Integrated Coastal Management in the Province Ca Mau - Vietnam

An Integrated Research to the Coastal and Water Resource Management Issues

Students:

Bianca Stoop	4023212
Dimitrios Bouziotas	4319826
Jill Hanssen	4240162
Johannes Dunnewolt	4254635
Mark Postma	4129237

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

TU Delft
Delft University of Technology

giz
Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

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 Zusamenarbeit).

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, that 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), who would otherwise be studied separately, are interlinked in the case of Ca Mau, as 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, prioritise 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.

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1

Introduction & Problem Definition

The province of Ca Mau

The Mekong Delta, also known as the nine dragon Delta, spreads out over 9 provinces in southern Vietnam. This delta is one of the biggest in the world, with its river starting in China and flowing through Laos, Cambodia and, finally, in Vietnam where it creates the deltaic area. The Ca Mau province is the most southern part of Vietnam and part of the delta. It is a low lying area, 0.5-1 m above sea level, and surrounded at East, South and West coast by the East sea and Gulf of Thailand respectively. Figure 1 visualizes the situation. Ca Mau is primarily a rural area, with most of the land being used for agriculture, aquaculture and forestry. The government of Vietnam aims to develop Ca Mau as a strong socio economic development province by 2020. Their goals are economic growth in the province by improving the efficiency and sustainability of the aqua- and agricultural sector and to improve the physical life and security of the inhabitants.

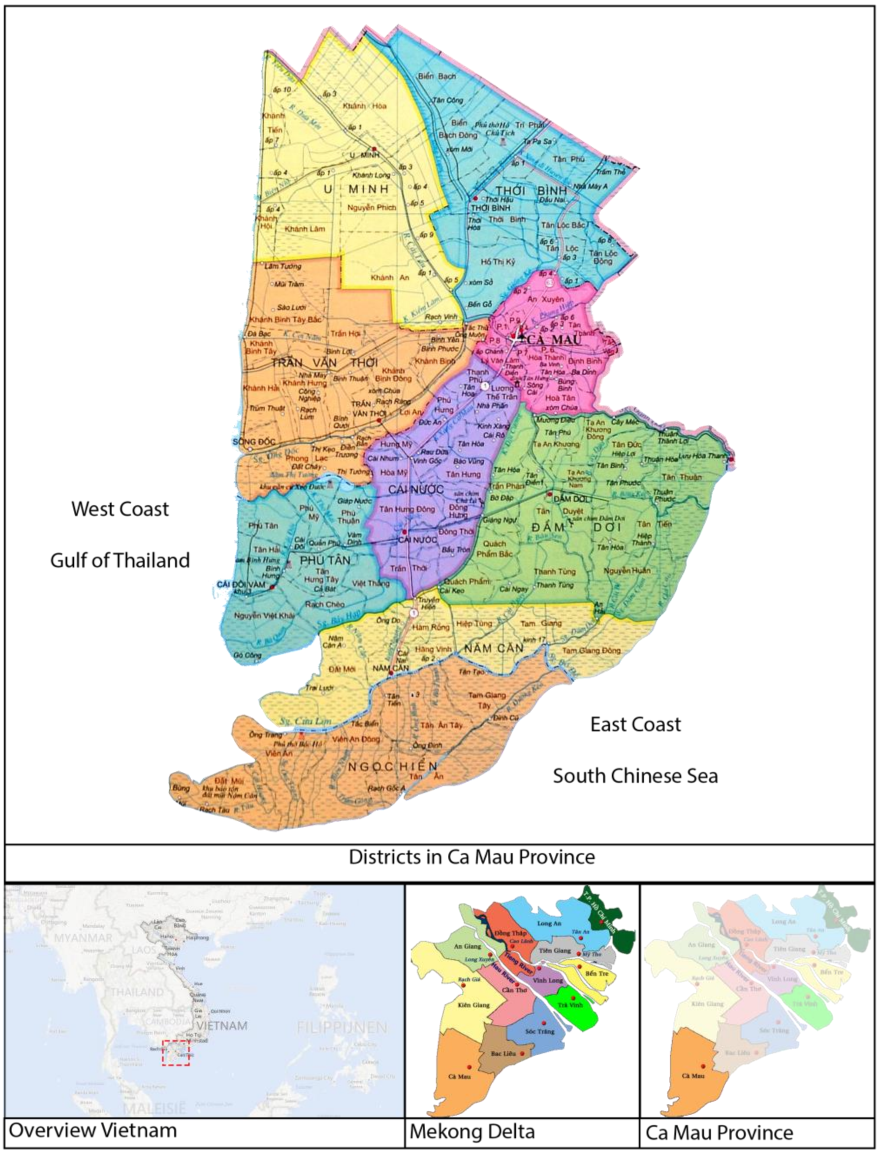


Figure 1: Ca Mau and its place in the Mekong Delta

Problem Definition

Ca Mau faces many challenges, both in its coastal zone and in its inland water system. The coast has a high erosion rate since the last decade and features a mangrove belt under pressure. Additionally the tide affects into the extensive canal system of the province, causing saltwater intrusion, especially during the dry season. In the wet season, the area is vulnerable for higher water levels during storms that lead to frequent inundation. Meanwhile, the rapid growth of the economy, population living close to water and poor operational water management increased the fresh water demands and led to an increase of pollution of the surface water.

Climate change and socio-economical drivers are expected to further challenge the status of the water system in Ca Mau further, mainly in the form of:

- Sea level rise,
- Changing rainfall patterns, with more pronounced floods in the wet season and droughts in the dry season,
- Further pressure to the natural system from human uses,
- More pronounced coastal erosion and retreat of the coastline

These problems, faced under the uncertainty of a changing environment, emphasize the necessity of effective management and policy-making in land and water use. An array of measures, from soft interventions to hard works, will be needed in the future to protect the local population, secure its water quantity and quality needs and enable sustainable livelihoods. At the same time, the unique conditions of Ca Mau mean that the coastal and inland water system are inter-connected and coupled in multiple ways, thus underlining a need for integration in the adopted policies. A main question for the water system of Ca Mau can be therefore formulated:

What measures contribute to realize a sustainable, durable environment that satisfies the protection and the social and economic needs of the inhabitants in the province of Ca Mau, in which coastal engineering, (inland) water management and land use can be integrated?

Based on the above questions, and having the scope and demands of GIZ in mind, the main goal of this research is verbalized:

Our aim is to 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 goal of the research is thus to analyze the current system of the coastal zone and inland water system for the province of Ca Mau. Based on that level of understanding, scenarios can be planned and integrated measures that offer the optimal solution for multiple problems can be outlined.

Methodological Approach

The methodology that is followed is dictated by the need for a holistic outlook on the combined coastal and inland water system for Ca Mau. The water system is treated from an engineering perspective, with the use of an analytical approach that aims at understanding key processes, schematizing crucial interactions and find cause-effect relationships. In order to link all processes in the water system, a System Dynamics (SD) approach is applied to the province on an aggregated scale. With the help of a qualitative System Dynamics diagram the sensitive and influential elements of the system can be identified. Socio economic and political influences on the system are also integrated and their effects are study.

The system dynamics diagram can be then used as a tool to let the stakeholders comprehend which elements are most valuable for them and how they can influence the elements and system. In addition to this, a scenario building approach is use to construct future scenarios and indicate the potential futures of Ca Mau. The most interesting scenarios to consider can be coupled in the diagram, to show key system weaknesses and potential. Hence the stakeholder can gain insight on the influence of the most valuable elements the system.

As an example, a set of scenarios is chosen and applied to the system. The most important or sensitive processes, that need interference of coastal- or inland measures, will become clear for these scenarios. Measures that should be taken (may) require additional research. These demands for research together with knowledge gabs found in the literature compose a preliminary research proposal which closes the project.

The spatial boundaries of this project are the boundaries of the province of Ca Mau. For determining the timescale two things are taken into account. A time scale that is too small, ignores the effect of the elements who have a long processing time in the system. Policy is a slow running element in the system. A tact takes roughly 10 years to develop and implement. To view the effect of policy changes a time scale larger than 10 years is needed. A time scale of approximately 30 years, until 2050, is therefore chosen. This study thus serves the needs for strategic mid- to long- term planning.

The research is not meant to be a profound socio-economic or political study of Ca Mau. Although due to the integrated approach, social, economic and political elements are superficially included.

Layout of the Report

This study is divided into nine chapters, with the first one being the introductory part. The second chapter explains the need for a holistic approach and describes aspects from Integrated Coastal Zone Management (ICZM) and Integrated Water Management (IWM) that help formulate the background for integration in this study. The third chapter is an extensive analysis of the current water system status in Ca Mau, taking into account the coastal system, the inland system, key stakeholders and the status of current policy. This chapter ends with a SWOT analysis, highlighting key strengths and weaknesses for the province.

After the literature study on the system status, a number of chapters that analyze the system follow. In the fourth chapter, a System Dynamics model is developed for the whole system, in order to study cause-effect relationships. Findings from the SD model are used, along with scenario building techniques, to identify possible futures and examine critical aspects of system failure or transformation in the sixth chapter. Key measures are outlined based on these scenarios in the seventh chapter, while 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 eight chapter, ending with the ninth chapter about the conclusion and discussions.

2

Need for Integration

The coastal zone and inland zone in Ca Mau share 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. By using a holistic approach, including socio-economic relations and policy as well, the system can be fully understood, what will lead to effective and efficient measures for the province of Ca Mau. To employ a holistic approach, one can look at integrated studies in coastal zone and in water management.

The coastal zone alone can be seen as a multi-faceted system that includes:

a) The natural (physical and ecological) system of the coast, and the boundaries it imposes to human development, design and management.
b) The socio-economic subsystem that defines the range of coastal human activities, the coastal infrastructure and, finally, the legislative or administrative limits.
c) Pressures exerted to the system by changes in either (a.) or (b.)

Given these aspects of the coastal zone, the purpose of Integrated Coastal Zone Management tools is to harmonize the socio-economic subsystem with the natural system, so that the coastal zone can be managed in a sustainable way. The afore-mentioned structure of the coastal zone can be further described with Figure 2, which presents the various subsystem components. These components are the natural system and the socio-economic subsystem, which comprises of user functions and infrastructure. Socio-economic development plans and changing natural boundary conditions (e.g. climate change) are the agents of change for these system elements, as can be seen by the arrows that lead from the outer circle of system constraints to the inner circles of the system components. These agents can be either demand driven, from the socio-economic changes, or driven by a change in natural processes. In the case of Ca Mau, both driving agents contribute to a change in the coastal zone. The central triangle, named the management control center, comprises the strategies and measures that aim at harmonizing the system components and mitigating changes.

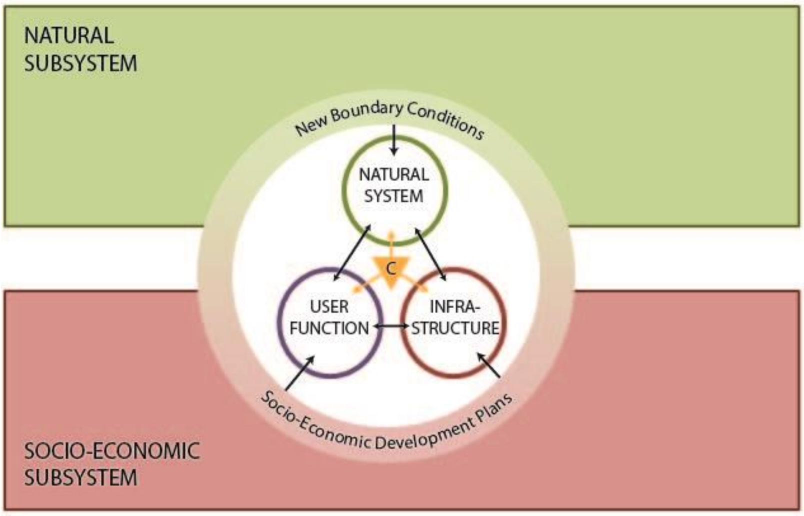


Figure 2: A systems view of the coastal zone, adapted from Bosboom & Stive, 2015.

Given this structure, a stepwise approach in management is usually proposed to handle problems in an integrated fashion. The steps may, for instance, comprise the following (Bosboom & Stive, 2015):

1.) Defining the case study area

In this stage, the socio-economic and geographical limits of the area have to be determined. This is represented by the outer circle in Figure 2.

2.) Delineating the system elements.

The second stage analyses the inner subsystems, which are represented by the inner circles (Natural System, User Functions and Infrastructure) in Figure 2.

3.) Assessing the subsystem relations

In this step, a model has to be made that depicts the relations between the various elements of the system. These interactions form the basis for the design of scenarios and strategies.

4.) Identifying the drivers of change and scenarios of development

In this stage, the natural and socio-economic drivers of change for the system have to be studied. These are represented by the arrows that lead from the outer boundaries of Figure 2 to the inner circles.

5.) Formulation of possible strategies

Having insight from the information gathered in previous steps, strategies and measures can be now designed which aim at harmonizing the different system components. This array of measures is represented by the central triangle in Figure 2.

6.) Assessment of system response to strategies

In this stage, the projected system response to the strategies proposed in step 5 can be assessed.

7.) Choice of actions

In this final step, the optimal strategies are chosen and the control center takes care that decisions are made, by all involved stakeholders, with regards to the preferred strategies.

The layout of this study reflects a logical sequence closely related to the stepwise approach that was described before. An analysis of the inner system elements, notably the three inner circles, is first performed. The socio-economic and natural boundaries of the case study are then studied, so as to identify the key drivers of change, both due to natural and anthropogenic causes that affect the system. The development of the SD model studies the interactions between these elements, thus elaborating on the arrows between inner circles. Finally, elements from steps 5 and 6 are incorporated to provide scenarios about possible futures and study integrated measures.

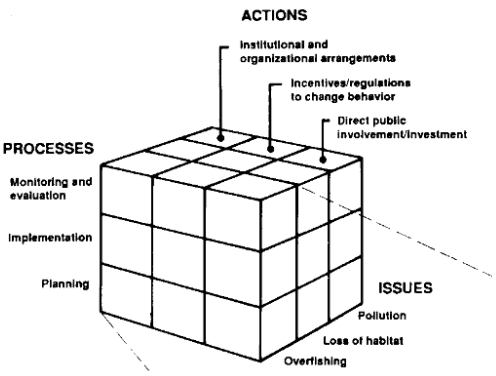
The challenge, in this case, is to fuse the coastal system with the inland water system. With reference to this, it is evident that the structural elements of Figure 2 are broad and applicable to coupled human natural systems. They can thus be readily expanded to include the aspects of the inland water system. Natural boundary conditions have to then incorporate inland hydrology, as well as coastal wave, current and sediment input, and socio-economic development plans have to encompass both human action on the coast and the inner land. Since, in this case, the inner water system is significantly affected by the coast, this integration is highly desirable and 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 understand better the concepts of ICZM, Scura, Chua, Pido, & Paw, 1992 depict integrated coastal zone management as a gridded cube of three basic dimensions (Figure 3, left panel). These dimensions are (Scura et al., 1992; Thia-Eng, 1993) management processes (notably planning, implementation and monitoring/evaluation) issues, related to resource use, environmental quality etc. and actions, which include organizational arrangements, regulations and stakeholder participation.

Having a similar layout, Savenije & Van der Zaag, 2008 sketch the concept of Integrated Water (Systems) Management (IWM) as a multi-dimensional structure (Figure 3, right panel), the dimensions of which are:

- the type of water resources, as a natural dimension, which includes aspects of the hydrological cycle, water quality and water quantity.
- the water users as a human dimension, which includes the (often conflicting) different water uses and the corresponding stakeholders, and
- the spatial dimension, noting the difference between strategies on a local, provincial, national or international level. The temporal dimension is also mentioned as a fourth dimension that adds to the evolution of the socio-hydrological water system.

Despite the differences in system context and in setting the perceived dimensions for each case of integrated management (Scura et al. focus on management aspects in the study, while Savenije & Van der Zaag, 2008 emphasize the socio-hydrological aspects of the water system as a two-dimensional basis), there is a strong common foundation. This is the need for a multi-dimensional viewpoint and the need for cross-cutting, cross-disciplinary efforts in managing the system. Multiple grid points in each cube have to be taken into account and linked together. Note that the Figure from Savenije & Van der Zaag, 2008 stresses the need for this link especially in the spatial scale of management, so that decisions at provincial or national levels are taken into account into larger levels. There is also the common basic assumption that the system is complex and needs to be addressed in multiple axes, with the natural system being only one of them.



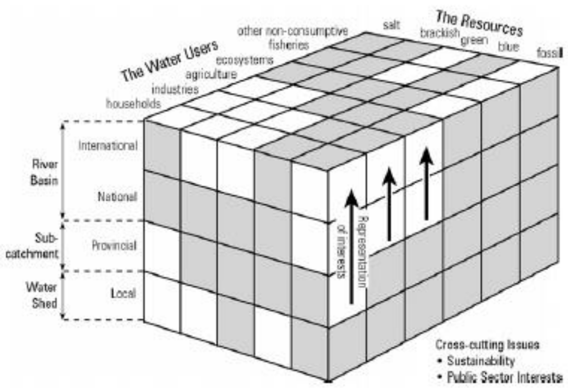


Figure 3: The "Rubick's cubes" of integrated management, in the case of ICZM (left panel) and IWM (right panel) (Savenije & Van der Zaag, 2008; Scura et al., 1992).

In the context of this study, where the coupled human-natural water system needs to be studied in both its coastal and inland zone, and where stakeholders and policy implementation is explored as another dimension of the problem, a similar 3D gridded cube is proposed as a fundamental viewpoint (see Figure 4). 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 (as in the case of Figure 3, left panel) is related to planning, implementation and monitoring/evaluation.

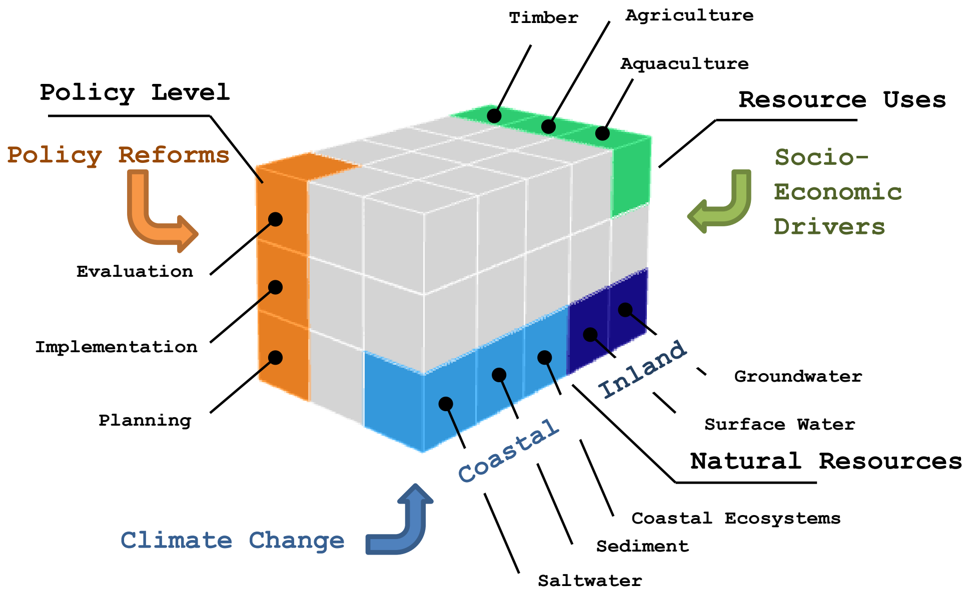


Figure 4: The multi-dimensional structure of managing the water system in the case of Ca Mau.

Indicative processes in each dimension are also mentioned in Figure 4. It is also useful to visualize a fourth, temporal dimension in the picture, which enables the key drivers of each dimension (climate change, socio-economic drivers and policy reforms), to progress and thus change the status of corresponding grid points over time. This puts the study on integrated water management under the context of change, whether it is climate, social or policy driven. The proceeding chapters aim at analyzing all aspects mentioned in Figure 4. The multiple facets of each element in the system (Natural Resources, Resources Uses and Policy Level) are explored in Chapter 3 – Current System, while Chapter 4 explores the climate and socio-economic drivers of change (see Figure 5).

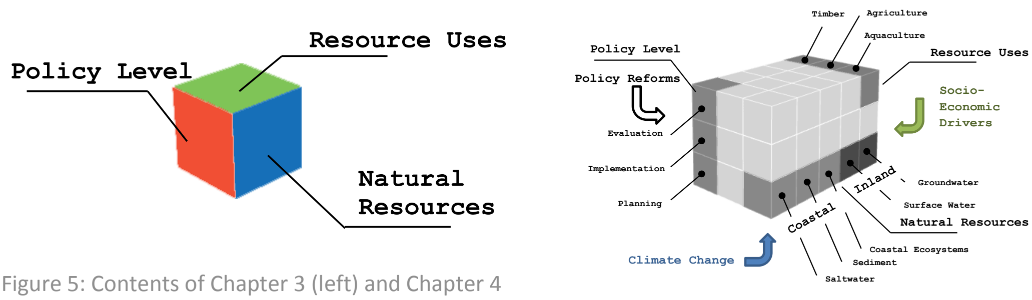


Figure 5: Contents of Chapter 3 (left) and Chapter 4 (right – arrows in color).

3

Current System Status

- Current System - Hydraulic Analysis
- Current System - Water management
- Current System - Policy
- Current System - Stakeholders
- Current System - SWOT

Current System - Hydraulic Analysis

For the project a literature study has been done to the current flow and sediment transport along the coast of Ca Mau. Therefor the tidal, wind and wave influence is viewed. Due to the location of Ca Mau, the processes differ at all three coastal sides of the province. the whole province is considered to have a good overview. Beside the hydraulic forcing and related sediment transport, the mangrove belt and the human interferences along the coast are described.

Tidal influence

Introduction

The global tidal wave is a result of the attracting masses of the sun, the earth and the moon. If there were no continents, it would travel around the globe without distortion. The distortions due to the continents lead to a global tidal variation in height and character (frequency). Four tidal constituents (mainly) govern the tidal pattern around the Ca Mau province:

- The diurnal components: K1 and O1.
- The semi-diurnal components: M2 and S2

K1 and M2 are the dominating tidal constituents for the west coast of Vietnam and in this paragraph the focus is on these patterns.

The tidal character around the province Ca Mau is determined by the ratio of the main diurnal components and semi-diurnal components, with the latitude and geography being influential factors. Ca Mau lies in the Northern Hemisphere (NH) on a low latitude. Generally one would expect a semi-diurnal tide that turns counterclockwise in these regions. However, this does not hold for the West coast of Ca Mau. The East and West coast show different tidal characteristics and are thus separately elaborated.

East

The semi diurnal tide (M2) is governing along the East coast and turns counterclockwise. It has a Meso tidal regime and the tidal amplitude varies between 3 – 3.5m (IMP, n.d.).

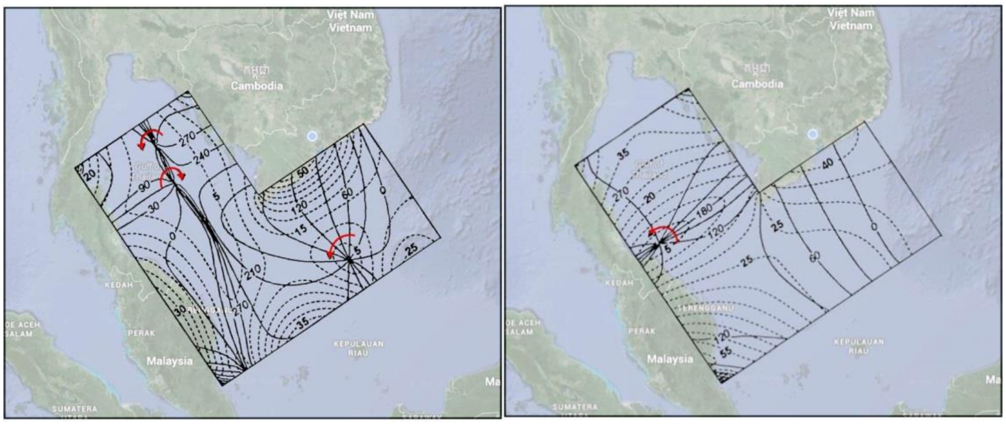
West

For the West coast the situation is more complex. The West coast borders the Gulf of Thailand. This is a basin where all four constituents can be found. The M2 tide from the East sea penetrates into the Gulf of Thailand south from Vietnam as shown in Figure 6.

Figure 6: Penetration M2 tide into Gulf of Thailand.

In the Gulf of Thailand all above mentioned tidal regimes are present and have one or more amphidromic points in the Gulf of Thailand. For the M2 and K1 tide the amphidromic points are depicted in Figure 7.

Figure 7: Left: Amphidromic points M2 Tide; Right: Amphidromic point K1 Tide



The Gulf of Thailand is a basin and due to its small dimensions, the Coriolis force is not (necessarily) the dominating force to determine the tidal direction. The bottom topography, the shape of the basin (and therefor the oscillation modes of the basin) and the periods of the tides also influence the propagation of the tide significantly.

The incoming M2 tide in the South of the Gulf of Thailand becomes an edge wave due to the bottom slope of the basin. It travels along the West boundary (Malaysia and Thailand) to the north. At the east boundary, the amplitude of the M2 tide decreases from North to South along the coast of Cambodia and Vietnam. Therefor the direction of the M2 tide becomes clockwise.

At the West side of the basin there is an amphidromic point of the K1 constituent. The period of the tide is large enough to be affected by the Coriolis force and therefore it turns counterclockwise. (Yanagi & Takao, 1998)

In former research the tidal energy flux of the M2 tide and K1 tide in the basin is investigated. It appears that the tidal energy flux of the M2 tide mainly appears along the East coast of Ca Mau. The energy flux of the K1 tide is largely spread along the West and South coast of Ca Mau because it follows the bottom topography. The tidal component is amplified where the sea bottom floor has steep gradients.(Tomkratoke & Sirisup, 2010).

Because of the location of the amphidromic points and the amplification due to the bottom topography, the direction of the tide along the West coast of Vietnam is determined by the M2 tide but the tidal ranges by the K1 tide. The frequency of the diurnal tidal component is close to the frequency mode of the basin. This leads to resonance and amplification of the tide. Therefor the diurnal component dominates and the tide becomes diurnal (K1 tide). The tidal amplitude is rather low, 0.5 – 1m (IMP, n.d.).

In Figure 8 an illustration is given of the recorded tides at four locations in the provinces Ca Mau and Kien Giang in 2013 (Southern institute for Water ResourcesPlanning, Dung, Ngoc, Thanh, & Cam, 2013)

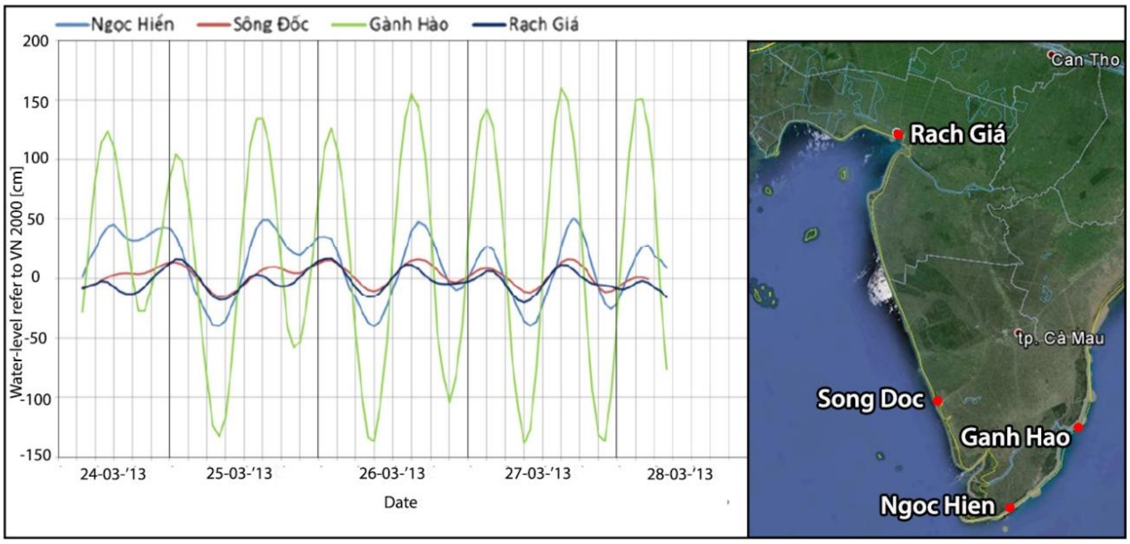


Figure 8: Overview tidal characters along the coast of Ca Mau

Inland coastal zone

The inland coastal zone is the location where coastal engineering and water management interact. Ca Mau has a widespread structure of canals who are connected to the seas. The tide on the East and West coast form the boundary conditions for the tidal penetration into the channel system in the Ca Mau province. In the chapter Current system - Water management the effects on the channel system are explained.

Wind and wave climate

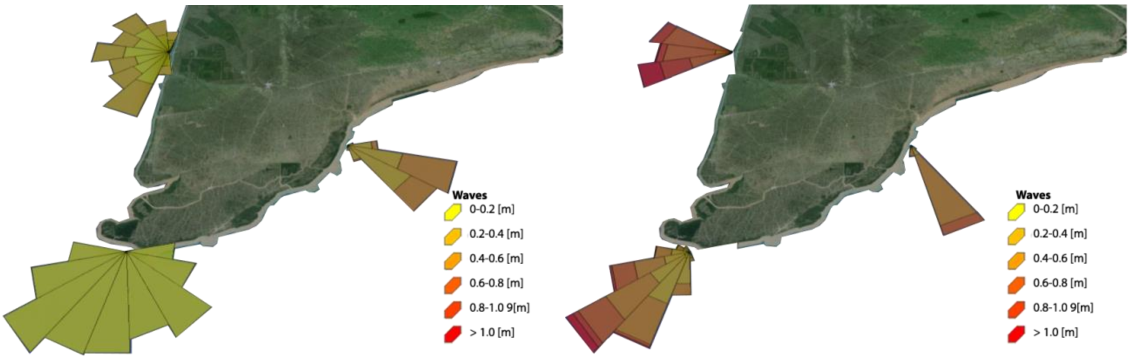
The global wind and current system are two coupled systems that influence each other. Both are driven by heat differences around the globe and the non-uniformity of the earth surface. Ca Mau has an equatorial tropical climate with only two seasons due to its location on the globe. The region is dominated by monsoon winds which reverse seasonally.

- In the NH summer months the air above Asia is much warmer and will rise. Due to the low pressure region above the continent, wind from the sea will flow towards the continent, causing the South West monsoon. Air currents transport water from the ocean which leads to large amounts of rainfall above the land. This leads to the wet season from May up to November. The wind speeds differ from 1.6 – 4.5 m/s. (IMP, n.d.)
- In NH winter months the air above Asia is much colder than the air above the ocean. Wind above the ocean will rise and flow towards the north. Due to the low pressure area above the sea, air from the North will be transported to the South over the continent. This is the North East monsoon. It appears during the dry season lasting from December up to April. The wind speeds differ from 1.6 – 2.8 m/s.(IMP, n.d.)

The (main) wind direction differs along the coast of Ca Mau. The wave environment around Ca Mau is determined by the monsoons. For the West coast of Ca Mau, the highest waves occur during the wet season when South West winds blow towards the coast. For the East coast, the highest waves occur during the dry season when East winds blow towards the coast. The waves due to the monsoon winds are moderate and constant in height and direction, comparable to swell waves. The waves due to cyclones lead to very high waves and storm surges.

The (main) wave direction differs along the coast of Ca Mau and differs per season as can be seen in the figures below. The figures are derived from measurements at three locations along the coast in the rain as well as in the dry season. In the rain season the wave height increases noticeably at the West and South coast and the waves are more uniform-directed. (von Lieberman, n.d.)

Figure 9: Left: Wave roses for dry season Right: Wave rose for wet season.



Besides the seasonality of the monsoons the area is also influenced by tropical cyclones. Figure 10 provides an overview of the main pathways of tropical cyclones in SE Asia (left panel), with arrows being proportional to storm frequencies along indicated tracks. While the most severe tropical cyclones follow a northerly path and pass through China and the Philippines, Vietnam is exposed to two sets of tropical cyclones:

- Northwesterly in summer months, passing through the Vietnamese hinterland and Cambodia.
- Lower latitude cyclone tracks in October, November and December, that pass south of Vietnam into the Gulf of Thailand.

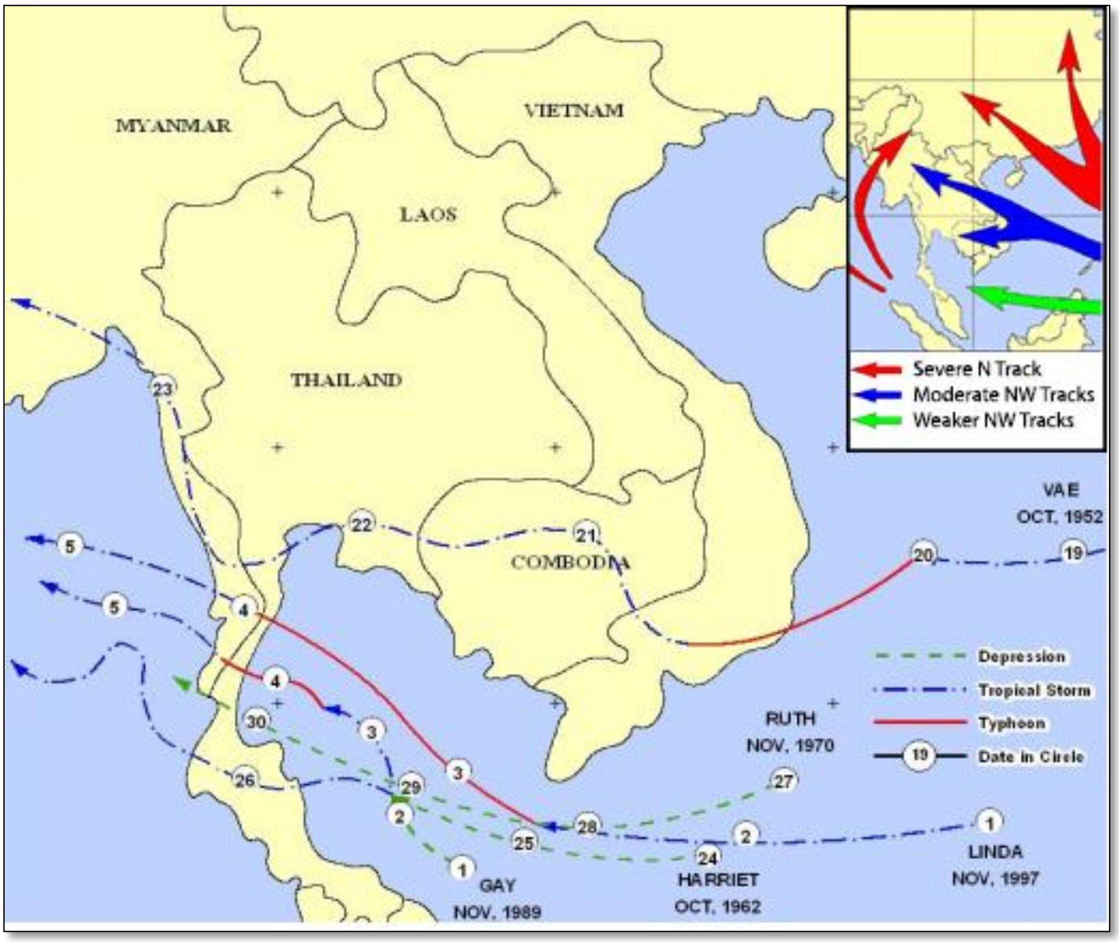


Figure 10: Tropical cyclone pathways in SE Asia and main historical depressions and cyclones that reached the Gulf of Thailand (adapted from (Vongvisessomjai, 2009)).

