Integrated Coastal Management in the Province Ca Mau - Vietnam

An Integrated Research to the Coastal and Water Resource Management Issues

Students:
Bianca Stoop
Dimitrios Bouziotas
Jill Hanssen
Johannes Dunnewolt
Mark Postma

4023212
4319826
4240162
4254635
4129237

Supervisors:
S.A. Groenewold
M.J.F. Stive
N.C. van de Giesen
Preface

This report is written in the form as Multidisciplinary project which is part of the masters Hydraulic Engineering and the master Water Management at the TU Delft. In such a project a group of students with different backgrounds work together on an integrated project with multiple disciplines. This project has been initiated on February 2015 on behalf of GIZ (Deutsche Gesellschaft Für Internationale Zusammenarbeit).

GIZ is a German federal enterprise which supports the German Government in international cooperation for sustainable development. GIZ is located in Vietnam on behalf of the German Government to provide advice for the Vietnam government to adopt its Green Grown Strategy, which is aimed to achieve efficient and sustainable economic development based on the sparing of natural resources.

The report is aimed to provide research proposals and stress research gaps in the analysis of the current System. It starts with a short summary of the current system, followed by an investigation in the drivers which change the system. The processes and its drivers are summarized in a system dynamics diagram and this diagram is used to look how these processes will develop in several future scenarios for the province of Ca Mau. The results can be used to search for measures against the problems and to find gaps in research that need to be further investigated.

The research described above would not have been possible without the help of Marcel Stive (TU Delft) who brought us in contact with GIZ and helped us in the preparation phase. On behalf of GIZ, Dr. Stefan Groenewold was a great help for us, arranging interviews and his weakly counselling. We would also like to thank Mr. Phan Thanh Tinh, GIZ employee in Ca Mau, who helped with arrangements on the fieldwork. The interview with and feedback from Martijn van de Groep (Mekong Delta Plan) was also very valuable for us and we appreciate the time he made for us. We also would like to thank Dr. Le Trung Thanh (Director) and Mr. Tran Dang An (PHD’er) from the WRU (Water Resource University, HCMC) for their help, hospitality and use of their working space and dorms.

Delft, 18 May 2015

Dimitrios Bouziotas
Johannes Dunnewolt
Jill Hanssen
Mark Postma
Bianca Stoop
Abstract

The province of Ca Mau is the southernmost part of Vietnam and the Mekong Delta. It is a low-laying area, with a typical height of 0.5-1 m above sea level, which is surrounded by the East Sea and the Gulf of Thailand respectively. The water system of Ca Mau faces multiple challenges, both in its coastal zone and in its inland regions. The coast is characterized by significant mangrove squeeze and high erosion rates in the last decades, while the inland water system faces the threat of salinity intrusion, freshwater scarcity during dry seasons and flooding during wet seasons. These threats in the two parts of the system (coastal zone and inland water), that would otherwise be studied separately, are interlinked in the case of Ca Mau. The sea, through tidal forcing, wave action and high-energy events, defines the status not only for the coastal zone but also far inland. Meanwhile, climate change but also human water uses are expected to further challenge the status of water and the coastal zone in the province.

In view of this, this study presents an integrated approach for combined coastal and inland water management in Ca Mau, under the scope of climate and socio-economic change. Firstly, an extensive literature study is performed on the current status of both the coastal zone and the inland water system. Key aspects and problems in the province are highlighted and information on the current level of protection is found. Secondly, a set of methods is employed that aims at:

- Creating a conceptual System Dynamics (SD) model for the combined coastal and inland water system of Ca Mau, incorporating both climate change and the human factor, that can be used both for system evaluation and stakeholder participation.
- Performing a scenario analysis, based partly on this SD model, to identify possible futures for Ca Mau and
- Using information obtained from the scenarios to identify strategies and, through them, prioritize arrays of measures that could be of use in Ca Mau, in order to achieve sustainability in the combined human-water system.

The objective of this study is therefore to identify measures that contribute to a realization of a sustainable, durable environment that satisfies the protection and the socioeconomic needs of the inhabitants in the province of Ca Mau, in which coastal engineering, (inland) water management and land use can be integrated. In order to reach that identification, a holistic analytical approach that couples water engineering knowledge, systems modeling, horizon scanning and strategic analysis needs to be used; a second objective of this study is thus to formulate the right set of tools for this task and demonstrate their use, so that they can be adapted in a larger context in the future, beyond this study, both within Ca Mau but also in cross-provincial studies.

Lastly, this process brings a top-down, complete perspective on all aspects of the water system, that eventually leads to the identification of areas where more research is needed. In view of this, this study reaches conclusions on focal points of research about water in Ca Mau that could form the base for more efficient measures and policy actions in the future.
Table of Contents

Preface................................................................................................................................. iii
Abstract ................................................................................................................................. iv
Table of Contents ................................................................................................................... v
1 Introduction & Problem Definition....................................................................................... 2
   Methodological Approach .................................................................................................. 2
2 Need for Integration.............................................................................................................. 3
3 Current System Status ........................................................................................................ 4
   Current System - Hydraulic Analysis ................................................................................ 4
   Current state - Water management .................................................................................... 10
   Current System- Policy ...................................................................................................... 14
   Current System- Stakeholders .......................................................................................... 16
   Current System- SWOT ...................................................................................................... 17
4 Drivers of Change ................................................................................................................ 18
   Climate change hazards .................................................................................................... 18
   The human factor and socio-economic drivers in the system ............................................. 20
5 Model Formulation .............................................................................................................. 24
   Methodology ..................................................................................................................... 24
   Scope of model development ........................................................................................... 25
   Results ............................................................................................................................... 25
   Conclusions ....................................................................................................................... 28
6 Scenarios ............................................................................................................................. 30
   Scenarios .......................................................................................................................... 30
7 Fieldwork ............................................................................................................................ 34
8 Measures ............................................................................................................................. 34
   Introduction ....................................................................................................................... 34
9 Research Proposals ............................................................................................................. 38
   Thematic Area B: The coastal zone .................................................................................. 41
   Thematic Area D: River and inland canal management .................................................... 42
   Thematic Area C: Policy and institutions .......................................................................... 43
10 Discussion & Conclusion..................................................................................................... 44
   Discussion ......................................................................................................................... 44
   Conclusion and Recommendations .................................................................................. 45
11 References ........................................................................................................................ 48
Introduction & Problem Definition

The Ca Mau province is the most southern province of Viet Nam and one of the twelve provinces lying in the Mekong Delta catchment. The province can be characterized as a low lying, rural area which is exposed to oceans at both east and west coast. In the wet season it faces problems due to storms and heavy rainfall, and in the dry season there is salinity intrusion in almost whole the province. The infrastructure lacks behind because of the difficulty of building roads and bridges in the deltaic depositions.

Under influence of climate change and economic development the province will face many problems in the future perspective, think of sea level rise, coastal erosion and domestic pollution. The government of Vietnam aims to develop Ca Mau as a strong socio economic development province by 2020. In order to reach this goal, there are many challenges for Ca Mau to be mastered. These challenges cover both the coastal zone and inland water system, and therefore it is necessary to have integrated management and policy-making for the land and water use. This report will go further into the question what measures can contribute to this integrated management of the coastal and inland water management zone. The main goal of this research is:

*Formulate measures that contribute to a sustainable, durable environment that protect both the coast and the social economic needs of the inhabitants of the province.*

The most important aspect of these measures is to integrate the coastal with the water management system, in such a way that the water system can be seen as a whole.

This project is approached within the spatial boundaries of the province of Ca Mau. The considered timescale is 30-50 years, until 2050, in order to see the effect of all elements and processes, slow and fast, working together in the system.

Methodological Approach

The first step in the methodology is to analyze the water system of the province. The system is analyzed in a holistic approach on the Coastal Zone Management, Integrated Water management and stakeholder management in the chapter Current Status. To integrate both coastal and inland water management system a System Dynamics approach is applied to the province on an aggregated scale, including also economy and policy relationships. The system dynamics model includes cause-effect relationships and with this tool sensitive and influential elements of the system can be identified (chapter Model).

In the next step (chapter Scenarios) the system dynamics model is used along with scenario building approach, to identify possible future states of the system and examine critical aspects of weaknesses and opportunities for Ca Mau. Key measures that could be chosen for different strategies are outlined based on the scenarios in the chapter Measures. Arrays of possible measures in combination with research gaps that were found during this study form the backbone for the research proposal on Case Studies for the chapter Research Proposal. Finally, the discussion of the performed work and the conclusion can be read in the last chapter.
2 Need for Integration

The coastal zone and inland zone in Ca Mau have many connections. The health of the coastal zone defines the level of flood protection of the whole low-lying area; at the same time, tide and salinity intrusion affect channels deep in the province. The challenge, in the case of Ca Mau, is to fuse the coastal system with the inland water system. By using a holistic approach, the system can be fully understood, which is necessary for an effective and efficient solution for the whole province of Ca Mau. The coastal zone alone can be seen as a multi-faceted system that includes:

a) The natural (physical and ecological) system of the coast
b) The socio-economic subsystem that defines the range of coastal human activities.
c) Pressures exerted to the system by changes in either (a.) or (b.)

In the case of Ca Mau, both Socio-economic as Natural agents contribute to a change in the coastal zone. To create an integrated plan the Natural boundary conditions have to incorporate inland hydrology, as well as coastal wave, current and sediment input, and the Socio-Economic development plans have to encompass both human action on the coast and the inner land. This will yield a more clear view on the total system dynamics, as opposed to isolated Coastal Zone (CZM) and Water Management (WM) studies.

In fact, besides differences in the viewpoint on the coupled natural-human system, integrated management aspects between CZM and WM show striking similarities. To better understand the concepts of ICZM, Scura, Chua, Pido, & Paw, 1992 depict integrated coastal zone management as a gridded cube of three basic dimensions, and in 2008 Savenije & Van der Zaag, 2008 came to a similar layout while sketching the concept of Integrated Water (Systems) Management (IWM) as a multi-dimensional structure.

In the context of this study, a similar 3D gridded cube is proposed as a fundamental viewpoint (see Figure 1). Its dimensions are:

- The natural system dimension, driven by climate variability, which includes aspects of both the coastal and the inland water system.
- The human dimension, driven by socio-economic changes, which comprises water uses related to both coastal zone and inland water resources.
- The management dimension, which is related to planning, implementation and monitoring/evaluation.

![Figure 1: The Multi-dimensional structure of managing the water system in the case of Ca Mau.](image-url)
Current System Status

Current System - Hydraulic Analysis
A literature study has been done after the hydraulic forcing and related sediment transport along the coast of Ca Mau, the mangrove belt and the human interferences in the coastal system.

Current
Ca Mau is boarded by two seas; Gulf of Thailand in the West and East sea in the East. This is the reason for a different current flow along the East, South and West coast. The current is influenced by the tide, (monsoon) wind and waves and the connection of the two water bodies.

