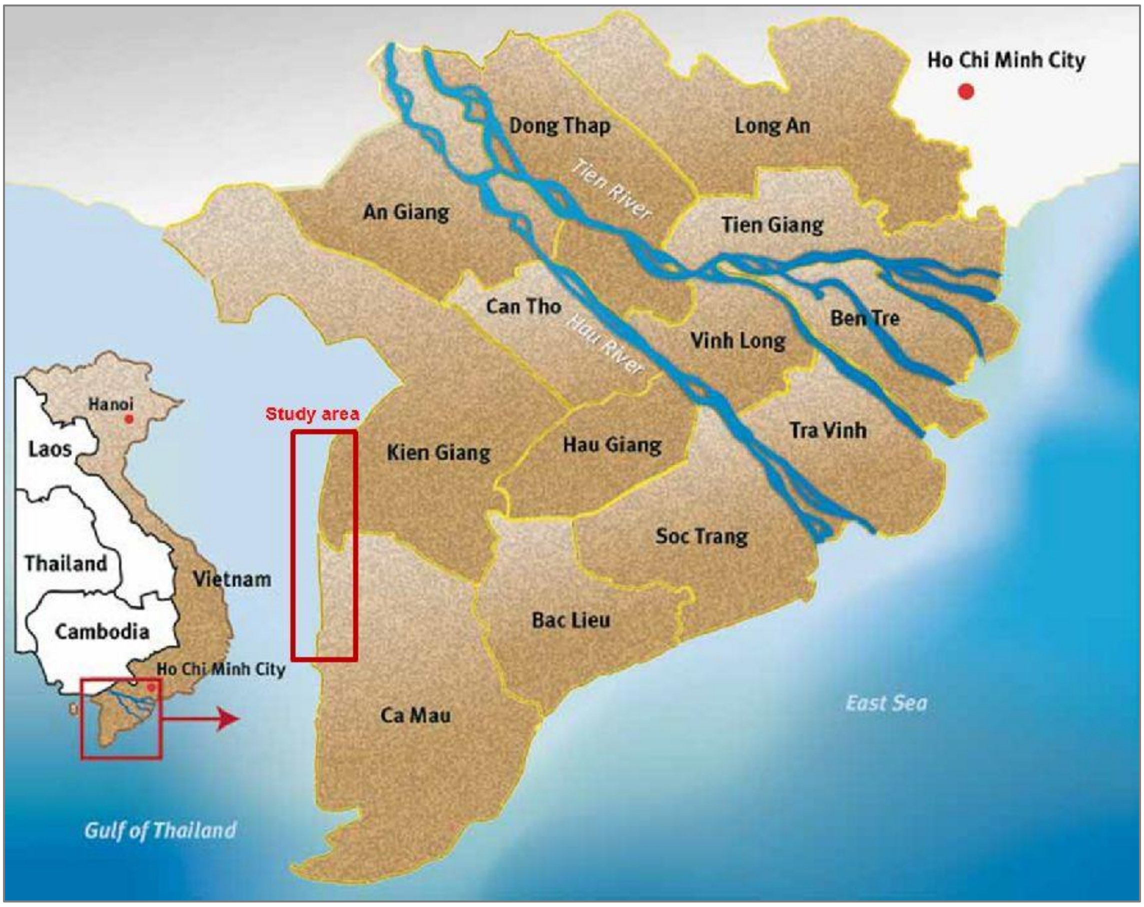


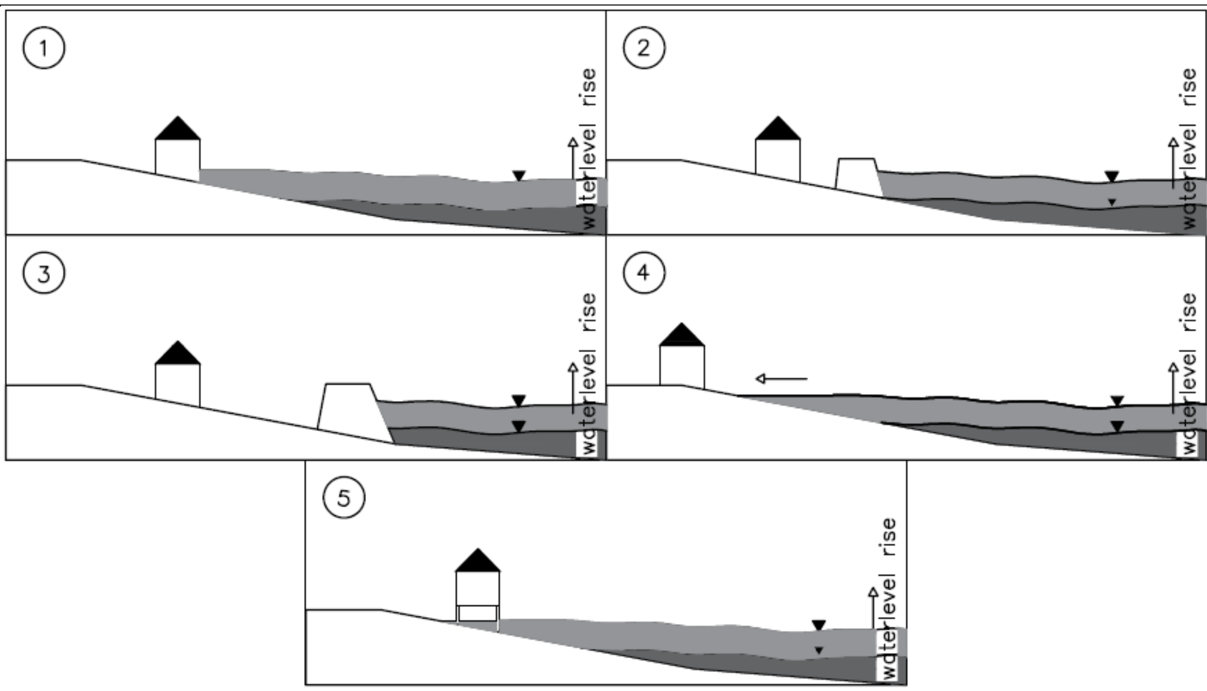
Figure 1-1 Position of the study area (Albers 2013)

For the development of a sustainable coastal protection strategy in the study area, a basis has to be established during the implementation process of this study. The first step is the development and implementation of an inventory from the existing coastal protection structures; this also includes the inventory of the existing foreshore. Furthermore, the morphological changes of the coastline will be estimated by the analysis of satellite imagery. The combined examination of both aspects may indicate hot-spot areas which possibly will have an influence on future decision regarding the development of a coastal protection strategy. The fact, that mangrove forests have a protective function is considered by experts to be true. However, the protection effect during a design event is not clearly answered yet. A literature research examines this issue in more detail. In a further step, the dimensioning of the existing dike system under different conditions of natural and human impacts is carried out, whereby this process has been based on given rating data and supplemented by justified assumptions. Based on the results of this analysis a discussion of the current coastal protection strategy and suggestions for improvement will bring the study to a close.

2 Coastal protection strategies

2.1 Types of strategies

The coastal area is exposed to the hydraulic forces of the sea every day; representing the interface between the land and the sea. The local condition of natural dynamic processes such as tides, waves and storm surges are the reason for a continuous change of the coastal environment (QGOV 2014). In addition, humans have a significant influence through its lifestyle, too. Using the coastal area for economic aspects like fishery, shipping, (aqua-) farming and other interests such as tourism and recreation or as a location for harbours and off shore installations an impact on the environment cannot be denied. Population growth, urban and industrial development in connection with sea level rise and the increase of extreme weather events caused by climate change creates a tension that needs to be solved continuously. Against this background the aim is “to create a balance between the benefits of economic development and utilisation of coastal regions by humankind, the benefits of protection, preservation and restoration of coastal zones, the benefits of minimisation of losses of human life and property as well as benefits of public access to and enjoyment of the coastal zones, at all times with the limits set by natural dynamics and stress-bearing capacity” (EU Commission, 1999, A European Strategy for ICZM, p. 16). Four general strategies are named by the Intergovernmental Panel on Climate Change (IPCC 1990)and Probst (Probst 1994) to solve the tension. They all represent adaptation measures by humans: managed retreat, accommodation (limited intervention), hold the line (protection) or move seaward (land reclamation).



1. Initial Situation 3. Land Reclamation (move seaward) 5a. Accommodation (human behaviour)	2. Protection (hold the line) 4. Managed Retreat

Figure 2-1 Coastal protection strategies (Sikora, following (Probst 1994), (IPCC 1990))

The primary intention of each strategy is to protect the human life, its goods and its environment against the impact of the sea like flooding or erosion. In general, each strategy always causes different consequents to the environment, the economic, as well as to social and cultural spheres. A retreat means a large burden for the individual as well as for the community. It may be prevent economic development of coastal areas, conclude contracts, which guarantees withdraw from the area if it is necessary by the locals independently or give them as much information about the threat that they can estimate the risk by themselves. Generally land abandonment means mostly cultural and economic losses but guarantee the least impact on the environment. For this an advanced planning and social acceptance is essential. Accommodation as a smart solution could be done physically by the change of construction methods or land use and also in a psychical way, which implies the change of lifestyle towards a closer connection to the coastal characteristic. The protection efforts measure to protect the area against flooding, tidal effects, coastal erosion, salinity intrusion and the loss of natural resources. Measures can be separated between hard and soft strategies. Thereby hard structures represent a significant impact on the natural appearance like dikes, seawalls, break water, sluices and revetment. The opposite are the soft structures with mimicking nature processes. Sand nourishment, dune rehabilitation or the support of increasing marsh land are some examples. The land reclamation is an additional strategy named by Probst (Probst 1994). Pushing back the sea with hard structures as dikes or soft structures like dunes, a new area is harnessed with improved safety against the coastal changing effects. Even the strategies are described independently of each other in reality a clear isolation is not always useful nor possible.

Which strategy should be chosen depends of course on different aspects. On the one hand there are social interests which have to be revealed contrary to the given natural circumstances, which request a sufficient expertise in the field of coastal engineering. To avoid an unstructured and parallel work of the different experts, a goal orientated action plan is needed to face the challenge of coastal protection. Therefore an authority has to be determined with the task for leading an analysis of the coastal situation and the definition of projection targets, which represents the common interest of a community. Thereby the community could include national and international interests. The projection targets finally have to set authoritatively at by law, regulations, remissions or specific plans.

2.2 Selection and implementation of coastal protection strategies

First of all, the establishment of a strategy is based on the protection target of the community, defined by common interest. Furthermore, boundary conditions like the environment and available resources have an effect on the decision. The wide range of variations of boundary conditions makes the simple comparison between the same strategies at different implementation areas difficult.

Following different possibilities in the implementation of strategies are represented, taking the protection targets of the respective investigation area into account. The projection target of the West Coast of the Mekong Delta is to reinforce the coastal area and guarantee a higher safety against future extreme events, in combination with sea level rise. This also includes the significant reduction of flooding and erosion processes. The following examples should just represent a way of implement similar project targets as determined for the study area of this study. The deviation of boundary conditions is not considered.

The first example is Germany, as a country with a historical way of coastal defence represents the systematic implementation of the protection strategy (Hofstede 2009). The complex dike system, which got optimised over centuries, is now one of the most effective dike systems worldwide, next to the Netherlands. While the earliest main issue was to protect the hinterland against flooding, the rise of agriculture and urbanising demanded land reclamation. The dikes also played a leading role as used structures. Today the focus of coastal protection strategies lies on reinforcing the dikes instead of land reclamation. As an example, Mecklenburg-Vorpommern, a federal state at the German Baltic Sea decided to implement a traditional, near-nature coastal defence strategy by an adjusted dike system due to the existing topography and usage. In particular with the precise determination of floodplain areas, connected with land use, the course of the dike line has been adjusted to a system of ring- and line defence systems. A ring dike system exists, if the size of the area, which should be protected against flooding, just represents a small surface size. This might be farmsteads or cultivated areas. To accept the resulting flooding of the areas outside the ring dike during floods is one form of accommodation strategy. Another type of accommodation is represented at urban areas without dike system. Mobile flood protection walls are named as one option. Furthermore, the dispatch from areas, which don't pose a risk while land losses are happening, is part of the near-nature coastal defence strategy (Hofstede 2009)

Another example is the US state Louisiana. In 2005, the state had to struggle with the two hurricanes Katrina and Rita. After the storms, damages of up to $ 100 billion in connection with enormous land losses and flooding indicate that the system does not offer the necessary level of safety against storm surges, erosion, subsiding of land and sea level rising. As a result, the decision to implement a new coastal protection strategy was set by the authorities. The following analysis of the strategies applied in the Coastal Master Plan (CPRA 2012) of Louisiana focuses on the southwest coast with almost straight coastline without natural cover through mangrove forest and the southeast coast with a mangrove belt. In general, the idea of the protection strategies in Louisiana, Southwest Coast is a combination of all the four strategies, but the basics represents the restoration of natural structures (land reclamation strategies) and also the construction and repair of hard structures (strategies of protection). Up to now the restoration of headland, marsh land and bank stabilisation by sediment dredging and placement is done and the first positive effects are visible (USACE 2015). The aim is to restore the lost land and to reinforce the existing, to guarantee wave and swell damping through natural foreland. Additionally, to prevent the ongoing erosion at the shore line, breakwaters as hard structures are built and restored. Furthermore, the target of the specific construction of levees; similar to the German strategy in Mecklenburg Vorpommern, is the protection of low-laying densely populated areas against flooding. All households and useful areas in front of the dikes have a potential risk of flooding and are responsible for their own safety. As support through the government, the affected parts receive information material and construction ideas for accommodation measure. Since 2005 are all hydrological structures checked regularly and restored if needed. The ongoing project provides the expansion of the bank stabilisation, the dike and breakwater system, as well as the increase of restored marsh land and ridges. Also decisions for new hydrological structures like sluices, weirs and pumps have been made. Therefore, the combination of the different strategies represents a cost effective solution.

The Golden Coast at Queensland, Australia gets taken as example for a small scaled implementation of coastal protection strategy. Here, the main problems are strong erosion along the coast and the impact of the tweet river estuary and further instabilities at estuaries in position and depth. A main goal is to achieve a level of stabilisation at harbour areas and creeks. The solution based on a detailed study by the Delft Hydraulic Laboratory, the “Delft Report” of the seventies (Delft 1970) results in a combination of protection strategy and retreat, whereas the retreat plays a minor role. The construction of ‘training walls’ at river entrances, creeks and ports should guarantee a stop of the erosion in this areas similar to the continuous sea walls along the shore line. In addition, sand nourishment as a soft strategy should keep the sand budget in balance along the coastline. Since 1999, an additional strategy is being launched (AUGovernment 2014). Seen as a soft accommodation strategy, the aim of the sand bypassing project is to create a natural means of moving by sediments. It is designed to ensure the transport of natural moving quantities of sand along the coast while the stability of position and depth of ports and river entrances is secured. A retreat of eroding areas will be reimbursed only if the policy and economy accept it.

Generally, the comparison makes it very clear that with the definition of a coastal protection target and the requirements building, a simple conclusion regarding the choice of effective strategy is not possible. Aspects like financial resources, socio-economic and ecological interest have a large impact as the technical aspect regarding the choice of one particular strategy.

2.3 Coastal protection strategies in Vietnam

Based on Vietnams prime minister decision of 2009 about the approval of reinforcement and upgrading of the existing sea dike system from Quang Ngai to Kien Giang, the protection target is: "to prevent the negative impacts from the sea, protect people's livelihood and sustainable socio-economic development in coastal provinces in combination of a coastal road system for socio-economic development and coastal defence" (SRV 2009 p. 1). Basis for the determination of the dike dimension is the Technical Standard for Sea Dike Design of the Ministry of Agricultural and Rural Development of Vietnam (MARD 2012). The current implementation of this protection strategy is still in process, which has the effect of self-help and first aid measures by individuals in the past (chapter 3.2.4). At many locations along the coast the implementation of accommodation strategy is visible and realised by the locals. Simple methods should protect their goods against flooding. One method consists of buildings, which are elevated on stilts. This method is mostly chosen when the settlement is close to the sea where flooding is likely to occur. Another common method is the acceptance of flooding in connection with temporary evacuation of the affected area by the locals; whereby the evacuation mostly takes place in individual initiative by annual flooding. An official evacuation initiated by the government only takes place in the case of extraordinary events like typhoons (Tuoi Trenews 2014).

Above Quang Ngai, for the northern Vietnam the report "Coastal Protection Strategies for the Red River Delta" of Mai et al. examines the coastal situations from the past up to know and also gives an advice for the future. The low-lying area includes six river mouths and the main issues are indicated as fluvial and coastal flooding and associated land erosion (Mai, Cong V. et. al. 2009). Here, the main sea defence strategy is a sea dike system with multiple defensive lines, which are separated by sectioning of sub crossing dikes. Still, an effective dike foot protection does not exist. The analysis of the past and current situation of publication date of the report, charges the high factor of failure mechanism for this system. Typical failure mechanism are overtopping of the dike, foreshore erosion, instabilities of armoured layer and geotechnical failures. Its solution is to separate between strategies and structures for protection the hinterland against flooding and measures which reduce the ongoing erosion along the sea shore.

Along the whole coast of Vietnam several methods were carry out, trying to avoid and compensate negative processes. Sea dike systems in combination with sea walls or shore revetment are individual protection methods which implement the protection strategy. Especially for the erosion issue, as an alternative strategy accommodation strategies are tested out at the Mekong Delta. Therefore Mangrove reforestation (natural or planted) with supporting structures like T-fences or simple bamboo fences should counteract the process of erosion (GIZ KG 2012), (Albers 2011). Additionally, the construction of breakwaters in front of the shore should support the accretion of the foreland caused by sediment deposition.

The following chapters analyse the existing coastal protection strategy of the study area and give a recommendation for the future course of action. The measure of reforestation of Mangrove forests is taken under special consideration.