While the latter two cyclone types are generally more rare events (only 1 typhoon over an 11-year period shifts from its usual northerly track in the summer and passes through Vietnam), they can have a devastating effect (Vongvisessomjai, 2009). Despite the low frequency of these paths, Ca Mau is particularly exposed to these events due to its low altitude and southernmost geographical position. Figure 10, right panel, shows the tracks of the main historical depressions and tropical cyclones that reached the Gulf of Thailand; the vulnerability of Ca Mau is evident due to its proximity to these paths. For instance, the crossing of typhoon Linda on 1997, which peaked from a tropical storm to typhoon close to cape Ca Mau, resulted in 125,000 damaged homes and $170 million in damages for the province of Ca Mau, totaling more than the provincial GDP.(AP, 1997)

Water flow in the basin

The East sea and the Gulf of Thailand (basin) have different high and low water phases and ranges. The tidal amplitude in the East sea is larger than in the Gulf of Thailand. This generates additional current is 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. This is shown in Table 1 and Figure 11. (Michael J Russell, 2012).

Table 1: Water phases and ranges

Water phases and ranges			
East Sea	**Gulf of Thailand**	**Flow East coast**	**Flow West Coast**
High water	High water	North to South	South to North
High water	Low water	North to South	South to North
Low water	High water	South to North	North to South
Low water	Low water	South to North	North to South

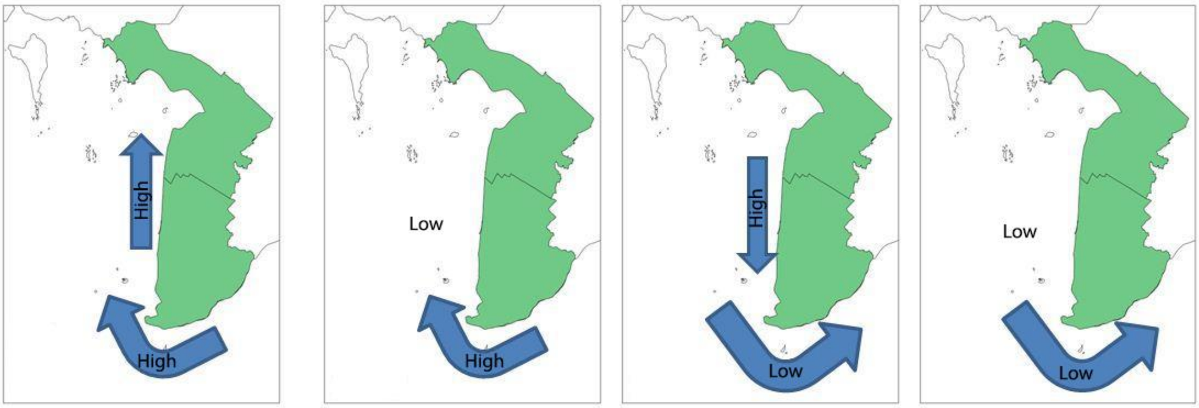


Figure 11: Ebb and Flood differences and resulting currents

Current

Due to the influence of the tide, monsoon winds and generated waves and the connection with the East sea, the current system along the coast of Ca Mau (especially the West) is complex. A lot of research has been done to the current flow along the coast, but still there is not a clear picture. This is partly due to the fact that the results of different investigations are contradictory. Next to it we noticed that lots of information and data is not easily exchanged by the different research institutes and universities. In the following two examples are presented which show the contradictories and remarkable conclusion from research carried out along the West coast of Ca Mau.

Research done by (Stolzenwald, 2013) and (von Lieberman, n.d.) shows the following results.

Table 2 Main current directions during SE and NW monsoon, (von Lieberman, n.d.)

NE-monsoon season		SW-monsoon season	
wind/wave influenced	Without wind/wave influence	wind/wave influenced	Without wind/wave influence
No significant influence due to offshore wind conditions	↑ 0.3 m/s	↑ 0.3 m/s	lower
	↓ 0.15 m/s	↓ 0.4 m/s	higher

The results are gained by a measurement campaign; one at the end of the dry season and one in the wet season. There some remarkable comments about the results of the West coast.

- The flood current is directed to the North without wind influence, while the tide rotates clockwise along the West coast as discussed before.
- During SW monsoon the flood current is to the North but the ebb current to the South has a higher magnitude. Besides the comment of the flood current it is also peculiar that although the wind blowing from the South to the North, the ebb current to the South has a larger magnitude.
- The campaigns only measured one ebb and or flood period. The influence of the wind is only qualitatively described. The influence of currents due to in and outflow of water into the basin is not at all mentioned, while other reports do(M.J Russell, 2012).

If the results are compared with documentation of the Southern Institute for Water Resources and Planning (SIWRP) about the main current direction during the NE monsoon and SW monsoon, contradictions can be found. These present that during the NE monsoon, the main current direction is towards the South as well as during the SW monsoon. The velocities during the SW monsoon are lower. This can be explained by the fact that during the SW monsoon the wind direction is towards the North while the tidal direction is towards the South.

Based on these findings it is advisable to start a current measurement campaign along the West Coast which takes multiple days (a week) in both monsoon seasons and in the 2 transitions towards the season.

Based on the information found about the tide, wind and water flow into the basin, an expected flow during the SW and NE monsoon is constructed below.

Tidal currents:

Along the East coast of Ca Mau the tide propagates anti clockwise (from North to South) which is also the dominating tide along the south coast. The west coast however is influenced by a tide propagating clockwise as explained before. It is assumed that the flood flow is in the same direction as the propagation of the tide. This is summarized in Table 3.

Table 3: Tidal currents

Tidal Currents		
Coast	**Tide**	**Flow direction**
East	Ebb Flood	Northwards Southwards
South	Ebb Flood	Eastwards Westwards
West	Ebb Flood	Northwards Southwards

Monsoon winds

The current is influenced by the direction of the tide and the wind. The wind driven currents for each coast side are shown in Table 4.

Table 4: Wind driven currents

Monsoon wind driven currents			
Coast	**Season (monsoon)**	**Wind direction**	**Flow direction**
East & West	Dry Rain	NE wind SW wind	North to South South to North
South	Dry Rain	NE wind SW wind	East to West West to East

Combination of currents

The combination of the tidal currents, the monsoon driven currents and the water flow from the East sea determine the resulting current. The directions of ebb and flood depend on the magnitude of each of the forcing's. Their direction may differ during the NE and SW monsoon. This is shown in Table 5 and Figure 12. A distinction is made between the dry and rain season. The influence of the East sea in and outflow is not included because the effect is at another time scale.

Table 5: Monsoon wind and Tidal current combination

Monsoon wind and tidal combination				
Coast	**Monsoon**	**Tide**	**Resulting current direction**	
East	Dry	Ebb	North	
		Flood	South West	Dominant
	Rain	Ebb	North	Dominant
		Flood	South West	
South	Dry	Ebb	East	
		Flood	West	Dominant
	Rain	Ebb	East	Dominant
		Flood	West	
West	Dry	Ebb	South or weakly North	
		Flood	South	Dominant
	Rain	Ebb	North	Dominant
		Flood	North or weakly South	

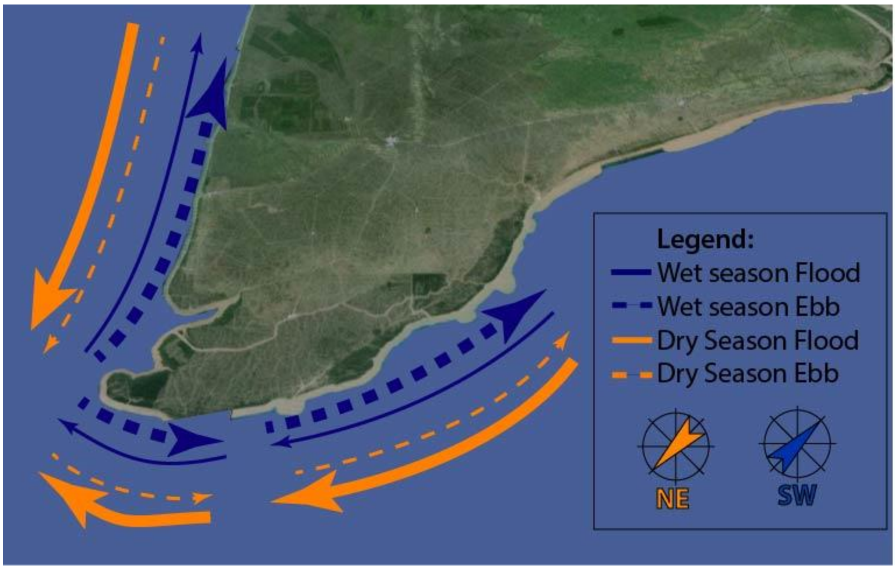


Figure 12: Wind and tidal currents

Sediment transport

The sediment transport is related to the magnitude and direction of the currents. Sediment can be transported in cross shore and alongshore direction. The cross shore processes define the contour of the shore face and are dominated by wave action. Mostly these wave actions are short-term (e.g. storm surge) or seasonal (e.g. winter-summer variation) events. The profile is thus morphodynamically active considering the short time scale. However, on a timescale of years, the profile is in dynamic equilibrium (if only cross shore transport is considered).

The long shore transport shapes the coast in longitudinal direction. The coastal response (accretion or erosion) is driven by gradients in the sediment transport rate. This can be due to a change in direction and magnitude of the waves approaching the shore or a change in the availability of sediments. Any gradient in sediment transport rates leads to structural changes of the coastline on a short term and long term until a new equilibrium state is reached.

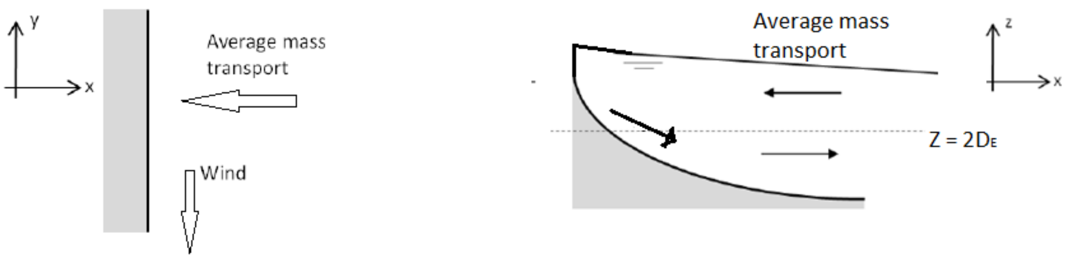
In this paragraph the longshore sediment transport along the coast of Ca Mau is elaborated. The cross-shore profile is assumed to be in dynamic equilibrium. The only cross-shore process which would be of interest is significant erosion when typhoons and storm surges occur. This process, however, leads to episodic erosion and not the structural annual erosion observed in most coasts; it is thus excluded from further analysis in the present study. The effects of typhoons on sediment transport have been analyzed in past studies. (M.J Russell, 2012).

he largest source of sediment for the province is the Mekong river North from Ca Mau. The Mekong Delta is slightly dominated by the tide. During the SW-monsoon the river discharge is maximal. Sediments from the Mekong River flow into the subaqueous area. Even some erosion may occur near the river mouth due to the high river discharges. The South West monsoon winds lead to a transport that is slightly directed to the North. During the NE-monsoon in the Northern Hemisphere winter, the sediments are transported to the South along the East coast of Vietnam and Ca Mau itself by:

- The tidal current
- Wind waves
- Coastal downwelling (Xue, He, Liu, & Warner, 2012)

Coastal downwelling is generated by the wind blowing parallel to the shore to the south (NE monsoon). The average water mass transport is at a 90^{0} angle from the wind direction (to the right in NH) and flows towards the west. This leads to coastal downwelling and a negative water level gradient perpendicular to the East coast as schematized in Figure 13. This water level gradient leads to geostrophic flow and sediment transport towards the equator (South).

Figure 13 Water mass transport due to the wind along the shore



The whole province of Ca Mau is a southwestward prograding spit (Ta et al., 2002), built up by (reworked) sediments of the Mekong river 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 expectation.

In the paragraph before the complex current system of the West coast is explained. Depending on the flow direction, sediment transport is also possible to the South along the West coast. There is no 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 the North of the province.

Still more profound research has to be done on the sediment flow along the West Coast of Ca Mau, especially with regards to sources and sinks and coarse and suspended sediment trajectories along the Ca Mau peninsula

Spatially there is a large variation in the deposited sediments at the foreshore of Ca Mau as can be seen in Figure 14. 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)

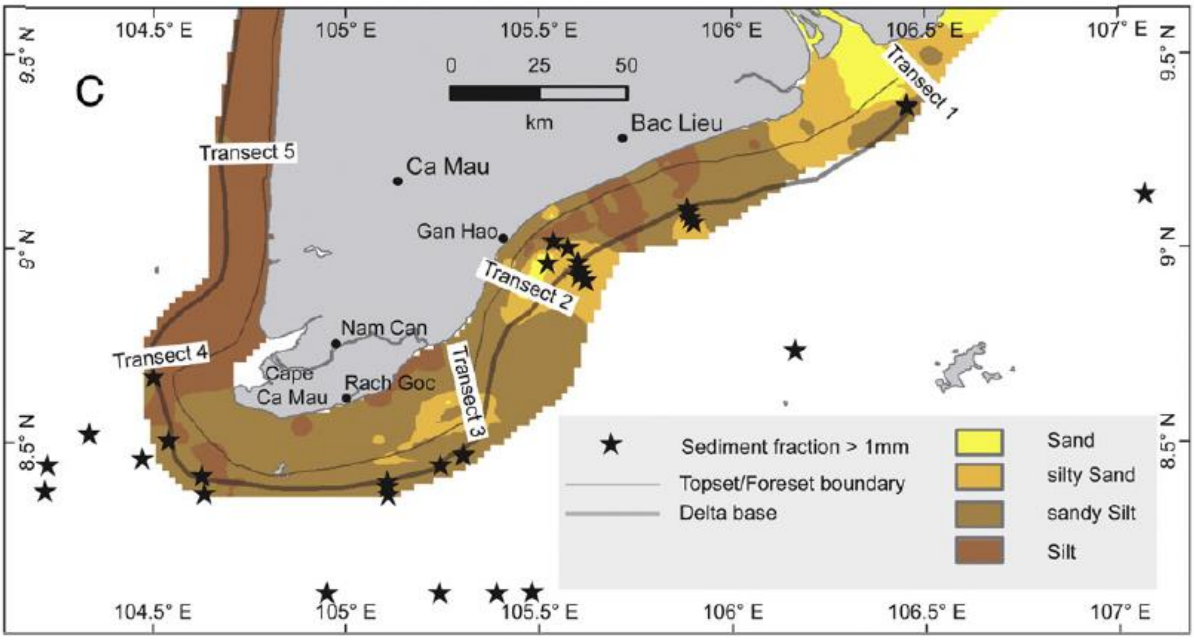


Figure 14 Sediment distribution along Ca Mau adapted from (Unverricht et al., 2013).

Coastal accretion and erosion

Transport of sediment doesn't necessarily lead to erosion or deposition. Only if there is a positive/ negative sediment balance in a coastal cell, deposition/ erosion will occur. As stated before, Ca Mau is a fast prograding spit. There are two elements which dominate the accreting process. On the one hand the fore shore which is very shallow due to the subaqueous delta (Unverricht et al., 2013) and secondly the mangrove forest is able to capture the sediments (V. L. Nguyen, Ta, & Tateishi, 2000). Although, the province of Ca Mau faces an advancing erosion process at numerous locations as also can be seen in Figure 19.

There are different causes for the erosion along the whole coast of Ca Mau

- The global climate change leads to RSLR, stronger monsoons, and a higher storm surge level. In all cases the wave height and magnitude of the current increases. This gives rise to an increase of erosion.
- 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 lead to less sediments that can be captured by the mangrove threes. The sediments are more easily transported by the current. In the chapter Mangroves this phenomena is further clarified.
- 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 gradient in the sediment transport rate. These (initially small) gabs grow fast until a new equilibrium of the coastline is reached.
- Erosion due to high river outflow. Besides sea level rise and extremer weather events, climate change also leads to higher precipitation rates during the rain season. Consequently the river discharges of the Mekong river are higher. 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 in Vietnam and other countries upstream. The structures may trap sediments. For downstream areas the sediment transport rate of the Mekong river is presumed to be decreased due to upstream construction of dams. The decrease of the sediment concentration of the Mekong river is hypothesized to have led (amongst others) to erosion along the East coast of Ca Mau. (Lu & Siew, 2006). More research and especially long term measurement campaigns are necessary the corroborate this hypothesizes.

The erosion rate along the East coast of Ca Mau has been around 20m per year in the last decade. The tip of Ca Mau, Cape Ca Mau was a relatively stable part of the province. There are parts which still gradual accrete. In the area a national park is located; Ca Mau Mui Park. The park is protected by legislations. Although large parts of Cape Ca Mau are also influenced by the human stress due to deforesting. Along the Song Bo De river there are measurements of 90m of erosion per year. The west coast of Ca Mau has a relative straight coastline. It seems that this straight coast has been in equilibrium for many decades. Currently due to human interference the shape of the coastline is interrupted. This leads to a spatial change which gives rise to a sediment transport gradient in long shore direction. In the last decade the West coast of Ca Mau has an erosion rate of 10m per year (von Lieberman, n.d.).

Mangroves

Introduction

The 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. The mangroves are part of an ecosystem and while there are many definitions for ecosystem, they all imply the strong relation between the ecosystem functions and the human wellbeing. (Tuan, 2013). The functions of the mangroves can be divided into the following three categories according to (Marchand, 2008):

1. Productive functions
2. Ecological functions
3. Protective function

These functions act as services from the mangroves which are used by the user. If one of the functions is disabled this will stop the service and creates a problem for the user as can be seen in Figure 15. In a lot of areas the management faces a balance between environmental protection and economic development. Excessive mangrove deforestation is one example of management where economic development was more important than the habitat and storm protection, which the mangroves offer.

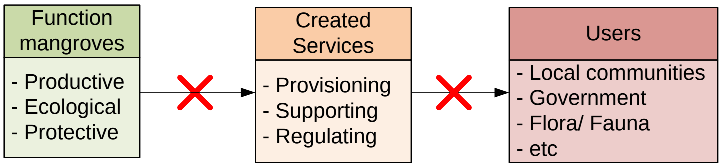


Figure 15: Function and services created by mangroves for the users.

Mangrove function

Mangrove forests tend to grow along muddy shorelines in sheltered tropical and subtropical areas. A special characteristic of these plants is that they have adapted to circumstances with high salinity, loose soil and tidal flooding's. Important is to indicate that mangroves don't prefer salt water but the plants can cope with the salt water and have therewith an advantage compared to other plant species. The mangroves are able to absorb the pore-water around the roots and filter out most of the salt water, which is left in the soil.

Productive function:

The mangrove forest is used a lot by the local communities in their daily life for food production, biotic resources, material for construction and production of fuel. In Vietnam the mangroves suffered a lot from deforestation and cultivation of mangrove forest for shrimp farming.

Ecological function:

The mangroves are the key in the nutrient circle of the mangrove ecosystem. Their main function is to provide dead organic materials to the marine ecosystem. This organic material in combination with the sheltered environment forms an ideal habitat for animals to live and thus it creates a small food web. The animals living in the mangroves create holes and tunnels in the ground which play a role in the reproduction of the mangroves and thus makes it a positive feedback loop.

The mangroves can reproduce during the whole year, during this process the seeds are segregated. This creates zones of different species which all grow in different tidal inundation, soil salinity and amount of fresh water availability. According to Watson (1928) there are 5 zones based on the flood characteristics. To create an optimal protected biosphere, a combination between these different mangrove species from different zones give the best protection. Also when SLR occurs the mangroves are more capable of adjusting to the higher grounds when more different species are available. The species who can handle more flooding's will shift to higher grounds. The increasing temperature and change in perturbation is possibly also a trigger for the mangroves to move higher latitudes (Gilman, Ellison, Duke, & Field, 2008). To make mangrove restoration a success, knowledge about the reproduction and the ecology of the mangroves is essential.

Protective function:

Because the mangroves are positioned along the coastline and rivers, they play a critical role in the coastal zone protection. They influence wave attenuation, storm protection and shoreline stabilisation.

<u>Wave attenuation:</u>

The mangrove belt is a natural protection against both short as long waves. Especially the long waves are expected to play an important role in the sediment transport process within the mangroves as they penetrate further into the mangroves. (Massel, Furukawa, & Brinkman, 1999). The thicker and denser the mangroves the more the waves are attenuated and the less far the long waves can penetrate land inwards. See Figure 16 where can be observed that the short waves hardly penetrate and that the long waves penetrate less far in dense mangrove forest than in sparse and that when there are no mangroves, more energy must be absorbed by the dikes.

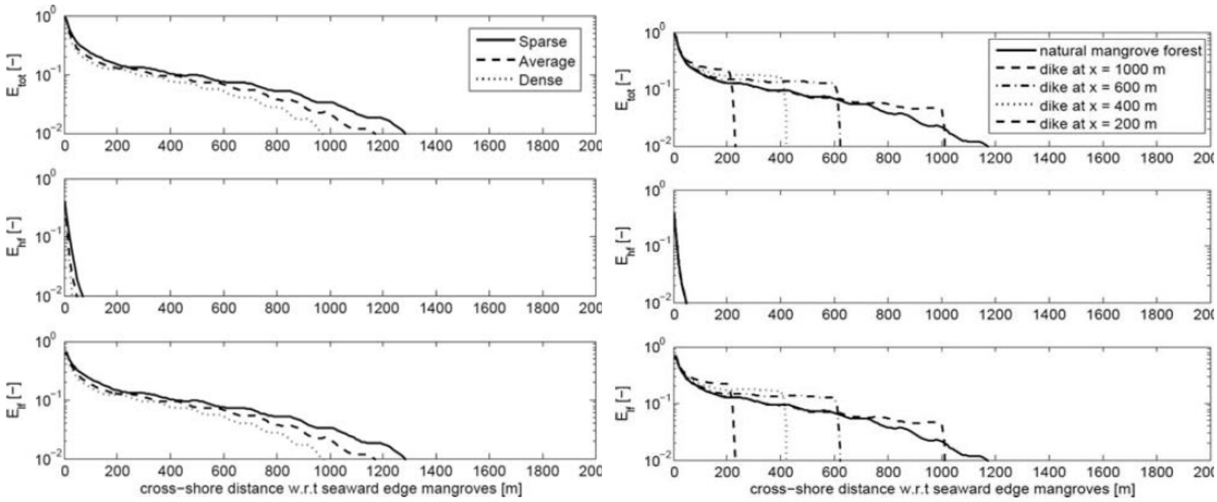


Figure 16: Wave transformation in case of different mangrove densities; Energy absorption Dykes (Phan, 2014)

<u>Storm protection:</u>

With the future prospects of climate change, it is expected that more hurricanes or typhoons will occur around Vietnam. These storms are associated with heavy winds and additional water surface elevation which are currently dampened by the mangroves and thereby protecting the houses and civilians.

Shoreline stabilisation:

With their roots the plants form a sheltered environment against waves and currents and strengthen the soil stability against erosion. During flood sediment-loaded water is distributed into the mangroves by the large waves. Due to the roots a ''low current'' area is created. The sediments are trapped and will settle. During ebb the water contains less sediment and flows back into the sea. A nett transport is onshore directed which causes the land to accrete. According to Nguyen mangrove trees are one of the reasons for the fast development of land in the Mekong Delta (V. L. Nguyen et al., 2000). This shoreline stabilisation can also play a role for the river banks which are also eroding in Ca Mau.

Mangrove threats

SLR (Climate change)

Mangroves are threatened by Climate change because they cannot keep up with the SLR change, and the coast will erode more severe due to higher waves and more frequent storms. There are two adjusting possibilities 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.

In the first case, when the elevation of the mangrove surface is less than the RSLR than the mangroves cannot keep up with climate change, which causes the mangroves to disappear and the coast to erode. This happens for most mangroves in the world and also in Vietnam.

The main contributors for surface elevation or degradation of the mangroves are sediment accumulation and ground water extraction. Sediment accumulation is dependent on the amount of sediment available and the capacity to hold the sediment. When there are less mangroves, the capacity to hold the sediment will decrease and so the erosion will be bigger (positive feedback).

The second option to adapt is the landward retreat of the mangroves so that they can keep their preferred hydro period of tidal flooding's. This is the best scenario but due to placement of sea dykes and erosion measures, there is no place for the mangroves to retreat which stresses the mangroves. This can be resisted with retreating coastal planning measures, where more space is given to the sea and all stresses on the mangroves are reduced.

Human

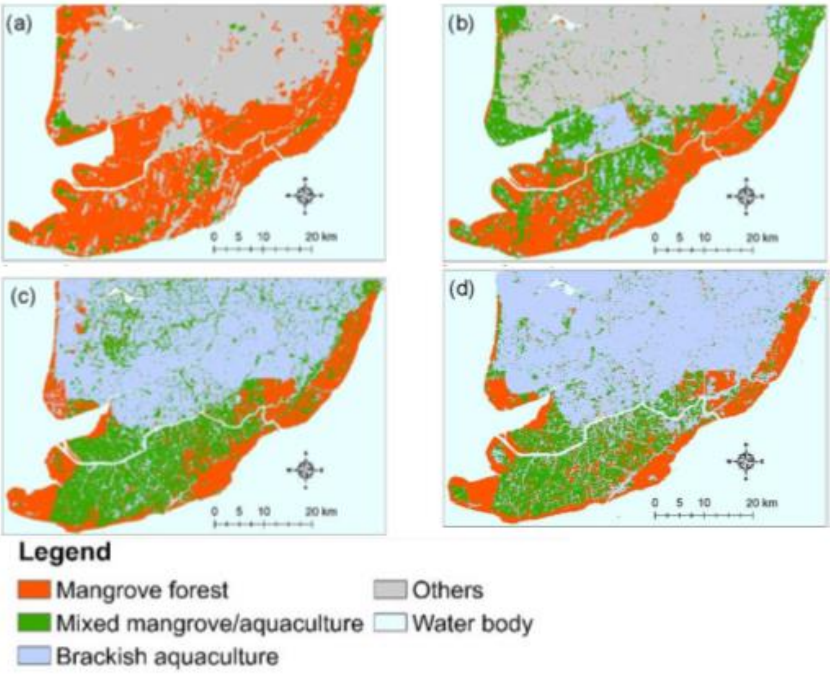
There are multiple theories about the mangrove squeeze and it is still not fully understand which factors contribute the most to the mangrove squeeze. Several reasons for mangrove squeeze are:

- Vietnam war
- Timber farming
- Cultivation new land

The Vietnam war, timber farming and cultivation of new land reduce the total area of the mangroves. (Tuan, 2013). When the mangrove belt decreases in width or density, it is called mangrove squeeze.

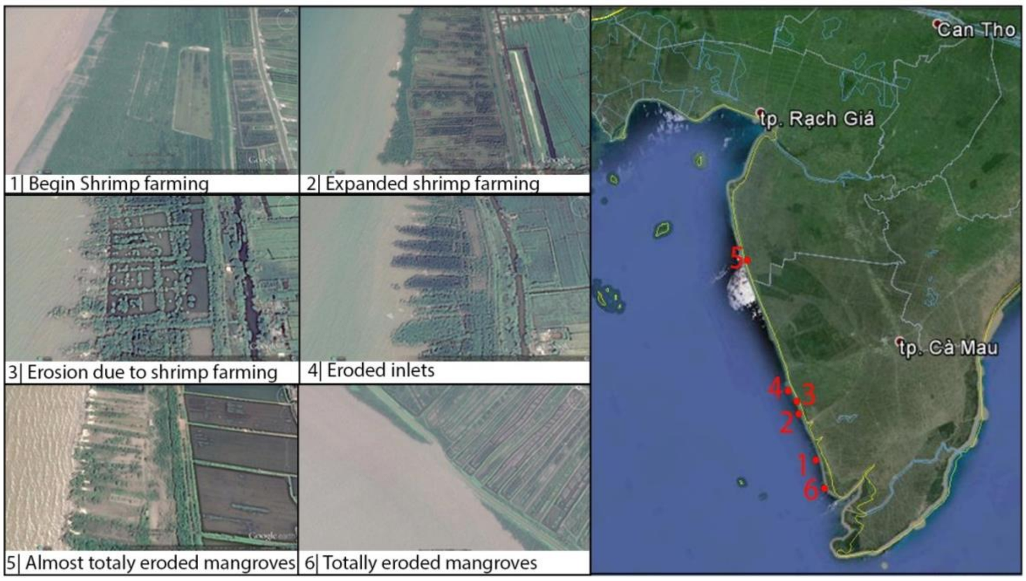
Estimations made by Hong in 1993 were that approximately 40% of the mangroves were lost in the Vietnam war (1962-1971) (Hong, 1993). After the war the mangroves increased again with replanting projects, but due to timber overexploitation in the 80s it dropped again. This timber was used for fuel (Coal) and it created new land to cultivate for aquaculture. The sheltered mangrove forest creates an excellent environment for shrimp production. In the 80s shrimp production became more beneficial than rice production as further explained in the next chapter on Water management. Between mid-90s and 1999 it was prohibited to timber mangrove forest so it could grow again but the aquaculture farms are still there. At the moment it is again forbidden to cut mangroves but it still happens. The mangrove forest in Ca Mau is studied with remote sensing method over the period from 1979 till 2013 and results are shown in Figure 17 in where is visible that the mangroves have degraded severely since 1979.

Figure 17: Distribution of mangrove forests in the study area in a) 1979; b) 1989; c) 2003; d) 2013. (Son et al., 2015)



The mangrove forest between the see and the shrimp farms erode currently and shrimp farms become unusable. The shrimp farms created big gaps in the mangrove forest which cause the forest to erode even more. This process is shown in Figure 18 where in picture 4 the gaps in the mangrove forests are clearly visible.

Figure 18 Erosion process due to shrimp farming.



The mangrove degradation is also due to cultivation of new land for agriculture, sea dykes where built near the mangrove trees. As a consequence of SLR the mangroves are retreating but they don't have enough space because of the sea dykes. Still there are human activities which stress the mangroves.

Conclusion current mangroves

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 19.

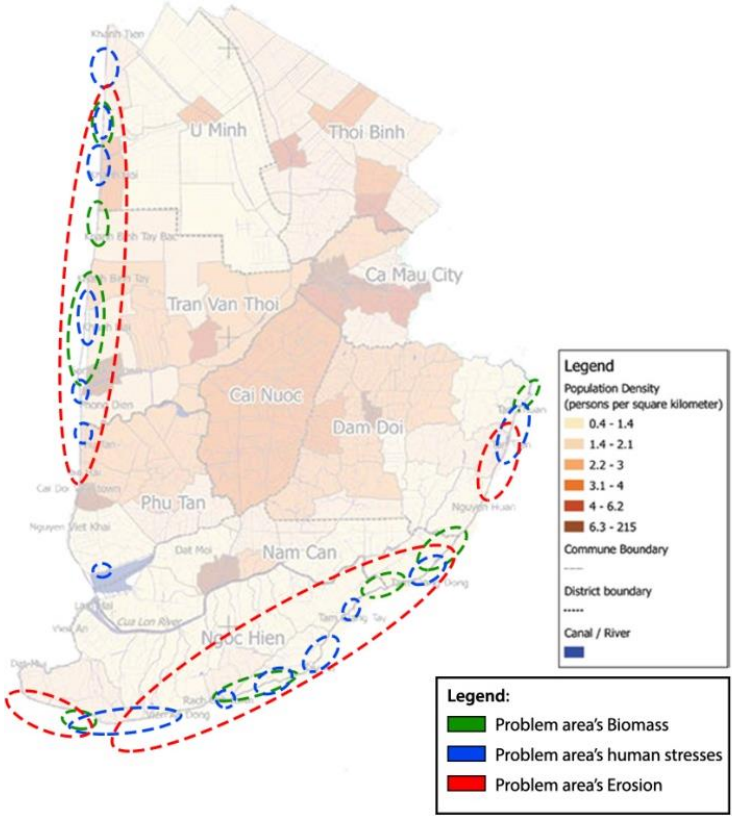


Figure 19: Overview problem area's for biomass, human stresses and erosion.

To stop further erosion mangrove restauration projects and coastal erosion measures are placed. To make the mangrove restauration more effective, knowledge about the ecosystem is essential.

Current coastal protection measures

The coast of Ca Mau is not stable anymore and it is eroding rapidly, therefore a lot of coastal protection measures are already placed to prevent the erosion. But not all the measures work that well. To make an overview of the current measures multiple sources are used:

- Video assessment study(GIZ, n.d.)
- Google earth
- The Water Resources Planning map of the Mekong Delta in the context of Climate Change and SLR from the Southern Institute for Water Resources Planning. (Southern Institute for Water Resources Planning, n.d.)

The combination of these studies and the field visit gave an overview about the currently placed measures and proposals for new measures. The following measures against erosion and mangrove squeeze are taken along the coast of Ca Mau:

- Gabions
- Vertical Breakwater (as it is called by the local authority)
- (dyke)Revetments: placed blocks
- Plastic fences
- Mangrove restoration project
- Plastic fences
- T-bamboo fences
- Temporary dyke protection


Culverts


Revetments: placed blocks


Gabions


Vertical Breakwater


Vertical Breakwater


Vertical Breakwater

Figure 20: Impression coastal measures in Ca Mau

Measures like the revetments, gabions and plastic fences are (mostly) directly placed on the dyke. In several cases the structures are undermined or subside in the soil which is too soft.

Mangrove restoration projects are mostly combined with a wave breaking measure to create a relatively calm water area in front of the coast. If this is not done, mostly the waves are too severe for the applied mangroves in the restoration project and the project miscarries.

Because of erosion threats (See chapter Coastal accretion and erosion), the government (DARD) decided to test with vertical hard breakwaters on critical erosion locations along the west coast of Ca Mau. The constructions along the coast are placed on places where the mangrove forest is thin or where there is an inlet. At the inlet the mangroves are not protected from the side and are erode more easily.. These constructions at the inlet and near thin mangrove forest can be seen in Figure 21.