There are two different tides affecting the coast and tidal penetration in Ca Mau (more about the tidal penetration can be read in the WM analysis). In the East Sea there is an M2 tide which rotates anti-clockwise while at the West coast, in the Gulf of Thailand, a K1 tide rotates clockwise. The clockwise rotation is due to the shape of the Gulf. Observations show that the M2 tide (in the East Sea) has a larger tidal amplitude than the K1 tide in the Gulf of Thailand, also the phase of the high and low waters are different. The South coast is influenced by both tides and the differences between them create an additional current along the tip of Ca Mau. This current reinforces or reduces the current of the tide and the wind, and depends on the phase differences between both tides (Michael J Russell, 2012).

Also the monsoon winds and generated waves influence the current. Ca Mau has an equatorial tropical climate with two seasons. In May to November the South West monsoon creates the wet season. Air currents transport water from the ocean which leads to large amounts of rainfall above the land. In December to April a dry period is caused by the North East monsoon. Air flow is from the continent towards the sea (dry season) lasting from December up to April. -

Lastly, the area is also influenced by two sets of tropical cyclones. Northwesterly in summer months and lower latitude cyclone tracks in October, November and December. Despite the low frequency of these paths, Ca Mau is particularly exposed to these events due to its low altitude and southernmost geographical position.

The current system along the coast of Ca Mau is complex due to the combination of all elements described above. Research has been done to the current flow along the coast, but the results of different investigations are contradictory, especially for the processes along the West coast. Secondly, information and data is not easily exchanged by the different research institutes and universities. This makes it difficult to understand all the processes and dominant directions of currents along the coast.

Sediment transport
The Mekong river, North from Ca Mau, delivers the largest source of sediment for the province. This sediment is transported along the coast, and processes of longshore transport, that shapes the coast in longitudinal direction, and cross-shore transport, that shapes the coast in transverse direction of...
the coast, are present. The cross-shore profile of the coast is assumed to be in dynamic equilibrium, what means that the sediment balance in cross direction is stable. The only cross-shore process of interest is significant erosion due to typhoons and storm surges. This process leads to episodic erosion and not the structural annual erosion observed in most coasts. It is excluded from further analysis in the present study.

Spatially there is a large variation in the deposited sediments as can be seen in Figure 2. At the East and South coast of Ca Mau, the sediment is sandy and contains silt as well. At the West coast the sediment contains predominantly silt. The relatively smaller wave action of the diurnal tide along the West coast is only able to transport the fines. (Unverricht et al., 2013)

The longshore transport is influenced by the magnitude and direction of the current. In the wet season, during the SW monsoon, the river discharge is maximal. Due to these high discharges, erosion may occur near the river mouth. During the South West monsoon winds lead to a transport that is slightly directed to the North, for both east and west coast. During the NE-monsoon in the dry season, the sediments are transported to the South along the East coast of Vietnam and Ca Mau itself by:

- The tidal current, which is southward along the coast;
- Wind waves from the North-East monsoon winds;
- Coastal downwelling (Xue, He, Liu, & Warner, 2012), caused by the NE wind and geostrophic flow at the Northern hemisphere.

The whole province of Ca Mau is a southwestward prograding spit (Ta et al., 2002), built up by (reworked) sediments of the Mekong river at the east coast that is transported from North to South. At the south coast of Ca Mau the interaction of the diurnal at the semi-diurnal tide influence the sediment transport and deposition. The tidal amplitude of the diurnal component is smaller and the current velocities decrease. Research (Unverricht et al., 2013) points out that fine sediments of the Mekong river can be transported around the tip of Ca Mau towards the North along the West coast. It is hypothesized (information gained from interviews) that silt particles in the upper layer of the water column are transported around the tip in Northern direction by the wind driven current, while...
coarser particles, in the lower part of the water column, flow in Southern direction into a sink. More research has to be done to verify this hypothesis.

As the processes defining the current along the West coast are very complex, as pointed out before, sediment transport is also possible to the South along the West coast. Although there is no significant source of sediments like the Mekong river on the West coast. The only particles that are transported into the coastal cell are eroded in the regions in at the coast North of the province. (There are outlets of canals, but it is expected that these are not a significant source for sediments.) Therefore, it is advisable to start a measurement campaign along the West Coast, to construct the expected flow during SW and NE monsoon, and to investigate the sediment transport at this coast. With the obtained data the expected flows during the SW and NE monsoon, the sources and sinks of sediments and the flows of coarse and suspended sediment can be verified.

Coastal accretion and erosion

An unstable sediment balance will lead to coastal erosion or accretion. As stated before, Ca Mau is a fast prograding spit. This is due to a shallow fore shore as a result of the subaqueous delta (Unverricht et al., 2013), and secondly the mangrove forest that are able to capture sediments (V. L. Nguyen, Ta, & Tateishi, 2000). These accreting parts can be found in the most southern tip of Ca Mau, the Ca Mau Mui Park. The park is protected by legislations. But, also large parts of Cape Ca Mau are also influenced by the human stress due to deforesting. Along the Song Bo De there are measurements of 90m of erosion per year.

The problematic and advancing erosion process occur at locations indicated in Figure 3. Erosion rates along the East coast of Ca Mau are around 20m per year in the last decade. The west coast of Ca Mau has a relative straight coastline, and is expected to have been in equilibrium for many decades. Currently due to human interference the shape of the coastline is interrupted, giving rise to a sediment transport gradient in long shore direction and resulting an erosion rate of 10m per year for the last decade (von Lieberman, n.d.). Other causes contributing to the erosion along the coast of Ca Mau are:

- The global climate change leads to RSLR, stronger monsoons, and a higher storm surge level. In all cases the wave height, magnitude of the current and therefor erosion rate increases.
- Extreme weather events, like typhoons, lead to higher waves and storm surges. Besides the mangrove threes cannot withstand these extraordinary forces. They lose sediment or even get destroyed. Loss of land is the consequence.
- Deforestation of the mangroves leads to less sediments that can be captured by the mangrove threes. The sediments are more easily transported by the current.
- Natural gaps (like river mouths) along the coastline or human induced changes of the coastline influence the angle of the wave approach with the coast. A varying coastline orientation leads to a gradient in the sediment transport rate. These (initially small) gabs grow fast until a new equilibrium of the coastline is reached.
- Erosion resulting from high river outflow due to large precipitation events. The higher discharges give rise to erosion at the river mouth.
- In the last years hydraulic structures (dams, hydropower stations, etc.) are constructed in the Mekong River, what (some think to be) is leading to a decreased sediment concentration downstream. This has led amongst Lu & Siew to erosion along the East coast of Ca Mau.
Mangroves have an important function in the coastal region providing a natural barrier stabilizing the coastline, adding high ecological value and providing high economic value for humans who use their resources. In a lot of coastal areas the management faces a balance between environmental protection and economic development. Excessive mangrove deforestation is one example of management where economic development was valued more important than habitat and storm protection, which the mangroves offer.

Functions
Mangrove forests tend to grow along muddy shorelines in sheltered tropical and subtropical areas. They have productive, ecological and protective functions.

Mangroves are the start in the nutrient cycle, they provide organic materials and shelter marine ecosystem. The reproduction of mangroves is very sensitive for (relatively fast) changes in the ecosystem, this is important to know for reforestation plans. Secondly, mangroves play a critical role in the coastal zone protection. They trap sediments, influence wave attenuation, and provide storm protection and shoreline stabilization. For these functions, a stable and thick mangrove belt is needed along the coastline. The belt is however threatened by the productive function mangroves have. It is used to provide food, biotic resources, material for construction and fuel. In Ca Mau mangrove forest is mainly used for shrimp farming and construction, this causes deforestation of the forest and squeeze of the mangrove belt.

Other human induced causes for the mangrove squeeze are the Vietnam war, where a lot of mangrove forest got destroyed and it was difficult to grow back, and cultivation of new land in the coastal zone area. Next to threats from human side, the mangroves are also threatened by the climate change. The growth of the mangroves cannot keep up with the RSLR, which means that the mangrove die. A less thick mangrove belt is less resistant against higher waves and storms, which means that the coast will erode more under these pressures. There are two ways for the mangroves to keep up with Sea Level Rise due to climate change, these are:
1. Growing together with SLR due to elevation of the mangrove surface
2. Landward move of mangroves to higher grounds.

The current mangroves is shrinking due to erosion by SLR and due to human stresses. These human stresses are currently still present and have already severely damaged the mangroves at certain areas. An overview of the problem area’s for all of these factors is shown in Figure 3. To stop further erosion mangrove restoration projects and coastal erosion measures are placed. Knowledge about the ecosystem is essential to effectively restore mangrove areas.
Current coastal protection measures

At the moment a dike system protects the hinterland of Ca Mau. This dyke system has however weak points, for example near culverts, and it needs to be heightened at many places. Currently there are also projects to heighten the dykes at critical locations from two to three meter above sea level. The households who live behind the dykes are relocated to so called relocation area’s to heighten the dyke. The relocation areas are however still very close to the dykes.

Next to sea dykes there are other coastal protection measures placed to prevent the severe erosion of land and/or of the sea dyke. These measures are gabions, revetments, vertical breakwaters, temporary plastic fences and T-/Melaleuca fences. But not all the measures work that well. The measures against erosion and mangrove squeeze which are taken along the coast of Ca Mau are shown in Figure 5: Current coastal measures.

Measures like the revetments, gabions and plastic fences are (mostly) directly placed on the dyke. The vertical breakwater is created to have a calm wave climate at the coast, trap sediment and create opportunity for mangrove rehabilitation. The vertical breakwater is tested on severe erosion locations along the west coast of Ca Mau. These constructions are located at the inlet and near thin mangrove forest can be seen in Figure 5. The construction of the breakwater is costly, $14 Mln/km. Due to the high cost, only a pilot study was done at one location.

Ca Mau and surrounding provinces like Kien Giang and Soc Trang also invested in less costly bamboo T- fences and Melaleuca fences. The cost of these alternatives are considerably lower with; $ 0.7Mln/ km for the T-Fences and, $ 10.000-17.000/ km for the Melaleuca Fences (Giz, 2012). These measures only work well if the sediment is also course enough.
During the fieldwork it was also observed that not all the coastal dykes are connected with the sluices. The sluices are in most of the case placed more landwards, which creates a weak link in the coastal protection.

Figure 4: Measures
Upper: vertical breakwater. Lower: melaleuca fences

Figure 5: Current coastal measures.

Legend:
- Breakwater
- Gabbions
- Under Construction
- Proposed measures
- Fences
- Stone Revetments
- Unknown
**Current state - Water management**

**Freshwater availability**
The main source for fresh water in Ca Mau is rainfall. Ca Mau receives rainfall with an average of 2360 mm/year and 165 rain days. 90% of the total annual rainfall is received in the wet season (May-November). We can conclude that in the wet season there is abundant supply of fresh water (IMP, n.d.). There are, however, limited well-functioning water retaining works (e.g. reservoirs, rainwater harvesting) to capture and utilize this water for the dry season.