3 Inventory of the coastal protection structures

The aim of each inventory is to create a basis to support political, economic and technical decisions for further investigations, plans and projects. An inventory requires always a reference time. It can be done periodically or irregularly, based on regular events, for example after the winter season or following a significant event such as after a great flood. In this work assignment, a one-time inventory is useful, because no other reference material or inventories are available to the author. For further coastal protection plans at Ca Mau – West Coast/ Vietnam it is essential to know the whole inventory of coastal protection structures of today. Only with this the actors can start to develop evaluations, needs assessments and general plans. The content of the following inventory should list all anthropogenic changes and existing structures which may have an influence on the ecological and morphological nature of the coastline at West Ca Mau. As seen below, one may differentiate between seaward structures, structures at the contact zone and landward structures; this also can be applied to anthropogenic changes of topography. Another option is to separate between structures which appear regularly and in line; and structures which constitute an exception.

Table 3-1 Coastal protection structures and types of coastal land use

Offshore structures	Contact zone land – sea	Landward structures
T-fences	Sluice gates	Bridges
Groynes	Canals	Roads
Barriers	Pumping stations	Houses
Wave breakers	Dykes	Pipes
Wind parks	Revetments	Others
Pipes	Harbours and shipyards	
breakwater	Weirs	
Others	Pipes	
	Others	
Seaward change	Change at contact zone	Landward change
Dredging areas	Forest	Agriculture land
Dumping areas	Beaches	Aquaculture land
Shipping areas	Dunes	Living spaces
Fishing areas	Salt marshes	Military zones
Protected areas	Military zones	Protected areas
Others	Protected areas	Tourism areas
	Others	Others

For the information acquisition, different sources are available, which have to be compared with each other and also get checked of topicality. Sources are the existing reports from GIZ and SIWRP and available data banks of the authorities. In addition, all information is double checked with a field visit. Also satellite pictures are a useful support to proof the locations and non-documented structures.

3.1 Design of the concept

To take stock of coastal protection structures means to build a basis for future investigation and also for influencing actual decisions. Therefore, a well-structured and transparent inventory is necessary. In this study, the main focus is represented by the dike line being the spatial line of orientation for the field visit. The coast line itself doesn't get a more detailed inspection, because except of sea walls currently (?) under construction no other structures are known. Naturally, the sea walls will get inspected during the field trip, but only selectively. A more detailed view of these structures is taken by Philipp Jordan, B.Sc. with his master thesis (Jordan 2015)..

3.1.1 Linear reference system

The first step is to give the investigation area a defined linear referencing. A significant stationing is necessary to facilitate later mapping of the different locations in the right way. As linear element, the dike line is selected. As no former inventory is present, the canal close to the landmark between Kien Giang and Ca Mau province is chosen deliberately as origin of the stationing. In consequence, kilometre zero (km+0) designates the border canal between these two provinces. Thence along the up going northern coastline is scaled positively, while going on in a southward direction from km+0 the stationing increases negatively with the distance. Other opportunities for setting the origin of the stationing are possible. On the one hand, taking the landmark, on the other hand the beginning or end of the investigation area also guarantees a defined referencing. The disadvantage of taking the landmark as origin is its landward laying position instead at the dike line. It makes it more difficult to combine it with other stationings which already exist without being noticed or will be set in future. To guarantee a complete inventory the practical implementation of the survey starts at the border between the two provinces, so that an obvious point is taken as a starting point. Due to the unknown time requirement to establish the inventory, the last stationing marks at each province aren´t as striking as the starting point. For the survey in Ca Mau, the last point is defined by reaching the southern end of the investigation area. Therefore, it is the last checked kilometre point before the canal. As being the last registered kilometre on the final survey day for Kien Giang, the last stationing point is at a random place in An Minh, close to a settlement with no other significant mark. That reflects the fact that the end points in the north and south of the investigated area are also not suitable for use as starting points of the stationing. Of course, the location can be found with the help of a GPS device, but a certain inaccuracy is always included. Therefore, recognition of the exact point cannot be guaranteed. In general, the distance between two position points is measured as the crow flies, as measuring the walking distance along the dike was not possible as described in the paragraph 3.1.3.

3.1.2 Positioning and measuring tool

To ensure the exact geo-referencing of the line reference system the coordinates of each stationing point and every anomaly is ensured by a GPS device. For this inventory, the GPS device “Garmin Oregon 550” is used. Thanks to the support of WAAS (Wide Area Augmentation System) the official maximal position deviation of the device is +/- 3 meters (TRAMsoft GmbH 2015) if the reception quality of the GPS signal is good enough. Additional deviation is given through the means of transport. As described below not every part of the dike is passable, so the distance between the stationing points can be varied.

3.1.3 Means of transport in the investigated area

The survey runs exclusively along the dike line, which is the main object of investigation within the inventory as described before. Therefore, the following types of movement are possible: by foot, motorbike, car and boat. However, the most effective way is to drive by motorbike directly on top of the dike given the limited time and also because this guarantees high precision. However, missing mounting of the dike crest in combination with the onset of the monsoon as well as a dense vegetation make the dike virtually impassable for a motorbike at most parts of the route. For this reason, most of the time the movement is done by boat as long as a canal exists next to the dike, landwards or seawards. The drawback of this option is that a visual check between kilometre points and, if going ashore is impossible, at the points can only be done from the boat. In this case, the back side of the dike and (missing noun?) cannot be taken into consideration. Even though it takes time to walk; some sections are inspected by feet. The great advantage is that the defect survey can be carried out very accurate and detailed due to the slow movement. All locations where a change of the means of transport takes place are pointed out in chapter 2.2.

3.1.4 Method of Evaluation of regular appearing structures and description

For the evaluation the different structures are viewed in isolation from each other. The overall evaluation will be done with a discussion in chapter 7. The survey differentiates between structures which appear regularly, like the dike or sluice gates, and structures or anomalies with an irregular occurrence. These are among other things pumping stations, canals and settlements. To ensure a uniform procedure, an investigation form is used for the dike and the sluice. All other structures and anomalies are recorded individually, depending on their characteristics.

3.1.4.1 Dike system

In accordance with the dike quick scan method of Scheres (2014) the dike is inspected in its three elements: seawards part, dike crest and landwards part. First the way of construction will be described including dike cover, revetments and toe protection in general. Further on each element gets analysed with regard to its condition, the rate of human impact and its type of foreland. Additional the condition is considered under several aspects, which are: erosion, vegetation cover, planted vegetables or fruit trees and impact due to wild animals, special animal borrowing. The condition of erosion at the three dike elements is differentiated in light and serious damage; whereas a serious damage has an adverse effect on the protective function of the dike, a light damage just represent a small loss of the cross section area without any negative effects regarding the dike function. To classify the vegetation it will be differentiated according to their size following the term stratification (horizontal layering of the forest). Therefore it will be distinguished in Canopy Layer, Understory Layer (up to 5 m), Field or Immature (up to 1,5 m) and also Ground or Herb Layer (up to 0,15 m) (Wikipedia 2015a). A Root Layer, as also defined at the ecological stratification doesn´t get estimated caused to its complexity of species identification even it is from high importance for dike security and stability. Furthermore, trees higher than 30 - 40 m are not expected, so a distinction between the Canopy Layer and Extended Layer isn´t necessary. The condition of animal borrowing does only get named without any further detailed description. Crabs are the main causes of the existing holes and small tunnels, which are used as borrows and go up to 2 m deep into the ground (C. Wesenberg-Lund 1943). In general roots and animal tunnel systems must be avoided at a dike system because they represent the basis of back-cutting erosion.

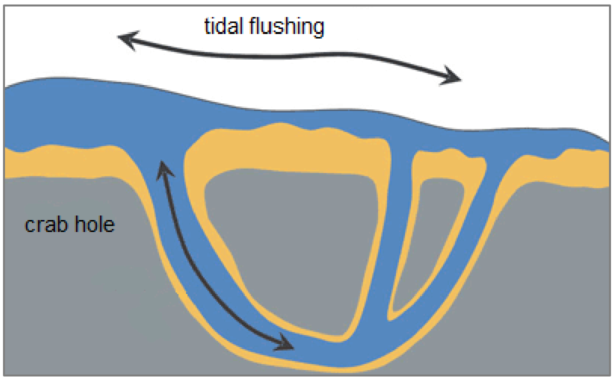


Figure 3-1 Wash out at the dike caused by animal borrowing or old root tunnels (ENACA 2001)

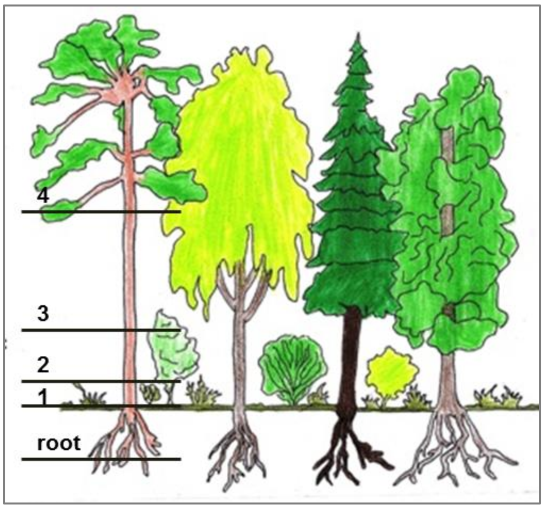


Figure 3-2 Layer of trees (BS 2015)

The degree of human impact is considered under several aspects in this analysis. One aspect is the use of the dike by the people in a variety of ways. Common possible uses are to utilize the dike as a path, a road, an area for cultivation of vegetables or for settlements and plantations. Other observed usages are noted as well. In addition, the land use directly in front of the dike is examined. A distinction is made between its usages as fallow land, settlement area, for aquaculture or mangrove forest. Also canals in front or behind the dike get noted. Finally the dike cover and toe protection is also analysed. The material and its type of construction with the dimensions will be written down.
For a quick overview of the dike inventory, all aspects are presented in a line system which represents the whole dike line. Each stationing point of the dike is represented by several rectangles, stacked on each other. Thereby each rectangle gives information about the existing condition and type of human impact by means of its colour. Green colour stands for “yes-the conceptual aspect exists at this stationing point” and red for “no-the aspect does not exist at this stationing point”, whereas a darker colour represents a serious damage through erosion and also a taller height of vegetation. Further, the visualisation of the different conditions of erosion, vegetation and animal borrowing separates between dike crest, landwards and seawards slope of the dike. The following explanation of Figure 3-3 is an example how to interpret the information of the line system (Annex A).

dike
no erosion
light erosion
strong erosion

forest
> 5 m, canopy layer
> 1.5 m, understory layer
> 0.15 m, Immature
< 0.15 m, herbal layer
no vegetation

structures
structure does not exist
structure exists

Figure 3-3 Introduction how to interpret the diagram „Inventory of coastal structures, annexes B

3.1.4.2 Sluices

Each sluice gate gets analysed using a detailed factsheet, which enquires data about the design and age of the building as well as information about the management plan. Regarding the design, the number of sluice gates and safety locks and their measures in wide and depth get investigated. For the measurement of dimension a laser measuring device is used. Information about age and management plan will be communicated verbally by an expert, who joins the inventory, and also from locals. This way has to be chosen because official documents are not available for this study. The revetment, which has the function of saving the embankment against erosion at the in- and outflow of the sluice, is visually analysed with respect to its material, dimensions, interlocking and condition. (Annex B)

3.2 Inventory

3.2.1 Investigation area and time

All in all, seven days were available for the whole inventory, whereby this time scale defined the extent of the investigation area. The inventory was carried out from June 3rd to June 11th 2015 and was accompanied by local authorities and experts during the whole time period. For the first three days the team had the permission for Kien Giang province, An Minh district and could estimate a distance of 29 km of dike line up to Thuân Hòa commune. The last four days (08/06/15 to 11/06/15) the team stayed in Ca Mau Province. The whole dike line of U Minh district and up to the end of Khành Bình Tây Bac commune at Trân van Thòi district got investigated, in total 38 km. Apart from the limited time, the weather condition due to the ongoing rainy season and uncertainties with permissions influenced the realization of the inventory.

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3.2.2 Existing types of structures

The inventory survey indicated just a small number of different structures in the investigation area, but going southward the number of several structures grows. For a first overview the existing structures along the dike line are listed separated by their position.

Beginning with seaward structures, only breakwaters which are located few meters in front of the shore are detected. At the contact zone several different structures exist. A dike line is always identifiable even though the condition doesn´t represent continuously the directive “Technical Standard for dyke design” set by the Vietnam government in 2012. 23 canals including 10 sluice gates interrupt the dike line. Another 4 sluices are under construction. In general, most of the sluice gate areas and canal mouths represent wharfs at the same time. Only one bigger area represents small harbour structures. Along the whole dike line just one pumping station is located on the dike. Revetments of the dike are represented in patchy.

Landward structures are represented by settlements which are built on top of the dike or close to it at the landward- and seaward side. Almost continuously a path is going on top of the dike line which represents a comfort way without any additional work effort for other connecting paths. It is used by motorbikes, bicycles and as a footpath to connect the settlements in the shortest possible way. Furthermore, a bridge and several pipes for shrimp farming or fresh water for the settlements in front of the dike line break through it.

Table 3-1 Types of coastal protection structures

characteristic	type and number of structures	
offshore structures	sea walls	
structures at the contact zone	1 sea dike line 9 sluice gates (2 under construction) several wharfs	23 branch canals 1 small harbour 1 pumping station
landward structures	settlements pipes	1 bridge Path

3.2.3 Overview plan

The general maps at annex C show the location of the different structures and conspicuities at the profile. Each map has the reference scale of 1:50,000 and shows on average 10 km of coast line. Following objects are featured: dike line, stationing, sluices, further interruptions of the dike lines, existing sea walls if visible at the used satellite pictures, settlements on the dike, pipes through the dike, bridges and in total all other conspicuities.

3.2.4 Detailed consideration

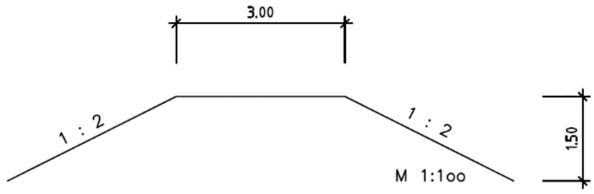
Building on the concept which got formulated under section 3.1, the existing structures get closely inspected and assessed in this sublevel, separated on their condition.

3.2.4.1 Dike system

During the available time for the inventory (3.2.1) 63 stationing points are gathered, whereby the distance between the highest and lowest point is 68 km. Referenced to the stationing, km (-25) to km (-28) could not be included in the inventory, because their exposed location between two canals in connection with the muddy condition of the dike crest after rain makes it impossible to check them during the limited time. Due to the condition of the dike and the additional dense vegetation the onsite visit of km (-19), km (+16) and km (+28) is not possible. For these locations only a visual check is done from sitting inside the boat. Another special feature applies to km (-3), km (-4) and km (-5), but this will be mentioned at a later point of this sublevel.
A general overview about the different aspects of dike condition, named at **Fehler! Verweisquelle konnte nicht gefunden werden.** is given in Annex A. The detailed summary gets presented in the following sections:

3.2.4.2 Construction of the dike:

In general the dike of the investigation area is a homogeneous earth dam, made by local soil. Since 2014 Ca Mau Province has started to reinforce the dike line down from the border of Kien Giang. The official dimension of the new dike cross profile are showed at Figure 3-5. The construction plan includes a fastened road on top of the dike. From km (0) up to km (-12) the reinforcement of the dike is under construction; stated that at the time of the inventory. The official dimension of the old dike cross profile gets estimated with a crest wide of 1.5 m and a high of 3 m (Figure 3-5); even the real dimensions are different, caused by erosion, settlements or ageing process of the structure.



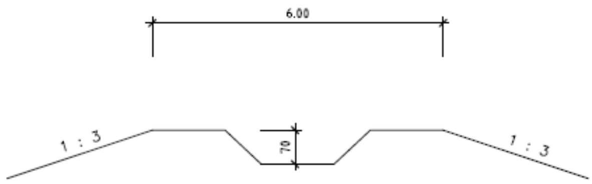


Figure 3-4 old cross profile, dike Ca Mau (Sikora)

Figure 3-5 new cross profile, dike Ca Mau (Sikora)

Starting in June 2015, the Southern Institute for Water and Resources Research (SWIRR) has carried out the measurement of the dike cross profile on behalf of GIZ Vietnam to get the exact information. The measurement data cannot be taken into account in this study, because the contract has not yet been completed.
Furthermore, a reinforcement of the dike line also has been implemented around km (+8) and km (+23). Instead of increasing the height of the dike, it got broadened. For extending the dike profile, the soil used for the construction gets mostly dredged directly from in front or from behind of the future dike line. As a result, flooded trenches occur parallel to the dike line and are used as waterways. First, the waterlogged soil gets placed on its future position for drying. At a later date, it gets solidified by hammering it into place using a bucket. The soil used in the construction has the characteristic of sandy silt. The position of the resulting channel placed at the dike hinterland is from km (-38) to km (-33), from km (-24) to km (-21), from km (0) to km (+16) and also from km (+26) to km (+29). In front of the dike line, the channel is posed from km (-31) to km (-29) and from km (-20) to km (-18). A channel at both sides exists from km (+17) to km (24), whereas at km (-17) to km (-1) no channel is located next to the dike. The process of earth deposit for the dike induces an untypical cross profile of the dike. The way of digging the soil close to the channel makes it nearly impossible to create a stable dike toe. This happens at the actual construction side for the reinforcement of dike between km (0) and km (-15) at Ca Mau and in the past also at all locations, where a channel close to the dike foot exists (Annex C). The effect of the dredged channel in connection with the dike foot is visible in Figure 3-7. It must be taken into account that fish or shrimp ponds could border at both sides of the dike and create a similar situation. This situation gets discussed at the section “description of the land in front of dike”.

A dike toe protection and revetment is not provided in the construction, so the few stationing points with a dike toe protection and revetment indicate weak points of the dike system. There the local residents have constructed first aid measures to stop on going erosion of the dike toe. Weak points due to this issue are at km (-16) and km (-15). Here, several layers of different barriers were built to stop the erosion of the sea ward dike side (see also: “Condition of erosion”). First wooden fences were constructed; followed by sheet metal to protect the dike toe. On a later time, gabions were placed directly in front of the dike toe by government, because the construction made by individuals did not have the necessary effectiveness (Figure 3-6). Further at km (+1) to km (+4) and km (+11) also a wooden dike toe protection exists, as well made by local residents. Due to the missing toe protection the effect of consequent contact between the channels and the dike toe is ongoing erosion caused by tidal effects or ship waves.