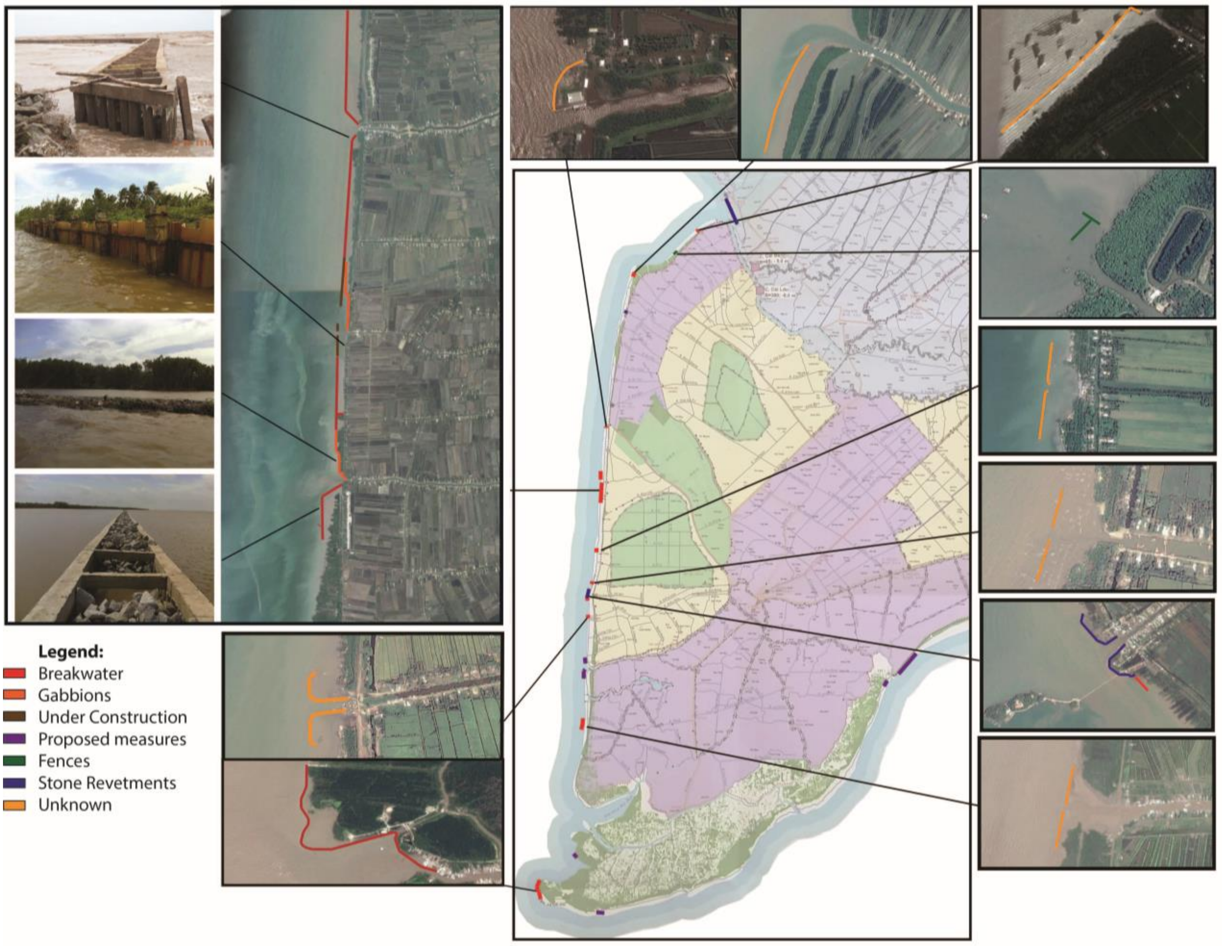


Figure 21: Current coastal measures.

In the past three years the government invested largely in the vertical breakwaters. This structure functions as a wave breaker and captures the sediment which is transported along the coast in the calm area behind the structure. The construction of the breakwater is costly, \$14 Mln/ km. The high costs have several reasons.

- The environment in which the breakwater is built has several challenges which led to high construction costs. First the soil which is the foundation of the structure is mud and silt. It does not have enough bearing capacity to support the structure. The structure had to be founded on a deeper sand layer by using foundation piles. Secondly, the project area is relatively shallow; large equipment cannot be used. The last point which thwarts the construction is the wave action. Especially during the rain season, the storms hinder the construction.

- Besides the construction difficulties, also the materials that are used, concrete and rock, are not materials produced in Ca Mau. Therefor the material costs are much higher compared to the local available materials (for instance wood).

Due to the high cost, only a pilot study was done at one location. The first impressions looked promising, there is a rapid accretion behind the breakwater. But a profound evaluation study has not been carried out. Although, the government decided to implement this costly construction at multiple locations along the coast. Because the breakwater catches the longshore transport it is expected that the breakwater creates a lack of sediment further downstream the coast and therewith erosion. It is advised to carry out a thoroughgoing evaluation on the efficiency, sustainability and cost benefit ratio of this construction


Melaleuca fences


T- bamboo Fences


Temporary dyke protection

Figure 22: Alternatives from other surrounding provinces.

Ca Mau and surrounding provinces like Kien Giang and Soc Trang also invested in less costly bamboo T- fences and Melaleua fences. The applied T-fences don not all work properly due to teething problems. Reasons are that the execution of the project is not according to the design or the structure is not maintained. Although at some locations the fences seem to meet the requirements; accretion can be observed along the coast. The cost of the T-fences are considerably lower than the cost of the vertical breakwater; $ 0.7Mln/ km. Within the project of the Melaleuca fences a first evaluation has been done. The first results are very promising. The costs per protected meter coast are even lower, $ 10.000-17.000/ km (Giz, 2012).These measures only work well if the sediment is also course enough. For the East coast this doesn't seem to be a problem. For the West coast of Ca Mau, additional research is required because the sediments are finer along this coast, compared the sediment in the project location.

At the moment not the whole coast of Ca Mau is protected by a dyke system behind the mangrove belt. In the south of Ca Mau there are no sea dykes and the land is only protected by mangroves. In the current proposals there are idea's to place a dyke as well. All information of dyke location, dimensions and structures in the dykes is reported by the Southern Institute of Water Resources and Planning (SIWRP) (Southern institute for Water ResourcesPlanning et al., 2013). The current dykes, and the new proposed sea dykes can be seen in Figure 23.

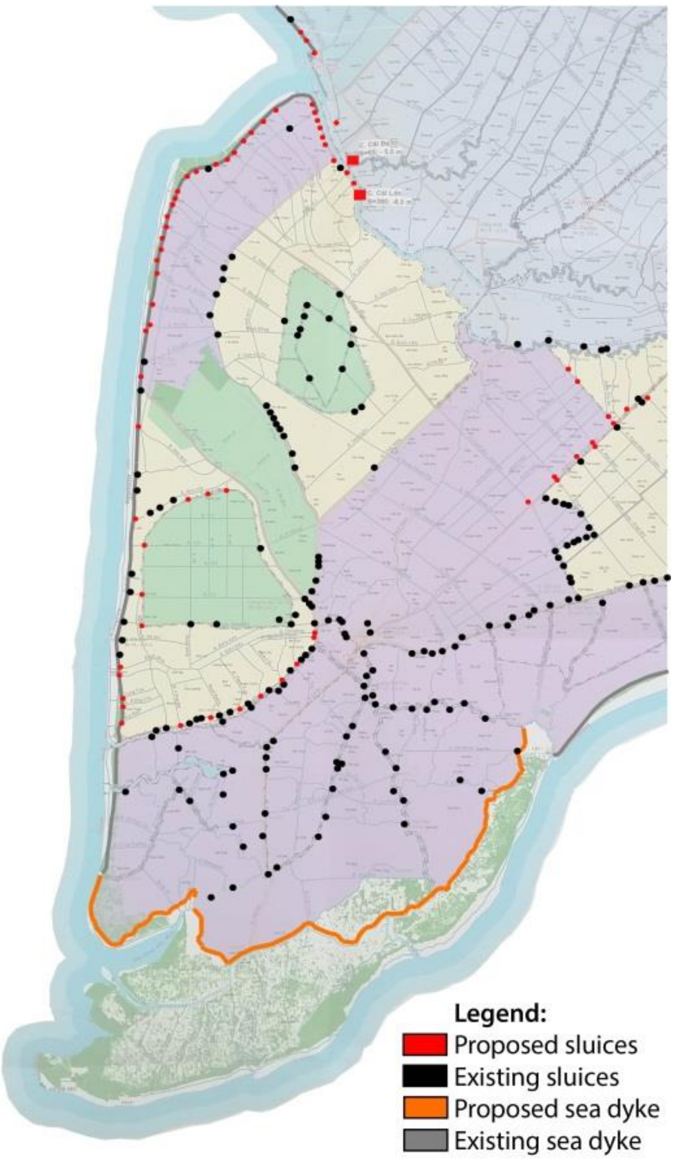


Figure 23: Proposed and existing Sea dykes and sluices/culverts.

Currently there are 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.

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.

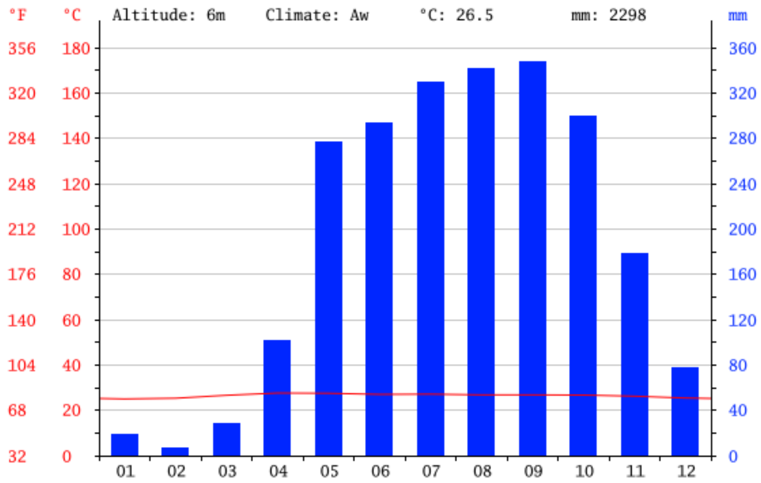
Current system - Water management

Freshwater availability

The main source for fresh water in Ca Mau is rainfall. The distribution of rainfall in the Vietnamese Mekong Delta increases in southern direction (Deltares & Delta Alliance, 2011). Ca Mau, being the southernmost province, receives more rainfall than other provinces in the Mekong Delta, 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. In the province of Ca Mau there are currently no fresh water reservoirs, but there are plans for future works. In the period of 2015-2020 a fresh water reservoir in the national park U Minh Ha will be constructed for domestic and rural water uses of the farmers in the area (VietnamNet, 2015).

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.

Figure 24: Average rainfall from climate-data.org/location/4244



The Mekong river, carrying fresh water from upstream, does not naturally reach the province of Ca Mau. Therefore the province is dependent on other freshwater sources (rainwater, groundwater). There are, however, hydraulic engineering works that connect Mekong river with parts of the province. The Quan Lo – Phung Hiep (manmade) canal leads from the Hau river, one of the nine branches of the Mekong, to the province of Ca Mau. This canal is operated with culverts, and currently supplies only poor quality water to the Quan Lo – Phung Hiep region, because this region is at the end of the fresh water source (IMP, n.d.) [p.26]. In the future perspective, the planning for the Quan Lo –Phung Hiep canal is to supply fresh water for North Ca Mau, using synchronous operation of culverts (IMP, n.d.) [p.144].

Groundwater resources are used by means of local wells, with the first wells in Ca Mau and Bac Lieu having been installed in the 1930's by the French (Kuenzer & Renaud, 2012). Nowadays, 178,000 deep (>150 m depth) wells are installed, which are used for domestic water supply, irrigation, aquaculture and industrial purposes. Extensive groundwater pumping can lead to land subsidence. 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. In this study, excessive subsidence rates measured with remote sensing are spatially correlated with aquifer drawdown measurements. The highest rates of subsidence were found along a SW-NE axis as can be seen Figure 25, where Ca Mau City (and HCMC) can be identified as major pumping areas. The pumping induced subsidence rate exceeds the sea level rise by an order of magnitude (Erban et al., 2014). This implies that relative sea level rise will be higher than absolute sea level rise for the Ca Mau province, thus highlighting the importance of groundwater extraction to relative sea level rise. Together with a low topography of the area, this will result in a high vulnerability to flooding (see Chapter Drivers of change).

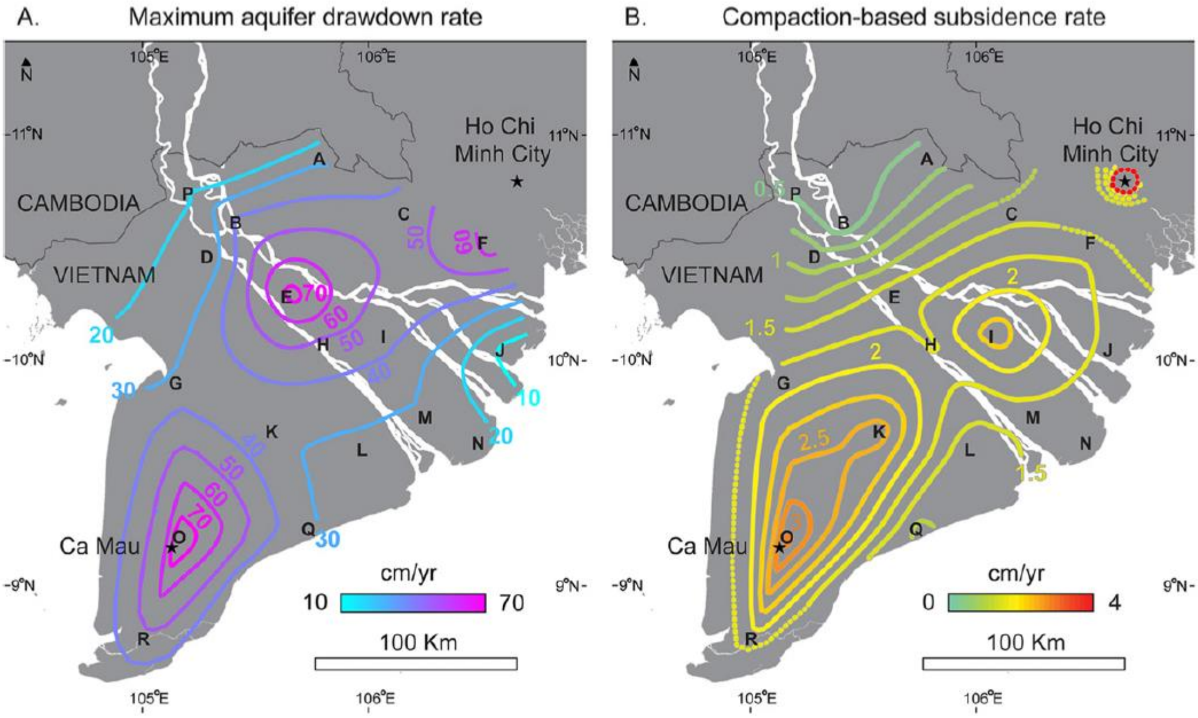


Figure 25: Subsidence rates (right) calculated from aquifer drawdown rate (left) (Erban et al., 2014)

Due to the lack of fresh water, the saline seawater is dominant in the province during dry season, and for the sub regions of South Ca Mau and the Nam Can – Ngoc Hien coastal area this is also the case in the wet season (see chapter Current System - Hydraulic Analysis). 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 have the following influence on the inland water:

- Penetration of the tide into the canal system influences the water levels and the salinity of the water in the canal. During low tide, and thus low water levels in the canals, the agriculture and aquaculture fields have the possibility to drain water to the canals. The next high tide will refresh the (saline) water in the canals. During dry season the tidal intrusion can penetrate further into the canal system, leading to brackish and saline water in large parts of the inland water system.

As discussed in previous chapter, the tidal range of the West sea is small and has a diurnal character. The small difference between low and high tide, and the frequency of ones per day causes drainage problems at the West part of the province. The tidal range at the East coast is bigger and semi-diurnal, and therefore the drainage from the fields to the canals is better at the Eastern part of the province.

The differences in tide together with the large amount of canals with varying dimensions and thus different effects on dampening the inward flow of saline water, make the saline water intrusion complex in terms of flood duration and salinity variations (White & White, 2002).

- 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 26, the land cover in Ca Mau is largely defined by these characteristics. Along the south and east coast, mangrove forest is located (dark green), in the Ngoc Hien and Dam Doi districts. More land inward, to the North, the land is used for aquaculture (purple). In the somewhat higher elevated area, in the Tranh Thoi district, fresh water is available for rice fields (yellow) and freshwater aquaculture and some Melaleuca forests are also located there (light green). These land and water uses will be further discussed below.

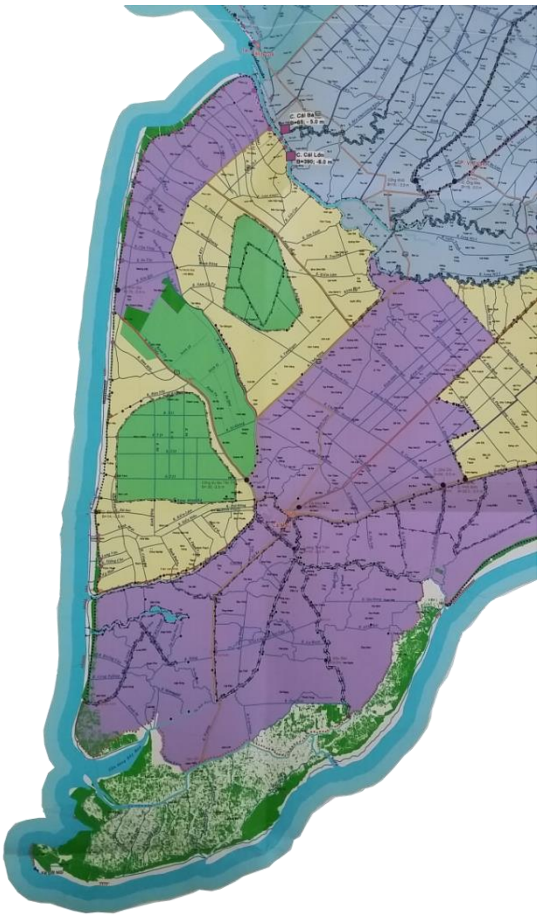


Figure 26: Land use map for Mekong Delta (Quyen & Brunner, 2009)
Purple = Aquaculture
Yellow = Rice cultivation
Green = Forest
Dark green = mangrove forest

Rice agriculture

Land where rice is cultivated with 2 crops a year is mainly located in North Ca Mau, including some parts of the Quan Lo Phung Hiep area. In total, there is approx. 51 000 ha of cultivated area with rice throughout the whole year. 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 tons and operate the culverts in the canals to store the fresh water. Groundwater resources are also used to cover freshwater needs.

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. In this type of agricultural alternation, there is still a need for fresh water to balance salinity levels and create good quality water for the shrimps in the dry season. 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. Furthermore, shrimp farming eventually leads to poor water quality, and this polluted water has to be discharged. The shrimp-rice fields are mainly located in North Ca Mau, including the Quan Lo Phung Hiep area (50% of the WL-PH area), and South Ca Mau, accounting for +/- 42 000 ha. In the Dam Doi district and Ngoc Hien district rice is no longer been produced after 2005. Together these rice and shrimp-rice fields cover approximately 130,143 ha, 24,4% of the land.

Aquaculture

Aquaculture in the province of Ca Mau can be divided into:

- Fresh water aquaculture

  Mainly found in North Ca Mau, surrounding the U Minh Ha forest in district of U Minh and Tran Van Thoi. In 2006 this covered an area of 40 530 ha, but this area has been changing in 2001-2011 due to more saline water from sea level rise and higher income from shrimp farming, thus a conversion to shrimp aquaculture took place. The total area of salinized fresh water aquaculture is around 28 281 ha, reducing the freshwater aquaculture after 2011 to +/- 10 000 ha (IMP, n.d.).

- Shrimp aquaculture

  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. During high tide water can be let into the shrimp fields, which will contain larvae. The shrimps also feed on the natural waters, no supplementary feed is given. The extensive farming gains low stocking densities, ranging from 3000-5000 shrimps per hectare (Kungvankij et al., 1986). The extensive shrimp farming can be combined with other aquaculture as crab, fish, clams and oyster, this is called polyculture. In total the extensive shrimp aquaculture covers +/- 163 148 ha.

  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 this will improve the stocking rates. The cultivation varies from 20,000-50,000 shrimps/hectare.

- Forest - shrimp aquaculture

In the coastal area Nam Can – Ngoc Hien, namely mangrove forests can be found. Half of these mangrove forests also give place for extensive shrimp farming together with polyculture, the forest – shrimp aquaculture covers about 60 676 ha. These shrimp farms have significant influence on the state of the mangroves (chapter Mangroves).

In total the aquaculture covers about 296,180 ha, which is 55,55% of the land in 2011.

Forest land cover

The forests in Ca Mau can be divided into two types:

- Coastal mangrove forests

  These forests mainly can be found in the Ngoc Hien –Nam Can districts, and a small strip of forests (1 000 ha) can be found in the Tran van Thoi and U Minh districts. These mangrove forests form a first, natural line of coastal protection and have an important function in the biodiversity of the local ecosystem (see chapter Mangroves). In these areas shrimp farming also takes place, which could lead to degradation of the forest. 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. In total the mangrove forests cover an area of approx.. 125,896 ha, included forest where shrimp and forest are combined.

- Melaleuca Cajaputi forest

  This forest is located in the U Minh and Tran Van Thoi district, and includes the U Minh Ha National Park (also recognized as World Biosphere Reserves). The Melaleuca Cajaputi have an important role in ecological balance of the coastal area and ecosystem. The forest area covers about 36 100 ha, which include production forest and protected forest.

In total the forested area covers about 162,000 ha, 30,3% of the land.

Domestic water uses and land cover

The population of Ca Mau in 2011 was 1 216 175 people. The urban area comprises one city (Ca Mau city) and 9 towns, with a total area of 29 382 ha.

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. Secondly, the domestic areas, especially those at river fringes cause heavy pollution to the environment.

Water transport

The waterways in Ca Mau and the whole Mekong Delta are offering a possibility for transportation since they are so widespread. Waterway transportation in Ca Mau accounts for 80%, and road transportation for 20%, as the construction of a road traffic system is more difficult due to the interlacing system of canals and ditches and poor soil conditions. Figure 27 shows the main waterways in the province of Ca Mau. 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. This causes damage to residential areas, gardens and rice fields adjacent to the canals. The Center (Ca Mau City) together with the provinces and districts are responsible for the management and maintenance of the waterways. The waterways generally have good conditions for the navigation. Droughts and tidal variability does 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. It is an old port, specialized in fishery exportation.

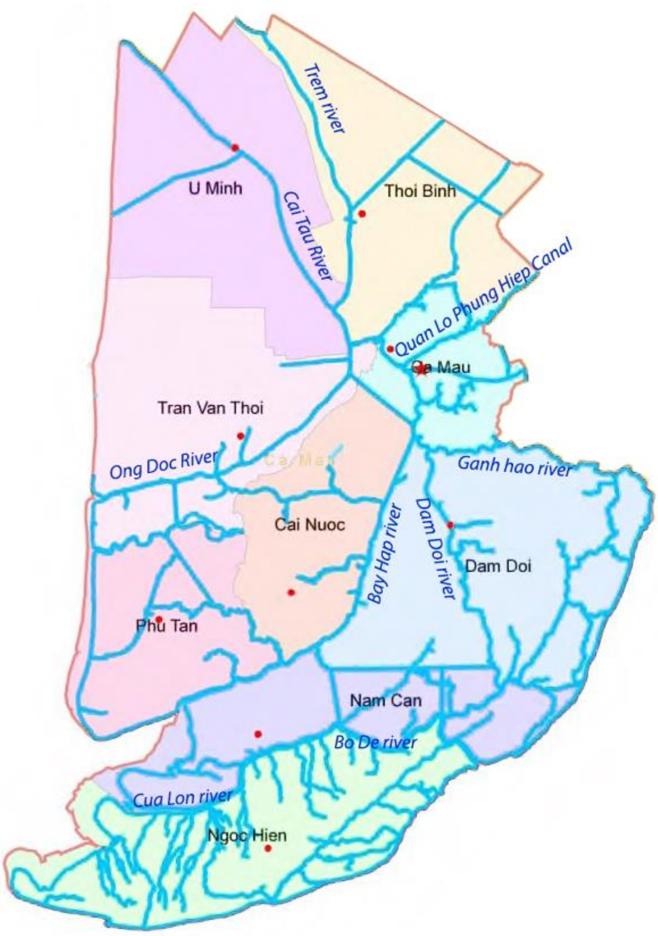


Figure 27: Main waterways in the province of Ca Mau (IMHEN, 2011)

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, which can be expected from this area. This sector is followed up by the industry of electricity, gas, water production and distribution. These industries, like domestic water use, may have a negative impact on water quality. There are two gas-power-fertilizer complexes which are located in the Khanh An commune (U-Minh district) and one in at 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. In the port of Nam Can, as stated above (waterways) is a coastal economic zone and a key transit center for aquaculture products in the southern part of Ca Mau province (IMHEN, 2011). Other small processing industries are expected to be spread out along the infrastructure, concentrated near cities.

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 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. The data used for this sections is taken from the Irrigation Masterplan for Ca Mau province (IMP, n.d.).

North Ca Mau

As can be seen from Figure 28 North Ca Mau exists out of five different sub regions, with each one being unique in their water requirements, however still similar on a larger scale. Each sub region aims for a closed loop canal system to prevent saltwater intrusion by the construction of several permanent and temporal culverts. Most of the culvert systems in this area are incomplete and damaged leading to a shortage of fresh water for rice production. As a result there is a tendency to shift from rice to rice-shrimp farming in this area. Sub region III is the only region with a successful closed loop canal system leading to a high rice production with two harvest seasons per year.

The canal system mostly consists out of shallow and narrow canals, with depths and widths ranging from one to two meters. Together with a relative small tidal influence these limited dimensions constrain the drainage capacity, leading to increased flood risk during the wet season. Furthermore fresh water supply and storage are also inadequate to provide the farmers in their needs for fresh water due to the limited design of the canal system. The canals are overall not well maintained and there is high variability in dimensions, conveyance and erosion patterns.

Every sub region contains a number of dikes and embankments to protect the geographically low positioned area against extreme events. However, due to poor maintenance and erosion most dikes and embankments are downgraded and unable to protect against sea level rise and inundation. This leaves the area vulnerable to flooding, leading to a severe potential for damage to agriculture and aquaculture.

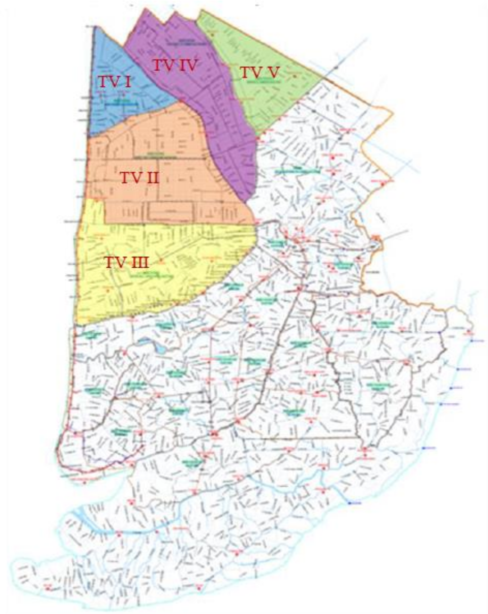


Figure 28: Sub regions of North Ca Mau (IMP, n.d.)

Quan Lo-Phung Hiep

This district contains Ca Mau city which is the administrative center of the whole Ca Mau province, for this reason the area has high attention for water management. Within Quan Lo-Phung Hiep there are several areas where rice cultivation prevails but rice-shrimp and extensive shrimp aquaculture are also popular in the area. Due to this diverse land use the water regulation is highly complex which leads to difficulties. In the past there have been major investments to build a number of culverts, but some of them have already been abandoned, leading to saltwater intrusion.

The canal system is well maintained and dredged, but still local flooding occurs because the canal system is not finalized yet. Furthermore the main roads in the area function as embankments due to the lack of dikes. Unfortunately the roads are not high enough and flooding occurs during every wet season for longer periods, resulting in damage to the flooded area.

Figure 29: Quan Lo-Phung Hiep (IMP, n.d.)

South Ca Mau

The South of Ca Mau is divided into 18 sub regions (Figure 30) . Generally the South of Ca Mau suffers more extensively from saltwater intrusion than the North. This is partly due to the geographic location and partly due to the lower funds available for this region. Since 2000 a strong trend of land use change perceptible in this part of Ca Mau (see chapter drivers of change). Farmers are massively changing from rice agriculture to either rice-shrimp or extensive shrimp farming. This trend renders the current irrigation and canal system to an inadequate state, because it was originally designed for freshwater agriculture and not brackish aquaculture. Generally canals are too small to provide the water supply and drainage needs for the area. Heavy bank erosion, up to 0.5 meter per year, and bottom deposition aggravate this situation even more.

None of the sub regions contain a closed loop canal system and most culverts are damaged either by physical causes like erosion or by human actions. This leaves the water system out of control and results in a predominantly passive water regulation. As a reaction to this, people try to take measures themselves by construction temporal culverts and other rainwater harvesting structures. These structures only benefit on the short term and most of them have a negative impact on the water system.

Furthermore the small tortuous canals in the region increase residence times and hence the effect of pollution in the water. Urban and industrial wastewater from Ca Mau City combined with the poor drainage from the aquaculture fields cause a reduction of production and enlarge the negative impact to human health.

Similarly to the North of Ca Mau, the South has severe problems with the dikes and the embankments in the area. Most dikes and embankments are too low and suffer from erosion. At some locations the dikes overtop at spring tide and cause severe damage to the fields behind it. The only embankments that are still adequate are the ones combined with roads, all other dikes and embankments are not prepared for any form of sea level rise or climate change.

Figure 30: Sub regions of South Ca Mau (IMP, n.d.)

Nam Can – Ngoc Hien Coastal Area

In this coastal area shrimp-forestry is the dominant land use (see Figure 31). The water supply and drainage are provided by 193 rivers and canals forming the irrigation network in Nam Can. On average the canals are quite deep and wide with high discharges, thus creating enough water circulation. Some canals show heavy deposition. As a result the marine transport, which is the main transportation means due to a lack of roads in the area, is hindered.

Because the area is surrounded by coast on three sides it is vulnerable to flooding. The area is protected by embankments, most of them are still in good shape but several sections are insufficient and cause flooding to occur during spring tides. Reinforcing these parts is difficult because the embankments interfere with the local transport means.

Figure 31: Nam Can – Ngoc Hien Coastal Area (IMP, n.d.)

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.

Groundwater

From the many groundwater wells in Ca Mau, about 40,000 wells are abandoned or out of order. These deep wells connect several, previously confined, aquifers. Once abandoned the wells degrade and cause saline and polluted water to infiltrate from the upper groundwater layer into deeper ones. As a result valuable fresh fossil groundwater is contaminated.

Domestic and industrial activity

In the province of Ca Mau, the number of settlements with high household densities are very low. Instead, households prefer to settle along the sides of rivers, canals and roads even in Ca Mau city, creating urban corridors along transportation routes. This makes it difficult to connect a large number of households to any kind of network like a power grid or a sewer system. As a result, 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)(1).

$$FeS_2 + \frac{15}{4}O_2 + \frac{7}{2}H_2O \rightarrow Fe(OH)_3 + 2SO_4^{2-} + 4H^+ \quad (1)$$

The produced acids interact with the clay particles in the soil and form toxic metals. An example is the acid hydrolyses of illite (common clay mineral)(2).

$$(K_{0.5}Na_{0.36}Ca_{0.05})(Al_{1.5}Fe^{3+}_{0.25}Mg_{0.3})(Al_{0.45}Si_{3.46})0_{10}(OH)_2 + 7.41H^+ + 2.59H_2O \rightarrow$$
$$0.5K^+ + 0.36Na^+ + 0.05Ca^{2+} + 0.3Mg^{2+} + 0.25Fe(OH)_3 + 1.95Al^{3+} + 3.46H_4SiO_4 \quad (2)$$

These toxic metals and sulfuric acids accumulate in the soil and flush out to the surface water during floods (Sammut, White, & Melville, 1996), thus causing a temporal decrease in water quality during the beginning of the wet season. Contaminated drainage water can cause decreased agricultural production, fish and shrimp diseases and mortality, corrosion of culverts and other iron or concrete structures (White & White, 2002). The extent of the acid soils can be seen in Figure 32.

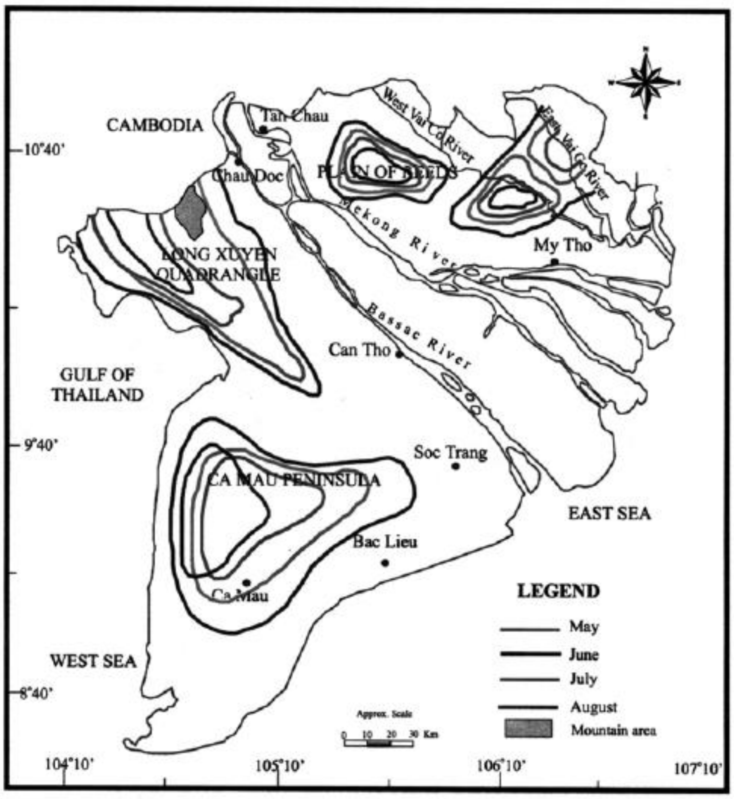


Figure 32: Extent of surface water acidification (pH<5) in the Mekong Delta in the early wet season (Ghassemi & Brennan, 2000)

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). This phenomenon is called hyper salinity, it occurs if the evaporation of a catchment is higher than the rainfall, and the salt sea water is drawn into the catchment (type 4, Figure 34). The increased salinity of the surface water influences the salinity of the soil as well. Tho, Vromant, Hung, & Hens, 2008 found that the fresh water from the wet season is not enough to flush out all the salts from the soil deposited there in the previous dry season. As a result the salts accumulate in the soil forming a threat for rice production. Generally the critical soil water salinity for producing most crops is 6 dS m^{-1} (Kijne, 1996). Rice however is able to produce yields up to 50% of non-saline yields if the soil water salinity does not exceed 10 dS m^{-1} before flowering of the crop (Phong et al., 2002). From Figure 32 it can be seen that rice production is problematic in most of the Ca Mau province during the dry season.

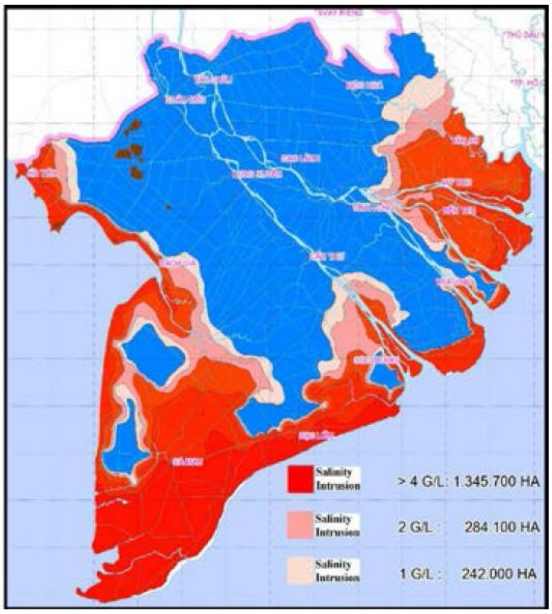


Figure 33: Salt intrusion front in the dry season (Mekong Delta Plan Committee, 2012)

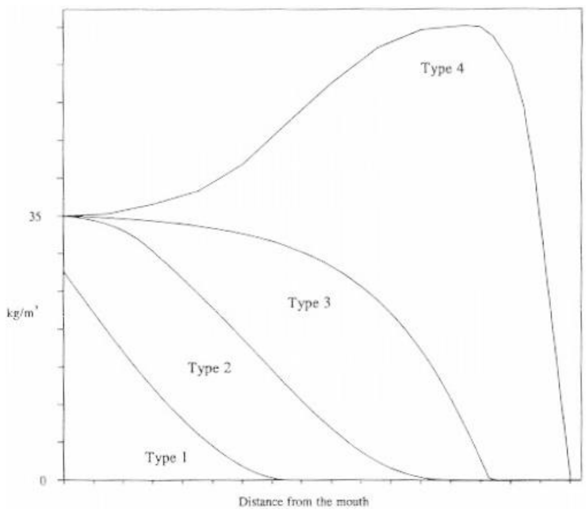


Figure 34: Four types of salt intrusion (Savenije & Pagès, 1992)

Moreover, high levels of suspended solids are measured in the canals and ponds of Ca Mau (Tho et al., 2006). A reason for this could be that shrimp monoculture and salinization have a negative effect on soil-protecting vegetation, thus leading to an increase in erosion. High turbidity levels of 200 g/l can lead to higher fish and shrimp mortality (Delincé, 1992).