The water system of Ca Mau consists of a very dense system of canals and rivers. In the wet season heavy rainfall causes drainage problems, which in extreme cases can lead to floods. On the contrary, in the dry season there is lack of freshwater, which means that saline sea water is dominant in a big part of the province.

Groundwater resources are used by means of local wells. In research on land subsidence and groundwater extraction, Erban, Gorelick, & Zebker, 2014 found that the land subsidence occurring in the Mekong Delta is typical for an over-exploited aquifer system. The pumping induced subsidence rate exceeds the sea level rise by an order of magnitude (Erban et al., 2014).

The tides in the East and West Sea, together with the available fresh water (dry or wet season) determine the tidal intrusion in the canal system. The tides influence the water system in various ways. Penetration of the tide into the canal system influences the water levels and the salinity of the water in the canal. Furthermore the tidal ebbs and floods cause sedimentation and erosion depending on the tidal wave characteristics (ebb and flood, slack times). This in turn influences the discharge through the channels, navigability in the channels and aspects of land use on the canal banks.

**Land and water use**
The province of Ca Mau has to deal with these large differences of fresh water availability per season, as well as with the regional and seasonal dominance of saline water. As can be seen in Figure 6, the land cover in Ca Mau is largely defined by these characteristics.

**Rice agriculture**
In total, there is approximately 51 000 ha of cultivated area with rice throughout the whole year in Ca Mau. The limiting factor, in this case, is the availability of fresh water in the dry season. Farmers have to keep the salt water out during dry season and high tides, and harvest rainwater in the area.

A transition to rice-shrimp cultivation is made when rice cultivation is not possible due to a lack of fresh water and too high saline water during the dry period. The alternation of rice and shrimp requests a good management of the water and soil. During the transformation from shrimp to rice cultivation the field should be flushed through to remove all salts.
Aquaculture
Aquaculture in the province of Ca Mau can be divided into freshwater aquaculture and shrimp aquaculture. Within shrimp aquaculture there is a division between extensive and intensive shrimp farming. Extensive shrimp aquaculture governs the biggest part of the shrimp aquaculture in Ca Mau (found in South Ca Mau). It is considered as the simplest form of shrimp farming. The ponds have irregular shapes and larvae are supplied from the natural tidal variation. Semi-intensive shrimp aquaculture is also progressing in the province of Ca Mau. The ponds are regular shaped, and have an inlet and outlet, in order to facilitate water exchange. Pumps are needed for a regular water management scheme together with supplementary feed which improves the stocking rates.

Forest land cover
Along the coast mangrove forests form a first, natural line of coastal protection and have an important function in the biodiversity of the local ecosystem. In the Ngoc Hien – Nam Can district the National park Ca Mau Cape is located. The park has a high value in biodiversity an natural landscape, and is recognized in 2009 by UNESCO as a World Biosphere Reserve, just like the U Minh Ha National Park (discussed below). This gives chances to invest in ecotourism in these forests. More to the North there are Melaleuca Cajaputi forests. These forests have an important role in ecological balance of the coastal area and the ecosystem. Furthermore Melaleuca is locally used as a source of timber.

Domestic water uses and land cover
Ca Mau is mainly a rural area; the population mainly lives in coastal and agricultural areas, (respectively 59,8% and 19,3% ), with a smaller percentage living in urban areas (21.8%). In the rural areas people settle along traffic routes, ditches, canals and rivers, creating a characteristic ribbon pattern of canals lined with settlements and gardens (Binh, Vromant, Hung, Hens, & Boon, 2005). This is limiting the efficiency for infrastructure investment, which is one of the reasons in the rural areas people have limited or no access to water distribution networks, sewage and electrical grid.

Water transport
The waterways in Ca Mau and the whole Mekong Delta are intensively used for navigation since they are so widespread. Due to the heavy use of the waterways, the waves caused by the boats can lead
to erosion of exposed canal banks. The banks erode, expanding the width with 1-2 m. Droughts and tidal variability do not have significant influence on the navigational function. The province of Ca Mau has currently two ports, in Ca Mau (a small size inland port) and in Nam Can. The Nam Can port is a seaport, and has been recognized as international and commercial seaport in 1990.

Industry zones
The industry sector in Ca Mau is important for the province’s economy. The three main branches are exploitation, processing and distribution of electricity, gas and water. The processing of forestry-fishery and food is contributing the most with respect to gross output. This sector is followed up by the industry of electricity, gas, water production and distribution. There are two gas-power-fertilizer complexes which are located in the Khanh An commune (U-Minh district) and one in the confluence of the Ong Doc, Trem and Cai Tau river, North west of Ca Mau city. Ca Mau city has some industries at the field of commercial and administrative center.

Operational system
To meet all water demands for agriculture, aquaculture, industry and domestic uses the water system has to operate efficiently. The dense river and canal system of Ca Mau province is divided into primary, secondary and tertiary canals which facilitate in the irrigation and drainage needs of the area. Apart from its main function of water supply the canal system also provides navigation opportunities (the main form of transport in the area), fresh water storage, in the form of rainwater storage, drainage of alum contaminated water and a source of water for domestic use.

Due to management reasons the province of Ca Mau is divided into four different regions: North Ca Mau, Quan Lo-Phung Hiep, South Ca Mau and Nam Can – Ngoc Hien Coastal Area, each of these consisting out of several sub regions. Management strategies aim at creating closed loop canal systems in each sub region that regulate salt water. In this manner the water resource planning can be adjusted to the production requirements of the area. See the (IMP, n.d.) or the elaborated report for a detailed description of the sub regions. Generally there is an overall increase in salt intrusion and the current structures like culverts and dikes are poorly maintained, which causes many problems in the region.

Water quality
Surface water and groundwater in Ca Mau suffer greatly from salinization, pollution and other forms of declining water quality. The main sources of pollution are domestic and industrial activity, acid sulfate soils and aquaculture.

Domestic and industrial activity
Due to the characteristic ribbon pattern of canals lined with settlements and gardens, waste water central treatment is very complicated and domestic and industrial waste water is discharged into the surface water without any treatment (IMP, n.d.). Especially during the dry season these pollution sources contribute to high organic matter content and probably also to high iron (Fe) concentrations in the canals of Ca Mau (Tho, Vromant, Hung, & Hens, 2006). Another source of pollution is the crowded boat traffic roaming the rivers and canals. Oil spills from the boats and from the petrol establishments along the fringe of the river pollute the water.

Acid sulfate soils
Ca Mau has one of the world’s largest accumulations of acid sulfate soils (White & White, 2002). These are soils containing sulfates in the form of pyrite or its oxidation products. As long as these
sulfates are submerged under water no problems occur. But if the soil is drained due to drought, excavation or dredging, oxygen can enter the soil and the pyrite is oxidized to sulfuric acid (Dent & Pons, 1995). The produced acids interact with the clay particles in the soil and form toxic metals. These toxic metals and sulfuric acids accumulate in the soil and flush out to the surface water during rain events (Sammut, White, & Melville, 1996).

Aquaculture
Due to the shift from rice to aquaculture and the effects of climate change, the salinity of the surface water has increased. Studies show that during the dry season the salinity in the ponds and canals surpass the salinity levels of the ocean (Tho et al., 2006). Due to the high salinity of the shallow ground water, salts accumulate in the soil and decrease the fertility of the soil. Besides the high salinity there are also problems with high levels of suspended solids, self-pollution due to poor drainage, high levels of iron and alum due to construction of new ponds, biological pollution and changing ecosystems. This means that the aquaculture model that was used up to the present (extensive aquaculture) leads to rapid soil and water degradation and is unsustainable.
**Current System - Policy**

**Structure of water governance in Vietnam**

During the 1990s the first conflicts concerning water management arose and since then the function of water resource management is included into the national policy framework of Vietnam (Biltonen, Phan Do, & Vu Tien, 2009). The Ministry of Agriculture and Rural Development (MARD) and the Ministry of Natural Resources and Environment (MONRE) are the key ministries in water related issues (Waibel, 2010a). The mandate of these two ministries can be seen in Figure 7. Generally the governmental system is top down and the centralization does not go much further than the district level. There are however several options for the households to interact in management issues via the commune Peoples Committee and Council.

Within the governmental institutions a distinction is made between legislative, monitoring and executing (implementation) functions. For legislation and planning there are three different time scales: the master plans (15-20 years) and the development plans (5-10 years), these plans are then detailed to annual plans. The different ministries are responsible for creating the master plans on a national level. Formally these master plans are aligned to form one integrated plan, but in practice there is hardly any feedback from the different ministries towards each other concerning the master plans. The ministries then pass on the different master plans to the provincial departments. At this point the master plans add up to an unrealistic mission for the departments to implement. This is why the departments only select parts from the regional master plans to implement on a local level, thus creating the detailed annual plans. Any contradicting or unrealistic plans are simply ignored till the next master plans come. Because of the low salaries government officials are more susceptible to corruption, this is reflected in the detailing of the master plans. Often decisions are made because they are beneficial for individual reasons instead of reflecting the national direction of the master planning. The adjusted local master plans are then executed by the departments and the subdivisions within them (Waibel, 2010a).

Regarding monitoring, Vietnam has an information reporting system comprising out of a national network on environmental monitoring stations and a provincial environmental monitoring system. From this environmental information, State of Environment Reports (SOE) are created. Since the establishment of the MONRE, the responsibility for making SOE’s lies with the Departments of Natural Resource and Environment (DONRE) (Wepa, 2015).
Figure 7: Delivery of state responsibilities for water resource water management, adapted from: (T. P. L. Nguyen, 2010).
Current System - Stakeholders

Within the water system of Ca Mau several groups or organizations are involved, as described in the chapter Current system state. Some of these groups can influence the system themselves, while others are affected by changes in the system. In Vietnam the government has a leading role in all water related issues. Beside the government, state enterprises (SEs), organizations and users (households, industries, farmers) are involved. In the last two decades and following the Doi Moi reform, there is an increasing trend of organizations which are not directly correlated to the government. All involved stakeholders can be divided in six main categories: Communist Party Vietnam (CPV), public authorities, enterprises, research and education, donors and households (Waibel, 2010b) Figure 8. A detailed description of each group is given in the elaborated report.

Figure 8: The six main stakeholders and there interaction
**Current System- SWOT**

From the current state system a summation of the strengths, opportunities, weaknesses and threats can be made. In Figure 9 the strengths and weaknesses of the system are illustrated together with the opportunities and threats driven from external factors.

This diagram stresses the importance to exploit the strengths and invest in the opportunities to make the system better. Simultaneously it is important to improve the weaknesses and protect against the threats.
Drivers of Change

Besides analyzing the status of key elements and processes, the water system of Ca Mau has to be studied in the context of change, both on hydroclimatic and on socio-economic grounds. Drivers of change related both to climate change, but also to human activities on the region, have to be accounted for.