Figure 3-6 First aid measures of dike toe protection and gabions km (-16) (Sikora)

Figure 3-7 Effect of dredged channels connected to the dike toe km (8) (Sikora)

3.4.3.3 Condition of erosion/ loss of dike body (soil erosion)

Next to the impact of the channels bordered at the dike toe, impacts of the sea, weathering and the human use of the dike are additional reasons for erosion. Looking at the erosion on the dike body only greater deviations are pictured, separated between light and serious damage (3.1). The effect of erosion through the channel does not refer to a deviation, because whenever channel and dike toe just touch each other, an erosion process is available. Thereby the impact is mostly without serious impacts to the stability of the dike body. All erosion spots which are in serious condition due to the actual or future stability of the dike are listed below.

Actual serious erosion effects are on the seaward side mainly at Ca Mau province at km (-31) to km (-22) and around km (-16). Just at two stationing points a serious seaward pointed erosion exist in Kien Giang; km (+1) and km (+13). One reason is the canal along the seaward side of the dike. For km (-31) up to km (-22) ponds, located at the dike toe, are the reason for the loss of dike body. The break-off edge at the seaward pointed supporting body of the dike reduces the cross section enormously. The same also applies for km (+1) to (+3) in Kien Giang.

Figure 3-8 Difference in height at the dike surface at km (-41) (Sikora)

Figure 3-9 Loss of dike body km (4) (Sikora)

Around km (-16) the erosion is effected by the sea. As visible in Figure 3-6 no foreland protects the dike and the erosion reached the dike crest already. The width of the dike crest in this area is less than 4 m. At the same stationing point serious landward erosion also took place. Ponds are responsible for this erosion. The following sketch represents the cross profile at these areas. The next serious landward erosion spots are located at km (+9) to (+16). Because of the way of construction the resulting edge through canal dredging is close to the dike crest. The last serious spot is at km(+29). At this point the erosion has already damaged the dike crest. Canal dredging in combination with a regular use as landing stage for the local settlement effected this strong erosion. The local residents have already recognised the serious damage and tried to protect the dike body with wooden piles over a length of 17 m. At this part, the dike crest is only 2.7 m wide, while next to it the crest has a width of 3.5 m. Light erosion damages, with the potential to become more serious in the future are around km (-19) in Ca Mau, at km (+4) to km (+6) and km (+18) at Kien Giang. There, the close connection to the sea with ongoing erosion caused by an adjacent inland canal in connection with a dense settlement (as described below) provides a risk. The cross profile of km (+24) pictures a similar issue between km (+23) and km (+26).

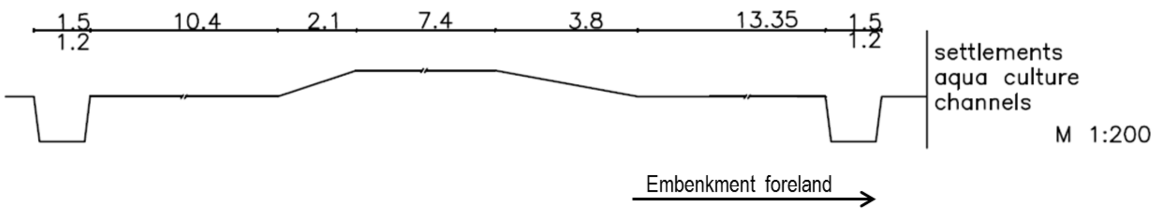


Figure 3-10 Cross profile dike with channels at both sides km (+24) (Sikora)

3.4.3.4 Condition of vegetation

The vegetation at the dike surface varies between cultivated areas and uncontrolled growth areas. The wild growing plants are undefined, whereas cultivated vegetation can get named. For the gardening the dike surface is usually ploughed to a depth of 20 cm, whereby the length of the ploughed area varies. Further, a burn cultivation of dike parts with wilder vegetation is carried out by local residents at some sections (e.g. km (27)) to make the dike usable for cultivation. Typical low growing vegetables and fruits are onions (km (2)), cucumbers (km (12)) or melons (km (3), whereas cultivated plants in medium height (<1,5 m) are most of the time corn plants (km (7)). Higher plants, planted by locals are banana or tamarind trees. Thereby it cannot be excluded that smaller growing plants still grow under these trees (km (-17)). The different plants with their crown shape and root system characteristic have a significant impact on the dike stability. The crown presents a large surface area for wind impact, which benefits uprooting processes and in consequence a destruction of the dike surface. The main source of danger regarding the vegetation on dikes is represented in their root system. Roots loosen the dike soil and their tunnel systems, which remain inside the dike body after death of the plant, support erosion processes at the surface and internal erosion with the result of a rapid reduction of stability. Thereby, the characteristic of the predominantly cultivated vegetation (Banana, Tamarind and Corn) are as follows:

The banana root system is a rhizome (promusa 2015) which can reach under good conditions a depth up to 1.5 m and a spread up to 30 m horizontally (Watkins 2015), but mostly the average depth is just around 50 cm. Because each individual tree gives fruits only once in its life time, the main stem has to be removed completely or destroyed regularly. After decomposition of the old stem a deepening remains on the surface and supports surface erosion on the dike. The Tamarind has a typical taproot system (El-Siddig 2006), which is characterised by one large, mostly central dominant root which grows directly downward. From the thick root, other roots laterally sprout (Wikipedia 2015b). Even though the tree is a long-live tree its death will leave a tunnel system back at the soil and gives a benefit for internal erosion. Instead of creating a dense interwoven root system, the fibre and brace root system of corn just builds up a local spot of dense network. This root system doesn´t show any resistance against washing out of dike surface (Drevale 2014).

Among km (-38) and km (-13) a constant change takes place between alleys of Banana trees or Tamarind trees, gardening areas with vegetable grow and small wild growing areas. Thereby the wilder vegetation can allocate between km (-37) and km (-32). Between km (-19) to km (-16) a low dense bush vegetation not higher than 1,5 m exists. Around km (-22) a great example for gardening usage of the dike is located, which always is represented in similar way close to settlements (see also “settlements”). From km (-13) up to km (0) no vegetation exists due to the reinforcement. Just at the landward side of the dike, some low growing vegetation exists at the old dike structure

In Kien Giang, the uncontrolled growth of vegetation takes place whenever no use of the dike through settlements or cultivation is done. Still the first 8 kilometres behind the boarder to Ca Mau are intensively farmed but from km (+9) up to km (+12) the wild growing vegetation prevails. With an interruption of 2 km caused by settlements and a canal, the mix of vegetation continues. A small banana plantation exists around km (+23) on the dike. 25 – 30 banana trees grow in a 5 m² rectangle on average. With the small break of natural grass covering at km (+24), the mix of cultivation and uncontrolled growth continues up to km (+29). Especially at km (+27) the uncontrolled growth is far too dense for going on top of the dike as unknown bushes cover the whole surface. The last stationing point shows typical cultivated vegetation such as bananas and corn.

Figure 3-11 Onions at dike surface km (1) (Sikora)

Figure 3-12 Corn at dike surface km (7) (Sikora)

3.4.3.5 Conditions of animal borrowing

Animal borrowing at a dike body has the same negative effects as root systems on the dike stability as named before. Caused to the vegetation cover, an infestation due to borrowing animals is not recognisable most of the time. Only at km (-16) on seaward side, at km (-5old) on the dike crest and at km (+9) on landward side animal borrowing caused by crabs is recognised during the inventory. Even though it represents a small infestation of animal borrowing, in the author's opinion the reality is different. Especially at the areas bordered to the sea a higher population of crabs is estimated.

3.4.3.6 Use of the dike

Dike areas which are not under usage are rarely in place. The following stationing points are too much overgrown as a use is conducted: km (+8) to (+9), km (+15) and km (+19) to km (+21). As visible in Annex A, bush vegetation is predominant in these areas. At the construction side between km (0) and (-12) the dike is also not in use, but is as visible at the construction plan (Figure 3-5) at least a use as a road is foreseen. Except as the listed sections, a path always leads on top of the dike body. Just around km (+6) the path is at the dike toe for a few hundred meters without any negative effect on its stability. The path is not attached by revetment of tar or paving stones at any point and is used by scooters, bicycles or as foot path. It constitutes the most direct land route between all fishing villages and settlements along the coast line. Driving with scooters on softened dike after rain deep ruts results along the path

A typical settlement on the dike profile includes a sum of different parts. The main structure is a small wooden cottage close to the canal with a docking station for resident's boats, which mostly result as a small indentation saved by melaleuca trunks. In case fresh water bowls and a toilet cabin exist, they are mostly placed outside of the cottage, whereby the pit latrine ends up at the canal. Next to patches on the dike crest, stables for chicken, ducks and a pig (in case of a little more prosperity of the family) are placed at the dike area. The area on the right and left sides of the settlement are always cultivated with Banana or Tamarind trees or other fruit trees. All in all the area of a settlement has a length of 30 m, the width depends on the dimension of the crest. In general, a settlement on top or close to the dike toe always results in a reduction of the dike height and crest width. The average change of the dike profile caused by settlements is a loss in height about 70 cm and an edge at the dike´s slope. Along the investigated dike line the density of settlements changes. The closer one comes to a canal the denser is the population and ends up in village structures around each sluice gate.

3.4.3.7 Land in front of dike

The type of the existing foreland is most of the time a mixture of mangrove forests, settlements, aquaculture areas and mudflats. For the first 20 km up from the south, a mixture of dense mangrove forest with mostly renatured ponds prevails in the foreland. After km (-20) the number of ponds decreases, but also the width of foreland. From km (-17) to km (-15) a foreland does not exit. Slowly the foreland width rises again after km (-15) and next to wild mangrove forest, renatured pond structures are visible up to km (-10). Between km (-10) and km (-7) a spare mangrove vegetation exists. Abandoned ponds are visible, but the old structures do not show a significant renaturation by mangroves. Additional settlement areas are one time per kilometre at least. From km (-7) the width of the mangrove belt increases together with the number of settlement areas, aquaculture areas and old pond structures. Upwards of km (0) the foreland is trenched by aquaculture areas, whereas settlements exist only close to the dike. Only at km (9), a line of settlements leads orthogonal through the foreland up to the sea. From km (13) up to km (22), the foreland is staggered by an approximate width of 100 m of wild mangrove forest and a much larger width of aquaculture area. Between km (22) and km (33) the wild growing forest does not exist. Instead aquaculture areas represent the foreland. Settlements exist only along channels and near the dike toe at the foreland. Upwards km (33) a wild growing belt of mangroves exists at the foreshore again, whereas the area between the mangrove belt and dike line is covered by aquaculture structures. In general a higher dense of settlements along the dike line in the foreland always occurs near sluice-gates over a distance of 1 km.

3.4.3.8 Sluice gates

As already written, 9 sluices exist and two more are under construction at the investigation area. Their position is pictured in Annex C at the general maps. In Annex B each sluice is described in detail with regard to their construction and condition. The oldest sluice is no. 10, constructed in 1998 between Ca Mau and Kien Giang. All sluice gates are miter gate and have movable concrete plates as safety gate. Except of sluice no. 4 which has 3 sluice gates, all other just have one gate. The sluices just vary in their gate dimensions, which is between 5.50 m and 11 m in width and between 4 m to 6 m in depth, whereby the smallest width of the canal is 30 m and in maximum 80 m. In general the sluice structure gets protected against erosion with concrete plates, whereas for the canal bank protection mostly paving stones and rip-rap prevent is chosen. Further at the sluice gates under construction a geotextile under the rip-rap prevent is visible. All paving stone are octagons with the span of 45 cm and a thickness of 35 cm. The granite stones used for the rip-rap prevent are classified as $LMB_{60/300}$, according to DIN EN 13383 (Eisenhauer 2002).
The regulation of the open- and closing process is not clear for all of them. In general it can be said that the gates are open during rainy season in June and July to ensure unhindered drainage of the rainfall. Another reason to open the gates is the need for saltwater for shrimp farming in the dry season. Additionally, some gates are tide gates and regulate their open- and closing process themselves. This information is based on local residents and the spoken word of an official employee of the local authorities.
Damages exist at each sluice. The main ones are settling of the revetment, scouring at the end of revetment and cracks at and between the concrete plates, but none of these damages hinders the function of the sluice. The expectation of visible corrosion damages caused by the contact with sea water has not been confirmed.

Figure 3-13 Rip-rap prevent and geotextile, sluice new 1 (Sikora)

Figure 3-14 Paving stones and scoure hole, sluice 8 (Sikora)

Figure 3-15 Settling of concrete plates,sluice 10 (Sikora)

Figure 3-16 Overview of typical revetment arrangement, sluice 7 (Sikora)

3.4.3.9 Interruption of the dike line

Next to the interruption of the dike line by sluices or canals, the bridge at km (25) caused an incorrect break at the dike line. For about 30 m the dike is interrupted by this structure. Even though the pumping station at km (9) just induced a gap at the dike profile, it represents an interruption of the dike line, because half of the dike profile is missing. It can be assumed that this condition is limited in time, as the dike is under construction at this location.

3.4.3.10 Sea walls

Since 2009, sea walls got built along Ca Mau West coast and are still under construction. Their positions are pictured in the overview map, attached in Annex A. The displayed current state corresponds to the topicality of the used satellite pictures from 2015 and 2014.
The sea wall construction is only described orally as follows: A sea wall consists of two lines of reinforced concrete piles, which have a diameter of 30 cm and a height of 7 m or 10 m (depending on the ground). The armouring is six times a diameter of 10 mm (ø10/6). As founding for the filling material between the two pile lines, trunks from Melaleuca are used to prevent settlement. The stones used as filling material are lime stones with an edge length of 20 cm to 30 cm.

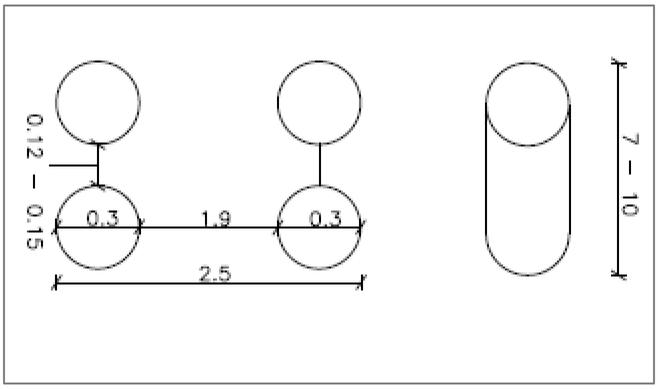


Figure 3-17 Detail view of sea wall (Sikora)

4 Evaluation of the coastal protective function of Mangrove forests

As described at the second chapter, the implementation of a coastal protection strategy depends on several aspects. One aspect is the financial resource. Regarding the worldwide distribution of Mangrove forests, it is noticeable, that most of their distribution ranges are located at the coast of developing countries or newly industrialised countries. Fact is that the financial resource for coastal protection measures of these countries is very low. The question, if the Mangrove forest can be a serious part of coastal protection strategy is currently discussed among experts, special with the interest of a cost efficient coastal protection measure. In Vietnam the Mangrove forest is already part of the coastal protection strategy (SRV 2009). Following an assessment of the protective function of the mangrove forest belt is made for the investigation area.

4.1 Ecological structure of Mangrove forest

In intertidal and flat areas like estuaries, deltas or river banks of subtropical and tropical climate the ecosystem of evergreen mangrove forest characterises the coastal areas. In these regions close to the equator they provide a social-economic and ecological function (FAO 2003). For the human being the mangrove forest represents an area that can be used for economic activities such as fish- and shrimp farming and also for the wood and non-wood industry; with a very negative impact for the environment. Being a habitat with a high biological diversity, the mangrove forest conserves living space for adapted mammals, reptiles, amphibians, birds and fishes. The Food and Agriculture organization of the United Nations (FAO) has documented a serious decrease of mangrove forests worldwide between 1980 and 2000 in their report from 2003. From all mangrove forests recorded in 1980 a loss of 25% is indicated in 2000, which constitutes an enormous thread to the coastal stability (FAO 2003).

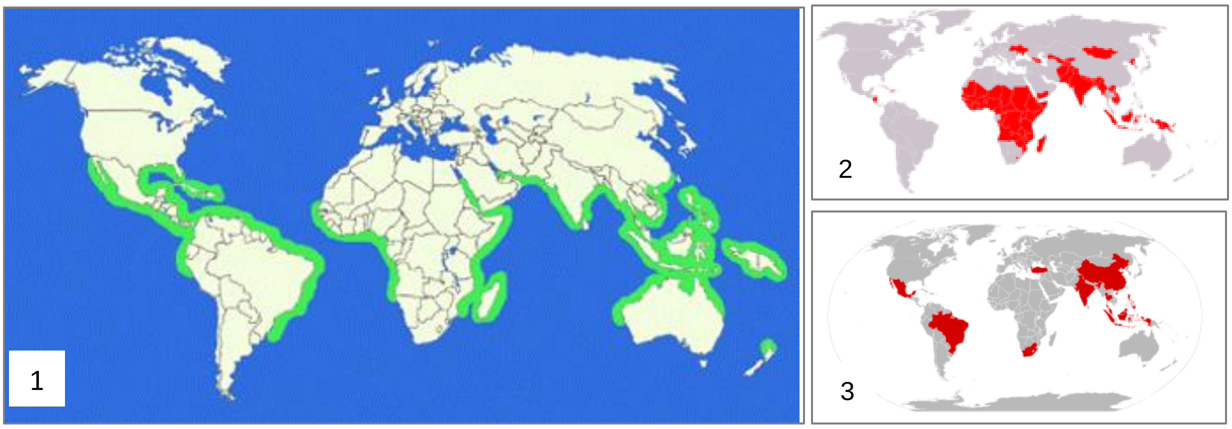


Figure 4-1 World wide distribution of Mangroves (Burger 2005), developing countries (2) (Wikipedia 3 2015), newly industrialised countries (3) (Wikipedia 4 2015)

By adapting to the environment of tidal influence and the consequent contact with salt water and oxygen-poor soil, the plant has developed an effective structure to resist these impacts. This adaptation might provide an effective strategy for coastal protection regarding erosion processes and wave attenuation, which will be described in detail in section 4.3.