Furthermore the construction of new ponds lead to iron(Fe) and alum (Al) deposition in the soil of the pond embankments (Tuong et al., 2003). At the beginning of the rainy season these metals are flushed out of the embankments, decreasing the pH of the effluent water. The polluted effluent can cause damage to neighboring aquaculture ponds because of the overlapping of drainage and intake water in the area (IMP, n.d.).

Another aspect of pollution from aquaculture is biological pollution and changing ecosystems due to eutrophication and high salinity (Páez-Osuna, 2001). It is not uncommon for exotic species to escape from the aquaculture ponds and disrupt the natural ecosystem. Furthermore, eutrophication, light reduction and oxygen depletion change the living environment of the local species drastically.

Poor water quality, discussed above, combined with inappropriate management can cause self-pollution of the aquaculture ponds. Since the irrigation system in Ca Mau is designed for rice instead of aquaculture the canals are unable to provide sufficient water supply and drainage. This leads to a lack of separated inlet and outlet systems, thus enhancing the self-pollution even more (de Graaf & Xuan, 1998). At some point the polluted sediments on the bottom of the pond will have a significant effect on the production and the ponds will be abandoned. For extensive aquaculture the lifetime of a pond is estimated at 7 to 15 years. (Flaherty & Karnjanakesorn, 1995). Once abandoned the rehabilitation of a pond is a difficult and time consuming process. This means that the aquaculture model that was used up to the present (extensive aquaculture) leads to rapid land 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 governmental organization tree of water related issues in Vietnam is quite extensive, roughly it can be divided into a national and a sub-national level. The National level contains the National Assembly and the Prime minister's Office which supervise the ministries and People Committees. The sub-national level includes the departments, provincial Peoples Council and the district offices (Figure 35). Concerning water related issues the Ministry of Agriculture and Rural Development (MARD) and the Ministry of Natural Resources and Environment (MONRE) are the key ministries (Waibel, 2010a). 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 managements issues via the commune Peoples Committee and Council (Figure 36).

Figure 35: annex: organization of Vietnamese political system based on the revised 1992 constitution (Waibel, 2010a)

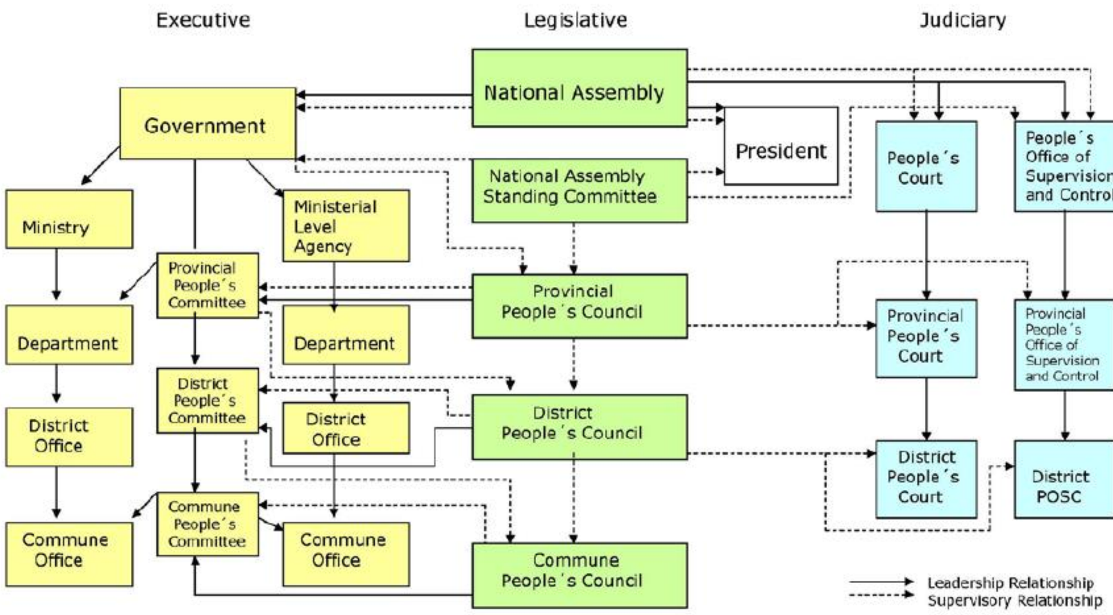
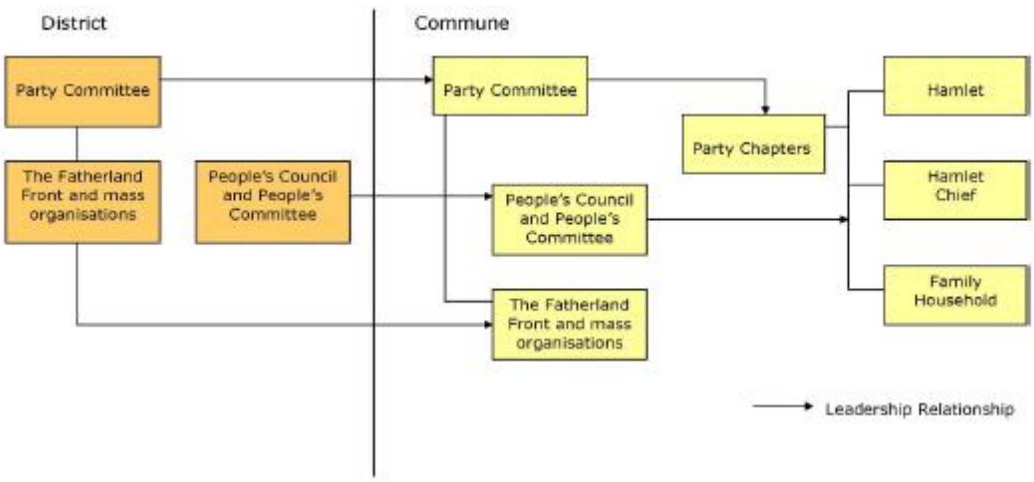


Figure 36: annex: Political System at the District and Commune level (Waibel, 2010a)



MARD is the ministry with the main responsibility for water resource management. In 2002 it was decided to establish a new ministry namely MONRE because there was a need to separate the water resource management function from the responsibility of public service delivery (Waibel, 2010a) . Several tasks from other ministries were included into the portfolio of MONRE and especially MARD had a lot of tasks transferred to MONRE. There were some delays in the transfer of tasks leading to several gaps and uncertainties in responsibility. In 2006 both ministries came up with conflicting long term strategies, this caused the prime minister to interfere and call a meeting between MARD and MONRE to redefine their roles (Molle & Chu, 2009). The result from the meeting can be seen in Figure 37 that lists the mandates of the different ministries concerning water resource management.

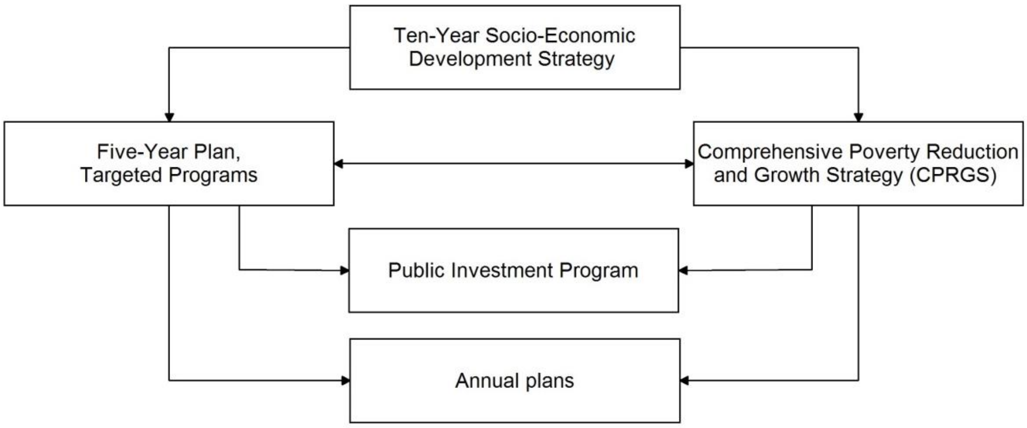


Figure 37: Key planning documents adapted from: (Waibel, 2010a)

Within the governmental institutions it is interesting to make a distinction 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 (Figure 37). The different ministries are responsible for creating the master plans on a national level. Formally these master plans are aligned to form one integrated whole 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 planes. Any contradicting or unrealistic plans are simply ignored till the next master plans come ("Interview Martijn van de Groep," n.d.) 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 sub-divisions within them (Waibel, 2010a).

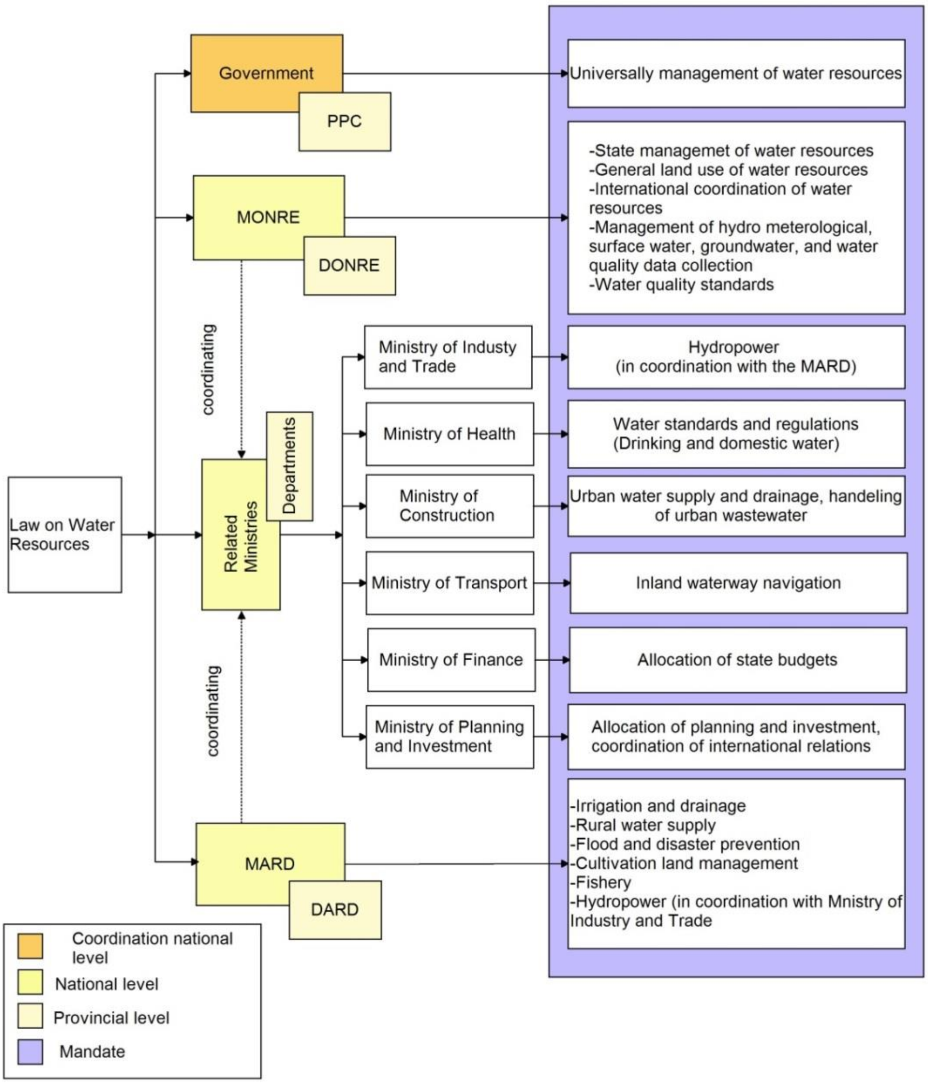


Figure 38: Delivery of state responsibilities for water resource water management, adapted from: (T. P. L. Nguyen, 2010).

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). The management of the monitoring system involves a number of ministries and agencies. For example management of the hydrological monitoring stations, which monitor the water resources, is the responsibility of the hydro-meteorological Services (which is part of the MONRE). But the regional hydro-meteorological centres are responsible for processing the data. (Wepa, 2015)

Water policies Ca Mau

This chapter gives a general overview of the political structure and legislations about water management and coastal management for the province of Ca Mau. It forms a base to define the involved stakeholders within the decision making process.

Master plans

General Master Planning is treated in a fragmented way – with each Ministry creating its own Master Plan related to its subject and extent. When integrated subjects, such as water systems, are considered, these Master Plans often show conflicts or contradict each other.

Firstly there are contradictions between the different elements. Especially the desired planning on economic growth and the decisions made to reach this are contradictory to decisions which protect against flooding's or the lack of freshwater.

Secondly cross-provincial integration still remains at a largely undeveloped stage. While Vietnam has created several national strategies for climate change and social economic development for the period of 2011 to 2020 (Dung, 2015), there are no overall integrated water strategy and action plans at the national or regional basin level (Wepa, 2014). Some sub regions however, have formed individual action plans and strategies. This can cause conflicting situations like the planes to construct an embankment between the province of An Giang and Kien Giang. For An Giang the embankment will reduce the salt water intrusion but for Kien Giang it will prevent fresh water from the Mekong river to enter the province ("Interview Stefan Groenewold," n.d.). This example indicates that and overall integrated water strategy would improve the management on water related issues on provincial and national level.

Policy of land use

In the past there has been a great diversity in land use within the Ca Mau province. Policies from the government concerning land tenure and several other regulations were an important driver in this process. Land use decisions are made at provincial level under the national framework, which is also influenced from local politics as well. Initially the whole of the Mekong Delta was seen as the rice bowl of Vietnam, and rice production was encouraged based on the food security policy of Vietnam (MDP, 2012). In 1986 the government introduced an economic renovation policy that enabled farmers to develop their land and diversify their product, subject to local regulations (Van et al., 2015). This generally led to an increase in aquaculture. Later in 2000 the coastal provincial aquaculture plan encouraged the expansion and intensification of shrimp aquaculture even more (Nhuong et al., 2002). As a result coastal areas which create a buffer zone in case of flooding are occupied for aquaculture. The trends in Master Planning show that, while rice production remains a crucial aspect in agricultural and land use policy, aquaculture is increasingly promoted, especially in areas that face severe salinity intrusion problems (Van et al., 2015).

Water management

For the long term planning concerning inland water management in the Ca Mau province the Vietnamese Government have introduced the Irrigation master plan (IMP, n.d.). This document describes several goals the Government wants to achieve before 2020 and it also offers several means to achieve these goals. The long term goals of the Irrigation Master Plan can be summarized as:

General objective:
Water resource solutions must address the tasks of agricultural development, rural development, domestic water supply, industrial water supply and tourism services. Develop an appropriate irrigation system to meet new requirements of production, adapt to global climate change and contribute to socioeconomic development of the province.

Specific objectives:

- Address saltwater prevention, freshwater retention
- Provide clean saltwater, drainage for shrimp farming
- Develop irrigation system
- Develop solutions for forest fire prevention
- Prevent, limit the damage caused by natural disasters and maintain shoreline stabilization, riverside areas and lagoons.
- Reduce water pollution, prevent depletions of water resources in the river and lagoons; protect environment, ecology and biodiversity.[(IMP, n.d.)*P. 138]*

Coastal management

In contrast with the inland water management, there is currently not a long term plan for the coastal zone management of Ca Mau. After the Vietnam war a sea dyke system is constructed as sea defense along a large part of the coast of Vietnam. The main functions were and still are:

- Prevention against flooding
- Prevention against salt water intrusion.

The national government is owner of the sea defense and the provincial government, DARD is involved in construction and maintenance. These different levels of governance involve different interests and approaches (Southern institute for Water ResourcesPlanning et al., 2013). As can be seen from earlier research (Scheres, 2014) and pictures, the maintenance on sea defense structures is relatively poor. Sea dikes lack standardization in geometry and physical properties and, at times, are subsiding, slip away or partly collapse. In 2014 a large part of the sea dyke along the West coast collapsed. The problem is further exacerbated by severe structural erosion along the coast of the province.

The mangrove forest is a natural defense system for the coast of Ca Mau. The mangroves are able to prevent flooding as well as erosion as seen in the chapter Mangroves. Therefore the various kinds of legislations of the past forty years influence the coastal zone as well as the inland region. Some of the legislations had a positive influence while others were negative.

Before 1980 mainly the national government defined the legislation and also executed it. Since 1980 it is divided over departments and local (provincial) governments. Besides a system was invented, Green book, in which people could rent mangrove land, contract based, from Stated owned ‘’Forest Companies’’. This led to more agriculture and aquaculture and a reduction of the mangroves. As seen before, the growing aquaculture and creation of fishponds where mangroves grow influence the penetration of waves and erosion rates. Since 1990 the government comprehended that a degradation of the mangroves forest may lead to severe threats and problems at a large scale. New laws and legislations conceptualised to protect the forest. One of the changes was the introduction of the ‘’Red book’’ in 2002. Farmers have a contract with the government instead of the forest companies and are land owner. Depending on the size of their land, farmers should maintain 50 – 70% of the mangrove forest. Although the regulations are more strict, farmers benefit more from it than in the old contracts. The DARD has made safety zones where mangrove must grow to protect against inundations. The ''full protection zone'' which is reserved for coastal protection purposes stretches from the coast till 1.000m landwards. No agri- or aqua culture is allowed in this area. From 1.000m- 4.000m the buffer zone is made, where it is only allowed to have around 60% forestry and 40% shrimp farming. See Figure 39 where both the zones are shown on the map. Behind this zone the ecological zone is situated and the red book regulation holds.

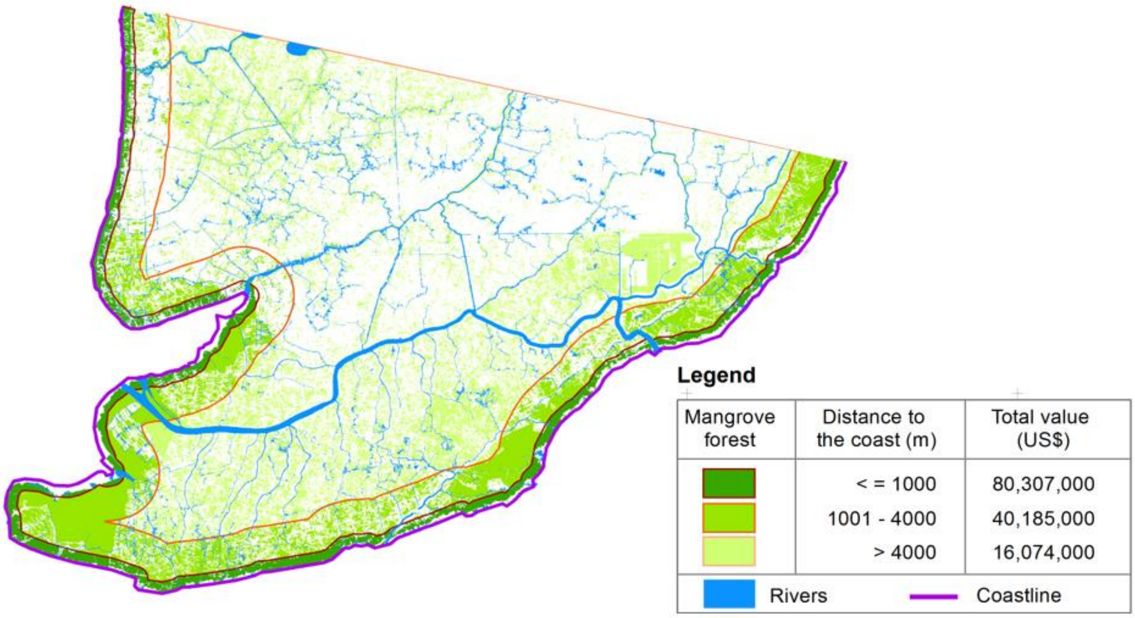


Figure 39: Different protection zones Ca Mau province (Tuan, 2013)

The Vietnamese government is aware of the effects of climate change and the human influence on the coastal system in the province of Ca Mau. Mainly due to typhoon Linda in 1997 it became clear that the policy had to be changed. In cooperation with international donor organizations and the Development Bank the government of Vietnam aims to improve the coastal zone. In cooperation with GIZ the government started the Integrated Coastal and Mangrove Protection and The Climate Change and Coastal Ecosystems Program (ICMP/ CCCEP). The objectives are an efficient management and protection of the coastal zone to the drivers of change and to develop a cost-effective protection. The program supports the provincial government in the management, research and development of the coastal area.(Climate, Adaptation, Management, Cta, & Hodick, 2013)

International policy

At international level there are also features that affect the inland water management and coastal status. The catchment area of the Mekong river is spread out over six countries as depicted in Figure 40.

Figure 40 River basin Mekong. Adapted from Asia Biomass Office

Vietnam is the last country in the chain the Mekong river passes, which can have positive and negative influences. The policy on the Mekong river in the upstream countries may influence the water quality and quantity of the Mekong in Vietnam. Examples are:

- Construction of hydraulic structures (hydropower stations, dams) that cause changes in the discharge and sediment regime.
- Drainage of urban and industrial activity to Mekong river.

Since 1957 there have been institutional arrangements for the management of the Mekong Basin. The evolution of these arrangements can be seen in Table 6. Since 1995 the Mekong River Commission was established. The framework agreed upon is as follows: there will be cooperation in all fields of sustainable development, utilization, management, and conservation of the water and related resources of the Mekong River Basin (Cosslett & Cosslett, 2014).

Table 6: Evolution of institutional development (White & White, 2002)

Year	Institutional Development
1957	Formation of the Mekong Committee
1970	Indicative Basin Plan
1971	Nam Ngum Dam Completed
1975	Cambodia withdraws from the Mekong Commission
1978	Interim Mekong Committee established
1987	Revised Indicative Basin Plan
1992	ADB commences Greater Mekong Sub region Initiative
1994	Hanoi agreement on Cooperation for the Sustainable Development of the Mekong River Basin
1995	"Run-of-River" mainstream hydropower dams proposed, Mekong River Commission established
1999	Restructuring of the Secretariat to achieve its goals

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 the following text an overview is given of the involved stakeholders in the system, how they are involved, what their interest is and how they are related to each other. 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 a trend of increased organizations which are not directly correlated to the government. All involved stakeholders can be divided in six main categories (Waibel, 2010b) Figure 41:

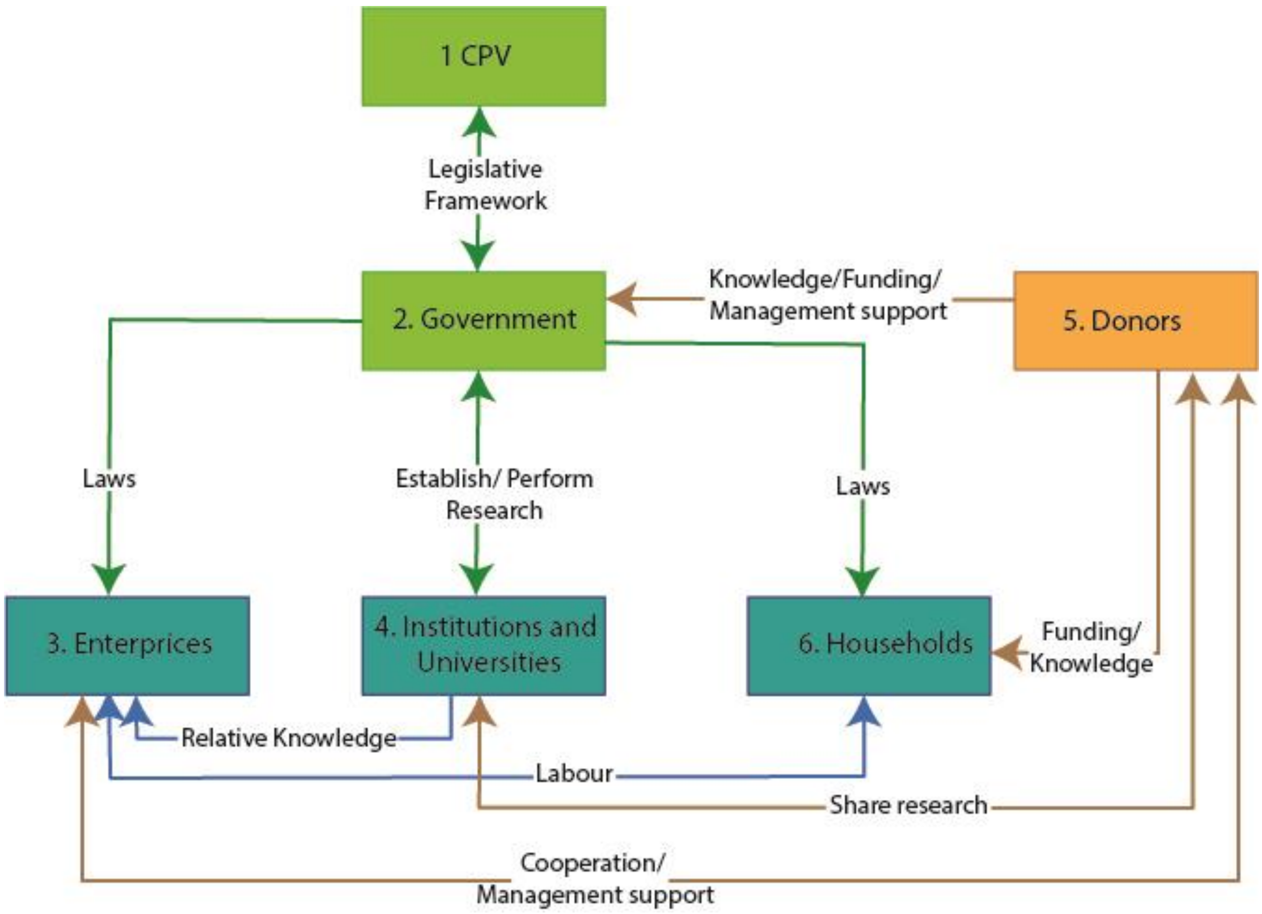


Figure 41: The six main stakeholders and there interaction

1. Communist Party Vietnam

Vietnam is a Single Party State; only one party forms the government. This is the Communist Party Vietnam (CPV). The CPV has its own structure; at every spatial level there is an administration which is able to exert its power in the decision making process, from central agencies to provincial and regional services. Members of the public authorities can be members of the CPV. The CPV sets the framework for the policy which is defined and executed by the Public Authorities. Hence, the CPV is largely involved in every decision making process, at any scale, in Vietnam.

The CPV has mainly a national interest. Vietnam is still a developing country and their aim is to have socioeconomic growth to be able to operate independent.

2. Public authorities

As explained in the chapter urrent system-Policy, the Public Authorities (government and national assembly) has a legislative as well as an executive function within the water sector. It is structured within 3 layers in the society; national, provincial and regional. The public authorities define and execute laws and legislation within the framework set by the CPV. These legislations influence (in)directly the enterprises, institutions and universities and the households in Ca Mau.

At a provincial level, the goal of public authorities is to improve the efficiency and sustainability of economic growth of Ca Mau. Their aim is to transform the province into a strong regional socioeconomic development province by 2020. This development is accompanied with the improvement of the livelihood and security of the inhabitants of Ca Mau and to ensure national defence. (Southern institute for Water ResourcesPlanning et al., 2013)

3. Enterprises

This group contains companies within the water sector which are directly related to design and construction of measures and enterprises which are situated in Ca Mau and have somehow involvement in the system. Examples of the first group are hydraulic engineering contractors, engineering consultancies, water treatment companies etcetera. Mostly the companies get involved after the initiation of a certain project by the public authorities. For instance a contractor gets the assignment to construct a hydraulic structure.

Secondly there are other water-related businesses which provide products for or work with product from the water sector. Examples are the traders, rise and shrimp factories, suppliers of farmer products and so on. Mostly these are the companies who provide labor for the people living in Ca Mau.

In the past most companies were state owned (state enterprises). Nevertheless, there is a growing private company sector (see chapter Economy) and the amount of privately owned enterprises, joint ventures and non-profit organizations is increasing. In Vietnam there is not a clear ‘’black and white view on integrity and corruption. There is a grey zone in which a service can be explained as privilege. Therefor it can be very beneficial if a company has contacts or relations with certain departments of the Public Authorities or the CPV. The probabilities to be assigned for a certain project can be higher in that case.

In general the enterprises have the aim to make profit within a predefined project/ task. Next to this they want to operate in a professional way to satisfy the demanded quality and have the opportunity to be requested for a new project/ task.

4. Research and education

Within the ministries (Public Authorities), governmental research institutes are established. An example for the water sector is the Southern Institute of Water Resources and Planning (SIWRP) of MARD. They perform research and monitoring on the coastal zone and inland water management. Adjacent to them universities, such as the Southern Water University, perform research on water related topics within Vietnam.

The institutions as well as the universities benefit from the research they perform. They have the possibility to sell the research they perform to the government, interested enterprises or institutions or donor organizations. This is a normal procedure and generation of their yearly revenue. The universities and institutions are interested in the accomplishment of research for multiple projects and promotion of knowledge. (“Interview Stefan Groenewold,” n.d.)

5. Donors

After the Vietnam War, the United Nations Development Program (UNDP) was one of the first organizations who cooperated with the Vietnamese government to develop water supply and sanitation. In the last two decades the amount of donors such as the World Bank development partners and investments of governments such as Australia and Germany increased. These donors can provide financial aid as well as providing knowledge and support in management related topics. The donors a related to all stakeholders mentioned in this part.

In cooperation with the national and provincial government they conceptualize and invest in development projects. During the project they have a leading role in the project management. The government in Vietnam depends on the financial funding for measures of the donors. This gives a certain degree of authority to the donors. They can decide up to a large extend in which projects they invest and therefore which projects will be developed. Within the projects the donors cooperate with enterprises and the research institutes and universities. The enterprises or mostly involved in the execution of the projects. The donors provide them knowledge and management guidance during the project. Together with the universities and institutions the donors perform and share research. Although it is not rear that the donors also have to pay for the research. Within small scale projects the donors provide knowledge, guidance and funding to households to improve their livelihood.

The donors do not have the aim to make profit but to improve the development of Vietnam in a sustainable way and promote international cooperation.

6. Households

The people who live in the province of Ca Mau are a large group of stakeholders in the system and they are both influential to and affected by it as they are able to influence the system. But their livelihood is also influenced by the system because they live within the system.

The basic human instinct is to survive in the environment it lives. The living standard for the people in the province of Ca Mau is low compared to other provinces of Vietnam (see chapter Economy) and a significant part of the population struggles with poverty. In most households both of the parents or even the whole family has to work, to provide the primary needs. Besides they live in the described environment which is affected by salinity intrusion, coastal erosion and a high probability of flooding, so they have to develop a high capacity for adaptation. As Ca Mau is largely rural, households depend on natural resources for their income, while at the same time they exert pressure to the natural system (sewage, pollution). Their activity can be, however, regulated by governance bodies such as Public Authorities.

Figure 42: left top: Water residence, right top: DARD in U Minh, bottom left: Shrimp factory near Ca Mau city, bottom right: Farmers living close to the dike

Current System- SWOT

From the current state system a summation of the strengths, opportunities, weaknesses and threats can be made. In Figure 43 the strengths and weaknesses of the system are illustrated together with the opportunities and threats driven from external factors.

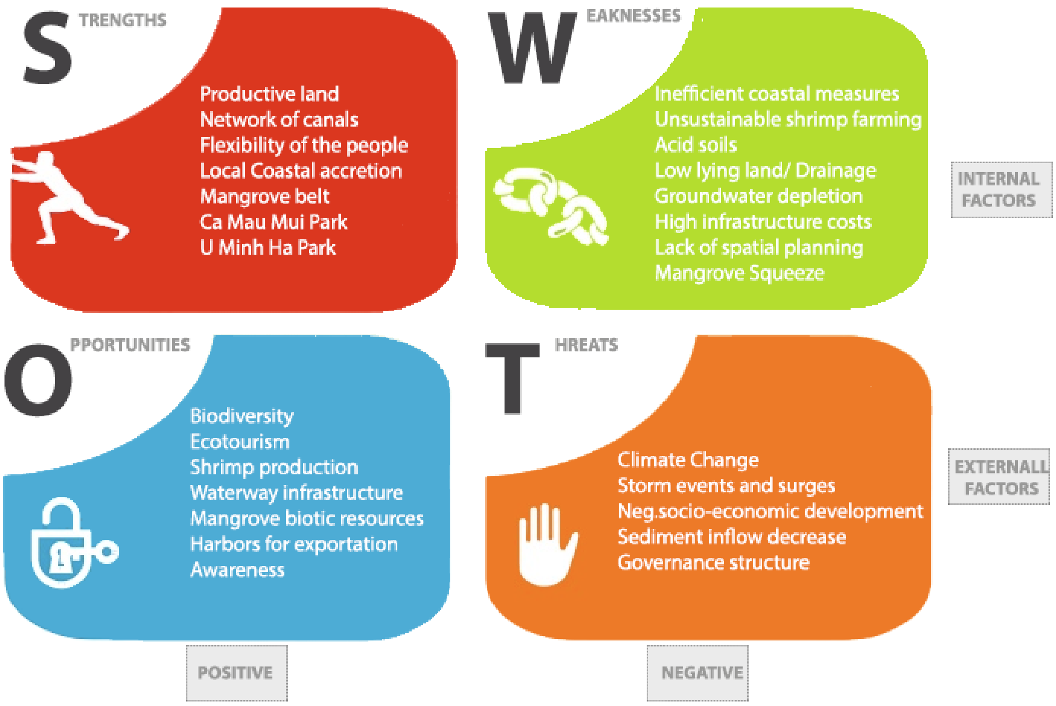


Figure 43: SWOT analysis of the Current State system

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.

The internal factors are part of the current system and detailed description of it can be found in the chapter Current system. The external factors are not yet, or not a big, part of the system but can in the future contribute to the system. This contribution can give opportunity but also a threat. So is climate change in the current system not so important, but estimations are that this will be a threat in the future with more saline intrusion, mangrove squeeze/ coastal erosion, and flooding's. A new threat can be a negative social economic growth with a decrease in livelihood and a reduction in production.

The goal for Ca Mau will be to protect itself to the threats of climate change and negative socio-economic developments (see chapter Introduction) and benefit from the opportunities the province offers.

4

Drivers of Change

- Climate change hazards
- The human factor and socio-economic drivers in the system

This section explores the main factors of change for the system of Ca Mau. It is therefore an analysis of the key drivers of change affecting the case study and of their impact on the system status. Having in mind Figure 4, one may see that this chapter mainly describes the context of change that was mentioned before, on hydroclimatic and socio-economic grounds. Policy reforms are not examined in this section and are treated as part of the Stakeholder Analysis and Scenario Development.