Climate change hazards

In terms of climate change, the most crucial hazards that have to be taken into account for the area of Ca Mau are Sea Level Rise, changes in the Rainfall regime, high-energy events such as Typhoons and Temperature variability.

Sea Level Rise

Sea Level Rise (SLR) is a concern since the whole area of Ca Mau is low-lying, with the prevailing elevation being in the range of 0.5 m – 1.0m ASL (DARD, 2014). It can be distinguished between Absolute Sea Level Rise (ASLR), due for instance to melting of the ice caps, and Relative Sea Level Rise (RSLR), which also takes into account the overland vertical movement of the coastal zone, such as e.g. land subsidence due to groundwater extraction. Relative sea level rise is particularly important in this study, as users of the coastal zone can directly attribute to. It is also the process most relevant for policy-making, as this matches the coastal users’ perception of sea level rise. It is therefore the process studied and mentioned in the System Dynamics diagrams of this study.

Regarding Absolute Sea Level Rise, Ca Mau is expected to experience rates of 0.2 – 0.4 cm/year in the short-term (Erban et al., 2014), both due to the global trend (0.31 ± 0.04 cm/year, IPCC, 2014), but also due to regional effects (amplification in the Pacific tropics, NOAA, 2014). Change in climate will aggravate the situation in the long-term; Ca Mau faces a SLR of 15-16cm in 2030 and 28-32cm in 2050 (depending on the emission scenario), extending up to 105 cm by the end of the 21st century in the worst case scenario (IMHEN, 2011). The projected SLR is associated with progressive inundation and further worsens saline intrusion problems.

Changes in rainfall patterns

Trends in precipitation caused by climate change, overall, will have high regional variability and will not be uniform (IPCC, 2014). Climate change in rainfall, therefore, may mean wetter or drier, more or less intensive patterns, depending on the region. The consensus is that, despite high uncertainties in climate modeling, there will be a change in the extremes for the worst: wetter and drier spells are expected to increase, and flooding in the wet season, as well as droughts in the dry season, is expected to occur more frequently. In the case of Vietnam (Figure 10, bottom panel), mean precipitation is projected to increase, while extreme precipitation will very likely become more intense and more frequent (IPCC, 2014).

Ca Mau is highly likely to follow that trend; regionally downscaled outputs of climate modeling provided by IMHEN, 2011 predict an increase in precipitation up to 25% for the region during the wet
season and a decrease up to 30-35% during the dry season by the end of the 21st century, while the overall precipitation increases slightly, 4-10%, depending on the emission scenario.

Change in rainfall patterns has an effect on **salinity intrusion** (especially droughts and less precipitation during the dry season will worsen salinity levels) and is also associated with inland **inundation** during the wet season, as the drainage system of Ca Mau has limited capacity. Shortage of freshwater in the dry season also means that more freshwater needs to be secured from unsustainable, **groundwater** sources.

**Local Storms and Typhoons**
Climate change is also likely to alter the frequency and severity of high-energy events, such as **local storms** and **typhoon**, which will lead to severe storm surges and, subsequently, **coastal erosion**. While Ca Mau is not frequently affected by storms and typhoons compared to other regions in Vietnam, it is particularly vulnerable due to its altitude and geographical position. While highly uncertain (M.J Russell, 2012), projections show that there might be an increase of frequency for severe storms (IMHEN, 2010).

Ca Mau has already experienced the devastating effects of typhoons, with the crossing of typhoon Linda in 1997. Observations from this event allowed the simulation of potential effects of typhoons and storm surge on the coastlines of Ca Mau and Kien Giang under different sea level rise scenarios (IMHEN, 2010; M.J Russell, 2012). These simulations show that the surge level for a large scale event could be in the order of 2m. This, in combination with high tide waters and local wave conditions of
4-5 m could result in severe damage in coastal infrastructure, such as fishing villages and coastal dikes, as well as in erosion in coastal infrastructure and rapid mangrove degradation.

Figure 11: Left Panel – The trajectory of typhoon Linda across the Ca Mau Peninsula and the gulf of Thailand (Unisys Weather, 2014). Right Panel – Devastation in the local communities of southern Vietnam from the typhoon crossing (Gunn, 2010)

**Temperature**

Other meteorological variables, such as temperature, which will have implications on the water cycle, are expected to change as well. Temperature is mentioned and studied, in the context of this study, as it will induce changes to evapotranspiration rates and thus agricultural freshwater needs, but also saltwater intrusion.

**The human factor and socio-economic drivers in the system**

Apart from climate change, the human factor is one of the most important drivers of change in Ca Mau. People define land and water uses and, thus, directly impact the condition of the water system. Any trends in population or changes in population patterns and habits therefore result on changes in pressures on the ecosystem, surface water and groundwater bodies. Aspects of demographics, land use change and economy therefore have to be taken into account.

**Demographics**

Ca Mau is mainly a rural province, with agriculture and aquaculture as the main source of income for the local population (Figure 12). Urbanization, especially compared to other Vietnamese provinces, is limited; as of 2012, the total population is 1,219,128, with approximately 80% living in rural areas and the remaining 20% gathering in urban centers, mainly in the city of Ca Mau (IMHEN, 2011). The net provincial migration rate in Ca Mau is -0.3% (IMHEN, 2011), meaning that there is emigration to other provinces in Vietnam, mainly to Can Tho; this comes in contrast with the projections that were taken into account initially in master plans for the deltaic areas, which predicted an explosive population growth (Mekong Delta Plan Committee, 2012). The emigration rate is just another indicator that Ca Mau does not compete effectively with other areas in terms of development opportunities. It effectively means that low population growth scenarios also need to be taken into account for strategic planning.
Economy

The economic prospects in the province are rapidly developing, with the average growth rate exceeding 10%. However, the gross domestic product is still lacking behind national average (see Figure 13, left Panel). This reflects the more general economic development conditions of the Mekong Delta, which shows declining economic development rates (Mekong Delta Plan Committee, 2012).

Aquaculture currently dominates economic activity in the primary sector in Ca Mau. As a result, the main driver on the economic prospects of the local population is the market demand of shrimp. This driver, following high demand from international markets in recent years, fuels the transition of land use from rice agriculture (and mangrove forest) to aquaculture (see the section below).

Land use change

In Ca Mau, land use change stemming from human pressure has been extensive and at the cost of natural habitat: a study in the district of Cai Nuoc (Binh et al., 2005) has shown vast land cover changes from 1968 to 2003 (Figure 14 – left panel): deforestation occurred between 1968 and 1992, along with a simultaneous increase in agricultural land (mainly rice). From 1997 to 2003, another transformation from agriculture to aquaculture, mainly shrimp monoculture, is observed at a large scale. As most of the area in southern Ca Mau is characterized in older studies as mangrove swamps (Tanaka, 1995), one may assume that a similar pattern of deforestation-rice cultivation-shrimp aquaculture has occurred in a larger part of Ca Mau. In the current system, approximately 56% of the total area of the region is used for aquaculture; of the 533,318 hectares of the total area, 300,000 hectares are used for aquaculture (IMHEN, 2011). Due to extensive saline intrusion, rice cropping is
now constrained only in controlled, salt-free zones with closed loop culvert systems, mainly in Tran van Thoi and U Minh (Figure 14 – right panel).

The interplay in land use between mangrove deforestation, rice cultivation and shrimp monoculture defines a lot of aspects of the local economy, but also of the water system. It has the features of both an opportunity and a threat. While shrimp monoculture has fuelled the short-term improvement in the total provincial income (IMHEN, 2011), it leads to severe environmental issues if left unregulated, such as a significant mangrove loss and an increase in salt intrusion (Binh et al., 2005; Son et al., 2015). Planning and careful management is thus required to provide the balance between aquaculture development opportunities and ecosystem health. Land use change has also implications on water use; in the dry season, freshwater needs for both rice cultivations and shrimp cultures, where freshwater is needed to tune salinity levels, are currently largely covered from non-renewable groundwater resources. This highly unsustainable practice leads to a land subsidence of 1-4 cm per year that further exacerbates Relative Sea Level Rise (see chapter Drivers of Change).

Figure 14: Left Panel - Changes in land cover between 1968 and 2003, Cai Nuoc district, Ca Mau province, Vietnam. Blue is rice cultivation, purple is shrimp monoculture, green is forest, red is mixed mangrove/shrimp farming, grey are rural settlements and dotted is other uses/wasteland. (Binh et al., 2005). Right Panel – Main land uses in the primary sector in Ca Mau (Source: IMHEN, 2011)
Model Formulation

In this Chapter, a conceptual model of the integrated, coastal and water system of Ca May is described, based on elements from previous work on the current system status and drivers of change. The model incorporates key physical processes, as well as the human factor and the response in terms of corrective policies and measures. Such a model serves as a mind map which forms the basis to assess the total system dynamics, including the feedback loops and the time scaling between processes and human response. It can be also used in combination with scenario-based horizon scanning, in order to reach conclusions on the prioritization of proposed measures to establish sustainability in the management of the total system.

Methodology

The Chapters on the Current Status of Ca Mau and the Drivers of Change highlight complex processes and driving forces that are behind both the coastal and the inland water systems. A number of elements that link these two systems emerge, including:

- Land use changes and mangrove squeeze as an enabling factor for coastal erosion and higher vulnerability in the coastal zone, but also further inland.
- Salinity intrusion and the impact on agriculture/aquaculture.
- Human pressures exerted in both systems, driven by socio-economic changes.
- Protective measures that influence the coastal, the inland zone or both.

In order to schematize the intricate interactions of the combined coastal and inland water system, taking also into account key socio-economic drivers and influential factors, a holistic modeling approach is needed. With respect to this, the methodology of System Dynamics (SD) (Winz, Brierley, & Trowsdale, 2008) is employed. This methodology acts as an integrated modeling tool, able to describe complex systems governed by feedback relationships, whose response over time needs to be studied and monitored (Baki, Koutiva, & Makropoulos, 2012). System Dynamics, in this case, is used only for qualitative modeling, so as to identify and highlight the interactions between various components of the system in the form of casual loop diagrams.

SD offers a number of significant advantages that make it particularly suitable for this case study, such as providing a unique modeling framework for the integration of physical and social processes associated with complex systems. Moreover, SD is an especially powerful tool for stakeholder involvement because understanding the visualized product of the complex system dynamics does not require any knowledge on the underlying methodology, processes and modeling. This makes the model accessible to any group of stakeholders and therefore assists stakeholder involvement and participation (Stave, 2003).

A qualitative SD model comprises a number of variables connected with arrows in the form of a casual loop diagram. In this layout, it is particularly useful to identify feedback loops, which have an amplifying (+) or dampening (-) effect depending on the type of interaction between variables.
Identifying time scales and tracking time delays between processes is also essential, as this difference determines which model paths propagate quicker and which have a slow evolution.