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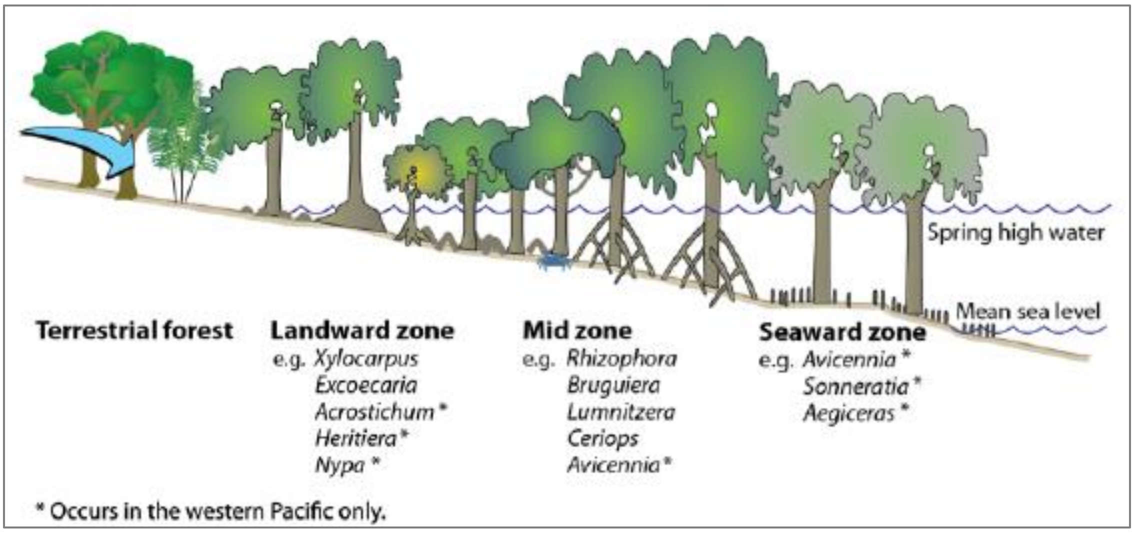

Figure 4-2 Cross section through a mangrove forest (Mah 2014)

The illustration above shows that the types of species change depending on the distance to the sea. The different species differ from each other in their physical parameters, primarily in their root system. While the species at the seaward zone are represented by a vertical low-growing pneumatophore root system, the species at the mid zone are characterised by a pneumatophore stilt-root system, which is growing from aboveground into the soil. The landward zone does no longer consist of mangroves only. Instead, the forest shows more a typical forest structure as described in chapter 3.2.4. Apart from various mangroves, the Nipa Palm, Meliaceae plants, ferns like the Acrostichum or other low growing plants characterise the structure. In the following, the main two mangrove species “Rhizophora Apiculate” and “Avicennia Marina”, which dominate at the investigation area (4.2), are described regarding their structure.

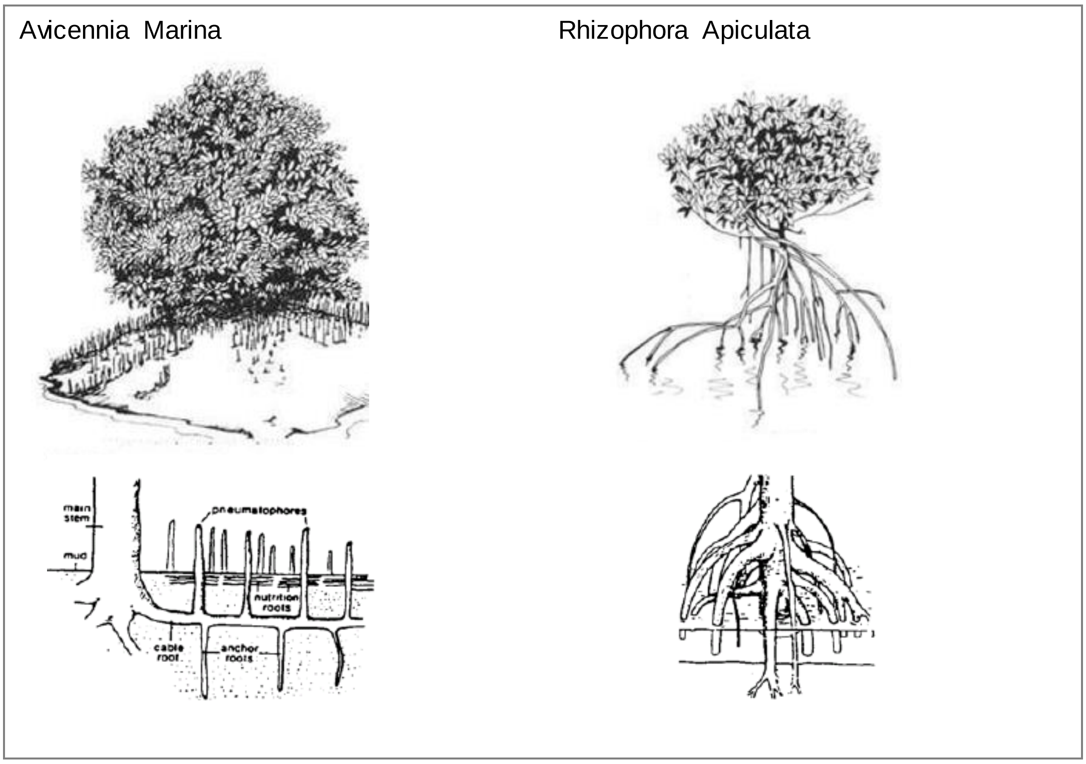

Figure 4-3 Relevant Mangrove species at the investigation area (Burger 2005)

Table 4-1 Fact sheet of relevant Mangroves species at the investigatino area

Avicennia Marina		Rhizophora Apiculata	
Coastal zone	Low tidal zone	Coastal zone	Medium low tidal zone
Root system	Pneumatophores	Root system	Silt roots
Height	Ø 2 - 5 m	Height	Ø 5 – 8 m
Diameter steem	Ø 0,15 – 0,35 m	Diameter steem	Ø 0,30 m

4.2 Inventory of the Mangrove forest in the investigation area

In parallel to the inventory of the coastal structures (chapter 0) the mangrove forest in front of the dike gets documented with the goal to win an impression about the structure and density of the existing forest at the west coast of the Mekong Delta. Further the average wide of the forest along the coast gets estimated with the compare of satellite pictures and literature references. Later, this information will be used for the implement case study at chapter 6.

4.2.1 Datas of existing literature

Besides this survey, other literature has written about the tree population in this area. In 2008, Dr. Norm Duke observed the biodiversity of mangrove forest at Kien Giang and summarised it as follows: "The local farmers living in the mangrove belt, seem to have limited knowledge for and techniques on appropriate forest management and aquaculture. The mangrove belt is in parts very narrow and therefore has poor capacity for resilience and a limited capacity to mitigate the effects of climate change." (Duke 2008, p. 1). Russel (Russel 2012) describes the current coastline condition of Kien Giang in 2012. For this purpose, he also takes a closer look at the condition of the mangroves. He mentions that the mangrove forests at Kien Giang are dominated by Avicennia Alta and indicates An Minh Province as the largest area of mangrove gazette into protective forest. About 40 % of the coast of An Minh is covered by mangroves, which represents the highest percentage at Kien Giang Province. The canopy of this coastal forest is described as a non-continuous, either fragmented or scattered, and more than half of it is marked as “active eroding”. Furthermore, Russel divided the coastline of Kien Giang in 19 coastal mangrove sectors, whereby each sector is classified with a specific land scape type, mangrove resources and erosion condition. Similar information is also available for Ca Mau. The General Report Ca Mau (SIWRP 2013) speaks about a reduction of the biodiversity of the coastal mangroves area at Ca Mau compared to 20 – 30 years ago. Chapter 5 of this report focuses on the sea dyke status quo and gives an average width of the existing mangrove coastal forest wide. The relevant areas of both reports are listed regarding their belt width and their species in the following table: even some locations could not be located exactly. This is the reason, why not every section in the following table has a kilometre mileage.

Table 4-2 Condition of coastal mangrove belt at investigation area based on literature (Russel 2012), (SIWRP 2013)

Kilometre mileage	Average width of Mangrove belt [m]	Mangroves species
(23) to (34)	>500	Avicennia Alta
(21) to (23)	>250	Avicennia Alta
(14) to (21)	>250	Avicennia Alta
(0) to (14)	<250	Avicennia Alta
Huog Mai to (0)	120	- not known
Rach Dinh to Huog Mai	70	- not known
Lunh Ranh to Rach Dinh	50	- not known
(-24) to Lung Ranh	200	- not known
T 29 to (-24)	300	- not known
Ba Tinh to T 29	200	- not known
(-37,3) to Ba Tinh	300	- not known
km (-41,3) to (-37,3)	250	- not known

4.2.2 Method for data collection regarding the mangrove forest

Parallel to the stationing of the dike inventory, the mangrove forest should be evaluated, to complete the picture of the coastal condition. To record all relevant parameters for wave attenuation by mangroves (section 4.3.1), a reference area is chosen at each stationing point for which all relevant factors are documented. This information will be used for a conclusion regarding the various characteristics of the existing mangrove belt along the investigated coastline. Based on the reports regarding the wave attenuation by mangroves (Sorgenfrei 2015), the ideal space for a reference square is 10 m². In practice, this dimension proved to be insufficient regarding the available time for the whole inventory. Therefore a square of 5 m² can be chosen, whereby it is reduced to one square meter, if the mangrove forest is too dense. Furthermore, if the variation of mangrove species and density is too high at a survey point, additional squares have to be estimated to present the reality as close as possible. At each square site photos will be taken, first at all photos will be taken clockwise in all four directions of the compass and further particularities, similar to the dike survey. Afterwards, the transect information is determined. This includes: the number of trees at a height of 1.3 m, average extent in cm, average height in m and the existing mangrove species. Also the connection to the sea will be analysed with respect to whether a closure canopy exists and if the swell impact line is lying inside the reference square. The last point is purely motivated by interest of getting an impression of the normal tidal range. With all this information, the density and structure at the survey points can be determined and therefore the rate of wave attenuation can be estimated. During the field trip, the poor accessibility of the mangrove forest close to the coast is proven. As the survey is done from the landward side of the dike, the position of the canal in front of the dike limits the possibilities for choosing a representable square closer to the coast. At these points (see Chapter 3) the square is taken as the situation allows. Further aspects regarding the chosen position of the square during the field trip are the marshy condition of the soil, ponds and other channels at the mangrove forest and the limited time.

4.2.3 Evaluation of the data set

The result of the implemented survey about the mangrove forest does not give the expected information as mentioned before. Caused by the limited time for the survey, the mangrove forest is investigated near the dike. The maintained information cannot set equal due to the whole foreland forest, which has shown the afterwards comparison between the evaluation of the survey and satellite pictures. However, the survey has given an interesting view into the different mangrove species and supports the statement, that Rhizophora Apiculata and Avicennia Marina represent the main mangrove species in this area. Further one, the rapidly change of densities between the survey points might be interferences with antrophogenic influences. The evaluation of the mangrove survey is listed in Annex D.

4.3 Mangroves as natural coastal protection structure

4.3.1 Parameters for wave attenuation

Besides its function as a habitat, its importance for the preservation of biological diversity and in contrast to its use for economic activities, the mangrove forest also plays an important role for coastal protection as mentioned above. Since the early nineties, the science deals with the physical processes in mangrove areas (Mazda et al. 1997 a) to underline this statement. Fact is that on the one hand its unique root system prevents strong erosion effects at the coast line. On the other hand the effect of wave attenuation caused by its structure reduces the forces of breaking waves at the dike toe or the area behind the forest in general; provided that a cross structure as shown at Figure 4-2 exist. In this section, a literature research is provided, which focuses on the possibilities to calculate the probable value of wave attenuation through mangrove forest systems in general and on the question whether the mangrove forest can be considered suitable as a generally accepted coastal protection system.
Authors of several studies have proved that mangroves effect significant wave attenuation depending on different parameters of the forest. A detailed overview of the different factors is described by MC Ivor et al. (McIvor et al. 2012). First of all, the physical structure of the trees, as described in Chapter 4.1, represents one parameter and based on this the density represents another factor. Because the more space of a defined volume is filled by mangrove structure, the higher is the drag against the water flow (Mazda 1997). Directly related to the structure and density of the mangroves, the distance the wave has covered through the forest has an influence on the force of wave attenuation. With his study "Effect of mangrove forest structures on wave attenuation in coastal Vietnam", Bao (2011) has demonstrated that with rising distance covered through mangroves, an exponential reduction in height of the waves results (Bao 2011). The water depth in relation to the density and structure of the mangrove forest and especially to tidal phase is named as another parameter (Quartel et al. 2007), whereas the bathymetry and topography of the area have a significant influence. Summarized the parame-

ters which determine the strength of wave attenuation are a function of "topography/bathymetry and tidal phase, wave height, and various aspects of the structure of mangrove trees, which depend on their species, age and size" (McIvor et al. 2012, p.10).

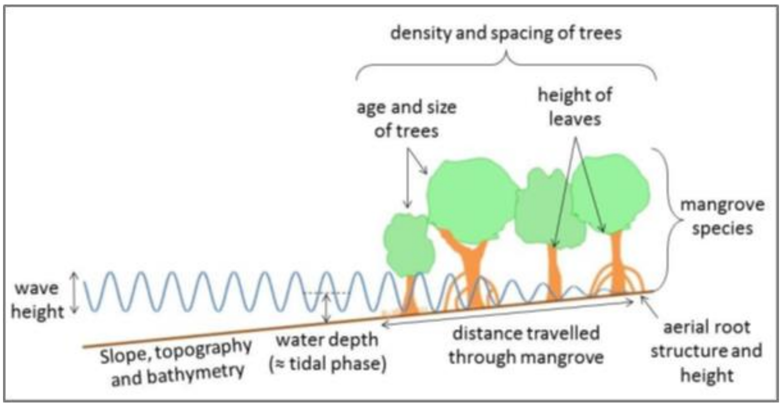

Figure 4-4 Parameters affecting wave attenuation in mangroves (McIvor et al. 2012)

Existing channels and pools in the mangrove area reduce the mangrove density in the foreland. The question how they can be taken into account when calculating wave attenuation is not answered yet. Another aspect is the reduction of surface wind by mangroves (McIvor et al. 2012 b). This is based on the fact that a forest canopy induces a reduction of wind and therefore in decrease in wind waves. The effect of this reduction is not quantified up to now. Information about distances or water depths are not stated. Still, a summary of the existing knowledge is given at that report, whereas this effect does not need to be looked at closely in this study.

Besides the mentioned parameters which all concern the resistivity of the forest, the influencing factors represent the main factors regarding the question of whether a mangrove forest is an effective coastal protection system. Of course the reduction of wave height and velocity is a positive effect on the coastal system, but the main aspect of this study is their reduction rate during the design event.

As design event for the investigation area an event with a period of twenty years is determined by the Vietnam government, which occurs the design wave height H_s between 1.0 and 1.5 m and a Peak-period of 8.64 s, caused by storm surges additional with the tidal impacts. In the following, Chapter 6.1 explains the design event for this study in more detail. Most of the authors who examined the wave attenuation by mangroves with field studies determine a wave attenuation rate (r_H) depending on given parameters (Sorgenfrei 2015).This wave attenuation rate can be parameterised by calculating a bulk roughness parameter, which depends on the vegetation-induced drag force and bottom friction (Mazda 2006), (Quartel et al. 2007).

$$r_H = \frac{\Delta \mathrm{Hs}}{Hs} \times \frac{1}{\Delta x}$$

$\Delta \mathrm{Hs}\ [\mathrm{cm}]$ is the difference between initial wave height Hs [cm] and Δx the running distance Another option to approach the wave attenuation rate is to determine a general vegetation-induced drag force coefficient whereby the mangrove forest can be splitted up in its three layers: root, stem and canopy. Then, this vegetation induced drag force coefficient can be transmitted into a bulk roughness or a single vegetation factor. This requires detailed information about the vegetation characteristics (4.3.1). However, in practice, this is not available in most cases (Massel et al. 2008), (Naranya 2012). The great disadvantage is that the results of most of the field studies cannot be generalized for all forest sites, because as Wolanski et al. demonstrate, each mangrove species has a unique structure with the result of a different wave attenuation rate (Mazda 2006) on the one hand (Wolanski et al. 2001). On the other hand, the factors (vegetation-induced drag force and bulk roughness parameter) also depend on local geography and hydrodynamic boundary conditions.
Most of the studies which investigated the wave attenuation were done during normal swell. Taking their results as a basis would not represent the reality at the studies condition and is therefore not conductive. Mc Ivor et al. (McIvor et al. 2012 b) mentions few existing field demonstrations for wave attenuation by mangrove forests and justifies the small number of field studies by the difficulty of taking measurements in this situation.
In their paper "Wave reduction in a Mangrove forest dominated by Sonneratia sp", Mazda et al. write about the "roles of mangroves protecting coastal human lives from sea waves in storms" (reference with page number). They claim that under the condition of enormous sea level rise due to a storm surge, the drag force of pneumatophores doesn´t work effectively is due to a similar reason responsible for the decrease in bottom friction in case of an increase in the water depth. During high water levels the leaves of the mangrove have to be taken into account as main parameter for wave attenuation, provided that the water level reaches the treetop. For this purpose, they estimated a wave reduction rate, modelled after their performed survey in northern Vietnam at a Sonneratia sp. area; whereby the Sonneratia species is almost similar to Avicennia species in their structures (Mazda 2006). The study of Krauss et al. makes estimation of the wave height reduction during a hurricane passage at mangrove-interior marsh and riverine mangrove habitat close to the Faka Union Bay in Florida (Krauss et al. 2009). The mangrove forest at both areas represents a transition from mixed mangroves (Rhizophora mangle, Laguncularia racemosa, Avicennia germinans) to salt marsh (Spartina bakeri, Distichlis spicata, Batis maritima) and has a width of several kilometres. During the field study, the water level gets measured at varying distances to the sea. For the mangrove-interior mars the level at km 2.3 and km 3.2 gets measured in a height of 0.40 m, whereby km 3.2 represents an abrupt mangrove marsh transition. The biggest difference to the studied site is the width of the area, further subdivided by river areas. In addition, the study doesn´t provide any information about water depths, significant wave height or wave period, which makes it even more complicated to use this study for an assumption regarding the wave attenuation during storm surges in the investigation area. Besides these two field observations, several studies examine the wave attenuation during an extreme event with a "Numerical modelling of wave attenuation by implementation of a physical description of vegetation in SWAN", (Burger 2005). As one of the first studies he tries to adjust field studies of with using the SWAN modelling. Therefore, the vegetation is being vertically subdivided into several segments or

layers, which will be calibrated only by the drag coefficient (C_D). In this research study, C_D does depend on the horizontal orbital velocity and the peak period. This occurs on further steps of this research study. “The Effectiveness of Mangroves in Attenuating Cyclones-induced Waves” (Narayan 2009) also analyses the wave height reduction of mangrove forests and classifies a vegetation factor for the two cases low and height and separates further between the three layer roots, stem and canopy. Both research studies bases on the Dalrymple formulation as a function of the spectral energy. Both studies trying to implement general wave attenuation factor regarding the different conditions of swell and vegetation parameters. Whereby their models can cover a wider range of various initial parameters, the need of being close to nature is important.