Climate change hazards

The most crucial hazards that have to be taken into account for the area of Ca Mau are:

1.) Sea Level Rise,

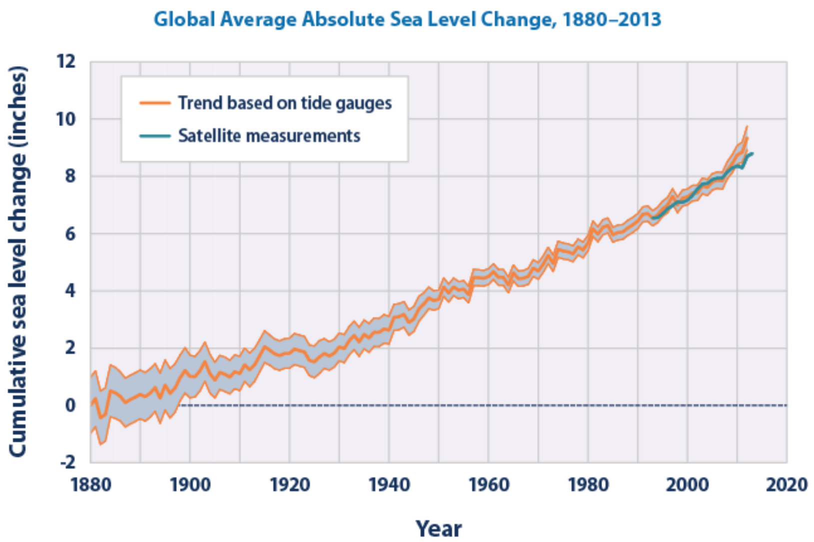
which is a concern since the whole area of Ca Mau is low-lying, with the prevailing elevation being in the range of 0.5 m – 1.0m ASL (DARD, 2014). Given that sea level is measured from a fixed reference point, one has to distinguish between Absolute Sea Level (ASL), which uses the center of mass of the Earth as a reference point and Relative Sea Level (RSL), which uses a fixed point of the coast as a reference for measurements (e.g. as in the case of a tidal gauge). This means that relative sea level variation also depends on overland vertical movements, i.e. movements of the fixed point itself.

The main factors that contribute to global sea level rise (GSLR) are mainly (Bosboom & Stive, 2015):

a.) Changes in the mass of ocean water, e.g. from the melting of ice caps due to climate change.
b.) Changes in the density and, therefore, volume of ocean water (steric changes), e.g. due to global temperature change. Thermal expansion is projected to play an increasingly important part in global sea level rise on the longer term, in the centuries to come (Church et al., 2013).
c.) Isostatic changes in the volume of the ocean basins (hydro-isostasy).
d.) Vertical crustal movements in the land, due to physical processes (e.g. glacio-isostasy) or human activity.

It is evident that only factors (c.) and (d.) may affect coastal land movement and thus relative sea level rise (RSLR), while the others contribute to absolute sea level rise (ASLR). In the context of this study, relative sea level rise is particularly important since it also incorporates land subsidence, which can be caused by human activity in the region, such as groundwater extraction (Erban et al., 2014). Furthermore, it is the phenomenon users of the coastal zone can directly attribute to and the process most relevant for policy-making, as this matches their perception of sea level rise. **Relative Sea Level Rise (RSLR)**, therefore, encompasses the effects of climate change as well as human contribution and it is the process mentioned in the causal models of the proceeding Chapter System Dynamics.

Regarding global ASLR, the observed rate of rise for the period 1993-2012 with satellite altimetry is 0.31 ± 0.04 cm/year (IPCC, 2014, see Figure 44, Upper Panel) and this trend is expected to persist or, possibly, be increased during the 21^{st} century (Church et al., 2013). This sea level change is not globally evenly distributed, as there are significant differences on a regional scale. Church et al., 2013 notes that strong regional patterns in sea level rise are likely to occur in the decades to come, and these changes may differ by more than 100% from the average global rate. Regional variability is caused by the additional effect of surface winds, oceanic currents, regional temperature and salinity changes and the gravitational attraction of sea water by land ice. In the case of tropical areas, amplification of sea level rise due to regional and loading/self-gravitation effects of ice-sheets is expected to be within the range of 20-30% (IPCC, 2014). In the case of Vietnam, as seen in Figure 44, Bottom Panel, the region of the Western Pacific faces higher regional sea level rates. For the area of Ca Mau, in particular, the ASLR for the period of 1993-2012 is expected to be in the range of 0.2 – 0.4 cm/year (Erban et al., 2014). IMHEN, 2011 has provided regionally downscaled data for Sea Level Rise, where the coast of 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. The effects of this sea level rise are further exacerbated by human actions, as analyzed in chapter Current system - Water management. The projected SLR is associated with progressive **inundation** and further worsens **saline intrusion** problems.



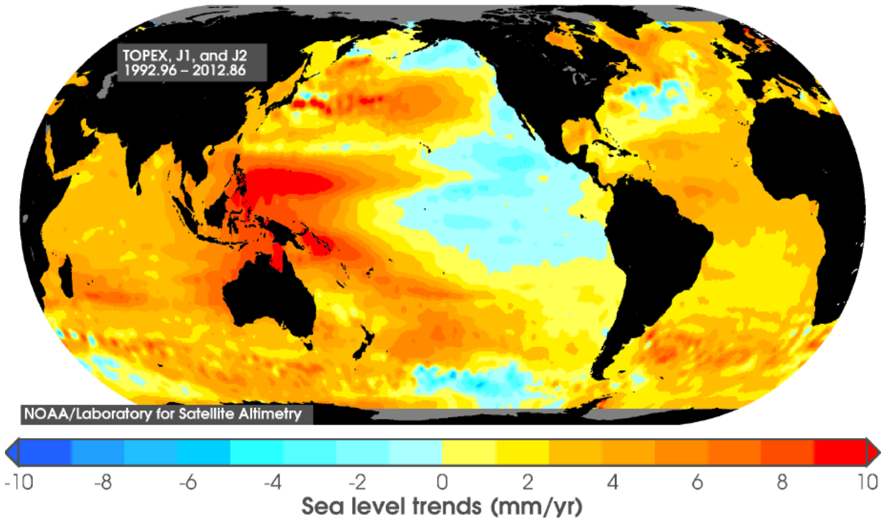


Figure 44: Upper Panel: The observed global average ASLR (EPA, 2014)
Bottom Panel: ASL trends for the period 1993-2012. The global average is 3.1 mm/year. (NOAA, 2014)

2.) Rainfall.

A change in rainfall patterns and the frequency of extreme precipitation events, whether they are floods during the wet season or droughts in the dry season. 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 results from studies and projections show inconsistencies, thus reflecting the high degree of uncertainty in estimating the impact of climate change to regional rainfall.

In the case of Vietnam, which belongs to the tropical wet regions, mean precipitation will likely increase under the assumptions of main climate change scenarios, while extreme precipitation will very likely become more intense and more frequent (IPCC, 2014). Figure 45 shows the results of two climate change modeling scenarios on average precipitation for the region of SE Asia, where Vietnam is projected to have 0-10% increased precipitation. Other studies on observed data, however, show a reduction in total rainfall and in the number of rainy days, while there is an increase in the proportion of annual rainfall from extreme events (Manton et al., 2001).

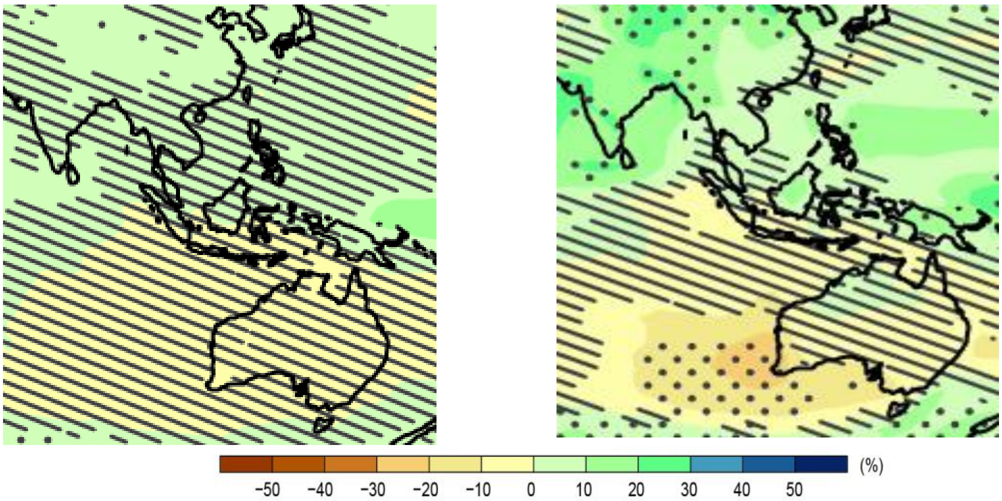


Figure 45: Change in average precipitation for SE Asia for 2081-2100, compared to the 1986-2005 mean. Results are based on multimodel mean projections, under the RCP2.6 (left) and RCP8.5 (right) scenarios. Stippling (i.e. dots) show regions of large projected change compared to natural internal variability, where at least 90% of models agree on the sign of change. Hatching (i.e. diagonal lines), show regions where the projected change is less than one standard deviation of the natural internal variability, i.e. regions with more uncertain outcomes (IPCC, 2014).

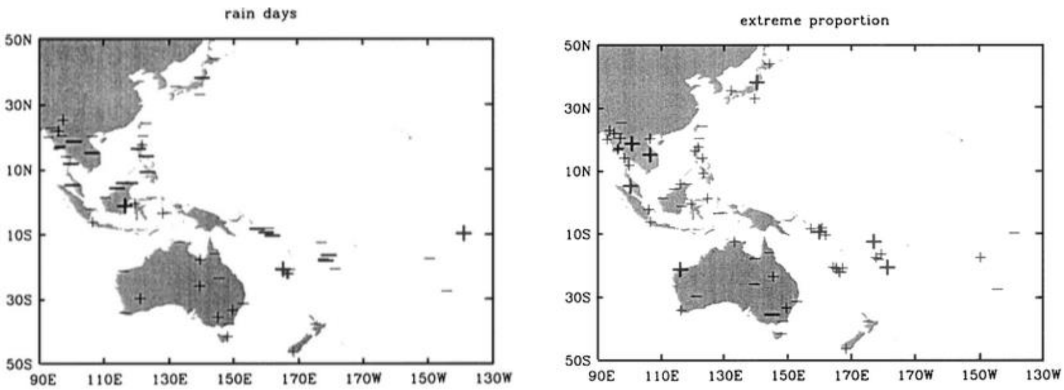


Figure 46: Trends in the frequency of days with at least 2mm of rainfall (rain days) and trends in the proportion of rainfall that falls due to extreme events. Time-series from 1961-1998 are used (Manton et al., 2001).

Regionally downscaled outputs of climate modeling provided by IMHEN, 2011 for the area of Ca Mau predict an increase in precipitation up to 25% 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. It is noted, however, that there are some inconsistencies in the rainfall results that require further investigation (IMHEN, 2011).

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.

In this study, more intensive rainfall patterns in the future are assumed. This means that there will be more rainfall during the wet period, less rainfall during the dry period, and slightly more rainfall on annual average. This is in accordance with the results provided by IMHEN, 2011 and provides the worst case scenarios in terms of salinity intrusion (during the dry period) and flooding (during the wet period) that are used for the systems analysis.

3.) Local Storms/ Typhoons

Increased frequency and severity of **local storms** in the coast or **typhoons**, which will lead to severe **storm surges**. An analysis of typhoon trends by IMHEN, 2010 showed that, while there is no clear trend for the frequency of typhoon landings in Vietnam, there is a shift in typhoon landings to the south and also an increase in the frequency of very strong storms. This indicates that areas that suffer from intense storm and typhoons on rare occasions, such as the southeastern parts of Vietnam and Ca Mau, may be increasingly vulnerable in the future. It is noted, however, that further modeling and prediction of typhoons in this area for the future is very difficult (M.J Russell, 2012). Despite this large uncertainty caused by limited predictability, Ca Mau is particulary exposed to storm surges (see also Chapter coastal) and they should be taken into account for future studies.

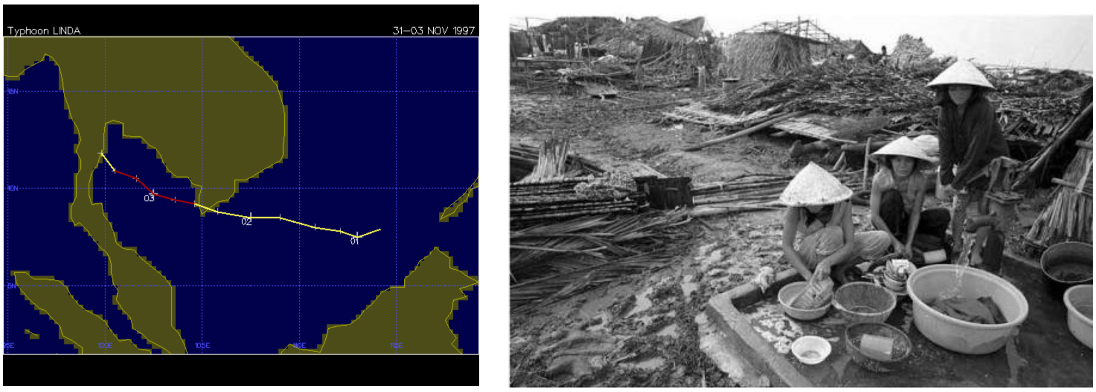


Figure 47: Left Panel - The trajectory of typhoon Linda across the Ca Mau Peninsula and the gulf of Thailand (Unisys Weather, 2014). Right Panel – Devastation in the local communities of southern Vietnam from the typhoon crossing (Gunn, 2010)

Observations from typhoon Linda 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. While data is scarce due to the lack of population and poor media coverage, the destruction caused by typhoon Linda had severe impacts in Ca Mau, including widespread coastal erosion, damaged housing and fishing boats, extensive inland flooding with large inundation depths and large areas of mangrove forest destruction which were later reported to be replanted (M.J Russell, 2012).

4.) Temperature

Change in other meteorological variables, such as **temperature**, which will have implications on the water cycle. For instance, an increase in temperature will in turn increase evapotranspiration rates and may thus increase freshwater needs for agriculture. Furthermore a higher evaporation will increase the saltwater intrusion, because a higher evaporation increases the salt concentration of the inland water and allows the salt sea water to move in further land inward (also see chapter Current system - Water management). More frequent and longer heat waves also add pressure to crops and increase the economic risk of farmer investments.

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 the Mekong Delta and, more particular, in Ca Mau. People define water and land 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 the status of the ecosystem and the condition of the surface water and groundwater bodies. In this section, aspects these human factors are addressed in terms of demographics, economy and land use change.

Demographics

Ca Mau is mainly a rural province, with agriculture and aquaculture as the main source of income for the local population. 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). Ca Mau city itself, with a population of 204,895 (in 2010), is the center of economic and industrial activity; most primary sector goods are transported through the extensive canal system of the province to the city, where they marketed and processed.

The net provincial migration rate in Ca Mau is -0.3%, meaning that there is emigration to other provinces in Vietnam, mainly to Can Tho (IMHEN, 2011); 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

General economic structure

The general economic structure in Vietnam, both in terms of investment cash flows and long-term structural changes, is influenced by both politics and (global) market conditions. Following the Doi Moi reforms in 1986, which added market-driven mechanisms to a system previously dominated by central planning, the structure of enterprises includes privately-owned enterprises, state enterprises (SEs) and joint ventures. State Enterprises (SEs), which were founded during the Soviet model of central planning, form an important part of the Vietnamese economy. In the current state of economy, there is a serious lack of investments in these SEs, especially in technology and upgrading the means of production. Most of the SEs still work with outdated equipment and lack efficiency in production (Beresford, 2008). In the meanwhile, SEs are prioritized in funding, so privately-owned enterprises get fewer opportunities therefore limiting further growth. For these reasons the SEs, despite efforts to rejuvenate them, generally failed in accelerating industrialization in Vietnam. On the other hand, it should be noted that SEs generally have a high value of welfare in Vietnam, as they guarantee employment security and worker services (such as children education); there is therefore an evident trade-off between profitability and equitable welfare generation in this case.

With the introduction of the Doi Moi reforms in 1986, the government encouraged Foreign Direct Investments (FDI) into the SEs in the form of joint ventures. FDI, however, preferred the private sector because of the 100% ownership that came along with it. This was the reason for the private sector to win ground from the SE and by 1995 FDI was responsible for one third of annual investments. As a result SEs reacted with a strategy of mergers, where smaller and often unprofitable SEs merged into larger bodies know as General Corporations (GC). Some of these GC became very successful like for example: Baoviet (insurance), Vinacomin (minerals) and VNPT (telecommunications). Initially the FDI invested into sectors that did not contribute to the development plans of the Vietnamese government, like hotels and real estate. Gradually and in more recent years, joint ventures with SEs gained more ground and FDI started to invest into industry. In 2005 the majority of the FDI was in industrial projects partly because the foreign companies felt safer to invest into the state protected SEs. Meanwhile, enterprises based on FDI are more extrovert: the majority of foreign-owned firms and joint ventures reports export-based activity, while SEs and purely domestic firms focus on the domestic market and sub-contracting (Beresford, 2008). These aspects highlight the high dependence of Vietnamese economic growth on external factors, such as the global economy.

Despite this dependence to foreign investment, Doi Moi has been particularly successful: since it initiation, per capita GDP has approximately quadrupled and there has been a reduction in absolute poverty, from 58% of the population in 1993 to 23% in 2004 (Beresford, 2008). This has, however, come at the price of an uneven distribution: there is a marked increase in regional inequality and a widening gap between urban and rural areas (Beresford, 2003).

Aspects of the provincial 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 48, left Panel). This reflects the more general economic development conditions of the Mekong Delta: until 2002, the average income of the Mekong Delta was slightly higher than the national average, but it has been decreasing in more recent years (Mekong Delta Plan Committee, 2012). Figure 48, Right Panel shows this increasing difference, which means that the broader deltaic area fails to follow the national trajectory of economic development.

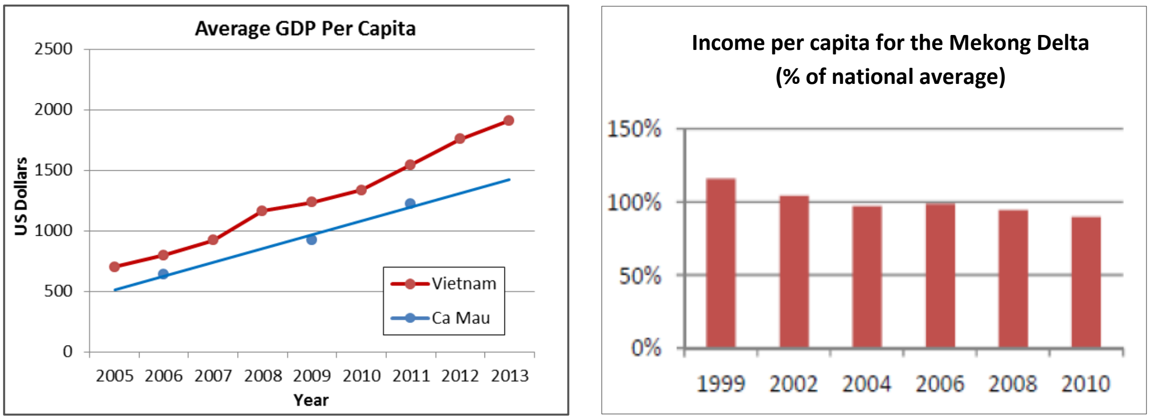


Figure 48: Left Panel – Average GDP per capita for the Vietnam and Ca Mau in recent years (Data sources: World Bank, Vietnam Investment Review), Right Panel - GDP per capita for the Mekong Delta, compared to national average (Mekong Delta Plan Committee, 2012).

In the case of Ca Mau, aquaculture currently dominates economic activity in the primary sector. As a result, the main driver on the economic prospects of the local population, apart from SEs, is the market demand of shrimp. With new markets opening for Vietnam after the reform like the EU and the USA, the demand for shrimp increased (Lebel et al., 2002). The people of Ca Mau readily adapted to this opportunity and Ca Mau quickly developed as the leading province in shrimp export: in 2005, it exported $500 million in shrimp, while the targets of production for 2015 are 560,000 Mt (megatons), 80,000 more than 2014, with a total export value of $1400 million (DARD,2014). This high demand from international markets is one of the main drivers in the transition of land use from rice agriculture (and mangrove forest) to aquaculture, see chapter Land and water use.

There is still a lot of opportunity for the shrimp industry to keep expanding in Ca Mau, not just for primary production but also for all the other industries that are linked to the process of shrimp production (see Figure 7). The bottlenecks for the supply chain in the case of Vietnam and Ca Mau are (Lebel et al., 2002):

- Dominance of middle-men in the production chain, as an intermediate step from local farmers in rural areas of the province to processing factories in urban centers: 89% to 98% of product yield is sold at the pond edge to shrimp traders.
- The lack of a central market that results in divergence in the supply chain and constrains further development of large processing industries.
- Lack in secondary service industries or state support for shrimp farming; consulting and training services is largely undeveloped and does not reach most local farmers. Meanwhile, shrimp farmer and buyer organization structures are few and weak.
- The form of processing facilities, with many of them being state enterprises (SEs). This results in inflexible management and a difficulty in decision-making to adjust to rapidly changing market conditions, while on the other hand gives access to prioritized credit.
- The high costs for larvae and feed, as well as supplies of chemicals. The former reflects the large risk of failure in hatcheries and the later reflects the fact that many of the secondary production improvement products need to be imported from other countries, thus increasing their cost.

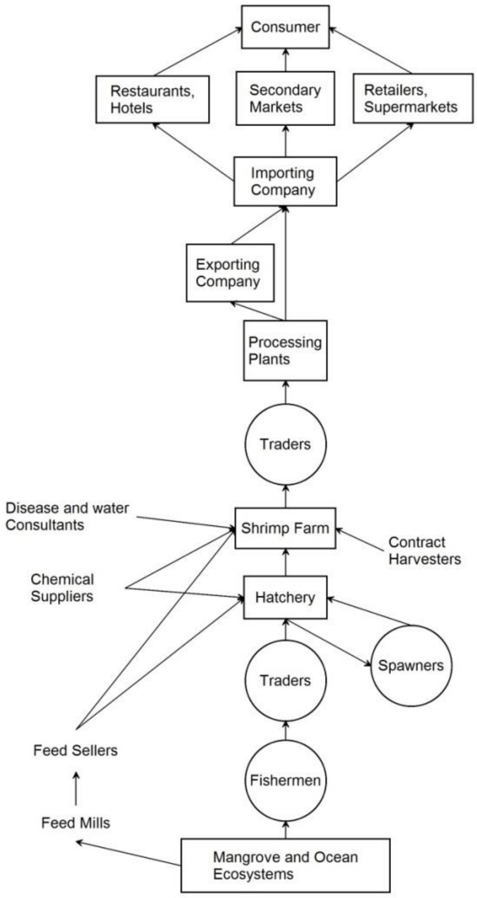
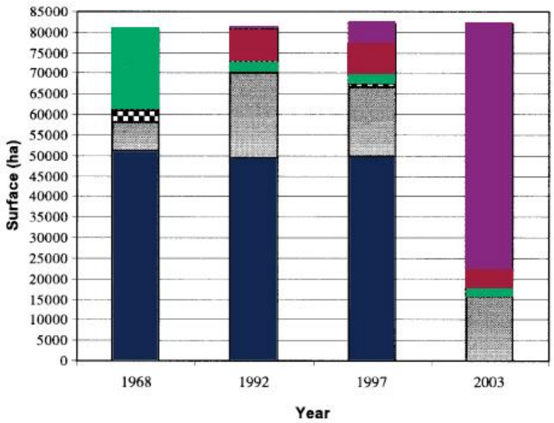


Figure 49: The shrimp farming production chain for the case of Vietnam, adapted from Lebel et al., 2002.

Land use change

Another crucial factor that is highly correlated with human activity is land use change. In the case of Ca Mau these changes have been extensive and serious: a study in the district of Cai Nuoc (Binh et al., 2005) has shown vast land cover changes from 1968 to 2003 (Figure 50 – 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). Rice cropping can now be seen only in controlled, salt-free zones with closed loop culvert systems, mainly in Tran van Thoi and U Minh (Figure 50 – right panel).

The transformation of significant areas from rice cultivation to intensive shrimp monoculture reflects a response of the local society to market conditions and has led to a short-term improvement in the agricultural income of the province, with significant spin-offs, such as the creation of jobs in the broader value chain (shrimp foods, transport, agro-processing) (IMHEN, 2011). This transformation, if put in a broader planning context, presents an opportunity for Ca Mau and other provinces of the Mekong Delta to further develop into an agro-industrial hub for aquaculture production and processing (Mekong Delta Plan Committee, 2012). However, the increase in aquaculture has led to and increased salt intrusion and a significant mangrove loss (Binh et al., 2005; Son et al., 2015) in the area. Another consequence of the land use change is that the current canal system, originally designed for rice cultivation, is outdated and cannot proved in the drainage and supply needs of the farmers. In this case increased salt intrusion combined with poor operational water management lead to water pollution, soil degradation and reduced yields, thus having a negative long-term effect in the household livelihoods, especially in the case of intensive shrimp monoculture (IMHEN, 2011). 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 Current system - Water management).



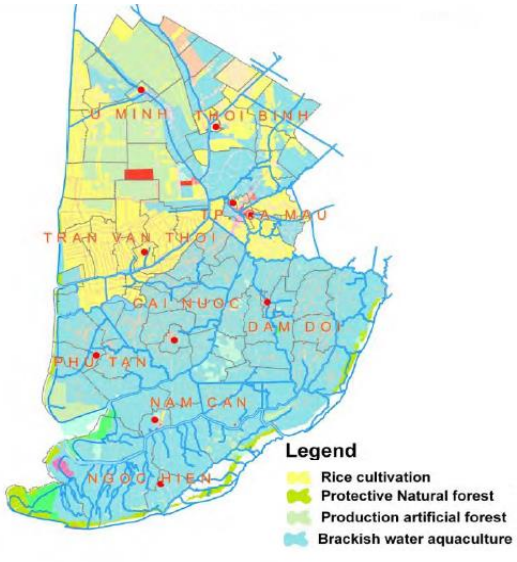


Figure 50: Left Panel - Changes in land cover between 1968 and 2003, Cai Nuoc district, Ca Mau province, Vietnam. Blue is rice cultivation, purple is shrimp monoculture, green is forest, red is mixed mangrove/shrimp farming, grey is rural settlements and dotted is other uses/wasteland. (Binh et al., 2005). Right Panel – Main land uses in the primary sector in Ca Mau (Source: IMHEN, 2011)

5

Model Formulation

- Methodology
- Scope of model development
- Possible advantages and pitfalls
- First modeling attempts at the separate systems
- The basic layer: climate change drivers and the system response
- Modeling the policy response and corrective measures
- Exploring socio-economic drivers
- Discussion
- Conclusions

This Chapter utilizes elements from the current system status and the drivers of change to build a conceptual model of the integrated, coastal and inland water system of Ca Mau. The human factor and the response in terms of corrective policies and measures is also studied as part of this model. This mind map is used as a basis to further assess the total system dynamics, including the feedback loops and the time scaling between processes and human response and, in combination with the horizon scanning that is enabled with scenarios, reach conclusions on the prioritization of proposed measures to establish sustainability in the management of the total system.

Methodology

The Chapters on the Current System 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 in order to analyze and model the integrated coastal and water system for the area of Ca Mau. This methodology acts as an integrated modeling tool, able to describe complex dynamic systems governed by feedback relationships, whose response over time needs to be studied and monitored (Baki, Koutiva, & Makropoulos, 2012). In system dynamics modeling the advantage is that the structure of the system model gives insight in the observable behavior of the system, thus making possible to make predictions based on these observations (Forrester, 1968, 1987). In the context of this study, SD 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. Data and time restrictions prevent the transformation of these interactions in a quantitative model for Ca Mau. However, the developed qualitative model acts as a backbone for further research and it can be transformed, at a later stage, to a quantitative Decision Support System (DSS) for Ca Mau. The System Dynamics methodology, in fact, offers a smooth transition from qualitative models and system structures to quantitative modeling methods (Dolado, 1992).

The System Dynamics methodology was initially used in business management and economics (e.g. see Sterman, 2000), but has more recently expanded to other sciences, and has been extensively used in a wide range of water resources management case studies (Winz et al., 2008). 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 visualization of the complex system dynamics does not require any knowledge of the underlying methodology and modeling, thus making it accessible for any group of stakeholders and assisting 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 affects the whole system. Both aspects can be seen in an example for an SD model for the urban water system of Singapore (Xi & Poh, 2013), shown in Figure 51. A (+) sign indicates an increase of the variable after the arrow if the variable before the arrow increases. The opposite is true for a (-) sign. Based on the number of (+) or (-) signs a loop can be identified as positive (amplifying) or negative (dampening).

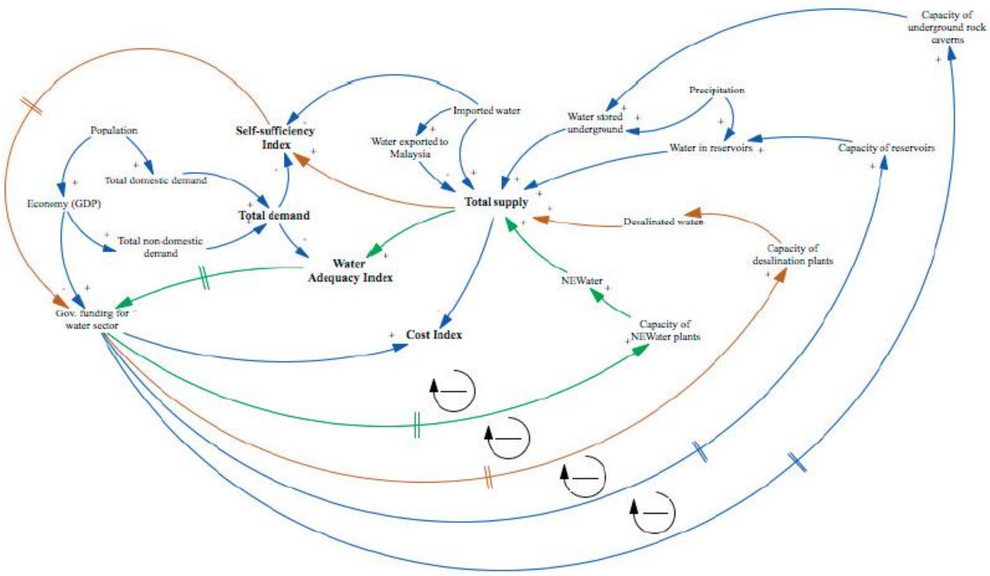


Figure 51: The supply-demand model for the urban water system of Singapore (*SingaporeWater*), showing a number of negative (dampening) feedback loops and a number of time delays-arrows with normal double lines (Xi & Poh, 2013).

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.

Possible advantages and pitfalls

Within every model framework there are strengths and weaknesses. Before modeling one should be well aware of these advantages and pitfalls. In this way the possibility is gained to avoid the know pitfalls and to exploit the advantages of the model framework. Table 7 shows the main strengths and weaknesses in the case of the SD modeling framework. From the advantages it can be seen that the SD modeling approach is suitable for the case of this research since it provides a flexible model that is able to show links and predict behavior of the water system in Ca Mau without going into the specialized and detailed knowledge of every process. Furthermore the SD model points out the opportunities for further research needed in Ca Mau. It is however very important for SDM to have a clear problem definition and project focus. That was a challenge in this case because the project involves a large integrated system with many processes and components. The decision was thus made to include the multiple dimensions of integration (see chapter Need for Integration) but structure the diagram on the rationale of independent yet interactive layers, so that complexity is built up gradually.

Table 7: Advantages and pitfalls for System Dynamics Modelling (Winz et al., 2008).

Advantages	**Pitfalls**
The structure of the model shows the observable and predictable behavior of the system.	Without a careful problem definition and project focus the model will not be successful.
Assumptions underlying the model help to find uncertainties and gaps in data availability.	It is easy to get stranded into to many details of the model or statistical validity.
Because the model is ex ante it has a high flexibility and adaptability.	Extending model boundaries during the modeling phase.
The model is transparent.	Do not expect exact solutions.
No knowledge of the methodology, modeling or computation is needed to work with the model.	Underestimating long term system effects compared to short term effects
Effective for communication and stakeholder participation. Accessible for any group of stakeholders	Too much focus on modeling the system correct instead of solving the problem

First modeling attempts at the separate systems

Before developing a model for the integrated system, diagrams for the separate systems of Ca Mau (coastal water system and inland water system) were developed. These models were formed with the aims of:

- Highlighting key or important processes that dominate the separate systems, as well as processes that can be excluded from the general graph for reasons of simplicity.
- Finding processes that are similar or overlapping in these two systems, so that links between these two systems become more evident.
- Achieving a level of process understanding that is more detailed (and aligned with the Current system Status chapter) for both systems. The integrated system SD graph can be then formed based on these two graphs through a process of abstraction.
- Key processes, shared processes among the two graphs and bridges

Coastal system

The coastal system is influenced by the drivers climate change and human interference. Below a short explanation is given about the system dynamics diagram which purely focuses on the coastal zone. Starting with climate change elicits three elements in the coastal zone;

- Sea Level Rise (SLR),
  - SLR together with increased subsidence increases the RSLR which increases erosion and
  - Increasing probability of coastal inundation
- More extreme events (storms)
  - Leads to an increase in erosion and
  - Increasing probability of coastal inudation
- Changes in temperature and perturbation.
  - Leads to mangrove degradation because the mangroves are not capable to adapt to the climate at a (relative) short time scale.

The human influence is integrated in the:

- Ground Water extraction (actor from outside the system)
  - Ground water extraction will lead to subsidence, and as mentioned above this leads to increase of erosion and probability of inundation.
- Cultivation of new land
  - The seaward placement of dykes will lead to an increased probability of inundation mangrove degradation
  - The cut of wood will lead to mangrove degradation.

In the diagram four loops can be found. A loop indicates that certain processes can enforce or decay each other.

- The two main elements influenced by human influence and climate change are an increase of erosion and mangrove degradation. These two enforce each other (positive feedback loop).

- Increase in erosion leads to coastal retreat. The coast will adapt to a new coastal equilibrium which decreases the erosion rate. This is a decay or negative feedback loop.
- The increase in erosion and increasing coastal retreat also lead to human awareness and result in more coastal protection. This is a critical point. Depending on the measure and the scale of a measure, it can lead to more or less erosion. For instance a hard structure well designed will decrease the local erosion but increases erosion downstream (larger scale). If the measure is not well designed it can even increase the local erosion. A soft measure like beach nourishment will not influence the erosion rate at all.
- The forth loop can be found within the mangrove degradation. Mangrove degradation leads to less nutrients in the water which negatively influences the flora and fauna leading to more mangrove degradation.

Lastly the drivers lead to two effects outside of the system:

- Increase of CO_2 release by degradation of mangroves. This factor will not affect the coastal zone severely given the spatial and time scale.
- Besides mangrove degradation leads to salt water intrusion which is further elaborated in the system dynamics of inland water management.

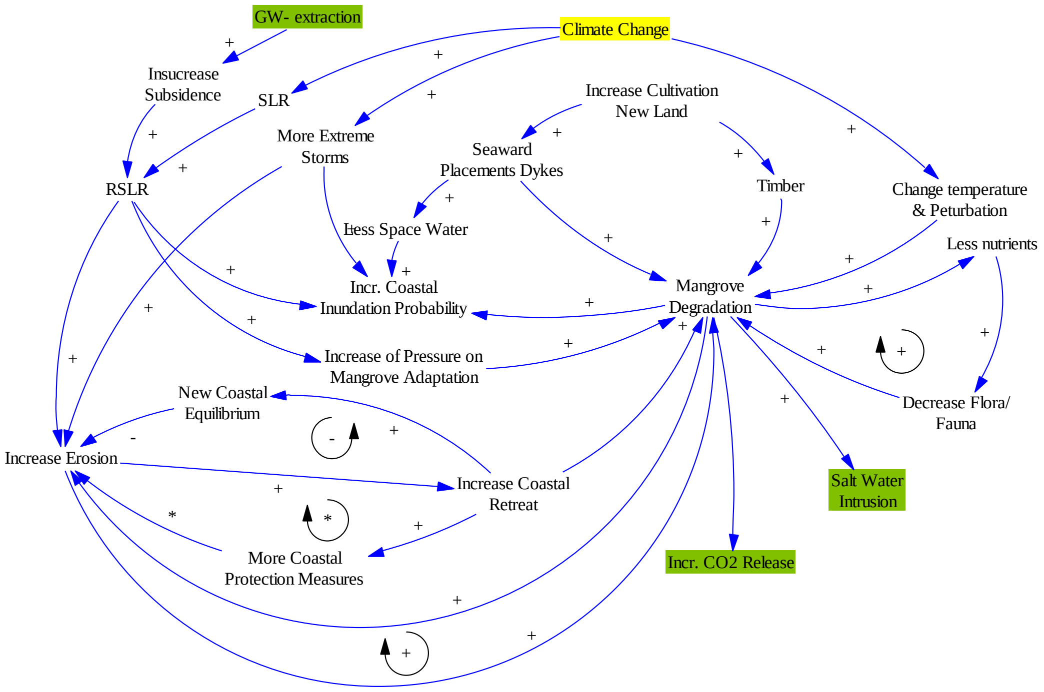


Figure 52: System dynamics diagram of the coastal system

Inland water system

Climate change has three consequences for the inland water system, namely: Changing rainfall pattern; which we divide into more heavy rainfall in the wet season, and more and longer drier periods in the dry season. Secondly, sea level rise and thirdly the increasing events of storm surges and typhoons. The last aspect is assumed to have the same effect on the inland water system as heavy rainfall events, so the consequences of storm surges and typhoons are not considered in the diagram. The processes due to the climate change events will be discussed below see Figure 53.