**Scope of model development**

In this study, the context-specific goals associated with the development of SD models are:

- To gather, review and concisely schematize understanding about the coastal and inland water system of Ca Mau, especially under the scope of climate change and local anthropogenic changes, as well as policy responses.
- To identify and explore key links between the coastal and inland water systems and the human factor. Furthermore, to identify ‘weak spots’ in these links in terms of knowledge and understanding and thus promote further research in specific crucial processes of the water system.
- To address the socioeconomic and policy aspects in integrated coastal and water management and attempt to study the hydro-social dimensions of the system (Linton & Budds, 2013; Sivapalan, Savenije, & Blöschl, 2012), rather than its mere physical processes.
- To provide a coherent scientific background in order to proceed with the transition from studying the total system dynamics to identifying gaps and needs in research and proposing measures and solutions for the area of Ca Mau.

Another important aspect to keep in mind is that the schematization serves multiple purposes: it acts as a knowledge mind map and a platform for scientific discussion but also can serve as a communication tool, to highlight the key dynamics and problems in the water system of Ca Mau. With respect to this, the model is built in a multi-layered fashion, adding complexity in each layer. This allows to control the complexity, gain a better overview of the causality of the many dimensions of the system and achieve clarity of context, while making the model design understandable to a broader audience.

**Results**

Preceding the model for the integrated system, diagrams for the separate systems of Ca Mau (coastal water system and inland water system) were developed. This helped to highlight key processes dominant in the separate systems, but also to find similarities and overlapping fields in a simpler context, before integrating and adding up complexity. Details about the separate graphs can be seen in the elaborated version of the Report. With these diagrams in mind, the model for the integrated system can be developed in a multi-layered way, taking into account the multiple dimensions of integration (see Chapter of Integration). These were:

- Key natural processes and human resource uses on the systems.
- The climate change and socioeconomic drivers as important drivers of change of the system status and
- The response of policy measures as a way to counteract negative changes in the status of the system.

The basic layer of the model includes two modules: **climate change and its impacts** (shown with red color) and the **response of the integrated system** (shown with blue color). For climate change and its
impacts, reasonable worst-case-scenario assumptions have been made that have been mentioned in chapter Drivers of Change.

When confronted with these impacts, the integrated water system changes its status and adjusts key elements. In terms of human water uses, two key variables stand out: freshwater needs, as an aggregated variable for water demands driven by land use, and coastal aquaculture, as a driving force for coastal changes. Based on the evaluation of the system status, the response path can be described as:

- More severe *salinity intrusion* during dry periods, which leads to an increase in *freshwater needs, groundwater extraction* as a means to cover them and, thus, *land subsidence* and *Relative Sea Level Rise*. This is an amplifying loop which worsens the situation for saline intrusion in Ca Mau. At the same time, *mangrove loss* induced by both SLR-induced *coastal erosion* and human land uses (*timber, coastal aquaculture*).
- An increase in *storms and thus coastal erosion* and inundation (*flooding*) during wet periods.

The basic layer describes the causes and effects that happen in the system in view of climate change. In light of a fully integrated approach, however, it is also important to include the response of decision-making and corrective measures, as a (re-)action mechanism that wants to lessen the negative effects occurring in the water system. The modeling approach for policy is based on a simple principle: certain problem variables of the water system are observed by actors and thus raise public and/or government awareness levels. These variables have to be directly observable by the water users or the actors in water governance. As such, they are catastrophic events (such as *droughts and flooding*) or structural changes (such as *coastal erosion* and rampant *mangrove degradation*). Most of them result in direct *economic damage*, which is quantifiable.

Once the government awareness has reached threshold levels, decisions are made to implement corrective legislation and policy frameworks. These frameworks aim at stabilizing the system through a number of negative loops that target human uses, such as reduction of *mangrove degradation*, e.g. through legislative measures (National Parks designation, reforestation projects, fines for illegal mangrove cutting etc.) or reduction of *coastal aquaculture*, through implementation of spatial policies and coastal protection schemes.

The reaction of decision-makers can be also transformed in the design and construction of a number of protective engineering measures (in purple colors, see Figure 16), with the aim of further reducing problematic variables in the inner system. A range of measures is possible in the case of Ca Mau (see Table 1).
Table 1: Types of stabilizing measures for Ca Mau and processes that are targeted.

<table>
<thead>
<tr>
<th>Type of Measure</th>
<th>Processes that are targeted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigation systems and sluices</td>
<td>saline intrusion, freshwater needs</td>
</tr>
<tr>
<td>Coastal protection measures</td>
<td>coastal erosion</td>
</tr>
<tr>
<td>Dike systems</td>
<td>flooding</td>
</tr>
</tbody>
</table>

These measures generally follow after the development of legislation and policy frameworks. This is the case in the usual Master Planning: an array of engineering measures has to be designed and implemented after central planning has been decided. Exceptions apply, in case of rapid response for catastrophic events; these have been studied as well (see Conclusions). Figure 16 reveals that the response of water governance, both through frameworks and through hard measures, acts as an extensive, negative loop with many recipient variables, either human uses or natural processes, aiming at stabilizing the system.

It is noted that several stabilizing measures feature time delays (notation: double lines in arrows), driven by both the governance structure and efficiency issues as well as the nature of engineering works (contracting times, expropriation etc.). Measures can also have positive or negative effects (notation: star [*] sign), targeting other variables apart from the ones they mean to protect (e.g. coastal dike systems may have impacts on mangrove degradation, depending on their design and placement). Apart from the complete policy response, the effect of population dynamics and demographics in the model has been explored. One may see an analytical example in the elaborated version of the Report.

![Figure 16: The response of policy-making (orange) and protective measures (purple). The basic system layer is shown with light grey lines.](image-url)
Conclusions
The complete system behavior can be summarized as shown in Figure 17: climate and demographic drivers cause the system to change state and create a response, while built-in feedback loops in its structure amplify that response. In turn, this response is used for the development of policies and, eventually, measures, to stabilize the system and restore it to a desirable state. The time difference between the inner, destabilizing system loops and the outer policy response determines whether policy will be effective and will lead to sustainable states or whether the system will continue to deteriorate, until it collapses.

Figure 17: The underlying mechanics behind the casual loop diagrams.

Studying the time-scales of groups of processes within the system is therefore particularly important. This will add a quantitative dimension to the model dynamics, and allow us to explore scenarios of possible futures. Based on knowledge about the coastal zone and the inland water system presented in previous Chapters, the time scales of particular processes can be mapped onto the casual loop diagram to gain an overview of characteristic time-scales in the system. Besides this, an array of indicators (i.e. quantitative performance indexes) is presented, based on variables of the diagrams that can be readily measured to monitor and assess the general system condition (see elaborated version of the Report). Sample results for of these steps for processes in the coastal zone can be seen in Table 2.

The results of a first time-scale mapping (Figure 18) show that destabilizing inner system mechanisms, especially in the coastal zone, are short-term and rapidly active in Ca Mau (Stolzenwald, 2013). This can lead to system degradation in short time-scales. At the same time, one can see that the processes able to stabilize the system (the policy-driven stabilizing outer loop) have a significantly lower time rate of application. This slow rate is further exacerbated by inefficiencies (lags) in the policy implementation mechanisms. The question that naturally follows is then one of temporal nature: will this stabilizing outer loop be initiated in time, before the inner, positive loops of the system build up negative effects and deteriorate the system status after a critical threshold point? This is a key question to be taken into account in scenario planning.
Table 2: Time scales and performance indexes of sample processes in the coastal zone.

<table>
<thead>
<tr>
<th>Name</th>
<th>Indicative Speed</th>
<th>Char. Time Scale</th>
<th>Comments</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coastal Erosion to Mangrove Degradation</td>
<td>22 – 90 m/year (extreme cases) ~20 m /year (average in erosive areas)</td>
<td>2-4 years for highly erosive areas. Up to 10 years for overall degradation.</td>
<td>Rapid mangrove degradation in certain areas. Time scale is calculated based on the average erosion rates, multiplied by the mangrove belt width.</td>
<td>(Stolzenwald, 2013)</td>
</tr>
<tr>
<td>Coastal Aquaculture - Mangrove Degradation</td>
<td>% of mangrove forests cut within a time interval</td>
<td>5-10 years</td>
<td>(Binh et al., 2005)</td>
<td></td>
</tr>
</tbody>
</table>

Performance Indexes | Possible Units
--- | ---
Coastal Erosion | • Annual Coastal Retreat [m/year], obtained through satellite data or in-situ investigation
Coastal Aquaculture | • Areal coverage with mixed mangrove-shrimp farming use (Binh et al., 2005), e.g. as % of total area
| Coastal area coverage where shrimp farming is active (e.g. land use classification as thin mangrove belt and fields). |

Having in mind the basic mechanics of Figure 17, one can also see the importance of proactive vs. reactive policies. In the case of Ca Mau, where the policy response is slow and delayed, having a proactive strategy, based on an expected/projected system response and several no-regret measures, might aid the system before inner mechanisms ‘run’ a lot of times – this can be vital in protecting the system and avoiding potential collapse.

![Figure 18: Mapping the time scales of processes onto the loop diagram.](image)

More general conclusions are also reached through this thought process. Firstly, human pressures have significantly quick rates of application in the system and may even surpass natural rate of change (e.g. climate change). An example is the comparison between the groundwater (GW) and climatic (ASLR) contribution to relative sea level rise (RSLR). Secondly, climate change acts as a gradually worsening factor to existing problems in the inner system. Lastly, certain chains of processes, such as flooding and the corresponding policy response, exhibit threshold mechanisms and a duality in the rate of policy response.
Scenarios

In this report, a scenario approach is used to explore the highly uncertain future for the province of Ca Mau. This approach enables the decision makers to take future developments into account. Thereby it improves the decision making process within planning and design of possible measures. It is important to know how to act now, what measures to establish now, and what measures to build later. In scenario development studies, scenarios can generally be divided into four different categories (Ratcliffe, 2000). These are: Collapse scenario, Status Quo scenario, Transformation Scenario and the Steady State scenario (Figure 19). In these scenarios the degree of problems within the system has different developments. The problems can grow very big, resulting in a collapse of the system, or they decrease and the system evolves to a better state (transformation scenario). In this study, analysing three of these categories (the steady-state scenario is excluded) together with an analysis of the driving forces result into five scenarios.

The drivers of change determine where the system will eventually end up (within a certain time scale). Therefore, the following conclusions are made about the drivers of change, in order to help us with the scenario building.
• Climate change
Climate change is considered to be a slow and steady process, compared with the changes in land use and industrialization which are more dependent on other factors as well. The trend for the coming 30-50 is predicted by the IPCC (see chapter Drivers of Change). With this knowledge, the climate change driver is assumed to be the most certain one of all three drivers.

• Socio-economic development
The socio-economic development is assumed to be dependent on the economics of the whole of Viet Nam and Asia, support from donors and Foreign Direct Investors (FDI). Where the economy of Asia and Viet Nam itself are again dependent on many factors. The population growth and migration are assumed to be dependent on the state of the economy and livelihood. This makes the socio-economic development very uncertain in the coming 30-50 years.