4.3.2 Functions for the calculation of wave attenuation

The literature review has pointed out that most of the existing formulas for calculating the wave attenuation by mangroves are based on the bottom friction, resulting of the drag coefficient. Thereby the vegetation parameter describe the grade of C_D (Mazda 1997 b), (Massel et al. 1999). Mazda et al. (2006) pointed out, that with a rising water level, the damping effect caused by bottom friction decrease. This condition makes these formulas useless for the current issues of wave attenuation during a design event. A first try to estimate the wave attenuation in combination with a high water level, is done by the author of this statement as well. For the purpose of height water level they transfered the bottom friction with the energy dissipation caused by the thick leaves and estimated a reduction rate of 0.005 m^{-1}, which corresponds to 50 %per 100 m. However, this assumption is too crude to overtake it for this research study. One formula has been founded by Bao (2011) which do not based on C_D and is generalized in an exponential equation. The objective of the foundation of the following equation is, to take the forest band width as an initial parameter for the wave attenuation. In his paper, he analysis the question, how wide a mangrove forest belt has to be for an acceptable wave height behind the forest. Therefore following equations have been derived:

$$W_h = a \times e^{b \times B_w}$$

W_h is the wave height behind the forest band, B_w is the forest band width, a is the intercept in log base e of the equation above and b is the slope coefficient in log base e of the same equation. Furthermore, the coefficients a and b can be determined as follows:

$$a = 0.9899 \times I_{wh} + 0.3526$$

$$b = 0.048 - 0.0016 \times H - 0.00178 \times \ln(N) - 0.0077 \times \ln(CC)$$

I_{wh} represents the initial wave height in front of the forest [cm], H is the average tree height [m], N is the tree density [tree/ha] and CC is the canopy closure [%]. The idea of this formula is helpful for the question to be answered in this research study, but founded on a field study with an average wave height from 20 to 70 cm it does not represent a design event as it might exist at the study area. A more universal formula is given by the Vietnamese national guideline for sea dike planning. This formula is also based on a SWAN Modelling and additional information in the guideline support the assumption that the equation of the guideline is based on the past research studies of Burger (2005) and Narayan (2009) A general wave attenuation factor K_t [-] in combination with the factor σ [-] which includes the deviation of model determines the wave height reduction by mangrove forest.

$$H_s = K_t \times (1 + \sigma) \times H_{s,k}$$

In this case, H_s [m] represents the wave height behind the forest and $H_{s,k}$ [m] the initial wave height in front of the forest. K_t has to be determined taking into account the width and the density of the forest. The determination can be done in direct reading of the specific diagram or calculated by using the correlation between K_t and the wave attenuation parameter r.

$$K_t\,(x) = e^{-rx}$$

The wave attenuation parameter depends in its height on the mangrove forest status, corresponding to density and coverage. The density is the number of plants per hectare and the coverage the percentage between total projecting are of canopies on cross section and soil surface. The case study in chapter 6 will chose this formula for a dimensioning of a dike system in the research area, because on the one side the equation is independent of C_D and bottom friction and also does not give any information regarding restrictions in use. However, this reason might represent a serious problem in the follow dimensioning. Because this formula only reduces the wave height, the wave period is waived. This may results in negative effects for the dimensioning of the dike structure in chapter 6 and points out that researches, regarding the wave attenuation of mangroves still has to be investigated more specific.

5 Change of the Coastline

5.1 Data base

The examination of the coastline evolution on the surveyed area is based on the compilation of satellite pictures between 2001 and 2015 and on a topographic map from 1960 (Table 5-1). The satellite pictures originate from Google Earth, whereas the map is created by France in 1960. Data for the following years are available comes from satellite picture, although not every year represents the whole investigation area from km (-41.3) to km (+36.8). The compilation of 2003 represents pictures from January and February 2003.

Table 5-1 List of available satellite pictures of the study area

Year	Represented Kilometres [km]	
2001_feb	(-41.3) – (-5.4)	∑ 35.9
2003_feb	(-17.8) – (+26.9)	∑ 44.7
2008_jan	(+11.8) – (+36.8)	∑ 25.0
2009_aug	(-19.1) – (0.0)	∑ 19.1
2011_feb	(+33.9) – (+36.8)	∑ 2.9
2013_feb	(+34.0) – (+36.8)	∑ 2.8
2013_nov	(-41.3) – (+36.8)	∑ 78.1
2014_feb	(+4.5) – (+36.8)	∑ 32.3
2014_aug	(-15.1) – (+5.9)	∑ 21.0
2015_jan	(-41.3) - (-7.1)	∑ 48.4

As visible in the table above, only the data sets of November 2013 and 1960 represent continuous coastlines along the investigation area, whereby the other years just picture different sections. The map has a scale of 1:50,000. The satellite pictures variate in their spatial resolution In general, a precision of 5 m is available, while even after the recused edition of geo-referencing, a coastal parallel shifting of 5 – 18 m between the data sets exists. This deviation between the different pictures becomes obvious during the comparison of the digitised lines, especially at canal mouths. For the purpose of analysis, a digitalisation of all coastlines is done manually, using the Geographic Information System software ArcGis. The coastline is defined as the visible border between the mangrove forest and the sea in the satellite pictures. The condition of the tidal level however at the particular time remains unknown. The visible coastline of the map represents the mean sea level at Ha Tien and is used for the subsequent digitalisation of the coastline. Plotted sandbanks are not taken into account in the digitalisation, but might be considered in analysis later. The digitised coastlines of the satellite pictures represent a tightly serrated line, while the coastline of the map has a smooth characteristic. It might be reasonably assumed that the smooth characteristic is caused by the process of mapping, considering the scale of 1:50,000.

5.2 Method

The analysis should indicate endangered erosion areas along the investigated coast in order to build a realistic basis for the case study. An endangered area is characterised by a high erosion rate per year

combined with a narrow width of current foreland in front of the dike. This combination results in a high coastal loss in a short period of time, which has a significant impact on the decision making of the choice for a coastal protection strategy. For the first overview the coastlines of the different dates are compared to determine erosion, accumulation and oscillating areas. To analyse only long-term trends, the oldest and youngest available data sets are compared. Due to the reason that the grade of accuracy of the map from 1960 is not sufficient enough, a comparison between the oldest and youngest satellite pictures is done as well. Please note at this point the incomplete data set, listed in Table 5-1.
In general, this examination does not give a statement about erosion height and displays only a potential coastal parallel shift of the specific areas regarding time. To give a statement on the height of erosion, the relative coastal erosion rate with the unit “meter per year” (following described with “r_{ce}”) is determined every hundred meter of the coastline. The analysis has shown that the calculation of r_{ce} over a short period of time presents short-term effects in erosion behaviour. These effects have a significant impact on the following evaluation, but do not represent the long term behaviour of the coast which is the actual aim of this investigation. Short-term effects of erosion are caused by storm events, the breakthrough of an old pond dam or other undefinable reasons. To minimise the influence of short-term effects of the variation between different periods in time the following steps are carried out:

- First the periods of time in the considered area should cover at least three to four years, if possible. The incomplete coverage of the coastline by satellite pictures of different years complicates this condition. A comparison of the same time period between all points is therefore not possible.
- Second, r_{ce} is calculated by dividing the absolute coastal erosion rate between two coastlines of different dates through the amount of months and after extrapolated over a full year. This guarantees a more exact rate than dividing only through the number of years. The result of step three represents the most realistic r_{ce} for each one-hundred meter point.

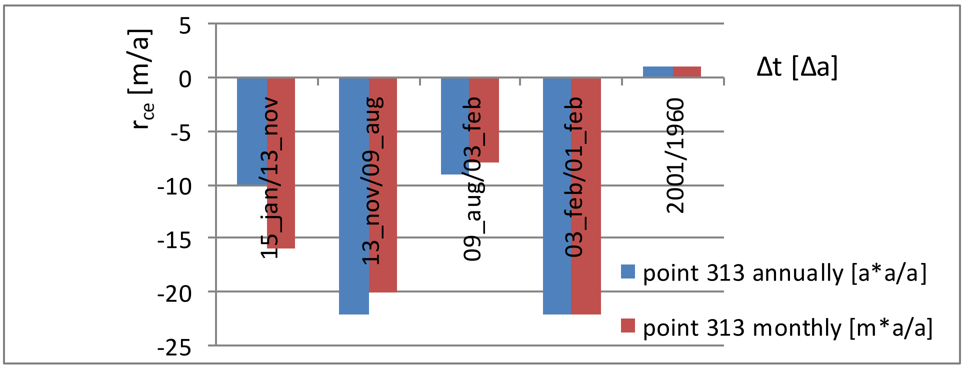

Figure 5-1Comparison of r_{ce} devided through number of years or months

- Third: The areas which show a significant impact caused by existing channels will be excluded for further examination, because the erosion process close to a channel mouth differs to the coastal erosion as visible in Annex E
- Fourth: The result of r_{ce} after step three is still as jagged as the digitalised coastlines. One reason might be caused by old pond structures in the mangrove forests (3.2.4) where a change in the resistance force against erosion is very likely. For further examination the serrated wave attenuation rate r_{ce} is smoothed using the moving average method. This method is used to smooth short-term fluctuations and underlines long-term trends of a data set. The

fixed subset size for this study differs for the different periods in time. Generally, the shorter the period of time is, the bigger is the subset size. This is only done to avoid punctual extremely high erosion rates which are more present at shorter periods of time. The reasons are named before.

A general overview on the change of r_{ce} over time is also set for each point. Therefore a classification into 11 classes is done. Class 1 to 5 represent different ranges of erosion rates, class 6 defines rates, which oscillate around 0 m/a and class 7 to 11 represent the existing ranges of sedimentation. The class ranges are choses as listed in Table 5-2.

Table 5-2 Classification of relative erosion rate r_{ce} [Δm/a]

Class	Range [Δm/a]
1	< -25
2	-25 < X < -15
3	-15 < X < -10
4	-10 < X < -5
5	-5 < X < 5
6	5 < X < 10
7	10 < X < 15
8	15< X <25
9	25 < X

5.3 Analysis

The first comparison of the different coastlines based on the oldest and youngest data set determines coastal parallel trend areas of the processesing erosion, sedimentation and alternation, but also their change in width and position over the time. Whereas the erosion area between 1960 and 2001 (2003, 2008, depending on existing satellite picture) covers a length of 9.5 km, a significant rise of erosion area is recognisable between 2001 (2003, 2008) and 2015 (2014) (for more details see annex E). Areas over a summarised length of 51.5 km of the coastline show erosion processes in this time period. The comparison of erosion and sedimentation area images that not a real balance between accumulation and erosion areas in the investigation area exists (for more details see annex E).

A primarily erosion area can be located in the southern part of the study area, whereas an accumulation trend lies rather in the north. The middle part of the study area has an oscillating characteristic, regarding the behaviour. This simplified representation can only be taken as a general behaviour of the coast development, but doesn't give any information about the range of the processes.

It can clearly be seen in the diagram relative erosion rates (Annex F) that the grade of r_{ce} is not constant over different periods of time. Of course, a consideration just between the youngest and oldest reliable data set (2001/2003/2008 and 2015/2014) can simplify the analysis, but may lead to wrong assumptions. In the following, this aspect will be discussed in detail, up from the southern part of the study area at Dá Bac city in Ca Mau Province to the northern end in Thuân Hòa commune, An Bien district, Kien Giang province. For the first 10 km a low r_{ce} predominates for all periods of time. Just at the beginning and the end of this section, the rate rises up to nearly -20 m/a. From km (-32) up to km (-27) the grade of r_{ce} increases in negative direction. Almost consequently the rate is higher than -

10 m/a. Regarding the period of time 2001 and 2013, it is even higher than -15 m/a. A reason for this phenomenon might be the old fishpond structures (visible at satellite pictures of 2001), which represent a lower resistant force against erosion processes. Another possible reason of a reduction of the grade after 2013 could be the start of a construction of sea wall, which is visible for the first time in satellite pictures of 2013. Generally, a decrease of r_{ce} exists up to km (25), where even the grade between all periods of time is high. Since 2013 it is conspicuous that between km (-26) and km (-25) the erosion process has slowed down, but the cause of this behaviour cannot be identified clearly. Even more the following section surprises with a turned behaviour. Between 2013 and 2015 r_{ce} rises enormously up to -25 m/a, whereas the long-term trend between 2015 and 2001 shows the opposite trend. Regarding this period of time, this area hasn´t changed a lot. The comparison of the satellite pictures at different times indicates a wider range of mangrove forest belt without any anthropogenic impacts. An oscillating behaviour is visible from km (-18) up to km (-12) only between the year 2013 and 2015. All periods of time show a drastically rise of the negative r_{ce}. Grades higher than -20 m/a and more are monitored before 2013. The comparison of the satellite pictures indicates just a small mangrove belt without any anthropogenic impacts even in 2001. Since 2013, a sea wall is visible, but its positive impact is not visible. Even in satellite pictures from 2009, the dike is already in direct contact with the sea. Therefore a small range of r_{ce} cannot be regarded as exclusively positive. The following cross profile pictures the development of the coastline in this section.

After this section including km (-12) r_{ce} decreases over the past few years. Up to 2014 this area doesn´t shows a real dynamic behaviour. The satellite pictures show that this area is being used less and less by humans, which results in an increase of mangrove density in this area. This behaviour is visible up to km (14) in Kien Giang province; even the anthropogenic influence in the forest structure is visible. From km (14) up to the end, r_{ce} is positive for most of the time periods, which results in an accumulation process. A rise of r_{ce} between the period 2003-2008 and 2008-2013 is visible. Whereas r_{ce} was under 10 m/a between 2003 and 2008 for km (14) to km (16), it grows with a factor of almost 1,5 up to a grade of 15 m/a between 2008 and 2013. A change in human behaviour or additional constructions is not recognisable. For the section of km (16) to km (18) r_{ce} also rises comparing the different periods of time, but its grade is higher; between 2008 and 2013 r_{ce} is even higher than 15 m/a. This high grade of r_{ce} decreases after km (18). Here, a decrease of r_{ce} between 2008 and 2013 is visible, which grows down to zero. Just for the period of 2003 to 2008 an accumulation process is still identifiable. The satellite pictures don´t show a reason for this behaviour. This decrease of r_{ce} continues even stronger between km (20) and km (32). There, an ongoing erosion process which has grown serious over the past years is identifiable. Whereas the grade of r_{ce} between 2003 and 2008 changes between zero and may be up to 10 m/a a few points, it increases up to 25 m/a and sometimes even higher for the period between 2008 and 2013. This behaviour might continue in the future, because the comparison of the satellite pictures shows that the erosion process has reached the part of mangrove forest with a dense utilisation by humans. After km (32) this strong erosion rate decreases again and for the last 4 km r_{ce} is positive again with ranges higher than 20 m/a. Even a reduction regarding the different periods in time is visible.

To identify hotspot areas as described in section 5.2 the current width of the dike foreland is divided by the representative relative erosion rates for each section of coastline. The representative r_{ce} is chosen under following aspects: long-term trend for a section, situation of the foreland and the relative erosion rate during the past 3-5 years. The worst case of these aspects will be chosen for the analysis. As a result the number of remaining years up to the situation of a complete eroded foreland is given for each location. Locations with a positive r_{ce} are not considered in this analysis, because their continuous accumulation does not represent a threaded area. If a location shows a number of years smaller than 25 until complete erosion, the foreland is defined as endangered. This number of years is chosen, because the prediction of the coastal behaviour is based on a very weak data base. Therefore the following statements can be taken for further studies only with the reservation of uncertainties.

The first hot-spot area is located at the first 34 km up from the south. For most of the locations in this area the foreland will be gone, if the eroding behaviour continues as between 2001 to 2015 and 2009 to 2014, which are taken as representative r_{ce} in this analysis. Km (-35) to km (-25) and km (-17) to km (-10) represent the weakest sections. There, the foreland will be gone during the next 5 – 10 years with these conditions. The area between km (-7) and km (0) is not in danger in case r_{ce} of 2003 to 2009 and 2009 to 2014 does not change in the future. Under these conditions, the foreland will have disappeared in 30 to 50 years or even later. The area between km (0) and km (9) is close to being endangered. The analysis shows that the foreland area might be gone in 30 years as well. Up to the end of the study area the foreland of km (27) to km (30) probably will be eroded after 25 – 30 years. All other sections are accumulation areas or at least an area with a very low relative erosion rate, which represents an eroded foreland after 100 years and more.