- More frequent and heavy rainfall in wet season causes floods (inundation) in the wet season. This flood has several consequences:
    - Inundation of land which can lead to crop destruction, and thus reduced production rates.
    - Erosion and sedimentation in the canals as a result of a reduced cohesion of the soil due to saturation. This sediment ends up in the canal system, and will settle, which will lead to a smaller drainage capacity, leading again to higher chances of flooding.
    - If the soil where the flooding occurs contains acids, these acids will flush out into the canals. This problem mainly occurs in the beginning of the wet season (see chapter: Current system - Water management)
- In the dry season, the periods of droughts are expected to get longer. This leads to fresh water shortage, which initiates a loop in the system. Fresh water shortage in the dry season will most in some cases be compensated by ground water extraction, which will lead to land subsidence and more salt water intrusion in the groundwater itself. And more salt water instead of fresh water will lead to a fresh water shortage.
- The relative sea level rise (induced by ground water pumping) causes the following processes:
    - Increased salt intrusion, which has major influences in the dry season. It decreases the fresh water availability and has an influence on land use change.
    - Due to higher water levels at the sea, the drainage in the inland water system towards the sea will be affected. A smaller water level slope reduces the drainage capacity from inland water to flow to the sea.

The human stresses can be explained by an increasing economy in which industries, population, and land cultivation is improved and expanded. Within Figure 53 arrows leading from land use change are marked with a star because it depends on the context if the links are positive or negative. The following links follow from the land use change and increasing economy:

- Increasing economy induces the development of industries
    - Direct pollution due to increased industry and domestic water use.
- The change of land use is contributing to:
    - Saline intrusion caused by the transition from rice agriculture to shrimp aquaculture (see Chapter Current system - Water management)
    - Saline intrusion caused reduction of the mangrove belt.
    - Acid deposition in the soil due to: timber harvesting of the melaleuca forest (Chu & Brown, 2011) and transition from rice to shrimp farming (See chapter Current system - Water management).
    - Direct pollution of the canal water due to change from forest to forest-shrimp aquaculture (See chapter Current system - Water management)
    - Increased economy due to higher profits from aquaculture compared to rice production.

From Figure 53 it can be seen that there are several loops in the inland water system. Three of them are positive loops which will lead to an instable situation if there is no interference in the process and one loop can be both positive and negative depending on the land use.

- The first loop is the one running from *RSLR-Salt intuition-fresh water needs- fresh water shortage-groundwater extraction- land subsidence-RSLR*. There are two ways to influence this loop, one is by the irrigation system that can reduce salt intrusion and reduce fresh water shortage. The other one is by policy measures and prohibit groundwater extraction.

- The second loop is the loop running from *salt water intrusion (gw)- fresh water needs- fresh water shortage-groundwater extraction- salt water intrusion (gw).* This loop is very similar to the previous one and can also be influenced by the irrigation system and policy regarding groundwater extraction.
- The third loop is the one running from *inundation-erosion and sedimentation in the canals-reduced drainage capacity-inundation*. This loop can be influenced by improving the irrigation canals by for example dredging or reinforcing the embankments.
- The fourth loop is the one from *salt intrusion-land use-salt intrusion* this loop can be negative and positive depending on the type of land use change. Currently there is a large change from rice and rice-shrimp to aquaculture, this change has an accelerating effect on salt intrusion, thus making the loop unstable. But again there is an option to influence the salt intrusion externally by improving the irrigation system.

All these unstable loops have a an option to be stabilized by an external force. This means that with the right set of measures and policies the inland water system is able to adapt to climate change at a certain pace. If there are no actions taken the system dynamics diagram points out a number of problems like: land subsidence, inundation and pollution but all these problems eventually lead to reduced production.

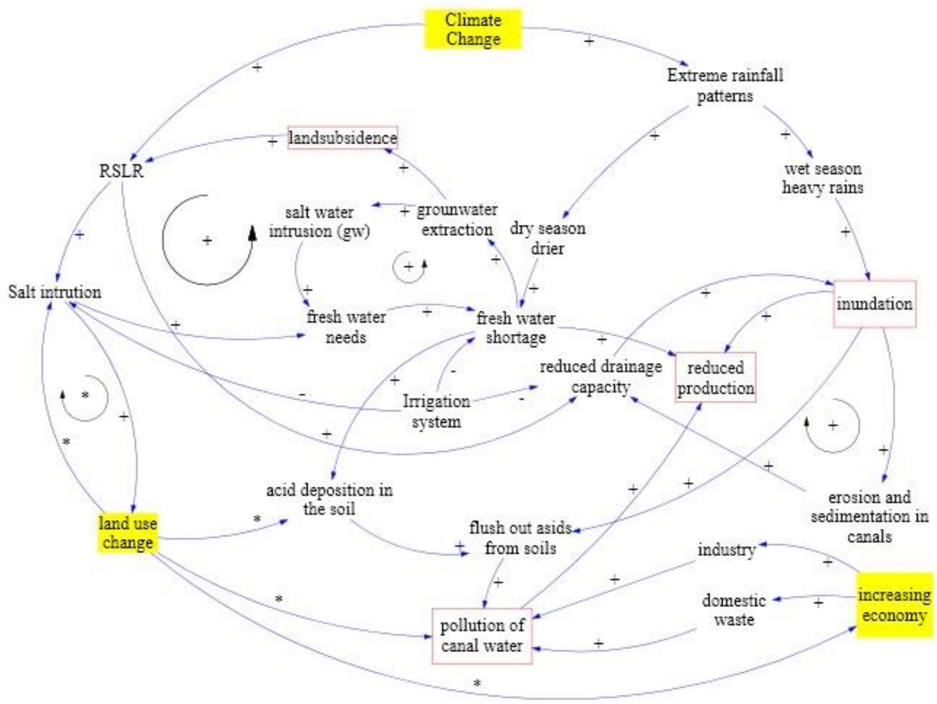


Figure 53: System dynamic diagram of the inland water system

The basic layer: climate change drivers and the system response

After getting a first idea of the underlying processes governing the two systems, a model for the integrated, general system can be developed. The system is developed in a multi-layered way, taking into account the multiple dimensions of the integrated system (see Figures 3 and 4), notably:

- 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 model is built by taking into account models of Figure 52 and Figure 53, retaining key processes through a path of abstraction. It is crucial, in this stage, to retain the minimum amount of needed processes so as to reduce the complexity of the system. Otherwise, there is a risk of the diagram being too complicated, having too many details and being incomprehensible to third parties (see Table 7). The decision was thus made to abstract problems such as soil, canal erosion and water quality and focus on coastal erosion, human uses of fresh and saline water and mangrove degradation. Omission of these problems does not mean that the model cannot cope with them; for instance, water quality can be implicitly assumed as being in a connection between *Industry* and *Economic Damage* (see below).

The basic layer of the model can be seen in Figure 54 and Figure 55. It includes two modules: **climate change and its impacts** (shown with red color) and the **response of the integrated system** (shown with blue color). The assumptions behind climate change and its impacts have been analyzed in chapter Drivers of Change; the **changing climate** is assumed to have several effects on the system that include:

a.) More intensive rainfall patterns per season, modeled as *more* (and more intensive) *rainfall during the wet period*, as well as *less rainfall during the dry period*. This means that there is a higher risk of *flooding* due to rainfall events during wet periods (Figure 55). Likewise, there is a risk of more *droughts* during dry periods (Figure 54).Less rainfall will also mean that *saline intrusion* is worsened during dry periods (see Chapter Current system - Water management).

b.) An increase in the frequency of extreme coastal events (*tropical storms*) that eventually leads to a higher risk of *coastal erosion* and *flooding*. These events are mainly correlated with the wet, monsoon period (Figure 55).

c.) An increase in overall temperature that in turn needs to *higher evapotranspiration rates and higher evaporation rates on aquaculture (ET)* and thus increases the *freshwater needs* of farmers in the area, especially during the dry period

d.) The effect of global Sea Level Rise (a factor that contributes to *Relative Sea Level Rise - RSLR*) on the coastal system. An explanation why *RSLR* was chosen as a variable in the model is given in Chapter Drivers of Change.

When confronted with these impacts, the **integrated water system** changes its status and adjusts key elements. For reasons of parsimony, human water uses in the model are represented with two key variables: *freshwater needs* and *coastal aquaculture*. *Freshwater needs* is an aggregated variable that concentrates the of water demands of (inland) land use; agriculture, inland aquaculture and urban water use are integral parts of it. It is evident that *freshwater needs* are defined by the status quo of land use and (up to a point) by the desired land use policy. In the case of Ca Mau, these needs are dominated by agricultural uses[1] (rice cultivation or shrimp farming). At the same time, a part of the local population might take up *coastal aquaculture*, instead of other competing land uses. *Coastal aquaculture* is separated from inland water use (agriculture/aquaculture) and thus *freshwater needs*, since it is a driving factor for coastal land use change and mangrove forest loss (see Chapter Mangroves). Inland aquaculture, on the other hand, if implemented correctly, does not have a negative impact on the coastal protection zone and can be fully integrated with the more general *freshwater needs* of the system.

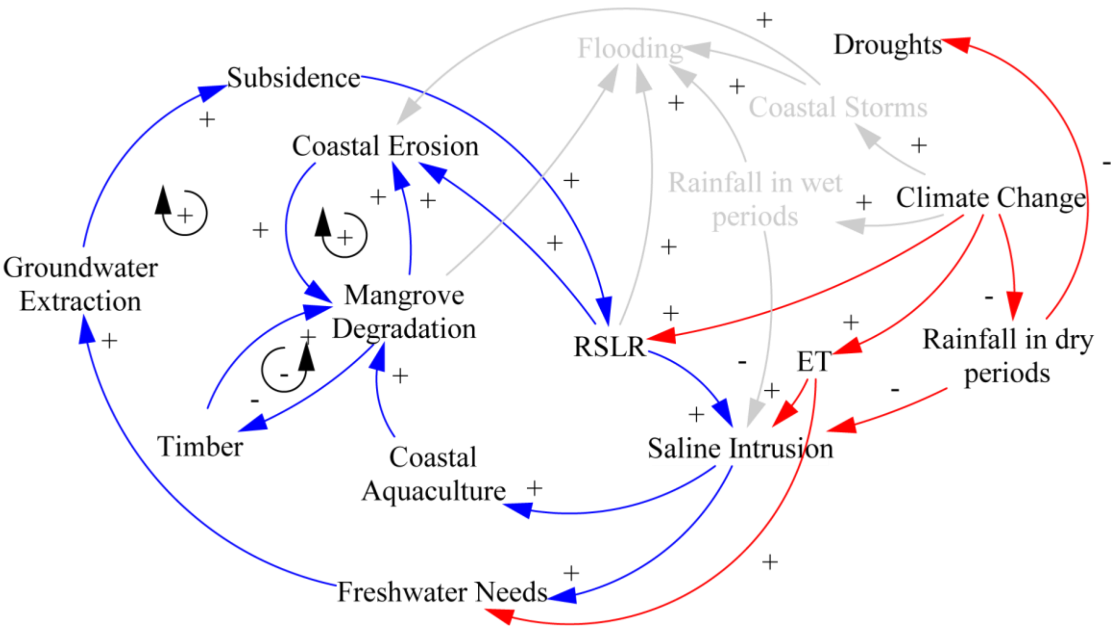


Figure 54: The basic layer of the model, comprising of the climate change drivers and the inner system response. The dominant processes during the dry period are highlighted.

[1] In the case of rice, there are obvious needs for freshwater, depending on the method and intensity of cultivation. In the case of shrimp aquaculture, freshwater is continuously needed to balance salinity levels and maximize productions. In both cases, the dry period is the critical period that limits productivity and maximizes risk of failure (see Chapter Current system - Water management).

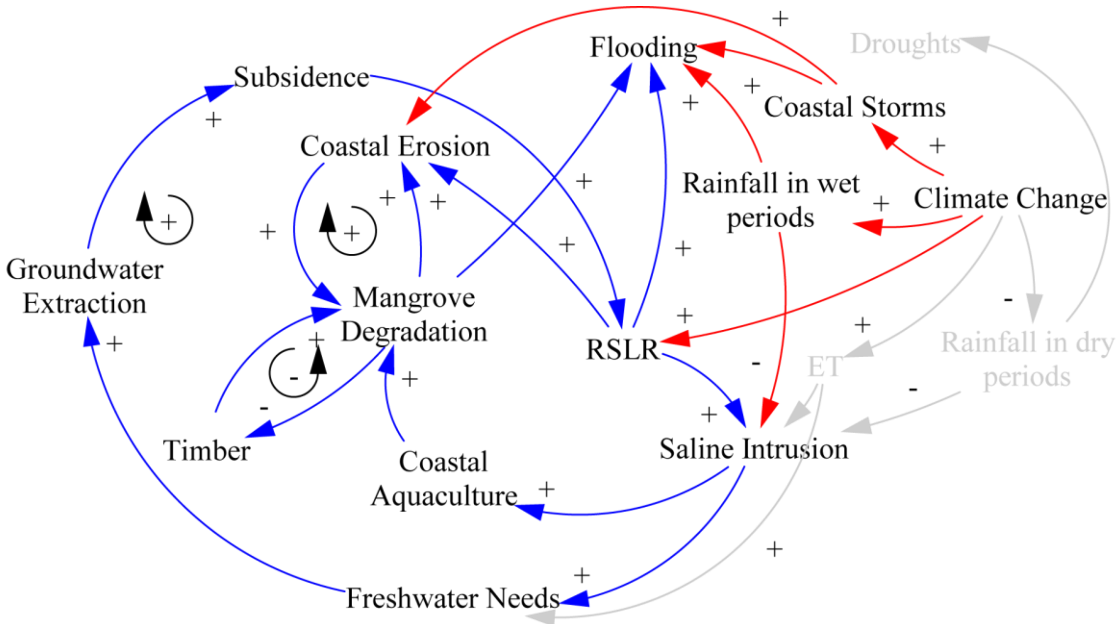


Figure 55: The basic layer of the model, comprising of the climate change drivers and the inner system response. The dominant processes during the wet period are highlighted.

The response of the water system to the impacts of climate change is explained as follows:

- An increase in *salinity intrusion*, especially during the critical dry periods, is propagated as increase in agricultural *freshwater needs*. In the absence of abundant freshwater sources for Ca Mau, these needs are largely covered by *groundwater extraction*, which then aggravates the problem of *land subsidence* and therefore contributes to *RSLR* (see Chapter Drivers of Change). *RSLR* is itself a contributing factor to *flooding* as the coastal zone is more exposed to tidal and wave action and also worsens *salinity intrusion* in the coastal zone. This set of responses marks the first positive (amplifying) loop of the inner system: the link between *salinity intrusion*, *freshwater needs*, *groundwater extraction* and *relative sea level rise*. This loop shows that the current status quo of covering water demands with groundwater is a highly unsustainable, destabilizing factor of the water system.
- An increase in *salinity intrusion* in the coastal zone drives more people to adopt *coastal aquaculture* as a reaction. Coastal aquaculture comes at a cost of a healthy coastal mangrove belt and leads to *degradation of the mangrove ecosystem*. Other human uses, noted as *timber* in the model, lead to further mangrove loss. The effect of *mangrove degradation* is to accelerate *coastal erosion* (see Chapter Mangroves). However, *coastal erosion* itself (e.g. due to other reasons) also leads to *mangrove degradation*; the second amplifying (unstable) loop of the system between these two factors can be thus identified. These interactions highlight the sensitive role of mangroves in the system: the mangrove ecosystem is affected by both human responses and natural processes, and can be easily destabilized by perturbations in the coastal zone, especially in the form of structural coastal erosion.
- A third loop between timber and mangrove degradation can be also identified: an increase in needs for timber leads to further mangrove degradation (+), but a more degraded mangrove system eventually leads to a reduction in timber as there are no more natural resources to take advantage of. This loop enhances mangrove degradation in normal levels but quickly fades out when mangrove degradation becomes critical.

Modeling the policy response and corrective measures

The basic layer that was described in the previous paragraph describes the causes and effects that happen in the system in light of climate change. In light of a fully integrated approach, it is important to model 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 effect of **policy implementation** is modeled as seen in Figure 56, in orange color. The modeling approach is based on a simple principle: certain problem variables of the water system are observed by certain 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 has a shock value to society and is measurable. 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 *timber* uses and *mangrove degradation*, e.g. through legislative measures (National Parks designation, reforestation projects, fines for illegal mangrove cutting etc.)
- Reduction of *coastal aquaculture*, through implementation of spatial policies and coastal protection schemes.
- Reduction of *freshwater needs*, through restrictive legislation about water uses or indirectly, through securing extra freshwater sources, such as rainwater harvesting (RWH).

Figure 56 reveals that the arrow leading from government awareness to actual framework development has a delay (double line). This delayed response can be due to reasons that render decision-making slow and inefficient, such as formalities in the structure of decision-making, bureaucracy and stakeholder overlap and has a strong impact on the *timing* of the policy reaction, as discussed below. The link between local awareness and government awareness is also notable: it depends largely on whether local stakeholders are able to affect or are involved in decision-making. In the case of Ca Mau, local households were found to be able to raise government awareness through their system of communes and through PPC (See chapter Current System- Stakeholders).

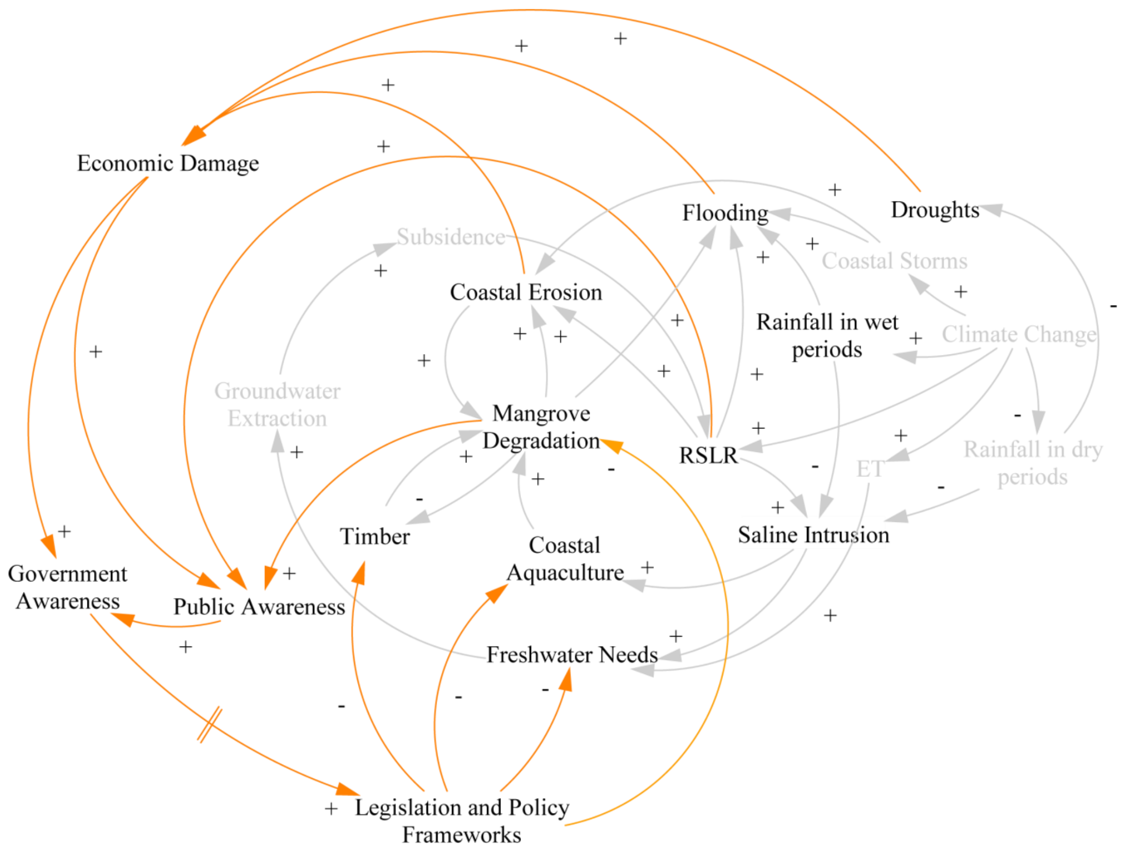


Figure 56: The response of policy-making to problems in the system (in orange). The basic system layer is shown with light grey lines.

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 57), with the aim of further reducing problematic variables in the inner system. A range of measures is possible for Ca Mau, including:

- *Irrigation systems and sluices*, with the aim of reducing *saline intrusion* and also lessening the dependence in unsustainable *freshwater needs*.
- *Coastal protection measures,* with the aim of counteracting structural *coastal erosion*.
- *Dike systems,* usually positioned behind the mangrove belt (see Chapter Current coastal protection measures), with the aim of protecting against *flooding*.

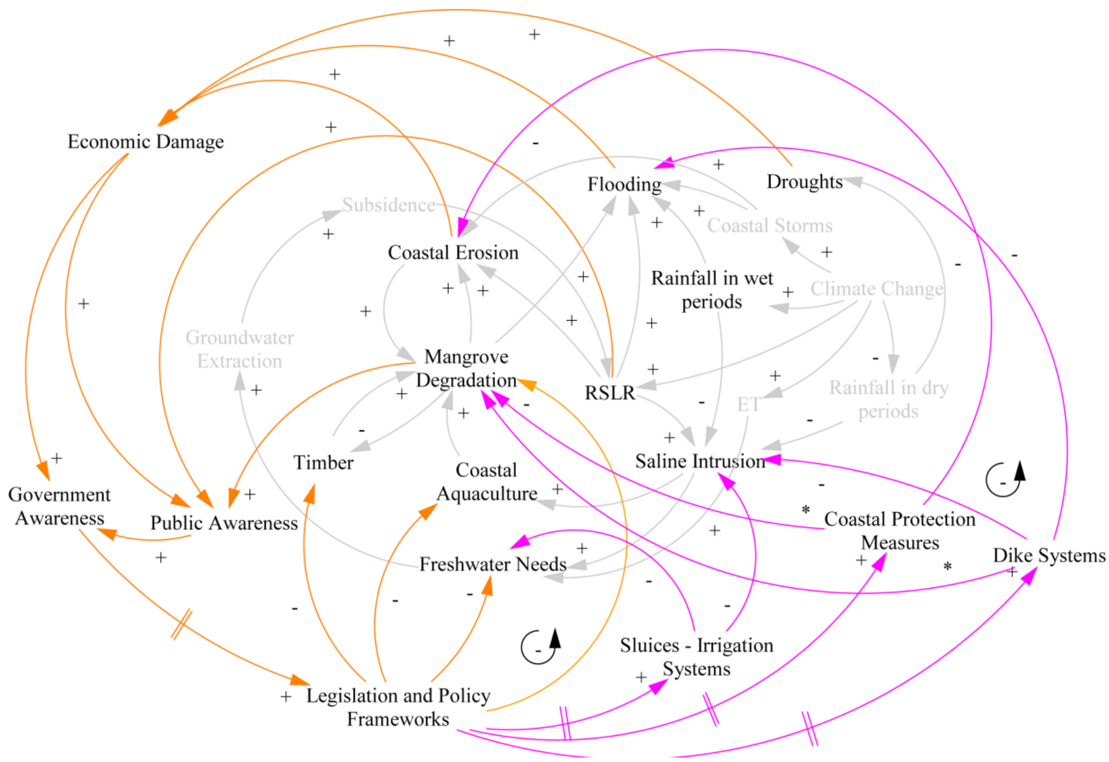


Figure 57: The response of policy-making (orange) including hard/construction protective measures (purple). The basic system layer is shown with light grey lines.

The hard/construction protective measures that are shown in Figure 57 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. Large-scale corrective measures that are effective on the whole system usually stem from policies and are therefore planned based on the approved master plans. There are, however, exceptions in this structure: in case of a sudden event on a local scale, high government awareness might lead to special construction works with the use of the current policy structure, so as to alleviate short-term damage. In that case, dike systems or coastal protection works may be accelerated, as they do not follow the delays of policy. This case of faster response on measures has not been noted in the diagrams, but has been studied in the time scaling of events (see section Time Scales in the SD Model), as a bypass process from government awareness to direct measures, without intermediate need for policy-making.

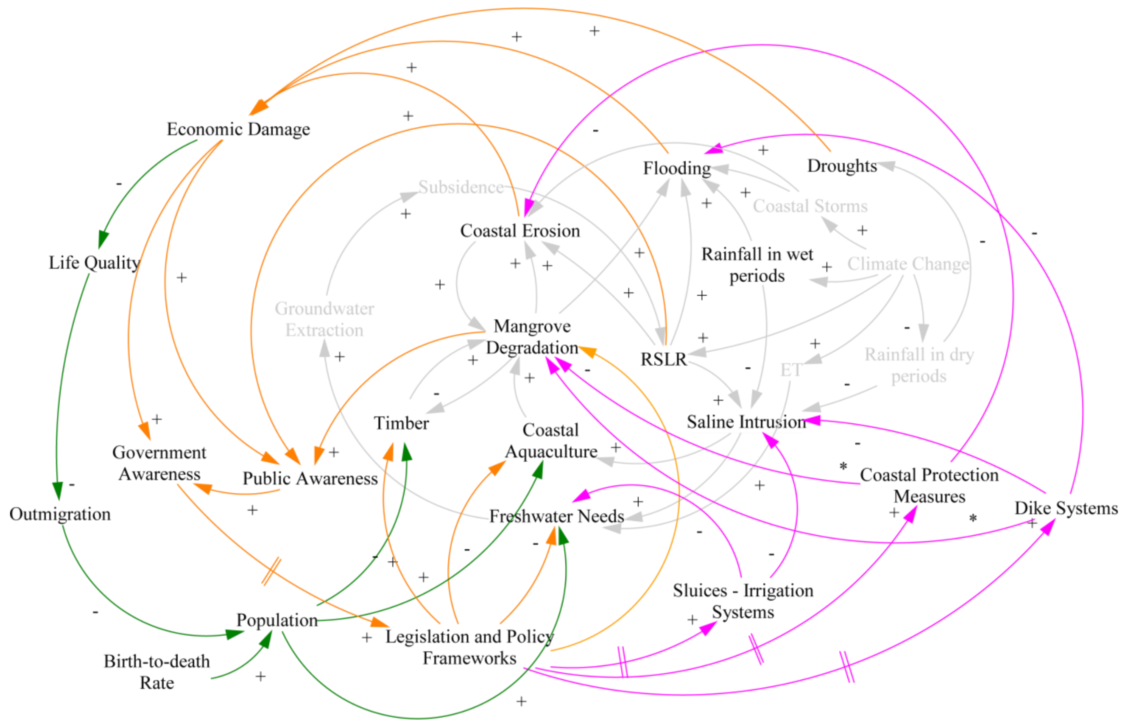
Figure 57 reveals that the response of water governance, both through frameworks and through hard measures, acts as an extensive, negative loop with many recipient variables, aiming at stabilizing the system. The recipient variables are either human (water) uses (e.g. *freshwater needs*, *coastal aquaculture*) or natural processes (e.g. *flooding*, *coastal erosion*) of the inner system.

Development of engineering, protective measures also comes at the cost of significant time delays (see double lines of arrows), driven by both the governance structure and efficiency issues as well as the nature of engineering works (structure of contracting and sub-contracting, time needed for design and construction etc.). What is also particularly interesting is that the measures might have unexpected effects, either positive or negative, targeting other variables apart from the ones they mean to protect. For instance, *coastal dike systems* or *coastal protection measures* might have impacts on *mangrove degradation*, either positive or negative, depending on their function and position. These causal effects are highlighted with a star (*) sign.

Exploring socio-economic drivers – Model with population changes

So far the model has been based on drivers of climate change as initial perturbations. However, as shown in Chapter Drivers of Change, there are key socio-economic drivers that are particularly important. In the context of this study, the effect of **population dynamics and demographics** is explored as a more dynamic aspect of human pressure on the system. In that case, seen in Figure 58, population differences, triggered by either high birth rates or immigration/outmigration, determine the degree of human uses on the system, such as *timber*, *coastal aquaculture* and *freshwater needs*. This layout can be used to visualize scenarios that include changes in demographics

Figure 58: The layer of demographics (green) superimposed on other model layers (inner model in light grey).



The layer of demographics shown in Figure 6 is dependent on one exogenous variable: the *birth rate* that determines the rate of increase for the *population*. Demographics are affected by catastrophic events and the resulting *economic damage*, which results to a loss of *life quality* that further fuels *outmigration*, thus stabilizing *population* in Ca Mau. This subsystem acts as a big, negative (-) loop, in the same way as the *timber-mangrove degradation* loop: pressures on the water system are bound to significantly increase in the beginning if population explodes, but will be then stabilized as the ever-increasing *economic damage* caused by uncontrolled human activity leads people to abandon the area.

The complete system, as described in the afore-mentioned pages, can be summarized as shown in Figure 59: climate and demographic drivers cause the system to change state and create a response, while feedback loops that occur 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. Both policies and measures are characterized by considerable potential delays, meaning that the system has the tendency to evolve unobstructed under the pressure of the drivers even after the policy response has been initiated.

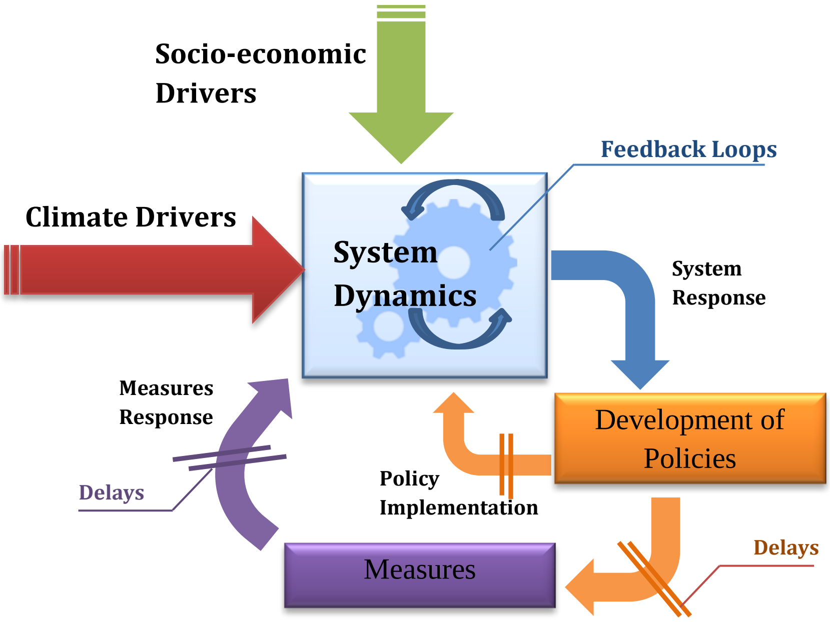


Figure 59: The underlying mechanics behind the casual loop diagrams.

Time Scaling and Performance Measures

Two major aspects that have to be studied after the casual loop diagram formation are:

- The time-scales of individual processes or groups of processes, within the inner system as well as within the outer loops. These time scales are particularly important as they define the speed with which the cause-effect relationships occur in the diagram.
- Defining an array of global system indicators, i.e. performance indexes that can be readily measured to reflect the condition of the system. These indexes have to be directly derived by some of the used variables in the diagrams.

These aspects are used to further elaborate the model relationships and add a quantitative nature to model dynamics. This is an essential next step needed before actually looking for data and converting the qualitative model to a quantitative one. In the context of this study, despite not reaching this step, these indicators need to be studied so as to judge, in more sound terms, the expected response of the system. The assessment on model behavior is still qualitative, albeit based on both qualitative and quantitative information, but now has a better grasp on how different chains of events evolve over time.

Time Scales in the SD Model

Time scales can be mapped on the SD Model presented in Figure 57 and Figure 58, based on knowledge about the coastal zone and the inland water system presented in chapter Current system. The following table depicts a first attempt at defining the time scale of important events or chains of events that are mentioned in the diagram. The list is not exhaustive but is merely indicative of the vast difference in time scales that spans up to one order of magnitude. In some cases, further studies have to be conducted to reach a conclusion about the rate at which the process is happening and its characteristic time scale. With respects to this, estimates based on personal judgement were made in case of lack of data; these estimates are subject to discussion or change. Having a clear view on these time scales is important, as it allows to find critical pathways that lead to system collapse, study the effectiveness of policy response and give a temporal dimension to the SD model.

Table 8: Rates of change and characteristic time scales in events of the SD model.

Class	Name	Indicative Speed	Time Scale for significant development *	Comments	Source
Climate Change	Change in rainfall patterns		30 years	High uncertainty Will be more in effect on longer time scales.	(IPCC, 2014)
	Increase in coastal storms		30-50 years	High uncertainty Will be more in effect on longer time scales.	(IPCC, 2014)
	Climate Change to RSLR	15-16cm in 2030 28-32cm in 2050 (0.9 cm/year)	10-15 years	Moderate uncertainty Gradual rise. Build-up effect as coastal zone becomes more exposed.	(IMHEN, 2011)
Integrated Water System	Coastal Aquaculture - Mangrove Degradation	% of mangrove forests cut within a time interval	5-10 years		(Binh et al., 2005)
	Saline intrusion – Freshwater needs	Conversion of 50,000 ha from rice agriculture to shrimp monoculture within 6 years	4-6 years	Reflects dynamic potential changes in land use.	(Binh et al., 2005)
	Timber to mangrove degradation			Unclear direct contribution of timber to mangrove loss – can be incorporated in other processes (e.g. coastal aquaculture)	(Son et al., 2015)
	Coastal Erosion**	22 – 90 m/year (extreme cases) ~20 m /year (average in erosive areas)			(Stolzenwald, 2013)
	Coastal Erosion to Economic Damage	22 – 90 m/year (extreme cases) ~20 m /year (average in erosive areas)	5-10 years	Land uses are still protected by mangrove belts. Low overall exposure means a latency in accumulation of economic damage from coastal erosion. The adaptive capacity of local population should be also taken into account.	
	Coastal Erosion to Mangrove Degradation	22 – 90 m/year (extreme cases) ~20 m /year (average in erosive areas)	2-4 years for highly erosive areas. up to 10 years for overall degradation.	Rapid mangrove degradation in certain areas. Time scale is calculated based on the average erosion rates, multiplied by the mangrove belt width.	(Stolzenwald, 2013)
	Groundwater Extraction – Subsidence - RSLR	1-4 cm/year			(Erban et al., 2014)
Policy Response	Flooding / Droughts-Economic Damage		Instant – 5 years	The latency in the response of economic damage is due to loss of future working time windows or crop yields.	(DARD, 2014)
	Problems to Public Awareness		5-10 years	Depending on the severity and the level of exposure of local population.	Estimate
	Government Awareness to Legislation and Policy	5 and 10 years Master Planning	5, 10 years	Bound by the governance structure (nature of Master Planning)	Estimate

	Frameworks				
	Government Awareness to Legislation and Policy Frameworks to Measures	Could be further elaborated with a study on past projects.	6-20 years	Horizon bound by structure of governance (e.g. Master-Planning times). Bound by construction times and funding approval.	Estimate
	Government Awareness to Coastal Measures (bypass)	Could be further elaborated with a study on past projects.	1-5 years	Bound by construction times and funding approval.	Estimate
	Public awareness - governmental awareness		1-3 years	There is no formal channel for the public to communicate with the Government. But informally there has to be some sort of communication that could be studied.	Estimate
Population Dynamics	Economic Damage - Quality of Life – Outmigration		<1 year, 15-25 years	Threshold process: Depending on the impact of economic damage there is a slow mode: a large scale (15-25 years) for small increments (e.g. low job opportunities that affect a generation). And a fast mode: <1 year for catastrophic events with large damage, which is less likely.	Estimate
	Population - Coastal Aquaculture / Fresh Water Needs / Timber	Uknown [ha /person] [m^3 / person]	3-7 years	Dramatic changes, such as land use change, may occur in relatively short time intervals.	(Binh et al., 2005)

* Significant development: development that affects the next arrows in line by substantially altering their status, e.g. from coastal erosion to economic damage, significant development can be the time scale of a storm event or several years with structural erosion that lead to considerable damage in the coastal zone.
** When one process is only mentioned (and not a chain of processes), all arrows (factors) leading to it are accounted for and aggregated.