• Policy development
The political development is very uncertain as well, because it relies on the vision of the decision makers. The decisions made by the decision makers have much influence on the system, they can stabilize the system or make the problems bigger, leading to a collapse. Therefore, stakeholder involvement is very important in this way of future planning.

The five different scenarios are distinguished as follows:

• Gradual collapse scenario
A gradual collapse can be the cause of: increased corruption and bureaucracy, unsustainable industrialization. This can be either in combination with extreme economic growth, or low economic growth, where money is not spend, or not spend for the right purposes.

• Fast collapse scenario
A big flood event will cause a further destruction of the mangrove belt, inundation of agriculture and aquaculture area, destroying the crops, houses and lives of people. This causes a huge damage for the economy. Dependent on the state of the economy and policy.

• Status quo scenario
A fragmented government, with high bureaucracy and slow decision making will not stabilized the problem. The measures are not integrated causing a lack of good alternatives. A moderate economic growth is assumed, where FDI and donor help will decrease. There is strong urbanization and moderate industrialization (lacking behind on the countries rate), but these are not combined with a good spatial planning.

For the transformation scenarios it is assumed that the circumstances of the policy and economy are favorable, to make it possible for the system to go through a big (positive) change.

• Saline adaptive scenario
With the focus on dealing with saline waters, there will be more rice/shrimp farming, more intensive shrimp farming. The irrigation system is adapted to the requirements for draining saline water and keeping the water quality high for shrimp farming in the dry season.

• Fresh water resources scenario
Enough fresh water is established by a well-functioning culvert system. Rice-shrimp farming is possible in parts of the province where the culvert system doesn’t provide sufficient fresh water to harvest rice twice a year.
The consequences for the system in 30-50 years are determined by using the changes in drivers of change as an input for the system dynamics diagram. The important consequences found for these scenarios are summarized in Table 3 and explained below.

- **Fast collapse**
  The economic damage caused by the big storm will raise awareness at government and public side, which means that measures will be taken fast and effectively to improve the system on a short timescale.

- **Gradual collapse**
  The economic damage/profit ratio in combination with non-integrated legislation and policy framework is not bringing a solution for the physical problems (coastal protection and fresh water needs). The threshold for collapse is surpassed, and hereby the awareness of the government will be raised. What eventually will bring good solutions, but not within the timespan we analyze.

- **Status Quo**
  The economic damage/profit ratio in combination with non-integrated legislation and policy framework is not bringing a solution for the physical problems (coastal protection and fresh water needs). The threshold of the system functioning is not surpassed yet, but the problems keep increasing.

- **Adaptive saline transformation**
  High economic growth and good legislation make it possible for the system to adapt to the saline environment and to invent smart solutions to cope with it. Important consequences are that the sluice system will not be used extensively anymore, and that new inventions need to be applied to cope with the saline water.

- **Fresh water resources transformation**
  Good coastal and inland protection against sea and saline water will have to be established (e.g. coastal protection, sluice system). This will need many investments, and therefore a high economic growth is needed. There will still be a risk on over-exploiting the fresh groundwater resources. It is important to have a sustainable solution for this.

With this analysis, the stakeholders and decision makers need to develop a strategy to deal with the system. The different strategies to reach a desired future system state will be discussed in the next chapter Scenario’s.
<table>
<thead>
<tr>
<th></th>
<th>Collapse Fast</th>
<th>Gradual</th>
<th>Status Quo</th>
<th>Positive Transformation</th>
<th>Fresh Resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mangrove degradation</td>
<td></td>
<td></td>
<td></td>
<td>Stabilizing/growing</td>
<td>Stabilizing/growing</td>
</tr>
<tr>
<td>Caused by:</td>
<td>- Coastalstorm - Too low resistance against a severe storm</td>
<td>Mostly retreated</td>
<td>Retreated</td>
<td>Stabilizing/growing</td>
<td>Stabilizing/growing</td>
</tr>
<tr>
<td>Coastal erosion</td>
<td>Most severe</td>
<td>Severe</td>
<td>Severe</td>
<td>Stabilizing</td>
<td>Stabilizing</td>
</tr>
<tr>
<td>Caused by:</td>
<td>- Coastalstorm - Too low resistance against a severe storm</td>
<td>- Bad state of coastal protection - Mangrove retreat - Relative sea level rise</td>
<td>- Bad state of coastal protection - Mangrove retreat - Relative sea level rise</td>
<td>- Proactive measures - Stabilized mangroves</td>
<td>- Proactive measures - Stabilized mangroves</td>
</tr>
<tr>
<td>Freshwater needs</td>
<td>High</td>
<td>Medium</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Subsidence</td>
<td>Large</td>
<td>Large</td>
<td>Large</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Caused by:</td>
<td>- High freshwater needs</td>
<td>- High freshwater needs - Low legislation</td>
<td>- High freshwater needs - Low legislation</td>
<td>- Medium freshwater needs</td>
<td>- High freshwater needs - Sustainable resources</td>
</tr>
<tr>
<td>Economic d/p ratio</td>
<td>Can be at any state</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>State of the public authorities</td>
<td>- Awareness high - Bureaucracy high, but will be ignored</td>
<td>- Awareness high - Bureaucracy high</td>
<td>- Awareness medium - Bureaucracy high</td>
<td>- Awareness medium - high - Integrated government - Less bureaucracy</td>
<td>- Awareness med – high - Integrated government - Less bureaucracy</td>
</tr>
</tbody>
</table>
This chapter provides an overview of the possible strategies to guide the system towards a certain scenario. A strategy can have two functions, either to achieve a certain scenario outcome or to prevent it. Following from the scenarios, preventing strategies are selected for the collapse scenarios and stimulating strategies are selected for the transformation scenarios. It is a proactive way of planning and policy making. By selecting a possible future that is desirable and then looking at the SD diagram one can find the key processes which are dominant in reaching the selected future. As a result measures can be taken in a proactive manner rather than reacting on observed problems.

Each strategy consists out of a number of measure packages that are needed for the realization of the strategy. A measure package is a set of individual measures that contribute to the same goal.

The measures can be divided into three categories: the policy driven measures (creating convenient legislations), physical measures (tangible measures in the water system), and measures that stem from or are driven through research (further mentioned in the chapter research proposals).

**Strategy of each scenario:**
In the elaborated report the strategies and measures are explained. Below a short description is given.
1. **Status Quo**
As described in the chapter Scenarios the current situation will not be influenced. Therefore there is not a strategy nor a package of measures required to reach the scenario.

2. **Prevent collapse**
As described previously, a collapse can occur in a rapid or gradual manner. The strategies may vary to prevent fast and gradual collapse and are elaborated below.

2.1. **Prevention of fast collapse**
The prevention of a fast collapse is only concentrated on preventing flood events. Although these kind of impacts can’t be prevented with certainty, it is possible to adapt the system in a way that the chance of occurrence is very low or that the system is more resilient in case of a disaster.

From the SD figure in the elaborated version it can be seen that a flooding is effected by natural elements (RSLR and coastal storms), as well as by human involvement (land subsidence, mangrove degradation, coastal protection measures and a dike system). The human factors can be influenced by a strategy. The strategy to prevent or be more resilient to a flooding contains:

- Integrated water and land use plan
- Managing coastal erosion
- Rehabilitation/ increase of mangrove belt
- Improvement of coastal defense system
- River and channel maintenance
- Groundwater extraction

2.2. **Prevention of gradual collapse**
The trigger who leads to a gradual collapse has a socio-economic background (low economic growth). The result is that political legislations and or changes are seriously delayed and are causing severe negative effects on different elements within the system; due to poor and delayed execution, measures will not reach its goal. First of all a strategy is needed to prevent the economic relapse and the political issues have to be solved. These reformations may have consequences on the land and water use in Ca Mau. The type of economic decisions is highly dependent on the situation. Within the scope of this project, only measures with a hydraulic engineering/ water management background are defined. For the socio-economic part a global recommendation is given. Such a strategy includes the following packages:

- Legislation and policy package
- Economic growth package

3. **Transformation packages**

3.1. **Saline adaptation**
Saline adaption is a strategy that embraces the salt water intrusion and the strategy exploits the benefits that come with it. Since salinity intrusion is one of the greater problems currently in Ca Mau, such a strategy aims at turning this problem into an asset. It has also been explored before in Master Planning for the Mekong Delta as well (Mekong Delta Plan Committee, 2012). High economic growth and effective legislation and policy are driving forces for the transition. From these drivers, effective measures follow against flooding and erosion. Also the transition from fresh to saline water is key for this strategy, so the irrigation system, currently designed for freshwater, has to be redesigned and...
reconstructed to allow the salt water into the canals. The saline water provides the opportunity for high income aquaculture, which in turn has a positive effect on the economy. To maintain this situation of economic growth the quality of land and water resources have to be guaranteed. Furthermore fresh water is needed for domestic use and for balancing the salinity in the aquaculture ponds. Currently groundwater is used for this, but alternatives are needed to prevent further subsidence and establish sustainability in water use. The packages included in this strategy are:

- Integrated water and land use plan
- Economic growth package
- Legislation and policy package
- Sluices and irrigation package (saline)
- Coastal erosion package
- Rehabilitation and increase of the mangrove belt
- Improvement coastal defense
- Canal erosion and inland flood protection package.
- Pollution package
- Ground water package

3.2. Maintaining fresh water
This strategy aims at maintaining the fresh water ecosystems in the districts that still have them. The essential difference with the saltwater adaption lies in diversification of industry versus specialization of industry and how this influences the adjustments that have to be made on the irrigation system. Again, the high economic growth and effective legislation and policy are key drivers of change and influence the effectiveness of the measures. To maintain the fresh water system the current irrigation system has to be updated and flood protection measures have to be increased. Furthermore the issues guaranteeing the quality of land and water resources also are important in this strategy. This strategy includes the following packages:

- Integrated water and land use plan
- Economic growth package
- Legislation and policy package
- Sluices and irrigation package(fresh)
- Coastal erosion package
- Rehabilitation and increase of the mangrove belt
- Improvement coastal defense
- Canal erosion and inland flood protection package.
- Pollution package
- Ground water package
Conclusions

An overview of the aforementioned strategies (and packages of measures) is given below (Table 4). This gives a clear view of measures that are required for more than one strategy and therefore have a high degree of usefulness.

Table 4 Overview of scenarios and related measures

<table>
<thead>
<tr>
<th>Package</th>
<th>Fast Collapse</th>
<th>Gradual Collapse</th>
<th>Maintaining Saline water</th>
<th>Adaption to fresh water</th>
</tr>
</thead>
<tbody>
<tr>
<td>I.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>II.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>III.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IV.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VI.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VII.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VIII.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IX.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>XI.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The measures related to prevention of a fast collapse (flood) return in several packages. The drivers that cause the fast collapse also influence the possibility to transform the system. But even if the fast collapse packages are secured, the system can move into a gradual collapse due to slow economic growth and policy. To be able to positively transform the system and secure its sustainability, effective policy and a certain degree economic growth are therefore prerequisites. Besides this, a number of packages targeting specific strategies exist as well.