6 Dimensioning of the coastal defense system

6.1 Design event

With its guideline “Technical Standards for Seadike Design” the Vietnamese government has set the conditions for the calculation parameters of a dike system in Vietnam. Depending on the grade of population and urbanization of the area to be protected, a different safety standard for a return period between 10 and 150 years should be chosen. For the protection area a safety standard of 100 years is necessary, taking the General Report of Ca Mau into account. When determining a design event for the study area the main problem is the availability of reliable data, because for this study a reliable storm surge and ocean wave statistic is not conducted. The “Technical Standard for Seadike Design” provides a design water level and design waves parameters for the different return periods in connection with the safety standards. These data base on a 2D-SWAN Model, which calculates the water level caused by storm surges and tidal impacts in separate way and adds them afterwards. The water level caused by storm surges is based on the original data of 349 storm events between 1951 and 2007, but all of these storms where coming from the Vietnamese East Sea and just a few were raging the study area of this paper. Thereby the water level was measured in a distance of 20 m from the coastline continuously over the years, directly after a storm event and during a storm event over three to five days.

As design wave parameters the significant wave height and period are also given for the different return periods. Calculated wave height and period at the coastline are transmitted from off-shore wave height to different band distances. It assumed that the waves input direction occurs orthogonal to the coastline. Furthermore, T_p, T_{m01} and T_{m02} are specified for each bank distance.

It is to be noted that the location of the measures, which have built the basis for the modeling is unknown for the author of this study. Additional studies (Mai et al. 2008, b), (Huan 2003), are reasonable grounds for suspecting that the most measure data comes from the northern coast of Vietnam. The acceptance of using an asymptotic Gumbel function of probability distribution for the extreme analysis of the storm events exists through the report of Huan in 2003, too. In the SWAN model the Anderson-Darling test is used to detect if the given distribution function of water levels deviates from the hypothetic probability distribution (MARD 2012). In general the Monte Carlo Model was used due to the uncertainty about the reliability of the existing data.

Along the coastline of the study area 7 different design events with a return period of 100 years are given by the “Technical Standard for Seadike Design”. They are listed in the table underneath:

Table 6-1 Design Events of the study area according to the „Technical Standards for Seadike Design“; return period 1/100a

Location: Coordinates	Design water level [m]	Design wave height [m]	Peak period T_P [s]	T_{m01} [s]	T_{m02} [s]
120: 140,797 9,151	2.75	1.23	8.64	8.21	8.06
121: 104,812 9,267	2.18	1.01	8.64	8.23	8.08
122: 104,827 9,365	are missing at annex B of the guide line (MARD 2012)				
123: 104,83 9,455	2.73	1.30	8.64	8.19	8.04
124: 104,833 9,559	3.29	1.50	8.64	7.66	7.50
125: 104,851 9,66	2.17	1.12	8.64	8.18	8.02
126: 104,872 9,752	2.14	1.23	8.64	8.16	8.01
127: 104,878 9,8	2.20	1.05	8.64	7.73	7.59

Additional other reports and studies have also estimated the swell and its extremes at the West Coast of the Mekong Delta. Even their parameters do not represent exactly the same locations; they are a good possibility to estimate the given design events in the guideline regarding their resilience. Tusinski speaks about a design high tide level of 1.44 m with a return period of 100 years for Rach Gia in Kien Giang Province. Furthermore, he estimates in the same report for a case study a water level of 2.34 m near the shore and an initial wave height of 1.39 m in Ca Mau province. Huan estimates in his report: "Extremum Sea Levels in Vietnam Coast" of 2003 a maximum sea level for Rach Gia of 1.23 m. Both reports do not give more information about extreme wave heights and period. Other reports, for examplte of Albers (2014) estimated the swell at the Vietnamese West Coast, too, but do not taking extreme swell into account. The comparison of all available extreme parameters shows, that probably the design events in the Vietnamese guideline is too low, but the given parameters of the other reports do not have enough additional information and are therefore too weak to count as reliable data. Therefore, the following case study will be done with the parameters, given in the "Technical Standard for Seadike Design".

6.1.1 Assesment of current dike system under design event

The inventory of coastal structures (3.2.4) indicates several weak points at the current dike system. Especially a loss in the dike height represents a threatened section regarding the function of the dike line (3.2.4). However, the question if the dimension of the current dike system resists the estimated local design event (see above) cannot be verified by a calculation. Missing topographical and bathymetrical information are the reason for this issue. However, following aspects support the authors opinion that the current dike system is not sufficient. During the inventory, the author consulted the local people on annual flooding of the dike. Almost every time the local people spoke of past flood-ing events over the last 5 years. Furthermore, the ongoing reinforcement of the dike line in Ca Mau (3.1.4) shows a significant rising in the dike height. Both observations definitely point out that a weakness of the current dike system exists, regarding the design event.

6.2 Case study

In chapter 4, the role of the mangrove forest as part of a coastal protection system is discussed. Additionally, hot-spot areas regarding the erosion process are determined for the study area. Now, the key issue to be resolved is how these examined aspects affect the required dike height for the design event in the study area. The following combinations of the given aspects and possible conditions will be evaluated to answer this question.

1. Reality: The dike height is calculated with the width of current foreland and the real density of mangrove forest.
2. Optimal case: The dike height is calculated with the width of current foreland and the density of mangrove forest is set up to optimal condition. This combination represents the condition, if the foreland is completely afforested and renatured.
3. Worst case: The dike height is calculated without any foreland. In this case wave attenuation by mangrove forest does not exist.

6.2.1 Conditions

The dimensioning of required dike height (Z_{dp}) is calculated using the given formulas in the national guideline "Technical Standard for Seadike design". It is the sum of the design water level, the aerial height (correspond to the wave run-up height), the height caused by sea level rising and the height increment (caused by sea level rising). The design water level is taken from the national guideline (MARD 2012) as described in the section above. The annual rate of 0.006 m/a for sea level rising is also taken from the guideline. To calculate the wave run-up height, the guideline uses the recommended formulas for a deterministic calculation by EurOtop (Kueste 2007). The deterministic design for the wave run-up height ($R_{2\%}$) includes an uncertainty of the prediction according the swell parameter. Which deterministic formula is relevant for the design event depends on the breaker parameter $\xi_{m-1,0}$. The guideline uses the factor of $\gamma_b*\xi_{m-1,0}$ (γ_b=berm coefficient) as condition parameter and differentiates between 0,5 <$\gamma_b*\xi_{m-1,0}$ <1,8 and 1,8<$\gamma_b*\xi_{m-1,0}$<8/ 10. Therefore, the formulas can only be used for breakers and reflection waves. Furthermore, for the calculation of the wave run-up height the mean period $T_{m-1,0}$ is taken, according to EurOtop.

The following simplifications and assumptions are made for the dimensioning of the dike heights:

- The reference point for the following dike heights refers to the zero-elevation surface. Bathymetry and slope of the foreland are not taken into account. The reason for this significant simplification is that for this study the available information of topographical condition is very weak.
- All calculations will consider the given sea level rise for the next 100 years in accordance of the guideline. This is equal to 0.6 m with an annual rate of 0,006 m.
- Non-overtopping waves permissible
- The design wave period is in accordance with the guideline determined as $T_{m-1.0}$ (mean period). As written in chapter 4.3 no exact information on the attenuation effect of the mangrove forest for the wave period exists. The report of Quartel et al. (2007) is the only one that takes a look at the wave frequency behind the mangrove forests. Anyhow, a significant change of the frequency hasn´t been proved. Due to this reason, $T_{m-1.0}$ is calculated dividing the design peak period T_p by the factor 1.1, without paying attention to the dampening effects of T_P by mangroves. This conservative assumption is taken, because the wave period behind and the wave spectrum even in front of the mangrove forest is not known.
- The wave direction is set to zero. Admittedly, the report "Coastal Engineering Consultancy in the Province Cà Mau/ Vietnam" of Albers (2014) analyses the wave directions at U Minh area, which is part of the study area, but its results represent only a period of time over two years. Additionally, the wave direction might have a positive influence on the wave attenuation rate by mangroves, because of a possible change in flow path. This option was not examined in

the guideline and literature. Therefore, the study is on the conservative side, with the assumption noted above.

- The seaward dike slope is chosen with a scale of 1:5, according to the guideline.
- The chosen density of the mangrove forest is based on the comparison between the determined densities of the mangrove forest in chapter 4.2.3 and the satellite pictures, whereby the variation in the density caused by ponds or other human impact are considered.
- The current width of foreland is set at the average value over all punctual current width for each section.

In annex G the assumed parameters for the dimensioning are listed.

6.2.2 Results

As envisaged, the more intense and wide the characteristic of the existing mangrove forest is, the stronger is the reduction of the required dike height. Especially the section H3 and H4 (Table 6-2), the positive effect of an afforestation is visible. There, the reduction in required dike heights between current and high forest density is approximately 1 m and in turn the required dike height has to be enhanced to almost 1.69 m for H3 and 0,75 m for H4. It is remarkable that with a decreasing width of the mangrove forest, the height of the density factor becomes more important. Furthermore, the assumption that for sure the mean period $T_{m-1,0}$ will decrease to an unknown height while running through the forest will lead to a higher wave up-run reduction. This statement is founded in the formula used to determine the wave run-up. There $T_{m-1,0}$ is set in with the exponent of 2, whereas H_s has the exponent 1. The reason, why a decrease of $T_{m-1,0}$ can be assumed is the rising energy dissipation with a rising forest density. Taking a look at section A2, H6 and A3 (see also annex H with the dimensioning results) it is visible, that after a specific width of foreland, the impact of changes on the forest density regarding the wave height reduction decreases. So the conclusion can be drawn that after a specific width of mangrove forest, the initiated wave attenuation by mangroves does not have a significant influence on the required dike height for a design event. Additionally, if the slope of the area was taken into account, it would support this statement. Due to the insufficient data it is not possible to name a specific width of forest for this statement in combination with its density and slope of the terrain. Combining these two statements, it can be assumed, that the protection of the mangrove forest only makes sense combined with afforestation on the one hand, on the other hand that not the whole foreland width has to be covered by mangroves only. A stagger between a sufficient width of wild forest belt and other land use is possible, taking into account that the wild belt is free of anthropogenic impacts.
For a general overview on the results the possible reduction in dike height, caused by the decrease of wave run-up height and regarding the density and width of present mangrove forest are opposed in Table 6-2.

Table 6-2 Differences in wave run-up

Section	Density	Width	Case 1 – Case 2 ΔR2%	Case 3 - Case1 ΔR2%
H1	medium	140	0,61	2
H2	medium	140	0,51	1,68
H3	sparse	230	1,07	1,69
H4	sparse	95	0,95	0,75
A1	medium	220	0,59	2,87
H5	medium	160	0,44	2,05
A2	medium	570	0,11	3,64
H6	sparse	550	0,43	3,32
A3	medium	1850	0,03	3,25

7 Conclusion - Discussion of evaluated strategies

The research study has clarified that under the current conditions only a continuous implementation and improvement of the protection strategy, already applied by the government may counterbalance the negative impact of the environmental and climatic changes. Especially in the South of the study area the implementation of the land reclamation strategy is not achieving the initial objectives. Caused by the high rate of relative annual erosion (chapter 5.3) this strategy would need enormous financial and technical efforts to be effectively implemented. The retreatment of the dike line only makes sense in combination with counteracting measures against the erosion process. If this cannot be guaranteed, the current situation (status quo) will be the same in future time as no significant changes in the erosion sections has been recorded during the period of time under consideration. Additionally the greatest drawback of implementing the retreatment strategy is based in the current land use of the coastal area. As described in chapter 3 the existing coastal protection structures in the study area have an impact not only to the researched section but also to the areas around these structures. The dense channel system in the hinterland in combination with a high pressure of agri- and aquaculture would require an enormous change in the land use in order to achieve the dike line retreatment. The strategic and economic feasibility of this adjustment is not straightforward and would require major adjustments. The accumulation strategy can be implemented as a short-term strategy, as already supplied in many areas by individuals. Therefore, the acceptance of a regularly flooded foreland by the locals has to ensure to implement that this strategy is applied without any requests for a higher safety standard. Still, the accumulation strategy does not constitute a long-term solution. Next to flooding, the main problems of ongoing erosion and soil salinity cannot be solved with this strategy, whereby the influence of a coastal protection strategy regarding soil salinity is generally limited. Being the only sustainable long-term solution the research underlines that the current implemented protection strategy requires fundamental improvements.

8 Recommendations

8.1 Strengthening of coastal protection structures

The inventory has detected several problems in the current protection system along the dike line of the study area (3.2). First, the degradation of the dike body has to be prohibited. This can be possibly achieved by resettling of the dike body and stop of its use as gardening and plantation area. Also the deforestation of the dike has to be enforced. A regularly dike inspection has to be performed on a regular basis. The main concern of this strategy is, if a complete retreat of the locals from the dike body is possible, due to the tense situation regarding poverty and spatial pressure. Furthermore, a modification of the current dike profile should be considered. Especially for the threated erosion areas (5.3), a reinforcement of dike toe and revetment are possibly useful solutions under long-term aspects. However, all other coastal protection structures such as sluice gates or sea walls have to be evaluated separately. In the course of this research is was only found, that the erosion process close to sluice gates and channel mouth are different and that a constructed sea walls might positively affect the erosion process.

8.2 Strengthening of mangrove forest

The mangrove forest can be seen as a coastal protection structure and it has to be taken into account separately. Being a soft protection structure it should not be judged equally as the structures mentioned above. Generally, the study has shown that theoretically a significant wave damping effect for a design event exists (6.2.2). However this statement is based on many assumptions and simplifications; the positive effect of a complete retreatment of anthropogenic influences is indisputable. Protection measures that safe the coastal forest line are only feasible in areas, where the current erosion rate does not pose a serious threat. In combination with afforesting measures, this might be an optimal solution for these areas. In the areas of strong erosion rates (5.3) a protection of the mangrove forest is only useful, if the difference between the required dike height with and without mangrove foreland is significant cost-effectively or if the terrain situation does not allow dike reinforcement. This applies, if the position of channels passes parallel to the dike or an intense use of the area close to the dike exists (3). Under these conditions a spatial pressure might occur, regarding the needed footprint for the dike reinforcement. In order to decide, whether one of these suggestions should be implemented, several aspects have to be analysed in further detail. On the one side, the data base regarding swell and wind parameters, elevation profiles, and topological and bathymetrical information has to be enhanced continuously. On the other side, the wave-attenuation due to mangrove forest requires a more detailed evaluation regarding their effectiveness during storm events. In case mangroves are seriously considered as a coastal protection structure, the change of the wave period caused by mangroves needs further analysis.

In conclusion this study provides several aspects for further examinations of analysing the development of the coastal area along the Vietnamese West Coast. It point out that the implementation of the protection strategy should be seen as staggered lines of individual hard and soft structures with as few anthropogenic influences as possible. However, the implementation of this requirement might be more a socioeconomically problem than a technical one.

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Annex A:

Inventory - Overview

	km_real	-38	-37	-36	-34	-33	-32	-31	-30	-29	-24	-23	-22	-21	-20	-19	-18	-17	-16
Erosion:	Seawards																		
	Dike crest																		
	Landwards																		
Plants on dyke	Seawards																		
	Dike crest																		
	Landwards																		
Animal borrowing	Seawards																		
	Dike crest																		
	Landwards																		
Trench infront dike	Taken from foreland																		
	Taken from hinterland																		
Use of dike	none																		
	path																		
	road																		
	Settlements																		
	plantation																		
	diggings																		
Land infront of dike	mangroves																		
	bareland																		
	settlements																		
	aquaculture																		
	other	0	0	0	0	0	0	0	0	0	0	0	C	C	C	C	C	sea/man	sea
dike cover/revetment	none																		
	Seawards																		
	Dike crest																		
	Landwards																		
Toeprotection		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	WB

Inventory - Overview

-15	-14	-13	-12	-11	-10	-9	-8	-7	-6	-5 alt	-5 neu	-4 b	-4 a	-3 b	-3 a	-2	-1	0	1	2	3	4
sea	0	0	sea	0	0	0	0	0	0	0	0	0	0	0	0	C	C	0	0	0	B	0
WB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	W	W	0	W

Inventory - Overview

5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
0	0	0	C	0	N	C	C	0	0	0	0	0	0	0	0	0	0	0	C	0	0	0
0	0	0	0	0	0	W	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Inventory - Overview

28	29
0	0
0	0

Legend	
keine Erosion	
leichte Erosion	
starke Erosion	
> 5 m	
< 5 m	
<1,5 m	
<0,15 m	
nein, nicht vorhanden	
nein, nicht vorhanden	
ja, vorhanden	
living on dyke	Liv
cultivation of vegetables	G
Wood used as food prote	W
undefiniend bushes	B
Constructions at dyke	Con
Canal	C
Nypa Palmtree	N
Bananas	BN
Corn	MA
Tamarinde	TM
wood and sheet metal	WB
Ponts	P
settlement	SET

Annex B:

Designation	No. 1	
Coordinates	104,819120 9,206480	
Year of construction	2012	
Details of construction	Number of sluice gates	1
	Safety gates available?	yes
	Gate wide	11 m
	Gate height	Unknown
	Canal wide	40 m
Condition of the structure	Compared with the other sluices, sluice no. 2 is in a good condition. Just small cracks at the concrete cover at in- and outlet side are visible. Further, the revetment slipped down the slope of the in- and outlet area.	
Connection to the dike?	Yes	
Sluice outlet	Type of revetment	Paving stones and concrete plate
	Condition	Slight slip of revetment at in- and outlet area. Bagging of concrete plate
Sluice inlet	Type of revetment	Paving stones and concrete plate
	Condition	Slight slip of revetment at in- and outlet area. Bagging of concrete plate
Regulation of the closing operation	Gate is open during rainy/flood season in June and July.	
Further notes	A viaduct for boats is integrated at the sluice. The difference between height of sluice gate and the viaduct is 80 cm.	