Performance Indexes

The SD model employs a number of variables that are inter-related. Despite the qualitative nature of the model, these variables are not abstract; they can be readily quantified, at an aggregated, effective scale that reflects the status of the whole system, either at an average or at an extreme level (minimum/maximum values). Use of average or maximum/minimum values depends on the context of use of the diagram. For instance, average values are useful to gain insight on overall system evolution, while extreme values are useful for what-if scenarios.

Table 9 shows key performance indexes, directly linked to variables in the SD model, along with their possible measuring units. They can be readily used to obtain a direct, quantitative notion on the status and rates of change of the system. It is noted that multiple performance indexes can be used per variable: for instance, mangrove degradation can be quantified with an array of indices, from the number of species to density and mangrove belt width. This can be desirable, in the case of multi-criteria system evaluation. One also has to distinguish between indicators of (natural or anthropogenic) change (e.g. rate of sea level rise, droughts etc.) and indicators that are internal to the system and show its health status (e.g. mangrove degradation).

Table 9: Indicative performance indexes and their possible measuring units.

Class	Performance Indexes	Possible Units
Climate Change	Rainfall in wet/dry periods	• Average seasonal rainfall • Number of extreme events (storm events surpassing a certain threshold of mm/hr)
	Droughts	• Length of dry spells
	Flooding	• Number of days of inundation/year • Inundation Depth [m]
	RSLR	• Sea Level Rise per year [cm/year], observed e.g. through gauging stations
Integrated Water System	Saline Intrusion	• Salinity levels [mg/L or ppm] and maps • Area with brackish water (water exceeding a certain salinity level) / Total area with water (per season, per year or per multi-annual period)
	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).
	Freshwater Needs	• m^3/year or m^3/season, obtained indirectly through water balance calculations or through simulation of crops and other human needs
	Mangrove Degradation	• Average number of mangrove species in belt • Average mangrove belt width • Area without mangrove belt / Total coastal area (%) • Mangrove belt density (e.g. number of trees/ha) • Coastal areal coverage where mangrove belt exceeds a certain threshold (e.g. as % of total coastal area) • Distribution of coastal mangrove belt width • Mangrove Health Index Status (Chellamani, Singh, & Panigrahy, 2014) • Leaf area index (WIOMSA, 2003)
	Groundwater Extraction	• % of total Freshwater Needs, obtained through in-situ investigation • Decrease in water pressure in aquifer [m]
	Coastal Erosion	• Annual Coastal Retreat [m/year], obtained through satellite data or in-situ investigation
Policy Response	Economic Damage	• Total loss per annum [10^6 $/year], obtained through vulnerability or flood damage studies
	Awareness Levels [public/government]	• Statistical Analysis of Questionnaires (e.g. see Digi.tv, 2012) If left unmeasured, can be a calibration parameter to assess policy delays by studying past projects/master plans.
	Hard Construction Works	• Number of completed projects • Number of approved projects/ budget allocated for works

At this point, it is important to realize the importance of performance indexes on decision planning and stakeholder participation. In the case of Scenario Planning, scenario-makers may identify indexes that lead to critical weakness, system collapse or transformation, either due to their fast or slow build-up and response rate (see Chapter Time Scales in the SD Model). In case the SD model is used as a tool for stakeholder participation, interested stakeholders and actors of the water system may be asked to choose one performance index which has the greatest interest to them. For instance, DARD might be used in irrigation measures and freshwater needs, while Donors like WWF will be interested in mangrove degradation. It is evident that different stakeholders attach and are interested in different variables and thus performance indicators and this has to be taken into account when communicating the system dynamics.

Discussion

Economy in the model

Having a complete economic model in the socio-economic drivers is out of the scope of this project and not treated extensively. Still, certain aspects of economy (such as livelihood – *Quality of Life*) are considered in the population dynamics budget. The economy is considered as an expansion of this demographics layer (green color in Figure 58). A complete economic model would have to include at least the following aspects:

- An exogenous driver (similar to the *Birth Rate* for population dynamics) that "feeds" socio-economic variables, such as livelihood and economic damage. This driver obviously reflects two aspects:
  - The influence of national economic policy and growth to provincial growth and
  - The dependence of regional and national economy to external factors, such as the influence of Foreign Direct Investment (see section Economy).
- The positive influence of economic growth on *Life Quality* (that further dissipates *Outmigration*).
- The influence of economy on human water uses, mainly *Timber* and *Freshwater Needs*. The direct influence could be better represented by the development of *Industry* (e.g. by having an intermediate variable such as level of regional industrialization, see Yefang Huang) and then assessing the impact on Mangrove Resource Use (e.g. Timber industry) and Freshwater Needs (Industrial needs). Note than *Timber* will be only affected in the case of uncontrolled, small-scale industrialization that affects the coastal (mangrove) zone.

Indirect effects of high economic growth such as concentration of capital (through provincial banking) and skilled labor market development that may affect speed of implementation of certain policies or construction works. This link is further enhanced by the activity of exogenous donors (see Chapter Current System- Policy), that accelerate policy implementation and certain protection measures.

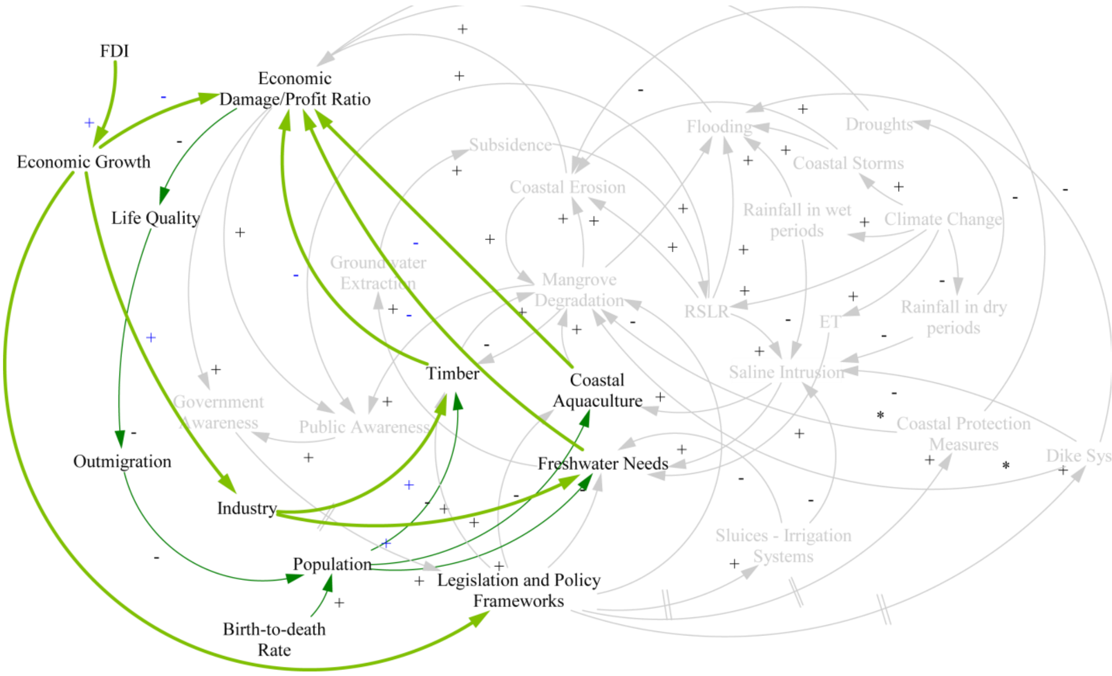


Figure 60: A rough suggestion on fusing economic aspects within the socio-economic dynamics layer.

Figure 60 shows a rough suggestion of how a more elaborate socio-economic model would look, taking into account the afore-mentioned key points. *Economic Damage* is now replaced by *Economic Damage/Profit Ratio*, an index that gets smaller with increased economic activity but is larger once degradation in the system builds in. *FDI (Foreign Direct Investment)* and *Economic Growth* fuel both the *Economic Damage/Profit Ratio* and activity of *Industry* and facilitate, through direct capital or through international collaboration, the development of *Policy Frameworks*. *Industry*, by itself, places additional pressure on human water uses on the system (*Timber*, *Freshwater Needs*), while the uses themselves generate profit so they are linked back to *Economic Damage/Profit Ratio*.

It becomes evident that further assessment of rates of changes, time scales and the exact interaction between variables would require specialized economic studies, on a provincial (e.g. Ca Mau) or regional (e.g. Mekong Delta) level. This would allow more detailed scenarios about economic growth to be developed for Ca Mau. Whether this layer needs to be elaborated or not depends on the interests of the stakeholders (particularly those related to the financial sector) and on the availability of data needed to reach meaningful conclusions. In other words, the added degree of complexity should be counter-balanced by data accumulation. It is noted, at this point, that performance indexes are related to macroeconomics and are not particularly data-intensive, so such an elaboration might be feasible. Examples of indexes for the case of Figure 60 are included in Table 10.

Table 10: Performance Indexes related to Economics.

Class	Performance Indexes	Possible Units
Economics	FDI	• Total Foreign Direct Investment per annum (10^6 $)
	Economic Growth	• Gross Domestic Product (GDP) per year
	Economic Damage/Profit Ratio	• Total loss per annum (10^6 $) / GDP for Ca Mau per annum (10^6 $)
	Industry	• Land cover allocated to industry (%), obtained through remote sensing. • Level of regional industrialization • Index of Industrial Production (IIP) for the province.

The limits of the SD model

The relative importance of performance indicators, described in the previous section, highlights that no single dominant process and measure is universal, but it must be chosen after a process of stakeholder involvement and interaction. With regards to this, the methodological approach that was followed in this study offers flexibility to choose different performance criteria and thus acts as a tool of effective communication among different groups of stakeholders.

The effectiveness of the tools has, however, certain limits (see section Possible advantages and pitfalls). As the complexity of the diagram builds up, effectiveness in communication is reduces. There is, therefore a trade-off between completeness in understanding and clarity/parsimony. In this study and with this trade-off in mind, certain processes such as soil properties, canal erosion and water quality were omitted, in favor of processes related to the coastal zone. This is intentional, having also in mind the interests and scope of GIZ. It would be valuable, however, to include canal erosion and water quality in future variants of this model for Ca Mau: these processes were found to be extensive and significant during the group fieldwork visit. They are expected to cause implications to the system, particularly with respect to inland human uses, in the short- or mid- term future (10-20 years).

It can be argued that the system dynamics diagram has a strong degree of subjectivity – in case multiple users attempt to model a system, the resulting diagrams would probably look different (Winz et al., 2008). This subjectivity is inherent when natural systems are coupled with socio-economic processes and is not necessarily a weakness – as long as there is trust in the model output when it comes from expert judgment. Instead, it offers clarity in the methodology underlying expert judgment, an attribute which is not as clear in many vulnerability studies. If stakeholder participation is an objective, it can be also used as an opportunity, e.g. for stakeholders to outline processes they are interested in, design their own simple version of an SD model in workshops about the water system and compare their perspectives, chosen performance indexes etc.

Despite high subjectivity, resulting in multiple diagrams by different users having different layouts, it should be expected that, in case of good engineering, fundamental underlying mechanisms of the system should remain the same. In the case of diagrams that couple policy responses with processes within the system, the diagram should at least demonstrate the difference in the timing of responses between natural processes, small-scale human pressure and large-scale policy response & master planning. It should also demonstrate destabilizing loops that are expected from the field, e.g. the interplay between mangrove loss and coastal erosion.

Conclusions

The results of applying indicative time scales to chains of processes (see Table 8) can be mapped onto the casual loop diagram (Figure 57) to highlight critical processes that occur faster than others. Figure 60 shows the results of a first mapping attempt of key processes (longer or more uncertain processes like climate change are omitted from this first application). One may observe that many of the **inner system response mechanisms** are abrupt and short-term. In fact, the critical processes in the case of Ca Mau can be assumed to be land use change (defining *coastal aquaculture* and *freshwater needs*), as well as *mangrove degradation*, in combination with *coastal erosion*. Especially coastal erosion and mangrove degradation, which have been studied more extensively, are indeed a rapidly active mechanism in Ca Mau, able to change the status of mangrove forest in small time scales (Stolzenwald, 2013).This means that these processes, if left untreated or in the case of lack of rapid policy responses, may continue unresolved and eventually lead to a collapse in a large part of the system.

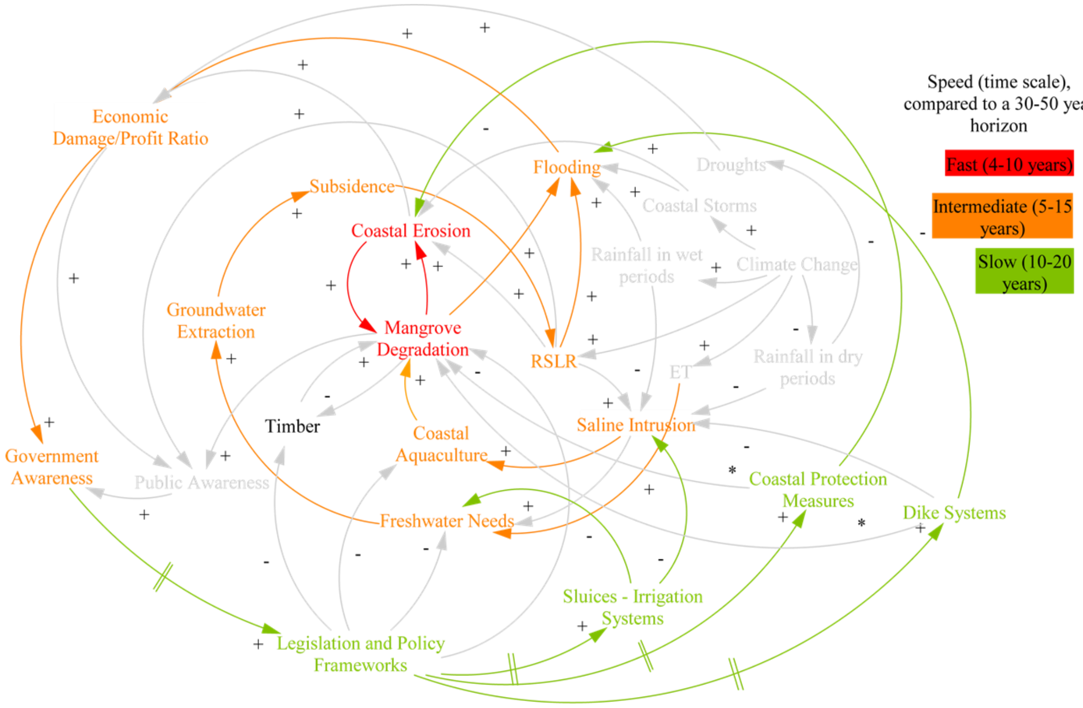


Figure 61: Mapping the time scales of processes onto the loop diagram.

At the same time, one can see that the processes that are able to stabilize the system (the policy-driven stabilizing outer loop) has a significantly lower 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.

Apart from this mapping, a number of more general conclusions can be reached based on the findings of the previous paragraphs:

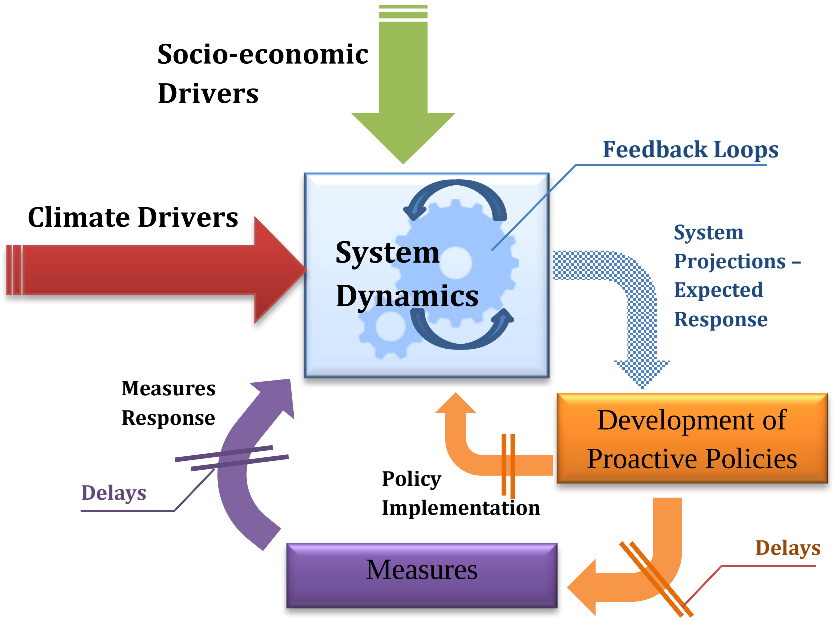
- Human pressures, in general, have significant rates of application in the system and may even surpass natural rate of change. An example is the comparison between the groundwater (GW) and climatic (ASLR) contribution to relative sea level rise (*RSLR*). Likewise, the adaptive rhythm of local population to new conditions (e.g. market conditions and shrimp aquaculture) leads to vast, rapid changes in large areas of the system (Binh et al., 2005; Son et al., 2015). The human factor is as equal an important factor as climate change, and therefore cannot be omitted or oversimplified in studies about the water system.
- Climate change drivers have a gradually additive effect as years pass-by, thus worsening existing challenges and problems of the inner system. With regard to impact over time, two mechanisms can be noted: steady structural changes (such as SLR), which have a progressive effect on awareness and economic damage, and catastrophic events, such as storms, which have a high return period but, when initiated, have a profound effect on economic damage, quality of life and awareness, thus driving rapid responses in terms of policy, measures and population dynamics.
- Most mechanisms have a direct (continuous) cause-effect relationship with steady rates, while others exhibit a threshold effect and present a challenge to further modeling (e.g. government

and public awareness show rapid increase after economic damage reaches a critical level). There are cases where some mechanisms display a duality in characteristic time scales, such as in the case of Economic Damage – Quality of Life – Outmigration (see Table 8).

- The same duality applies in policy. While urgent measures might take from 1-5 years to be implemented and active, depending on type of measure, funding availability and construction times, policy implementation is generally (and in non-catastrophic scenarios) bound by the master planning structure. This means that if something occurs during the time period when a Master Plan is active, 5 or even 10 years are needed to change the Master Plan philosophy and adapt that policy to the new challenge. This imposes a hard constraint and a long delay on policy measures: they effectively need more than 5 years to yield fruitful results. Fundamental policy changes need more than a decade to have a strong effect in the system: this is the slow, delayed policy response.
- Apart from the slow policy response, there is one more gear of policy implementation, based on the shock value of a catastrophe. In case of urgent, catastrophic events that lead to great economic damage, severe implications to people in the system along with high level of awareness dictate an immediate policy response for alleviation. This results in quick implementation of measures. Policy response, similarly to emigration dynamics, displays characteristics of a threshold response with two characteristics speeds. An example of fast response in the Netherlands was during the 1953 flood events in Zeeland (North Sea Flood), which resulted in extensive property damage and loss of life (1,836 deaths). As a result, major studies were rapidly initiated to upgrade coastal defenses in both the UK and the Netherlands (NL), resulting in ambitious flood defense systems (Delta Works for the NL) which were conceived and constructed over the next years.

The complete diagram, seen in Figure 58 and Figure 59, highlights another interesting aspect of Policy: the stabilizing loop of Policy can be initiated as a feedback loop (meaning it waits for actual deviations from the desired state to be initiated) or as a feed forward loop (meaning it can be initiated based on an expected/projected response). In the first case, the policies are reactive, which is the usual case. In the latter case, the policies are proactive, thus taking place before real problems start to accumulate. In the case of Ca Mau, where the policy response is delayed and slow, the philosophy of proactive policy (see Figure) can be vital in protecting the system and in avoiding its collapse

Figure 62: The proactive policy response, based on the expected response of the system.



In the simplified case of proactive policy shown in Figure 62, the policy loop now starts at t=0 (start of simulation) and does not need to wait for climate and socio-economic changes to propagate in the system. It can therefore stabilize the system before inner, short-term loops run a lot of times and bring the system close to major degradation.

Obviously, the effectiveness of proactive policies highly depends on the uncertainty of projections and the credibility of our perception on future system response. In the usual case of long-term horizons (such as in Master Planning), high uncertainty about the future strongly limits the array of proactive measures that can be implemented and, thus, the allocated budget. Still, there is a number of low-cost, no regret options that could be particularly effective such as:

- Soft methods of coastal protection with combined mangrove restoration.
- Monitoring and evaluation of current works and supportive/complementary measures to them.
- Stricter policies on mangrove restoration, national park designation.
- Effective mapping of the changes in the total system per year (i.e. through remote sensing).
- Stakeholder update on the integrated system status.

These measures do not directly stabilize the system, but can potentially “speed up” the reactive policy response in case there is a need to implement it. In the context of proactive measures, short-term potentially unstable aspects of the system, such as the mangrove belt and the groundwater reserves, should be treated first. Long-term planning and adaptation against climate change can then follow, based on the available funds and the exogenous economic prospects.

Weak Spots and Gaps in Research

The model formulation, along with the mapping of time-scaling and quantifiable information done for its processes, allows finding out ‘weak spots’, i.e. arrows where information is scarce and more research is needed. With regards to this, the following links are mentioned as hot spots of future research:

- The loop between mangrove degradation – coastal erosion – further mangrove erosion could be further studied, in terms of acceleration of erosion rates (when the mangrove belt is lost) or prediction of the time when the belt is about to fail. The response of the fully exposed coast needs also to be taken into account.

- The response of policy shows interesting multi-scaling effects and links with the governance structure, especially with Donor involvement (funding) and Master Planning. A review of past case studies of policy response is thus needed for Vietnam, especially related to large-scale coastal projects and irrigation planning. Elements of planning (in-)flexibility and adaptation to change need also to be taken into account. Such a study could also focus in the mechanism of 'fast' response – i.e. policy response after catastrophes, with typhoon Linda being a primer for study.
- There are arrows between measures (dikes and coastal protection works) and mangrove degradation, shown in Figure 57, that have a (*) sign. This means that these measures might have a positive (+) or negative (-) effect on mangroves, depending on their type, design and placement. The interplay between hard measures and mangrove is a prime research topic and should be studied extensively in the case of Ca Mau; measures should be supportive to a richer mangrove belt, not restrictive. Otherwise, the reinforcing-stabilizing loop of policy might turn into an even greater long-term threat: measures that are called to protect from flooding might turn to even put more pressure to natural flood protection and ecosystem services.

These indicative gaps in research, along with the experience obtained from the literature study (Chapter Current System Status) and fieldwork (Chapter Fieldwork) offer the basis for the Case Studies that are demonstrated in the Chapter Research proposals.

6

Scenarios

Introduction

In the previous chapter the system dynamics has explained the relationships in the water management – coastal management system, which is used to involve stakeholders and to show them how they can influence the system now and in the future. The future state of the system is highly uncertain and therefor it is chosen to explore possible futures with a scenario building approach. With insight in the interesting, probable and important scenarios and involvement of stakeholders, knowledge based feed forward interaction with the system is possible (see Chapter Model Formulation). Figure 63 shows how the system can evolve in the time, and that the decisions that are made now will determine the future scenario the system will end up. Among these future states, there is also an inevitable part of the future which will happen no matter what kind of strategy is used. The strategy space indicates the total possible space where the system can end up.

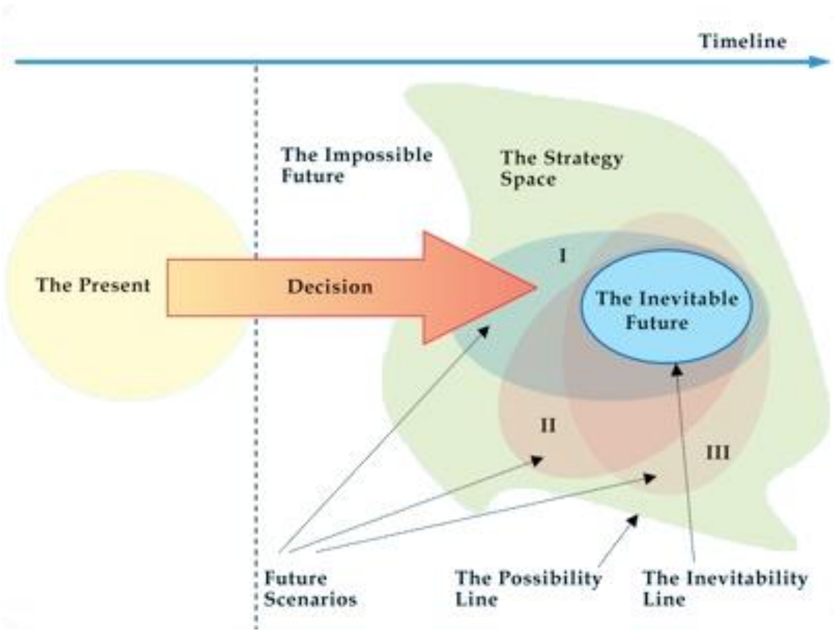
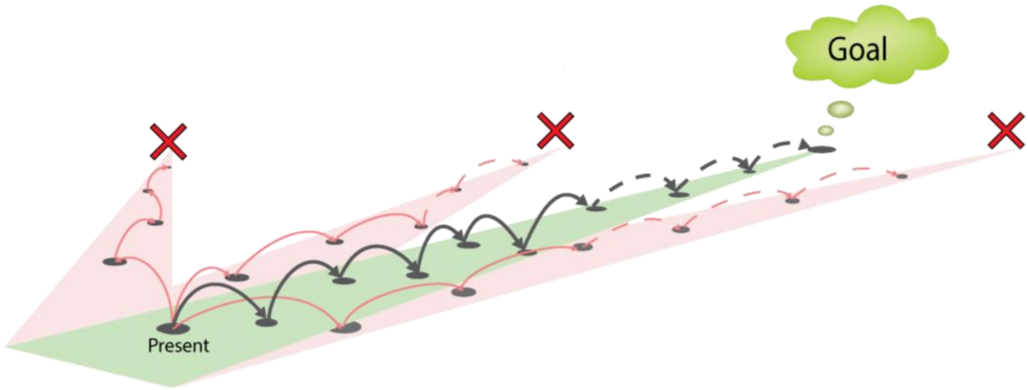


Figure 63: Evolving state of the system

For the formulation of scenarios a future forward method is used (see Figure 64). It is based on an analysis of the driving forces of the system and from there plausible futures can be generated (Ratcliffe, 2000). The drivers of change (see Chapter Drivers of Change) drive the system into different pathways to possible scenarios for the province of Ca Mau. This is indicated with the green and red pathways to the futures in Figure 64. The different pathways can be taken via taking different measures. From this picture it becomes clear that stakeholder involvement is very important. The stakeholders should be aware of the possible scenarios for the system. It is important for them to have a common desired future state of the system together with a common strategy (scenario) to reach this future state, otherwise the efforts of the separated stakeholders can hinder each other, resulting in inefficient measures and policy. A good consultation of the stakeholder analysis is therefore needed (see Chapter Stakeholder analysis).

The aim of the scenario approach is that decision makers can elaborate a strategy to apply on the system of Ca Mau. The timespan that is used for the scenarios is 30-50 years (see Chapter Introduction).

Figure 64: Future Forward Approach Scenario Building.



Scenario Building

Scenarios can be built in many ways, the approach chosen here combines some of the approaches used in literature. The scenarios are based on different scenarios for the drivers of change. The different scenarios for each driver specific are explained under “certainties and uncertainties”. In literature it is said that scenarios can be generally divided up into four dimensions (Ratcliffe, 2000) , which are very different. In order to create different future scenarios for the province of Ca Mau, these dimensions are taken into account. For 3 of the four dimensions, scenarios are created by making a storyline, taking into account the specific scenarios for the most important drivers of change and their key aspects.

In the previous chapters, the drivers of change are analysed elaborately (Chapter Driver of Change). The aspects influenced by the drivers of change are summed in Table 11, these can also be found from the system dynamics diagram (Chapter Model Formulation). In the scenario building, different developments of these aspects are taken into account. But before going to the storylines, first the certainty and uncertainty for the aspects of the drivers of change are analysed.

Table 11: Key aspects per driver from the SD diagram

Socio – Economic driver	Policy driver	Climate Change driver
Population growth	Government awareness	Sea level rise
Migration	Public and governmental transparency	Rainfall patterns
Public awareness	Integration of policies	Increased storm events
Economic damage	Investments in measures	
Industrialization		
Donor influence		
Foreign Direct Investments		

Certainties and Uncertainties

From the system dynamics diagram (Chapter Model Formulation) it can be concluded that the system status is mainly influenced by human pressures on the system, due to fast responses of the system to population growth and speeding up of processes by the economy. The effectiveness of policy is able, via measures, to counteract these negative loops (see this chapter for further elaboration). From these conclusions of the previous chapter, it can be said that the socio-economic and policy driver are the two most important drivers, steering the system into a certain scenario.

The climate change driver puts serious threats on the system (see Chapter Vulnerability) and leads the system into the direction of a collapse scenario where the problems are very severe (see chapter Model Formulation). This is considered to be a slow and steady process, compared with the human induced processes of land change and industrialization. For the coming 30-50 years the climate change models from the IPCC advises to take into account the highest scenario (see chapter Drivers of Change) as it is the most likely scenario. With this knowledge, the climate change driver is assumed to be the most certain one of all three drivers.

The socio-economic development on the other hand is very uncertain. For the following scenarios it is assumed that the socio-economic driver is determined by the economics of the whole of Vietnam and Asia and external factors as donors influence and FDI (Chapter Drivers of Change). This makes the economic development very uncertain and hard to predict. The population growth and migration is assumed highly dependent on economy and livelihood, in such that if these factors in Ca Mau improve, the population will grow as well.

The development of the policy is the third very important driver, which can stabilize the system and is influenced by (part of) the stakeholder themselves. Therefore, stakeholder involvement is a key aspect in the process to drive the system into the right direction. The future development and state of the policy are considered as uncertain, because the strategy chosen by the stakeholders is highly dependent on the vision of the decision makers on the system.

Scenario Dimensions

Generally, scenarios can be divided into four dimensions (Ratcliffe , 2000), Table 12. These four scenarios are used to create scenarios for the system of Ca Mau.

	Dimensions scenario's	Explanation
1	Status quo	Present situation will continue in future
2	Collapse	System cannot continue which lead to an internal decay or crash
3	Positive Transformation	Fundamental changes
4	Steady State	Return to a previous time which was more quiet

Table 12: Four most common scenario's. Red: scenarios with negative consequences Green: scenarios with positive consequences (Ratcliffe , 2000)

The status quo scenario is a continuation of the present situation in the future, it is also known as "more of the same". The other scenarios are based on a future where the status deviates from this direction under the influence of some external triggers. When the triggers are negative this can steer the current situation into a collapse scenario. When the triggers are leading to positive consequences, the system is steered to a positive transformation scenario in which the problem gets less. In a collapse scenario the problems in the system are very big, and the system cannot function anymore as it is functioning now. Finally, the fourth most common scenario describes the possible scenario, where the system returns to a previous state which was more stable. As can be seen in Figure 65, it is important to steer the system in the scenario to end up with a situation which decreases the current problem (Status Quo), and prevent the collapse scenario.

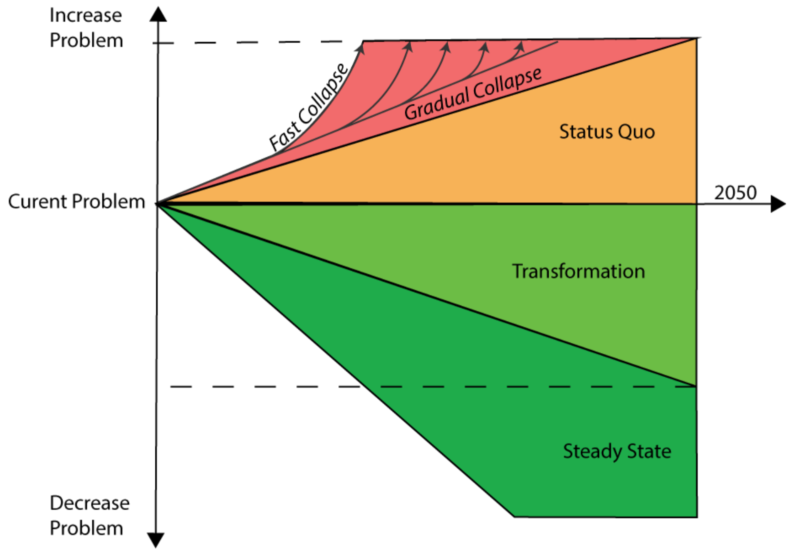


Figure 65: 4 different dimensions in scenario building

In this report, only the scenario category 1, 2 and 3 will be elaborated (below), because the steady state scenario is assumed to be unrealistic because due to proceeding consequences of climate change the problem will stay and even increase.

Scenario 1 - Status Quo

In status quo scenario the current situation will proceed the coming 30-50 years. This results in a scenario where the government is fragmented and provincial decision makers have to deal with non-integrated master plans every 5-10 years. The bureaucracy is high, which slows down the policy making and thus the implementation of measures against current problems. This bureaucracy and slow decision making will lead to an ineffective way of money spending (due to corruption). The implemented measures (coastal protection, irrigation system) are not well maintained and are not well evaluated with a lack of good alternatives as consequence. There is also a preference in the policy to implement hard measures which have proven itself in some locations, over soft experimental measures, which are could be more sustainable (under the condition that there is a donor building the hard measure). At last, the cooperation of donors mainly determines what measures are implemented, what can lead to a gap between the integration of governmental plans, and even more fragmentation in policies. The economy will continue with a moderate growth, an increase in Foreign Direct Investments and a decrease in donor help is expected. It is expected that there is a growing population, but the growth is low compared to the rest of the country. Strong urbanization around the city Ca Mau will proceed, without good spatial planning. The industry is lacking behind compared to the rest of the country due to the state of the infrastructure and the big distance from big export cities as HCMC.

Scenario 2 - Collapse

For the collapse scenario we consider two possible ways to end up in this scenario. One being a collapse as a result of a gradual change of the system, where no accurate measures have been taken to solve problems and avoid the collapse scenario. The second one is a collapse scenario due to a sudden event/catastrophe that destroys (part of) the system. The distinction between these two collapse scenarios is made because both scenarios will have different consequences for the system. The collapse is caused by triggers that can steer the system in the direction of a collapse. The summation of triggers at the same time, or fast after each other, determines the potential of the system to develop into a collapse scenario (both fast and gradual collapse). Since there are many possibilities to end up in the collapse scenario, the triggers that lead to a collapse scenario will mainly be discussed.