For the current situation of the province of Ca Mau, it is important that policy becomes more efficient and that the economy keeps growing (at least at the rate it is growing now). Otherwise the implementation of other measures will not be (executed) efficiently or will not secure financing. Besides these social-economic packages, the most important hydraulic-/ water related packages are the packages requested for preventing a fast collapse. They are requested for every other scenario as well, have a high degree of usefulness and therefore get the highest priority.

If a certain strategy is chosen, the planning of the execution of the measures will play a role. Some measures can be executed within one year, while others take five or even 10 years before they become effective. The measures can be categorized as short, mid and long term. These time scales also affect prioritization in the measures that have to be taken.
Research Proposals

From the measure packages mentioned in chapter 6 ‘Measures’, it became clear that many aspects of the water system need to be further researched before the appropriate measures can be found. By making use of the SD diagram and the different scenarios it was possible to isolate the most urgent fields of research. These research fields are divided into topics containing bundles of case studies. Furthermore research questions are formulated for the different case studies. These case studies can function as catalysis for further research in this area.

**Topic A. Balance between freshwater and saltwater**

*Case Study A.1 – Are freshwater areas sustainable for the future?*
Freshwater areas operate as closed loop systems currently in Ca Mau. It is important to evaluate their operation, assess their sustainability in the long-term and propose action to either continue their operation or adapt to a brackish environment, if environmental factors dictate so.

*Case Study A.2 – Operational Aspects of Canal Systems/Sluice Gates*
Ca Mau is dominated by a complex channel system, which includes both saltwater and freshwater channels operated by sluices. It would be interesting to gain insight on operational aspects of these sluice networks and find ways to optimize them. For example:

- What is the exact way of operational decision-making in sluices? PPC takes feedback by the people, and then regulates the door opening times (fieldwork). Perform a short study on the exact way this is done and make suggestions on how to improve this.
- Help PPC by forming standardized operational rules, based on the seasonal/weather patterns, the feedback from farmers and the quality status of the water system.
- Investigate bottlenecks for water supply and drainage in such a network (either freshwater or saline), including concentration of waste/pollutants and residence times. Combine it with operational data on the culverts to find weak spots, either in operation or the structure of the channel networks.
- Bullet points (b.) and (c.) (Operational rules and bottlenecks) could be further integrated and investigated with the use of WM modeling tools, e.g. SOBEK for irrigation systems. This would help quantify the system and outline optimal solutions.

*Case Study A.3 – Investigating the potential of RWH for Ca Mau*
Ca Mau currently suffers from freshwater shortage during the dry periods that limits its agriculture uses, intensive shrimp monoculture and household (domestic) uses. With reference to this, it would be interesting to investigate the potential of securing freshwater from RWH specifically for the low-lying area of Ca Mau. This would lessen the pressure to groundwater and would lessen the problem of subsidence and SLR for the whole system.
• Investigation of the potential of RWH (possibly with a natural filtration system, e.g. filtration trench) for Domestic Use. Try to reduce GW dependence on household use.
• Investigation of areas that could potentially serve as freshwater basins for the system.
• Investigate possibilities for RWH in aquaculture. For example: In current fresh water systems some rice fields could be allocated to retain fresh water during the rainy season and cultivate fresh water fish. During the dry season these fresh water ponds can discharge their water into the canals if the water level starts to decrease. If the ponds discharge their water they can switch back from aquaculture to rice production. In this way there is a larger quantity of fresh water available during the dry season. Feasibility study on this (how many ponds, incentives for farmers, feasibility of fresh aquaculture). Issues to investigate in this case is:
  1.) Area issues (how many ponds).
  2.) Is it possible to discharge the fresh water in the canals without pumping (head difference)?
  3.) Is it possible to combine the two cultivation methods of rice and aquaculture?

Case Study A.4 spatial planning
Although spatial planning has been part of the master plans created by the ministries for many years there are still questions unanswered. A strategic spatial plan can be a key to success for Ca Mau that is why additional research on this topic is advised.
• One of the possible measures for coastal protection is to move the dikes land inward. This of course has great influence on the land use and allocation of people living behind the dike. Research can be done on suitable reallocation locations.
• Moving the dikes is a quite drastic measure that should first be tested on small scale to see if it gives the desired results.
• Identify suitable areas for certain land use types like rice, forest, aquaculture, based on the resources available and the future sustainability. This can help to use the land and water resources optimally without damaging the environment.

Case Study A.1.5 Land management methods
Ca Mau has large areas with sulfuric acidic soils, these soils can cause acidification of the surface water and decrease the yield for the farmers. Interesting topics to look into are:
• How do farmers cope with the acid soil?
• What are sustainable ways to counteract the acidity?
• What is the scale of the damage done by the acid soils?

Case Study A.6 Towards sustainable and effective aquaculture in Ca Mau
A large portion from the provincial growth in Ca Mau comes from brackish aquaculture, mainly shrimp farming. This is one of the key strengths of the province, but it is limited due to a number of factors (see Scenarios, see Drivers of Change – Economy). A strategic planning for improvement in aquaculture is needed, including:
• Improvements on the knowledge and communication network among shrimp farmers / Capacity building on local farm communities. Farmers currently rely on empirical knowledge and personal communication with colleagues to maximize their yield and deal with production problems. A trial-and-error approach is followed, often with mediocre results and higher risk. A more effective network, possibly with the help of experts and scientists, is needed to actively aid farmers to cope with problematic processes, illness of crops and
operational/technological questions. At the same time, this network can be built in a bottom-up fashion, utilizing the local expertise and experience farmers have already obtained, in every type of aquaculture (local knowledge).

- Primary research on the right type of aquaculture (e.g. shrimp, fish, poly-aqua, seasonal variations), given the surroundings, and on the right properties of fields (e.g. ratio of mangrove to shrimp in mangrove-shrimp farms). Assessing the sustainability (e.g. by assigning indexes) to every type of aquaculture, for every interested area within the province. At a later stage, awareness campaigns and workshops with farmers on how to achieve these attributes.
- A consultation study on improving the product value chain for shrimp could be performed. Fixing the supply chain for shrimp, removing bottlenecks (multiple middle-men, more flexible management in factories, quicker response to market needs).

**Topic B Improving Water Quality**

Ca Mau suffers from multiple water quality problems, linked to both urban and agriculture/aquaculture activity. These problems, however, have not been thoroughly studied on a holistic level, let alone linked with preventive measures and master-planning. The following Case Studies aim at helping towards this direction.

**Case Study B.1 Improving waste management in Ca Mau**

Waste disposal appears to be a problem in Ca Mau, with many households disposing their material waste directly in canals. An integrated strategy for waste management is needed for the province, that may include the following array of measures:

- A mapping study on ‘hot-spots’ of waste, obtained from visual inspections or after a correlation study with certain activities (urban, light industrial). When integrated with land use management, this could help identify key risks in neighboring land uses.

**Case Study B.2 Mapping water quality: pollutants and activities**

This study is a field research that aims particularly on water quality aspects different from the salinity levels that are usually measured. It may include:

- Research on possible pollutants and their concentrations (e.g. BOD/COD, pathogens, pesticides, heavy metals, microplastics) and their effects on human water uses, especially aquaculture. Are there other factors that affect shrimp production apart from salinity levels?
- Mapping these pollutants with specific places, correlate with industrial or urban activity.
- Link the presence of these pollutants with existing or planned work (e.g. wastewater treatment in the city of Ca Mau) in an integrated plan.
- Provide health risk maps for the local population based on these pollutants. This will lead to advice about water use (limitations, needs for treatment etc.).
- Based on the following studies, provision of advice on how to revise/adjust land use planning to harmonize urban activity, industrial activity and aquaculture. This would lead to lower risk for farmers and a maximization of product yield.

**Case Study B.3 Water Quality and Aquaculture, Links and Practices**

This is an integrated case study that combines elements of Case Study A.1.4 and Case Study A.2.2. Aquaculture is the most important source of income for farmers in Ca Mau. However, the water
quality aspects that are related to it, particularly for this province, are poorly understood, let alone transferred to the farmers.

This Case Study aims at bridging this gap in knowledge by enabling water quality measuring in the shrimp farming communities of Ca Mau, particularly in households with less means. It can be implemented in two different ways:

a. Giving simple measuring devices to selected farmers and training them in regular uses.
b. Enabling farmers to take periodic samples of water from their shrimp ponds and measuring canals and processing them at an affiliate research institute (e.g. SIWRP), to scan for multiple water quality indices.

The goal would be to set up a monitoring network in aquaculture, which would be able to combine farmer feedback on crop productivity with quantitative data. This would shed more light on the links that connect environmental factors and farmer practice.

This study could be materialized in the form of a pilot project in a selected shrimp farming commune in Ca Mau. Mangrove-shrimp, rice-shrimp or intensive shrimp cultures could all be of interest, depending on the scope of this project and the interests of stakeholders.

Case Study B.4 water treatment on a local scale
Water treatment is mostly associated with large expensive and high tech treatment plants. Since the province of Ca Mau does not have the financial means nor the network to construct such plants other solutions have to be investigated.

- Studies on local small scale wastewater treatment for urban wastewater and water from intensive shrimp ponds have to be explored.
- Investigate if research already done on this topic (like: (Massoud, Tarhini, & Nasr, 2009)) is suitable for Ca Mau. In a project from the Netherlands (de Ceuvel, Amsterdam) residence are not connected to the sewer and do all the water treatment with homemade low tech materials, they even produce power from the black water. Starting up a pilot project like this in Ca Mau could give insight to the possibilities of local small scale wastewater treatment.

Thematic Area B: The coastal zone
The coastal zone of Ca Mau has to cope with erosion and mangrove degradation. Different case studies can be executed to have a better understanding of the coastal zone but also about how to integrate coastal measures with land planning and inland water management. Dike Relocation Scheme + People Relocation + Sluice gate operation +Mangrove Belt + “Room for the Coast”

Case Study C.1 – Evaluation and monitoring of current flow and sediment transport
As explained in the chapter current state there is not a clear understanding of the current flow and sediment transport along the West coast of Ca Mau. Understanding of the mechanisms is necessary to invent and design proper measures for the coast of Ca Mau. The following studies are advised to gain this understanding
• A measurement campaign to measure the current flow along the West coast of Ca Mau during at four moments: February (dry season), May (transition), August (the rain season) and December (transition).
• Together with the current flow, sediment transport can be measured at the same time to define the sediment transport rates.
• Gathering samples to investigate the type of the transported sediment. This information is needed to design measures which are able to trap the specific type of sediment.

Case Study C.2 – Soil investigation along the coast and seabed
There is not an existing database of the bathymetry and soil type along the West coast of Ca Mau. There are plans to build structures against the coastal erosion in the future. To have a reference on the behavior of the coast and to design properly measures this information is significant.