Designation	No. 2	
Coordinates	104,825664 9,248864	
Year of construction	2002	
Details of construction	Number of sluice gates	1
	Safety gates available?	yes
	Gate wide	5.50 m
	Gate height	5.50 m
	Canal wide	30 m
Condition of the structure	Condition seems good, slight bagging of concrete plates	
Connection to the dike?	Yes	
Sluice outlet	Type of revetment	Stones, gabions, concrete plates
	Condition	Bagging and scour holing at the end of the revetment
Sluice inlet	Type of revetment	Concrete plates and rip-rap prevent
	Condition	Bagging and scour holing at the end of the revetment
Regulation of the closing operation	Gate is open during flood season in June and July.	
Further notes	-	

Designation	No. 3	
Coordinates	104,826259 9,311176	
Year of construction	2012 - 2015	
Details of construction	Number of sluice gates	1
	Safety gates available?	yes
	Gate wide	8 m
	Gate height	6 m
	Canal wide	40 m
Condition of the structure	Condition seems good, slight bagging of concrete plates	
Connection to the dike?	Yes	
Sluice outlet	Type of revetment	Paving stones
	Condition	Good, no remarks
Sluice inlet	Type of revetment	Paving stones
	Condition	Good, no remarks
Regulation of the closing operation	Unknown	
Further notes	-	

Designation	No. 4	
Coordinates	104,849310 9,355642	
Year of construction	2014	3
	Safety gates available?	yes
	Gate wide	10 m
	Gate height	Unknown
	Canal wide	80 m. estimated
Condition of the structure	Construction seems in a good condition, slight bagging of concrete plates, crack and bagging between revetment connection of plate and paving stones	
Connection to the dike?	Yes, but in 800 m inland, behind the dike line	
Sluice outlet	Type of revetment	Paving stones
	Condition	Bagging of the paving stones and scoure holing at the end of revetment.
Sluice inlet	Type of revetment	Paving stones
	Condition	Bagging of the paving stones and scoure holing at the end of revetment.
Regulation of the closing operation	Unknown	
Further notes	No more than 2 gates are open at the same time until now.	

Designation	No. 5	
Coordinates	104,830423 9,375868	
Year of construction	2007	
Details of construction	Number of sluice gates	1
	Safety gates available?	yes
	Gate wide	5.50 m
	Gate height	Unknown
	Canal wide	38 m
Condition of the structure	Condition similar to sluice no. 7, distance between the concrete plates is around 5 – 10 cm	
Connection to the dike?	Yes	
Sluice outlet	Type of revetment	Concrete plates, gabions since 2013
	Condition	Settling of the concrete plates and gabion, close connection between plates and gabions
Sluice inlet	Type of revetment	Concrete plates, rip-rap prevent
	Condition	Scour holing at the end of revetment.
Regulation of the closing operation		
Further notes	At the right side of the sluice outlet, pond structures exist. Therefore, just a small earth dam exists between sea, pont and sluice canal. Further, in direct connection to the gabions, a sea wall construction exists.	

Designation	No. 6	
Coordinates	104,831167 9,391632	
Year of construction	Unknown	
Details of construction	Number of sluice gates	1
	Safety gates available?	yes
	Gate wide	5.50 m
	Gate height	5.20 m
	Canal wide	39 m
Condition of the structure	Cracks due to settling	
Connection to the dike?	Yes	
Sluice outlet	Type of revetment	Concrete plates, paving stones, old gabion structures
	Condition	Scour holing at the end of revetment, gabion wall is broken down and settled
Sluice inlet	Type of revetment	Concrete plates, rip-rap prevent
	Condition	Scour holing at the end of revetment.
Regulation of the closing operation		

Further notes	Except of the broken gabion and the scour holing, the structure seems in good condition

Designation	No. 7	
Coordinates	104,836669 9,413493	
Year of construction	Unknown	
Details of construction	Number of sluice gates	1
	Safety gates available?	yes
	Gate wide	9 m
	Gate height	4.3 m
	Canal wide	41 m
Condition of the structure	In better condition as no. 9	
Connection to the dike?	Under construction	
Sluice outlet	Type of revetment	Concrete plates, paving stones, new gabion structures
	Condition	scour holing at the end of revetment
Sluice inlet	Type of revetment	Concrete plates, paving stones, new gabion structures
	Condition	scour holing at the end of revetment
Regulation of the closing operation	Unknown	
Further notes	Sluice gate is fenced, but still fisher men use the gate area for fishing with fishing rods.	

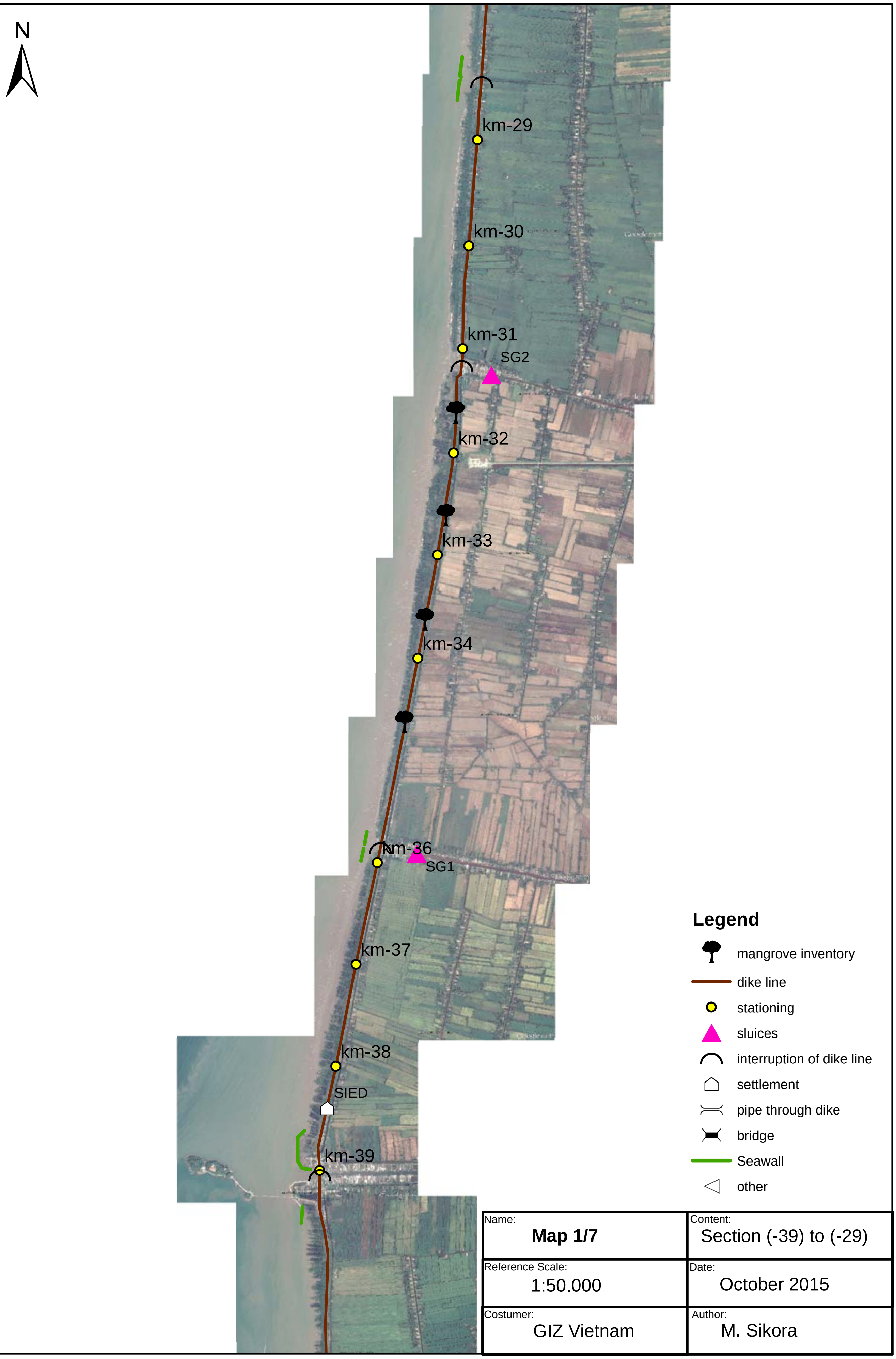
Designation	No. 8	
Coordinates	104,839346 9,530235	
Year of construction	2010/2011	
Details of construction	Number of sluice gates	1
	Safety gates available?	yes
	Gate wide	8 m
	Gate height	6 m
	Canal wide	Unknown
Condition of the structure	Setting of concrete plates	
Connection to the dike?	Yes	
Sluice outlet	Type of revetment	Concrete plates, paving stones
	Condition	scour holing at the end of revetment
Sluice inlet	Type of revetment	Concrete plates, paving stones
	Condition	scour holing at the end of revetment
Regulation of the closing operation	Regulation by flood current or closed by men power if sea water for shrimp farming is needed or not.	
Further notes	-	

Designation	No. N1, under construction	
Coordinates	104,861058 9,693901	
Year of construction	Under construction	
Details of construction	Number of sluice gates	1
	Safety gates available?	yes
	Gate wide	8 m
	Gate height	6 m
	Canal wide	Unknown
Condition of the structure	Under construction	
Connection to the dike?	Yes	
Sluice outlet	Type of revetment	Concrete plates, rip-rap prevent
	Condition	Good
Sluice inlet	Type of revetment	Concrete plates, rip-rap prevent
	Condition	Good
Regulation of the closing operation	Unknown	
Further notes	Geotextile under rip-rap prevent, stones are fixed by wire mesh, located at border of two communes	

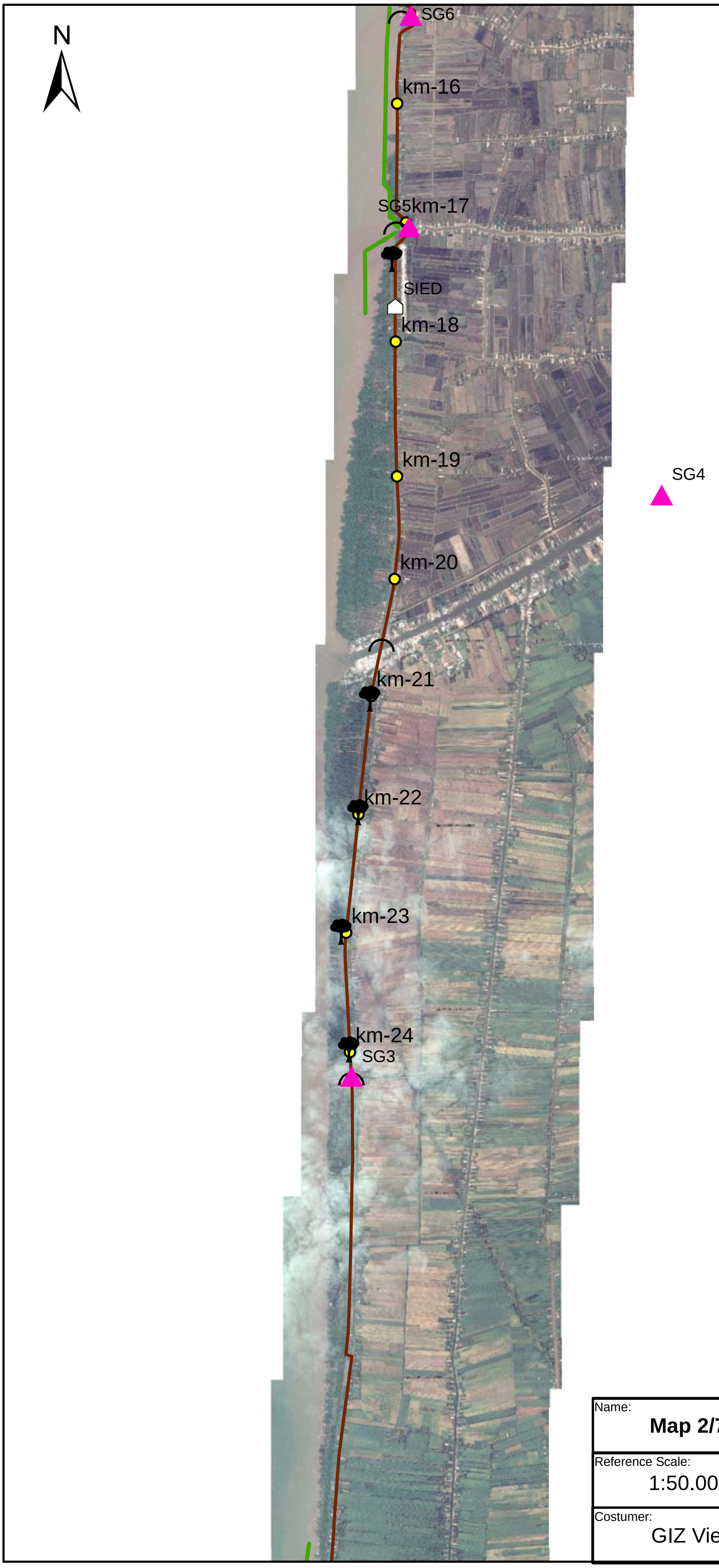
Designation	No. N2, under construction	
Coordinates	104,864628 9,710319	
Year of construction	Under construction	
Details of construction	Number of sluice gates	1
	Safety gates available?	yes
	Gate wide	Unknown
	Gate height	Unknown
	Canal wide	Unknown
Condition of the structure	Under construction	
Connection to the dike?		
Sluice outlet	Type of revetment	-
	Condition	-
Sluice inlet	Type of revetment	-
	Condition	-
Regulation of the closing operation	Unknown	
Further notes	-	

Designation	No. 9	
Coordinates	104,839643 9,568265	
Year of construction	1998	
Details of construction	Number of sluice gates	1
	Safety gates available?	yes
	Gate wide	8
	Gate height	4,8
	Canal wide	45
Condition of the structure	bad condition, settling of concrete plates	
Connection to the dike?	Yes	
Sluice outlet	Type of revetment	Concrete plates, paving stones
	Condition	Settling of revetment and scour holing at the end of revetment
Sluice inlet	Type of revetment	Concrete plates, paving stones
	Condition	Settling of revetment and scour holing at the end of revetment
Regulation of the closing operation	Unknown	
Further notes	-	

Annex C:



Name: **Map 1/7**	Content: Section (-39) to (-29)
Reference Scale: 1:50.000	Date: October 2015
Costumer: GIZ Vietnam	Author: M. Sikora



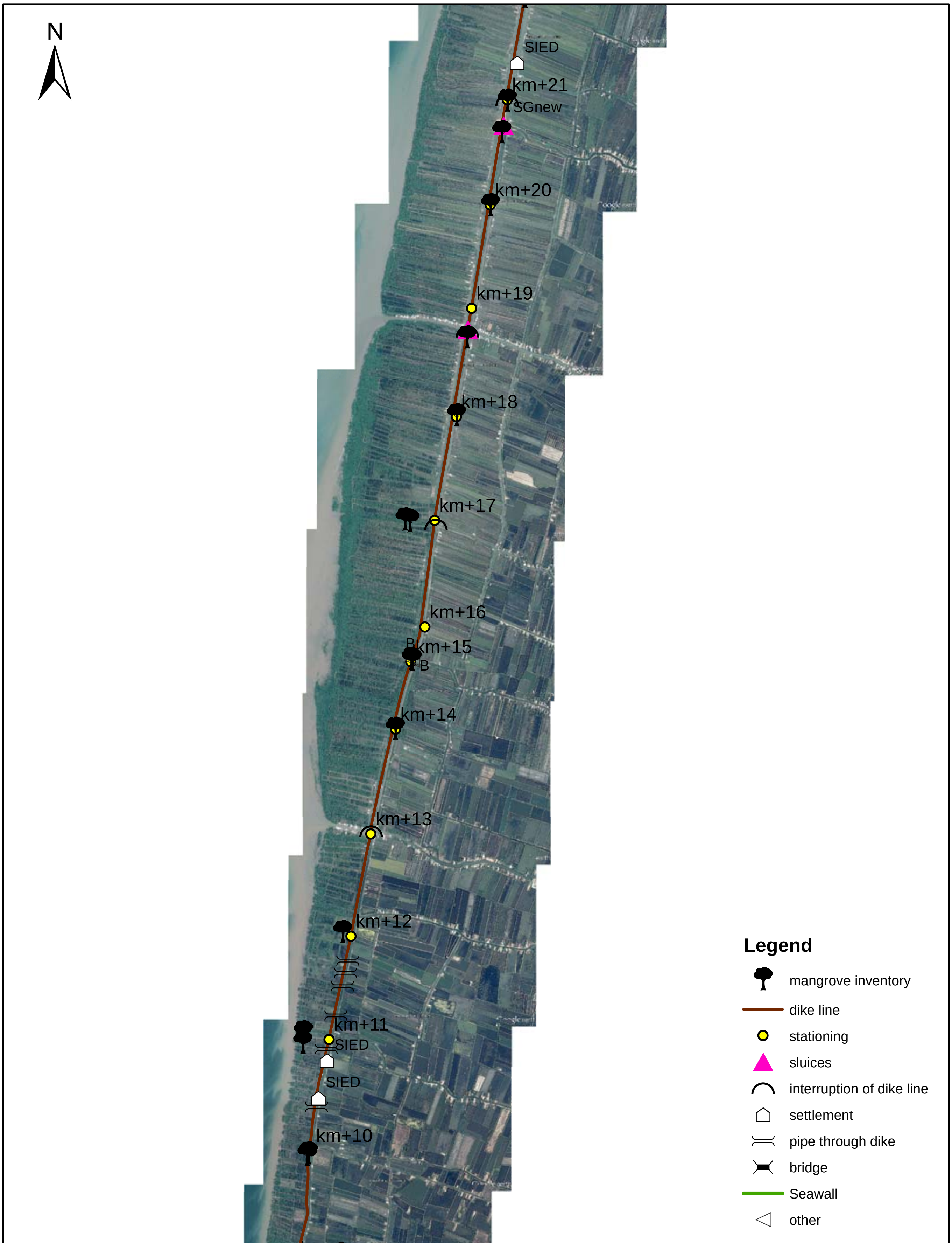
Legend

- mangrove inventory
- dike line
- stationing
- sluices
- interruption of dike line
- settlement
- pipe through dike
- bridge
- Seawall
- other

Name: **Map 2/7**	Content: Section (-28) to (-16)
Reference Scale: 1:50.000	Date: October 2015
Costumer: GIZ Vietnam	Author: M. Sikora

Name: **Map 3/7**	Content: Section (-16) to (-4)
Reference Scale: 1:50.000	Date: October 2015
Costumer: GIZ Vietnam	Author: M. Sikora

Name: **Map 4/7**	Content: Section (-4) to (8)
Reference Scale: 1:50.000	Date: October 2015
Costumer: GIZ Vietnam	Author: M. Sikora

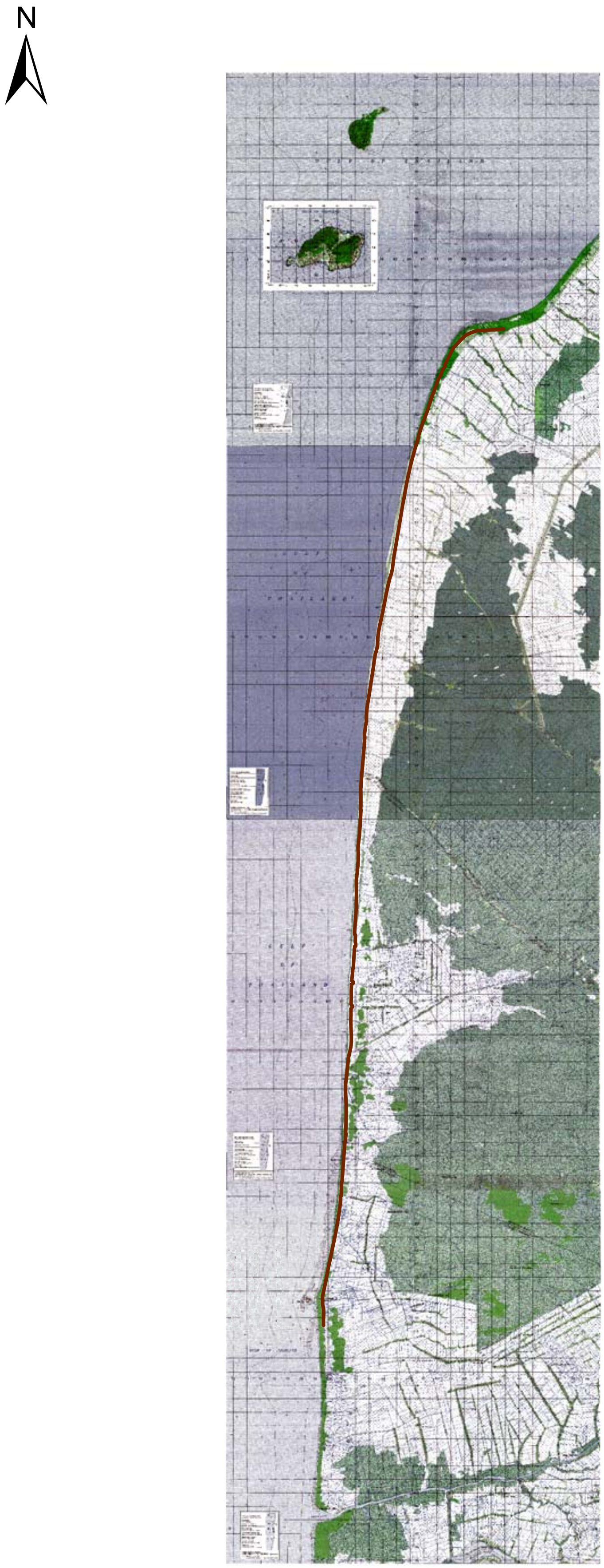


Name: **Map 5/7**	Content: Section (8) to (21)
Reference Scale: 1:50.000	Date: October 2015
Costumer: GIZ Vietnam	Author: M. Sikora

Legend

- mangrove inventory
- dike line
- stationing
- sluices
- interruption of dike line
- settlement
- pipe through dike
- bridge
- Seawall
- other

Name: **Map 6/7**	Content: Section (13) to (29)
Reference Scale: 1:50.000	Date: October 2015
Costumer: GIZ Vietnam	Author: M. Sikora



Legend

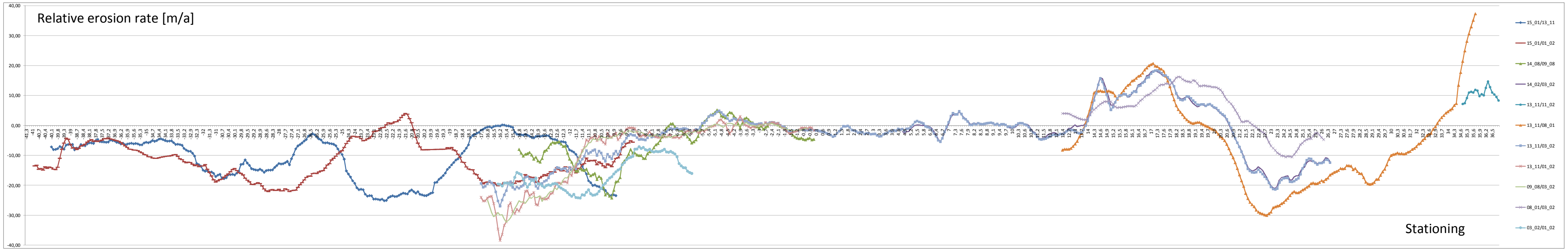
dike line

Name: **Map 7/7**	Content: Map of 1960
Reference Scale: 1:500.000	Date: October 2015
Costumer: GIZ Vietnam	Author: M. Sikora

Annex D:

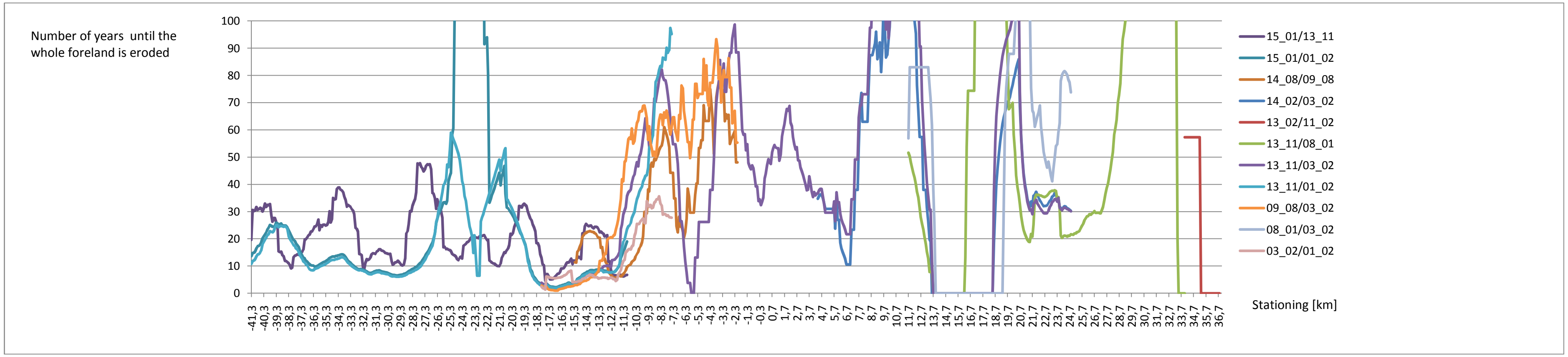
	lat	lon	**Dimension of transect [m²]**	trees per t	density [plants/ha	average extend [cm]	average height [m]	connection to the sea	yes	no	if yes, canopy closure?	yes	no	if no, swell impact line before or behind transect?			
p21A	9,218090	104,818040	5x5	37	14800	10,20,16,10,13	5			no			no	before	*Rhizophora apiculata*		
P24A	9,245120	104,822520	5x5	10	4000	21,30,18,15,15	6			no			no	before	*Rhizophora apiculata*	*Avicennia marina*	
P20A	9,313590	104,826100	5x5	23	9200	25,30,9,15,10	3			no			no	before	*Avicennia marina*	*Thespesia populnea*	*Excoecaria agallocha*
P19A	9,322500	104,825510	5x5	46	18400	20,25,8,7,10	2,5			no			no	before	*Rhizophora apiculata*		
P18A	9,331540	104,826820	5x5	30	12000	45,50,8,15,20	1,5			no			no	before	*Avicennia marina*	*Thespesia populnea*	*Excoecaria agallocha*
P17A	9,340150	104,827700	5x5	21	8400	30,20,6,10,10	2			no			no	before	*Avicennia marina*		
P13A	9,403440	104,830870	5x5	28	11200	6,5,43,16,12	2			no			no	before	*Avicennia marina*		
P12A	9,421330	104,831500	5x5	18	7200	26,12,3,1,15	1,2			yes			no	before	*Avicennia marina*		
P11A	9,430330	104,832020	5x5	44	17600	6,10,18,40,2	1,5			no			no	before	*Excoecaria agallocha*		
P9A	9,448910	104,832480	10x10	52	5200	20,15,8,5,2	3			no			no	before	*Rhizophora apiculata*	*Thespesia populnea*	
P6A	9,476510	104,834120	10x10	44	4400	60,40,20,7,3	1,5			no			no	before	*Avicennia marina*		
P5B	9,485420	104,834060	5x5	20	8000	55,40,20,5,7	1,5			no			no	before	*Rhizophora apiculata*	*Avicennia marina*	
P5A	9,485530	104,833350	5x5	21	8400	30,25,12,2,5	2			no			no	before	*Excoecaria agallocha*	*Avicennia marina*	
P4A	9,494550	104,834940	10x10	70	7000	50,40,20,10,7	5			no			no	before	*Rhizophora apiculata*	*Excoecaria agallocha*	
P3A	9,503600	104,835110	5x5	27	10800	50,5,20,0.5,7	2			no			no	before	*Avicennia marina*	*Thespesia populnea*	
P3B	9,503890	104,834980	10x10	13	1300	30,200,25,1,3	1,5			no			no	before	*Thespesia populnea*		
P2A	9,512600	104,835620	10x10	67	6700	30,20,7,4,1	5			no			no	before	*Xylocarpus mekongensis*	*Rhizophora apiculata*	
P1A	9,521930	104,835730	5x5	67	26800	5,30,25,42,2	3			no			no	before	*Avicennia marina*	*Nipa fruticans*	*Xylocarpus mekongensis*
P1AF	9,530800	104,836600	no forest														
P2AF	9,540500	104,836700	5x5	44	17600	41,11,5,12,19	6		yes				no	before	*Avicennia marina*	*Bruguiera cylindrica*	
P3AF	9,549990	104,837630	5x5	12	4800	14,21,30,29,23	5		no				no	before	*Rhizophora apiculata*		
P4AF	9,559890	104,837990	5x5	25	10000	15,12,36,5,22	6		no				no	before	*Rhizophora apiculata*	*Bruguiera cylindrica*	
P5DF	9,567780	104,839370	5x5	17	6800	45,9,6,19,27	5		no				no	before	*Avicennia marina*	*Xylocarpus mekongensis*	
P5CF	9,568150	104,839570	5x5	19	7600	7,10,10,13,10	3		no				no	before	*Avicennia marina*		
P5AF	9,568330	104,839840	5x5	16	6400	20,9,21,27,17	5		no				no	before	*Excoecaria agallocha*		
P5PF	9,568400	104,839680	5x5	8	3200	9,18,20,4,6	1,5		yes				no	behind	*Excoecaria agallocha*		
P6AF	9,577880	104,839480	5x5	11	4400	31,13,27,23,25	8		no				no	behind	*Rhizophora apiculata*		
P7AF	9,586750	104,841920	10x10	22	2200	19,34,41,43,38	12		no				no	before	*Rhizophora apiculata*		
P7BF	9,586890	104,841010	10x10	6	600	84,14,80,24,13	8		no				no	before	*Thespesia populnea*	*Lumnitzera racemosa*	
P8BF	9,595970	104,843280	10x10	21	2100	38,39,56,27,34	10		no				no	before	*Rhizophora apiculata*		
P8AF	9,595980	104,843430	10x10	27	2700	45,31,11,43,34	8		no				no	before	*Rhizophora apiculata*	*Thespesia populnea*	
P10AF	9,614110	104,846110	5x5	30	12000	14,13,8,4,6	4		no				no	before	*Thespesia populnea*	*Avicennia marina*	
P11BF	9,623290	104,847500	10x10	29	2900	26,32,36,22,31	6		no				no	before	*Nipa*	*Rhizophora apiculata*	
P11AF	9,623410	104,847610	5x5	30	12000	9,23,9,45,11	3		no				no	before	*Thespesia populnea*	*Lumnitzera racemosa*	*Excoecaria agallocha*
P12BF	9,632800	104,847140	5x5	38	15200	29,10,7,43,16	4		no				no	before	*Avicennia marina*	*Rhizophora apiculata*	*Bruguiera cylindrica*
P12AF	9,633680	104,847180	5x5	27	10800	27,12,12,6,6	2		no				no	before	*Avicennia marina*	*Bruguiera cylindrica*	
P16AF	9,665400	104,856360	5x5	33	13200	4,4,6,52,8	1,5		no				no	before	*Avicennia marina*		
P17AF	9,677100	104,856260	5x5	21	8400	12,32,14,30,6	5		no				no	before	*Avicennia marina*	*Rhizophora apiculata*	*Bruguiera cylindrica*
P17BF	9,677240	104,855840	5x5	43	17200	110,4,16,13,46	4		no				no	before	*Avicennia marina*	*Rhizophora apiculata*	
P22AF	9,712820	104,864530	no forest, pond, aquaculture														
P23AF	9,721650	104,866020	5x5	49	19600	17,6,5,13,9	3		no				no	before	*Avicennia marina*		
P24AF	9,730300	104,867670	5x5	19	7600	15,21,8,7,17	2,5		no				no	before	*Avicennia marina, Thespesia populnea*		
P25AF	9,739340	104,869760	no forest														
P26AF	9,748180	104,872060	5x5	36	14400	6,11,13,7,12	2		no				no	before	*Avicennia marina*		
P27AF	9,751730	104,871900	10x10	54	5400	10,30,24,7,6	7		no				no	before	*Rhizophora apiculata*		
P28AF	9,756670	104,874650	5x5	29	11600	7,20,8,17,10	3		no				no	before	*Avicennia marina*		
RanhgioiTI	9,761670	104,876010	5x5	45	18000	4,3,4,6,2	1,5		no				no	before	*Avicennia marina*		
P30AF	9,766710	104,877550	5x5	34	13600	7,9,18,9,17	3		no				no	before	*Avicennia marina*	*Avicennia officinalis*	*Thespesia populnea*
P31AF	9,775530	104,880920	5x5	31	12400	21,10,7,18,24	2,5		no				no	before	*Thespesia populnea*	*Avicennia marina*	*Rhizophora apiculata*

Annex E:



Relative erosion rate [m/a]
40,00
30,00
20,00
10,00
0,00
-10,00
-20,00
-30,00
-40,00
Stationing
15_01/13_11
15_01/01_02
14_08/09_08
14_02/03_02
13_11/11_02
13_11/08_01
13_11/03_02
13_11/01_02
09_08/03_02
08_01/03_02
03_02/01_02

Annex F:



Number of years until the whole foreland is eroded
100
90
80
70
60
50
40
30
20
10
0
Stationing [km]
15_01/13_11
15_01/01_02
14_08/09_08
14_02/03_02
13_02/11_02
13_11/08_01
13_11/03_02
13_11/01_02
09_08/03_02
08_01/03_02
03_02/01_02

Annex G:

	Name Location								
Location/ Parameter	H1	H2	H3	H4	A1	H5	A2	H6	A3
Section [km]	-41,3 to -37	-37 to -25	-25 to -18	-18 to -8	-8 to 0	0 to 9	9 to 27	27 to 30	30 to 36
Width of current foreland [m]	140	140	230	95	220	160	570	550	1850
Density of current forest	medium	medium	sparse	sparse	medium	medium	medium	sparse	medium
$Z_{tk,p}$ design water level at dike toe	1,092	1,1107	1,1146	1,1178	1,24	1,333	1,4	1,4	1,432
Wave direction β	0	0	0	0	0	0	0	0	0
seaward Slope α (1:5)	11,3	11,3	11,3	11,3	11,3	11,3	11,3	11,3	11,3
Significant wave height $Hs_{dike\ toe}$	1,23	1,01	1,01	1,3	1,51	1,12	1,23	1,23	1,05
Kt-factor real	0,37	0,37	0,4	0,7	0,22	0,32	0,03	0,1	0,01
σ real	0,2	0,2	0,1	0,1	0,2	0,2	0,2	0,1	0,2
Kt-factor optimal	0,22	0,22	0,09	0,4	0,11	0,2	0,01	0,01	0,005
σ optimal	0,3	0,3	0,3	0,3	0,3	0,3	0,3	0,3	0,3
Tp	8,64	8,64	8,64	8,64	8,64	8,64	8,64	8,64	8,64

Annex H:

	Result:								
	Current situation			Optimal situation			worst case		
Location	Zdp	ξ-1,0	R2%	Zdp	ξ-1,0	R2%	Zdp	ξ-1,0	R2%
H1	4	2,65	1,81	3,4	3,31	1,2	6	1,77	3,81
H2	3,72	2,3	1,51	3,21	3,65	1	5,4	1,95	3,19
H3	3,71	2,29	1,5	2,64	5,7	0,43	5,4	1,95	3,19
H4	5,38	1,96	3,16	4,42	2,39	2,21	6,13	1,72	3,91
A1	3,69	3,11	1,35	3,1	4,22	0,76	6,56	1,6	4,22
H5	3,88	2,99	1,45	3,44	3,63	1,01	5,93	1,85	3,5
A2	2,67	9,32	0,17	2,56	15,51	0,06	6,31	1,77	3,81
H6	2,99	5,33	0,49	2,56	15,51	0,06	6,31	1,77	3,81
A3	2,58	17,47	0,05	2,55	26,67	0,02	5,83	1,91	3,3