• Bathymetry measurement to monitor the changes (erosion or accretion) of the coast and seabed.
• Soil samples of the coast and seabed to be able to design suitable measures which can be founded on this soil type.

Case Study C.3 – Evaluation and monitoring of existing measures
The coastal zone of Ca Mau features a number of different projects, including gabions, T-bone fences and hard seawalls-breakwaters. These measures need to be compared and evaluated on the basis of accretion rates, cost-effectiveness, sustainability and ease of implementation.

• An in-depth evaluation and comparative study between existing measures, either in the East or the West coast. The evaluation and comparison can be based on effectiveness in accretion (e.g. stopping coastal erosion) and/or financial feasibility and cost-effectiveness.
• The risk/chance of failure for each structure (e.g. for vertical pile breakwaters) and the measures that need to be taken in case of failure.
• A comparison between measures in both East and West coast, taking into account differences in sediment transport mechanisms.

Case Study C.4 – Evaluation of measures to prevent erosion
Based on the information gained from research B.1.3, research can be done which set of measures are the most effective and how to integrate this into a master plan for the whole coast of Ca Mau. This investigation should be based on effectiveness, sustainability and a cost-benefit analysis.

Thematic Area D: River and inland canal management
Water supply and drainage are sometimes insufficient in Ca Mau due to the limited dimensions of the canal system. This problem is enhanced by canal erosion and sedimentation. The sediments erode from the side of the canal and accumulate at the bottom. The main cause of the erosion is presumed to be navigation in the canals. More research is needed to understand what are the driving forces of this erosion and more important how to stop it.

Case study D.1 – Cause of river bank erosion
Although navigation is assumed to be the main driver of erosion no evidence for this has been presented to us. Investigating the effect of possible other drivers improves the understanding of this problem:
• Investigate the effects of floods on canal erosion compared to navigation.
• Do research on the effect of different velocities of the boats on bank erosion.
• How does the tide influence the bank erosion.

Case study D.2 – Investigating bank protection alternatives
Because of the vast majority of rivers and canals in Ca Mau, low coast solutions are essential for tackling the problem of erosion. Riverbank vegetation has proven to be effective in at least slowing down the process of erosion.
• Research on what kind of vegetation is suitable for bank protection and in what densities.
• The vice director of the SIWRP mentioned the possibility of using water plants to reduce the wave impact on the banks. This might also be an interesting research subject.

Case study D.3 – Increasing the water conveying capacity of the canals
The canal system in Ca Mau is originally designed for a fresh water environment with rice cultivation. Nowadays things are different in the province and aquaculture is the dominant land use this change puts stress on the canal system. More water has to be conveyed through the canals to meet the drainage and supply needs.
• A feasibility study on dredging the canals and using the dredged materials for embankment construction or coastal nourishment.
• Study the crucial points in the canal system to find the most effective places to increase the cross section of the canals.

Thematic Area C: Policy and institutions
From the system dynamics diagram and the scenarios it is apparent that policy is a very important driver in the water system of Ca Mau. In order to improve the policy making process and effectiveness more research has to be done

Case study C.1 – Policy making:
One part of effective policy is to have a good integrated approach with a quick response to different actors. Especially if there are many parties involved in the matter.

• In what way can the communication between different departments be enhanced in order to create integrated master plan.
• A Study on how to translate public and governmental awareness into effective policies.
• What is a suitable structure of governmental institutions to reduce bureaucracy.

Case study C.2 – Policy enforcement:
Policies are of no use if there is no possibility to enforce them. Within Ca Mau this is apparent in the amount of pollution and illegal mangrove timber, which are forbidden by law but there are limited means to enforce the laws.

• Study on how to empower the government to enforce their policies.
• Investigate the effect of corruption on the lack of policy enforcement, and find ways to avoid this corruption.
Discussion & Conclusion

Discussion

While the approach to Ca Mau that is regarded in this study aims at integration in multiple levels (coastal zone and inland water, water and socioeconomic factors, water and policy), there are still aspects of integration that need to be explored in the future. For instance, the province of Ca Mau is observed as an autonomous entity, independent of problems and challenges of other provinces. This is in reality not true, as there are multiple dependencies on both the central level (national government, e.g. financing), but also on a cross-provincial level. There are strong connections with bordering provinces, both from a coastal dynamics point of view but also from a hydrological (catchment) perspective. These inter-provincial and governmental relationships could in a further stage be studied and could be also incorporated in the SD diagram.

Another point of discussion is the limitations and scope of the SD modeling approach. The structure of the SD diagram is based on our own view on the system, as are the colors in the graphs of the performance qualification of the scenarios. There is therefore a current degree of subjectivity in the outcome and the product is up to discussion, judgment, re-evaluation and, eventually, correction. This is not a weakness per se, as one of the goals of these studies is to provide the “sparks” for discussion and evaluation across agencies, disciplines and actors. On these aspects, input from stakeholders and local researchers can change and contribute to the system dynamics diagram. When stakeholders are more involved, they will be more convinced of the model itself, and more willing to think in this holistic way.

More specific issues stemming from the SD diagram that could be discussed are:

- Pollution and riverbank erosion is not been taken into account in this version of the SD graph. These problems were not reflected in literature about Ca Mau, but their severity was discovered during later fieldwork studies. Measures and research certainly have to be made on these issues as well. As these problems mainly follow from the human pressures on the system, this stresses once again the importance of the human pressures on the system. To include the aspects of pollution and riverbank erosion, a more in depth view is needed on their mechanisms of generation.
- More expert knowledge is also needed on the fields of policy and economy. This study tried to integrate the system as much as possible, also involving politics and economy. Although the group was interdisciplinary, it lacked in-depth knowledge on economy and politics. For a truly integrated approach, this expert knowledge needs to be incorporated in future work.
- Even though there is a strong theory about the processes in the current system, in the future, the system can change drastically the elements and/or the drivers of change. These changes are highly uncertain and cannot be easily predicted. The system dynamic diagram then needs to be looked again critically and adjusted to these changes. For the future it is important to keep the SD tool modular and interactive, in order to keep it updated as time passes by.
Because of the highly uncertain future of the system and the many different pathways for the system to evolve, many more scenarios could be created and defined as likely than we will describe in this chapter. The scenarios that are interesting to analyze further, are dependent on stakeholder involvement.

**Conclusion and Recommendations**

The Mekong Delta Plan recognized that the Delta stands at crossroads (Mekong Delta Plan Committee, 2012). This also stands for Ca Mau; great potential for development lies ahead, but at the same time threats and future change will worsen existing challenges within the water system. In light of climate and socio-economic change, Ca Mau already experiences significant problems: poor coastal protection status, mangrove squeeze and deforestation, salinity intrusion and seasonal freshwater scarcity, groundwater depletion and therefore land subsidence. At the same time, lack of spatial planning and pollution of the canal waters are signs of unsustainable development of the area. At the same time, however, Ca Mau offers opportunities for brackish aquaculture, industrial diversification and eco-tourism.

Ca Mau offers unique characteristics in water management: a low-lying area that is exposed to seasonal flooding, with an alteration of freshwater surplus and scarcity, where the sea defines the status of water far inland. For these reasons, it is important to look at the system from a holistic point of view and try to integrate coastal and inland water management issues. The relationship between coastal and inland water management zone has many features that are inter-linked, with the most significant ones being:

- The link between mangrove belt width and coastal erosion
- The underlying link between mangroves and human land use changes (aquaculture and rice fields)
- The operational status of water management (with closed-loop freshwater systems, along with brackish canal systems, both regulated by sluices)

In order to formulate suitable measures to protect the whole water system, apart from having a holistic perspective on system dynamics the future states of the system needs to be explored as well. Therefore a scenario approach is used, where potential scenarios are scanned and strategies to channel them are found.

For the scenarios made by the project group and their links to measures, it can be said that coastal protection is very important to invest in, as it is key to achieving positive outcomes in many possible futures. Apart from negating coastal erosion and stabilizing the coast, maintaining the mangrove belt is also very important in this. Apart from engineering measures, it can be seen that effective and efficient policy is also very important for making the right decisions, when looking at a future perspective. For inland water management, the most important aspect will be to decide on a long-term strategy, either for freshwater canal systems protection or brackish adaptation, and regulate groundwater extraction in the region, as this will greatly aid sustainability in water practice in Ca Mau.

The integrated approach that was used in this study is not a closed product with ready-made solutions; it is meant to be an assessment subject to judgement, evaluation and discussion by many actors within the water system. With regards to this, one of the main aims of this study is to provide
a platform for that discussion. In light of this, stakeholder involvement is very important. A first step to involve the stakeholders in the province of Ca Mau should be to convince them of this scenario approach as a tool to analyze future problems and plan sustainable, flexible measures for the future. These stakeholders should also be involved while evaluating (and, possibly, re-forming) the system dynamics diagram, because this lies at the basis of the system evaluation and scenario planning.

This holistic approach for finding suitable measures for the province of Ca Mau leads to a stakeholder dependent situation. Therefore, our recommendation is to use the proposed methodology as both a platform for decision-making but also as a chance to involve all stakeholders to participate in the process, review the outcomes and help formulate more suitable measures. For this research there are a lot of measures suggested in different scenarios, but it must be kept in mind that only with more stakeholder involvement will these measures become more well-defined, feasible and tailor-made for the case of Ca Mau. Next to stakeholder involvement, with a future perspective on the system it is important to realize that the SD diagram is not a static artifact of expert modeling but a dynamic tool, which acts as a mind map subject to changes, additions or modifications. It is therefore recommended to use it both as an awareness tool of the situation of the water system, but also as a chance for stakeholder participation.

Future work on the SD diagram and the general methodology may include:

- An upgrade of the system dynamics diagram, especially for the economy. Parts that were not there, such as river bank erosion and pollution aspects in the diagram, could be added as well.
- Convincing local actors about the validity and usefulness of such an integrated approach, that includes ‘softer’ tools (such as the SD modeling) than the regular hydrodynamic modeling.
- Forming, based on (some of) the steps of this method, a platform for active stakeholder collaboration and participation for Ca Mau, where different actors can evaluate the system dynamics, propose strategies and possible futures and add measure packages.
- Quantifying the relationships in the SD diagram in more detail, by means that it then can be used as a full, running Decision Support System.
- Using this tool could be also involved for cost/benefit computations. If the tool works well, the consequences for certain measures can be easily analyzed, and included in the costs and benefits for that measure. With the help of this tool, the overall impact of the measure can be seen on the holistic system.

Apart from the tool set-up, the scenario scanning and measure prioritization, this study identified a number of areas that have research gaps. Multiple research proposals have been thus formulated based on this study, which can be further added in integrated long-term planning and management, as options to gain more insight in the water system of Ca Mau. It is therefore recommended to consider these suggestions for future planning, both as stand-alone modules in specific scientific fields but also as units within a more integrated strategy for the development of Ca Mau.
References


DARD. (2014). *Adjusted Irrigation Planning for Ca Mau Province until 2020*.


IPCC. (2014). *Fifth Assessment Report (AR5)*.