2 a. Fast Collapse

As above been said, for the fast collapse scenario it is assumed that there is a large influence from one trigger, or several triggers add up at the same time. Triggers which can cause such a fast change of the system are major nature events which can destroy the system. Due to climate change the chance for big storms increases and when such a storm happens this can destroy a lot of the remaining mangroves and inundates big areas of land with as consequence loss of crops, life's, houses and a huge damage for the economy. A second major nature events can be the fast spread of a big disease in the agri- and/or aqua cultural sector can also have a major impact on the economy of Ca Mau, because the economy is currently based on aquaculture and agriculture and loss of food due to diseases has therefore a major impact on the economy, food security and the livelihood. It is assumed that the policy and management of the water system is not adapted to possible the collapse on beforehand, and therefore these events have severe consequences leading to a collapse of the system. In the further analysis, we will only focus on the big flood event possibility.

2 b. Gradual Collapse

The gradual collapse is defined as the transition zone between the collapse and status quo scenario in Figure 65. As a result, the problems will keep increasing, and can cause a collapse of (part of) the system. There are again multiple ways for the system to collapse, important triggers that steer the system in this direction are:

- Increase of inefficient investment (corruption) and bureaucracy;

  The political state of the system will hinder the establishment of (effective) measures which slows down the process of improvement of the system. As a consequence the policy cannot influence the physical processes adequately, because the physical processes go much faster (see Chapter Model Formulation), this will cause problems which can lead to a collapse of the system.
- Unsustainable industrialization;

  In the scenario that the process of industrialization goes too fast, it will create unsustainable industrialization. This will make multiple sectors, like economy and environment of the system vulnerable due to competition of industries. Also the increase in industrialization can cause severe pollution which must be bounded by effective policy which is yet not the case yet. In the case for Ca Mau this would be a likely scenario, since the industries are growing. Especially quantity of shrimp factories is high and this could in the future lead to vulnerability of the environment and economy.
- Extreme economic growth;

  High economic growth leads to an increase in population and capital (see Certainties and Uncertainties). This will put more pressure on the resources of Ca Mau, and extreme economic growth can even cause so much pressure, that without efficient investment of the available capital it could lead to a collapse.
- Low economic growth;

  With a low economic growth there is less capital available to invest in measures, (which makes the system more vulnerable for floods and erosion). This leads to lower life quality in the form of a less safe livelihood, and an outmigration of the population to other provinces. As a result the economy will decrease even more.

Scenario 3 - Positive Transformation

The future state of the system could also be steered into a positive direction as a result of triggers with more positive consequences, reducing the problems. These triggers are:

- Integration of the public authorities;

  Integration and communication between different departments and provinces of the government will result in more integrated master planning, spatial planning and planning of measures for the provinces.
- Efficient investment and adequate response on the system due to governmental integration (less corruption);

  With an integrated planning (the above item) the chances are higher that investments for measures can be made more efficient and effectively. Secondly investments in application of research in the field and sustainable improvement of technologies will help local farmers to upgrade their harvests. Lastly, investments will also be needed to raise awareness and knowledge of the farmers, which will increase the sustainable use of resources.
- Medium to high economic growth;

  For the transformation scenario, investments need to be made, which means that capital needs to be available. Therefor a medium to high economic growth is necessary for the transformation scenarios.

In past 30 years, Vietnam has gone already through big steps in a short time. Under the condition that the triggers for positive change for a transformation are there, this gives confidence in the likeliness of this type of scenario.

There are many different possibilities how the system will look in the future considering the transformation scenario. The direction of the system is highly dependent on choices of the stakeholders. Two possible scenarios will be analyzed in this case. In the first scenario the focus will be on acceptance of saline intrusion and focusing on the shrimp farming. The second scenario takes into account the maintenance of the fresh water resources where rice and shrimp cultivation go together.

3 a. Saline adaptive scenario

With focus on how to cope with the saline environment, the following system properties could be identified for the future state:

- The agricultural rice land will be adapted to the salinity, and in the dry season all rice ponds are used for shrimp farming. This will result in a transition from rice farmers to rice/shrimp farmers;
- There is an increase in farmers executing intensive shrimp farms;
- The irrigation system is adapted to function well for the shrimp aquaculture, this means it is more focused on drainage and water quality in the whole of canals;
- The industry will be focused on processing and production of shrimp.

3 b. Fresh resources scenario

When the focus of the policy will mainly be on the resources of freshwater for the dry season, the following system properties could be identified for the future state:

- There is enough fresh water due to a well maintained and upgraded culvert system and other improvements for fresh water such as a working Quan Lo –Phung Hiep canal connection from the Bassac River which brings fresh water to the northern part of the province;
- Farmers can cultivate rice and fresh water fish in the dry season;
- Rice-shrimp farming is possible in the (large) parts of the province where the culvert system doesn't safe enough fresh water;
- Intensive shrimp farming will not be developed extensively.

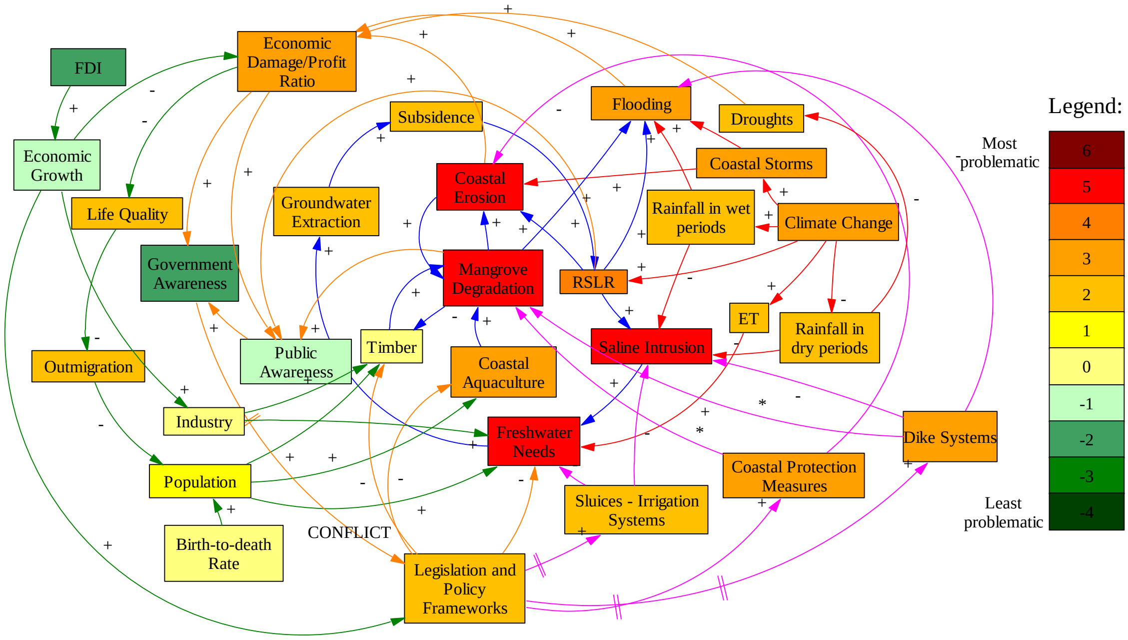
Performance of the scenarios

The performances of the possible future scenarios are analyzed by using the system dynamics diagram from the Chapter Model Formulation. The system diagram is considered for each of the future scenarios. In the diagram, colors are assigned for the performance different aspects of the system. The performance of each aspect is compared to the current state of the problem per aspect. Red colors are used for aspects that are problematic, where the darkest red color indicates the most problematic aspect compared with the current state of the system. Green colors are indicated for aspects that are no problem, with dark green as least problematic (see Figure 66). Starting from the problems of the drivers of change (aspects Economic growth and Legislation and Policy implementation), the influence can be seen on all the aspects in the system.

The climate change driver, together with the human pressures on the system puts the system in serious threats, where the human pressure speeds up the processes. The problems considered due to climate change (Coastal storms, Rainfall in wet periods, Evapotranspiration and Rainfall in dry periods) are kept the same in each scenario (red 4) but the fast collapse scenario. In this scenario the impact of the occurrence of a strong coastal storm will be analyzed in the fast collapse scenario where the storm gets very problematic (red 6). As a result, differences between the scenarios will mainly be caused by different socio-economic (FDI, Economic Growth) and political (Legislation and Policy Frameworks) situations.

Status Quo Scenario

Figure 66: Performance in the future in case of a Status Quo Scenario



In the status quo there is a medium economic growth in Vietnam, this economic growth will however not result in a smaller damage/profit ratio for the province of Ca Mau because the problems with severe probability of flooding, coastal erosion and draughts will only increase in the future, increasing the damage. In the status quo, the industry will keep lagging behind the national industry. The economic damage ratio affects the life quality and will increase the outmigration to other provinces, decreasing the population of Ca Mau. However, this has to be seen as a threshold process (see Chapter Model formulation), and only will have significant effects if the threshold is surpassed, which will not be the case for the Status Quo scenario.

The policy in the status quo scenario is getting more efficient but the reactive character of policy will not be able to counteract the physical processes with effective measures (see Chapter Model formulation). This policy will result eventually in more mangrove degradation and coastal erosion more freshwater needs and more saline intrusion in the future, which are the critical processes in this scenario. Secondly, it is assumed that the fresh water needs which are problematic, will increase the groundwater extraction as well, resulting in increased land subsidence.

The awareness of the government is expected to improve in the future and the public awareness follows after that. In the dynamics of the system, the raise of awareness should lead to more effective policy, but due to continuing bureaucracy this interaction will be hindered, resulting in a delay of the adaptation in policy and legislation. This is considered to be a conflict in the System Dynamics diagram, see Figure 66.

Collapse Scenario

For both collapse scenarios an inefficient policy, with less and also ineffective investments in measures, are projected. Resulting in a lack of adaption to the effects of climate change. The consequence is a system which is very vulnerable for the pressures from climate change and human behavior (Population and Industry). Increased mangrove degradation, coastal erosion, and bad maintained dike systems will increase the chance of flooding. The consequences are economic damage resulting in more economic damage, increasing the Economic Damage/Profit ratio. This economic damage has its effects on the life quality and population of the province of Ca Mau.

Fast Collapse

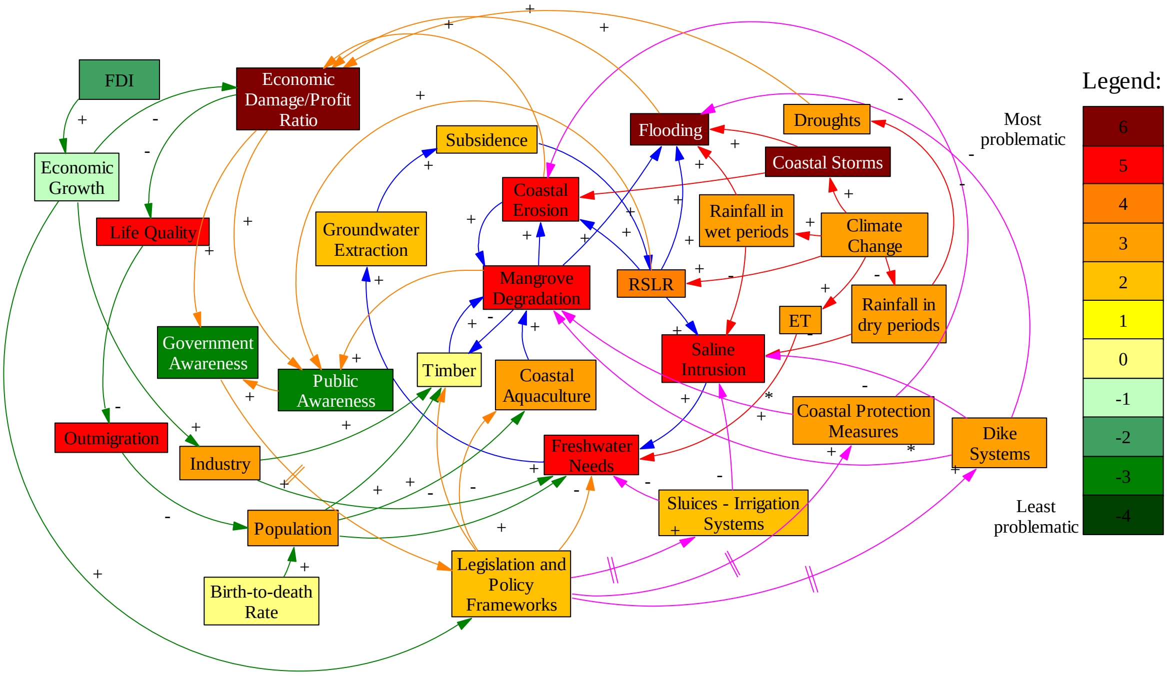


Figure 67: Performance of the Fast Collapse Scenario.

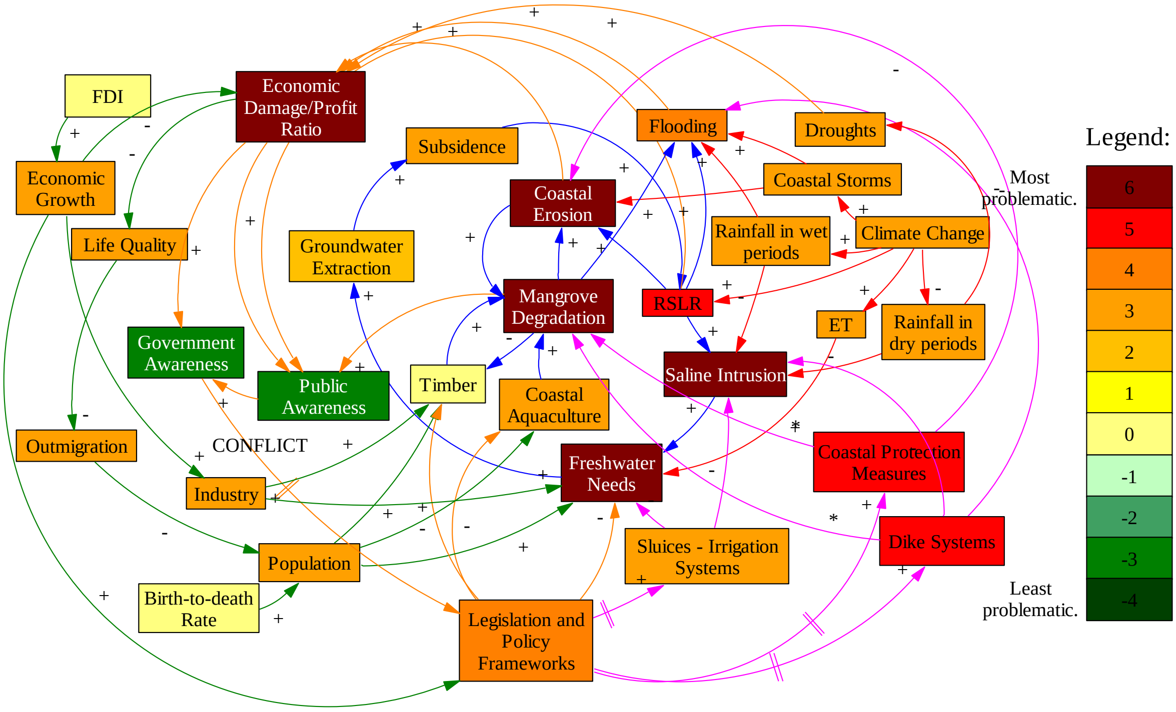
A big storm is considered here as the trigger for the fast collapse (indicated as red 5). Together with the continued mangrove degradation this big coastal storm will flood a large area with severe consequences of economic damage (indicated as red 6).

This scenario can occur with different economic growth and in any state of the system. It is dependent on the state of protection of the province against severe storms, which can be different due to differences in applied policies. The combination of the economic growth and the resistance to the consequences of a big storm will determine the Economic Damage/Profit ratio. For this collapse scenario, where we assume that the resistance to big storms is at current state, the resistance to consequences of a big storm is low (see Status Quo scenario). This results in a high damage/profit ratio (red 6). Hereby the life quality is drastically reduced and as a consequence outmigration and population decrease (red 3) will occur. The fresh water needs and subsidence rates will be the same as indicated in the status quo scenario because there will be less people, but due to the flood there will be less fresh water available as well.

The feedback to the public and governmental awareness in this scenario is very strong, which gives high potential to speed up the effectiveness and efficiency of policy making after the occurrence of a fast collapse. This could even lead to a positive transformation of the system after the collapse (under certain conditions) . In the Netherlands this happened after the storm of 1953 after which the government was more aware of the problem and more money became available for protection against the sea and rivers.

Gradual Collapse

Figure 68: Performance of the Gradually Collapse Scenario.



The gradual collapse analyzed here is based on the situation for low economic growth which results in less capital for investments. Therefor slow adaptation to the physical problems is expected. These problems (mangrove degradation, saline intrusion, coastal erosion and fresh water shortage) will only accelerate and the fast inner physical-human pressure loop will not be stabilized, resulting in a high economic damage/profit ratio (red 6). This again leads to a decrease in life quality and a decrease in population for Ca Mau.

The second amplified problem is the problem of saline intrusion; due to bad maintained sluice systems (and relative sea level rise) this will increase the freshwater needs (red 6). Without good legislation, there will be a serious threat of subsidence (red 4) due to groundwater pumping to compensate the need for fresh water.

Worst case scenario

In the worst case collapse scenario (either fast or gradual) the mangrove belt could be destroyed completely. This could be considered as a gradual collapse, where the government didn't take any effective measures to protect the mangrove belt. The consequences of the totally degraded mangrove belt (more flooding, coastal erosion resulting in much economic damage following Figure 68), will be severe and there will be much hard constructions and huge investments needed to restore the coastal erosion and protect the land from flooding. This process can be seen as a threshold process, in which there is no (or at least a very hard and expensive) way back.

Transformation

For both transformation scenarios hold:

- Governmental Awareness stimulates the integrated, effective and efficient legislation and policy. This results in less problems for land use planning such as timber, coastal aquaculture and fresh water needs. Also the measures included in the diagram (Irrigation system, Coastal Protection Measures, Dike systems) will be associated with less problems than in the status quo scenario, which impacts coastal erosion, floods and droughts;
  The difference between the scenarios is in which part the emphasis of the measures is placed.
- For both scenarios a mid to high economic growth is assumed, which results in a better life quality, and less out migration, and thus less problems with the population. The population will grow steadily, in proportion to the economic growth, and not causing big problems for the system;
- The consequences of climate change will be bounded as result of integrated, effective and efficient measures.

Saline adaptive scenario

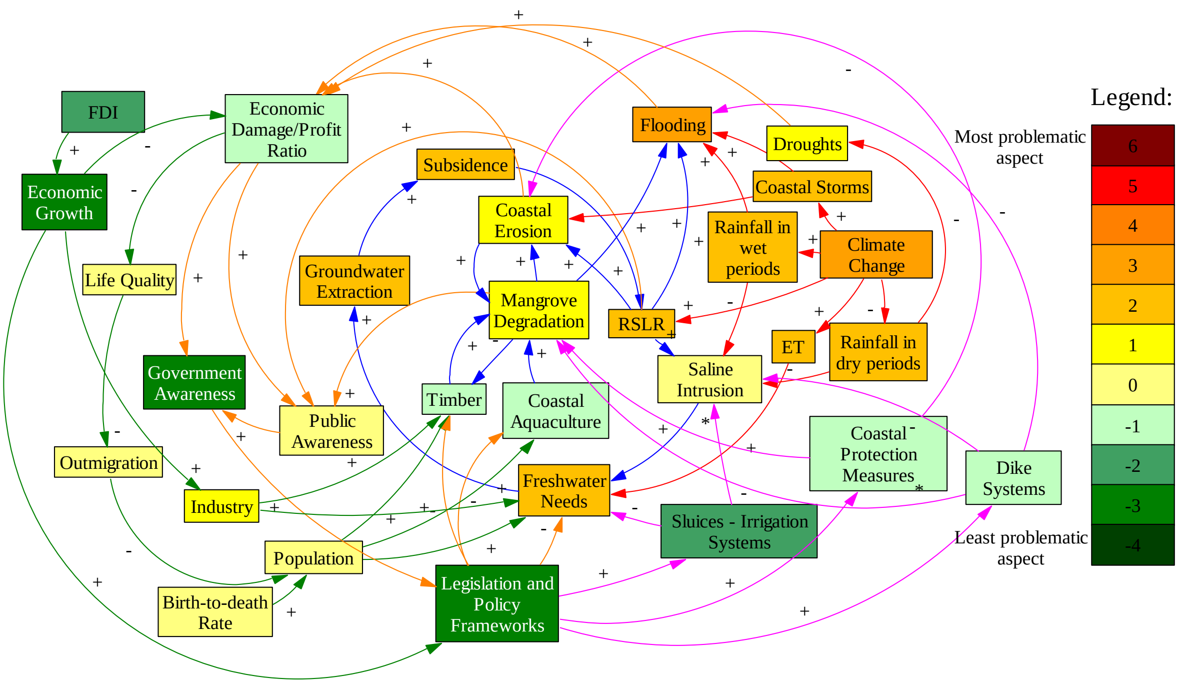
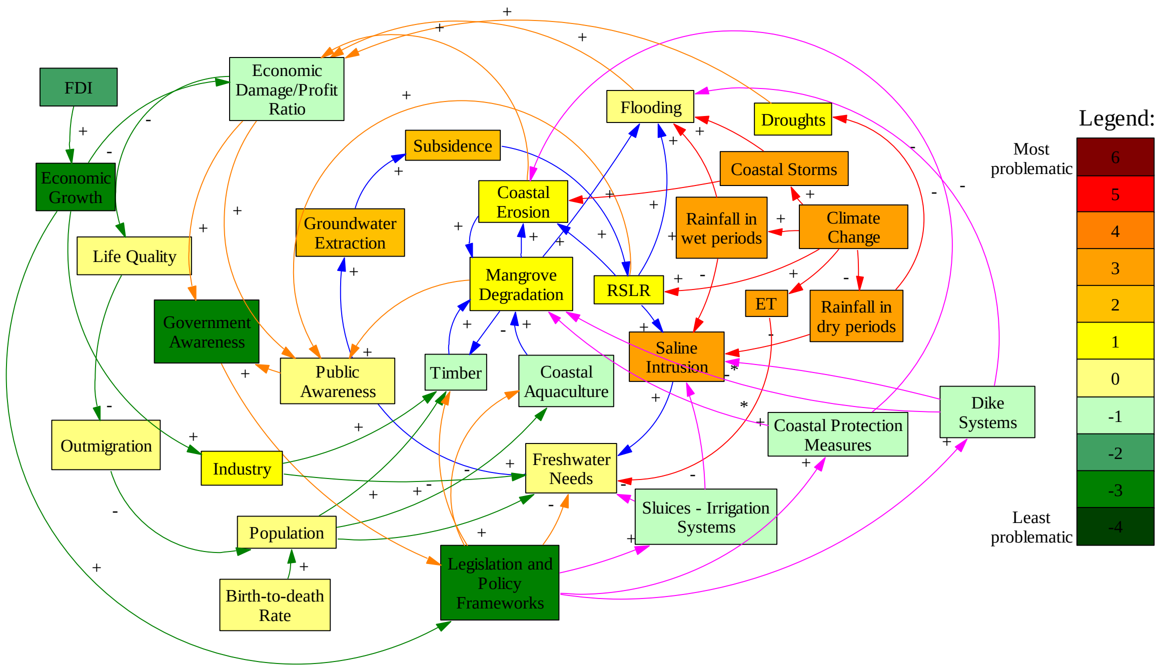


Figure 69: System status in Saline adaptive scenario; Green boxes indicate that the problem is less than in the current state, red boxes indicate that the index will have more problems.

In this scenario the policy is mainly focused on coastal protection measures, dike system and land use planning (timber, coastal aquaculture and fresh water needs). The maintenance of the irrigation system is not feasible anymore and saline water in the fresh water areas is accepted and the people can cope with the saline intrusion. Therefore the saline intrusion problem becomes less in the diagram (neutral 0). Together with increasing industrialization, (more shrimp factories expected), the intensive shrimp farming will still put pressures on the fresh water needs (red 2). The legislation on shrimp farms should bound the fresh water needs and focus on finding sustainable resources is important. Until sustainable fresh water resources are found, subsidence (red 3) is a serious threat in this scenario. Further looking into the diagram, less problems for coastal erosion (red 1) and mangrove degradation (red 1) can be found. Although, for the future in 30-50 years, this problem will never be fully solved, and attention should be paid to this for the long term.

Fresh resource scenario

Figure 70: System status for Fresh opportunity scenario



In this scenario the policy mainly focusses on fresh water resources by good maintenance of the culvert systems, other water harvesting techniques and legislation of groundwater pumping. For this scenario it is assumed that due to the good irrigation systems the fresh water needs (neutral 0) will mainly be covered by rainwater harvesting techniques such as the sluice system, in this way sustainable fresh water resources are used. This reduces the problems during dry season, (droughts – red 1). The sustainable use of fresh water, namely in industries and households, will reduce groundwater extraction and land subsidence. But since the source of fresh water in Ca Mau is rainwater and groundwater it is assumed that groundwater will always be needed to cover the needs, that's why groundwater extraction will stay problematic (red 3).

Due to effective measures at the coast and the dike system, the saline intrusion will be less than in the status quo scenario (red 2), but might saline intrusion still occur, it will then have severe influence leading to problems in the system for this fresh resources scenario. The reduction of the flooding (due to less subsidence and a focus on mangrove forest), drought and coastal erosion has positive impact on the Economic Damage/Profit ratio, making this ratio smaller than one (green 1).

At last, it can be said that much capital is needed and thus high economic growth, to invest in the irrigation systems for building and maintenance projects.

Table 13: Performance of the scenarios

	Collapse Fast	 Gradual	Status Quo	Positive Transformation Saline Adaptive	 Fresh Resources
Mangrove degradation *Caused by:*	**Totally destroyed** *- Coastal storm* *- Too low resistance against a severe storm*	**Mostly retreated** *- Bad state of coastal protection* *- High bureaucracy*	**Retreated** *- Bad state of coastal protection* *- High bureaucracy*	**Stabilizing/growing** *- Effective measures* *- Coast and dike system*	**Stabilizing/growing** *- Effective measures* *- Coast and dike system*
Coastal erosion *Caused by:*	**Most severe** *- Coastal storm* *- Too low resistance against a severe storm*	**Severe** *- Bad state of coastal protection* *- Mangrove retreat* *- Relative sea level rise*	**Severe** *- Bad state of coastal protection* *- Mangrove retreat* *- Relative sea level rise*	**Stabilizing** *- Proactive measures* *- Stabilized mangroves*	**Stabilizing** *- Proactive measures* *- Stabilized mangroves*
Fresh water needs *Caused by:*	**High** *- Bad state of sluices* *- Industry* *- Population*	**Medium** *- Bad state of sluices* *- Industry*	**High** *- Bad state of sluices* *- Industry* *- Population*	**Medium** *- Industry* *- Population*	**Low** *- Population* *- Sustainable fresh water resources*
Subsidence *Caused by:*	**Large** *- High fresh water needs*	**Large** *- High fresh water needs* *- Low legislation*	**Large** *- High fresh water needs* *- Low legislation*	**Medium** *- Medium fresh water needs*	**Medium** *- High fresh water needs* *- Sustainable resources*
Economic d/p ratio *Caused by:*	**Can be at any state** -	**High** *- Migration* *- Damage due to saline intrusion and coastal erosion*	**Medium** *- Coastal erosion* *- Medium economic growth*	**Low** *- Med – high economic growth* *- High resistance to floods; stabilized coastal erosion*	**Low** *- Med – high economic growth* *- High resistance to floods; stabilized coastal erosion*
State of the public authorities	- Awareness high - Bureaucracy high, but will be ignored	- Awareness high - Bureaucracy high →*Conflict*	- Awareness medium - Bureaucracy high →*Conflict*	- Awareness med - high - Integrated government - Less bureaucracy	- Awareness med – high - Integrated government - Less bureaucracy

Conclusion

As the scenarios show us what future states of the system could look like, there are as many scenarios as there are possible futures (indefinitely). Therefore, a set of distinct scenarios is analysed, based on drivers of the system. As the stakeholders have much insight about the system, it is important to involve them in scenario building and testing the performance of each scenario on the system dynamics diagram. In this way, also the stakeholders will be more involved with the process, and they have better feeling of the processes in the system.

The important consequences found for these scenarios are:

- *Fast collapse*
  Failure of the coastal protection (due to the big coastal storm) causes a large flooding. The economic damage caused by this 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.
- *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 much 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 plan for this.

With this analysis, the stakeholders and decision makers need to develop a strategy to deal with the system. This is the last part of the future forward approach. The future is be explored with the scenarios (see Figure 71) and to reach the desired state it is important to make (small) steps into the direction of the desired future state of the system (see Figure 71). The different strategies to reach this future state will be discussed in the next chapter, Measures.

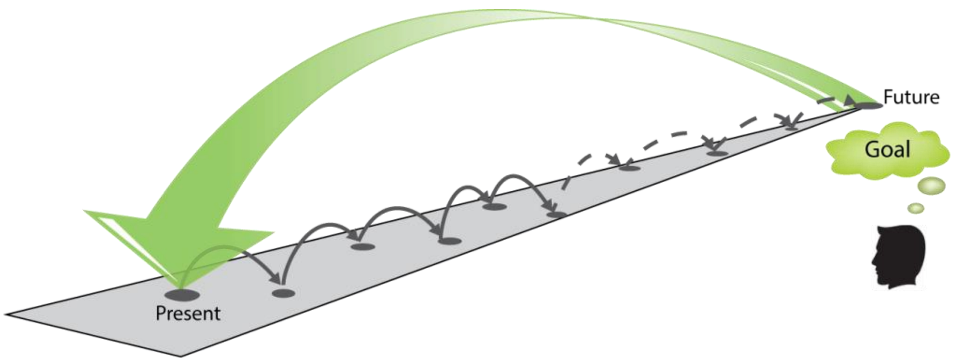


Figure 71: With the possible futures in mind it is possible to invest in the strategy which lead to such a future.

7

Fieldwork

- Coastal protection
- Canal system
- Land uses
- Main conclusions

As part of this study, a number of visits were performed in the province of Ca Mau, with the aim of verifying the links made in the system dynamics diagram, looking for previously unmentioned or unseen relationships and problems in the province, and to get a feeling about the most important processes and problems in the province. The visits were concentrated at the West part of the province, see Figure 72.

The specific focus was on certain aspects of the water system, namely:

- In-situ investigation of existing coastal protection measures in the Tran van Thoi and U Minh districts (field visits 1 and 2 indicated in Figure 72);
- Assessing existing sea dike systems, in terms of design, placement and maintenance; also investigating coastal land uses close to the sea dike systems.
- Looking at mangrove belts at the coast, as well as estimating their status and degradation causes.
- Studying freshwater resources and how local people adapt to and deal with saline water;
- Investigating the existing culvert and sluice system in Ca Mau, with a focus on maintenance and operation;
- Obtaining first-hand information about the saltwater and freshwater canals, their uses and users and their operation.
- Finding other aspects of the water system that haven't been studied so far, like for instance canal erosion.
- Locating signs of domestic pollution and finding possible sources of pollution;
- Assessing water quality issues in the canals, by performing measurements (pH, salinity levels) in the canal systems of Ca Mau. These measurements were indicative, so as to obtain a quantitative sense about water quality and salinity intrusion problems and so as to link them with neighboring water uses and operational issues.
- Obtaining information about the uses in the water system, after sample visits and interviews with key influential and affected stakeholders (DARD, PPC, local population).

Figure 72: Locations of the field visits

Assessment of existing coastal protection

Fighting Erosion in the West Coast

The erosion along the west coast of Ca Mau in the last years has been severe, with a local magnitude exceeding 1 km at certain sites. This has caused the mangrove belt to thin out, and, locally, disappear, as can be seen in areas near the field visits (Figure 73). Generally, the coast has many changes and there is large spatiotemporal variability in the coastal erosion and sedimentation patterns. This makes it hard to unify the coastal protection policy and secure funding for larger areas. The measures that are adopted are thus highly dependent on third-party funding sources, mainly donors. If there is money, hard measures are usually prioritized, such as concrete pile breakwaters, filled with gravel, in highly erosive areas. These measures are featured at specific, highly erosive locations of the coast and were part of the group visits (see Figure 73). In field visit #1, such a measure was seen; its placement was effective in creating a mudflat in the leeside. In field visit #2, a hard measure protecting the canal inlet was visited (see Figure 74): it was effective at not allowing the coastal mouth near the inlet to retreat, but, at the same time, induced sedimentation in the canal. As a result, dredging is needed for navigation and to effectively convey the inland water drain to sea. The following conclusions can be drawn for the visited sites that featured coastal protection works:

- Most hard measures were effective: big mudflats have been created, and biodiversity is growing (birds, mud scrapers, craps, and small mangroves). We believe there is potential for these area to start further rehabilitation projects, but the impact on the downdrift coastal zones and the corresponding mangrove systems has to be evaluated, as the works act as large sediment traps.
- The construction of these measures is very heavy, placed on very soft, muddy soil layers. We have been told by stakeholders that the foundation is only 2 m deep, and that the gravel in the breakwater has to be refilled every year. This indicates that the construction is sinking rapidly, and that monitoring is very important. In combination with the fact that it is difficult, and therefore expensive to build such a hard measure, we think this solution, while effective, is not cost-effective, not sustainable on long-term and not applicable for many cases. For the future, there is a need for better solutions, perhaps of ‘softer’ nature.
- These structures are in specific places, but they could be integrated within a more general policy for coastal zone management. They should therefore be monitored, evaluated and integrated with other measures in ICZM.

Sea Dike System in the West Coast

The sea dykes are mainly located a bit more inland than the coastline, right behind the mangrove belt (Figure 73 and Figure 74, places 3,4,18 and 20) and they act as supplementary spatial flood protection measures to sluice gates. Some years ago, they were up to 1 km more inland, a sign of severe mangrove squeeze; indicative mangrove vegetation was found at the toe of the sea dikes on the coastal side, meaning that the mangrove belt is retreating. Regarding human uses, the sea dykes provide road access for inhabitants, which means that coastal areas became more accessible after their construction. As a result, it was observed that people illegally built homes very close to the sea dyke and even made shrimp ponds at the coastal side of the dyke, putting further pressure on the mangrove belt. The dimensions of the sea dykes are small (2-3m) and therefore there is overtopping almost every year due to floods from the sea in July and August. Its maintenance structure is also not good; vegetation is rampant in the dike area. Moreover, the sea dyke suffers from erosion due to this yearly overtopping, but also due to heavy rains in the wet season. At some parts, the mangrove belt has fully disappeared and the dyke is at the coastline, being exposed to the waves. In field visit #1, policy measures to enforce the dike systems are made and a reallocation area is built to have less human activity close to the dyke (Figure 73, point 7). People, however, were more motivated to stay close to their zone, where they have access to more resources, and it will be thus difficult to move the people to this area.

Canal system evaluation

Sluice gates and culvert system

Provincial stakeholders (PPC with DARD) are responsible for the operation of the sluice and culvert systems. The operational status in the U Minh province (field visit #2, Figure 74) is mainly based on allowing brackish water for the shrimp farms in the dry season. In the wet season the sluice gates are mainly closed, keeping the freshwater for rice agriculture. This leads to a seasonal variation in land use (mixed aquaculture/agriculture use). The sluice is occasionally opening in order to provide navigation from inland to sea. In the U Minh province (field visit #3, Figure 75), there is a small part, at the Melaleuca forest, where the culverts prevent saline water to flow in, keeping the water in the forest fresh. The system thus acts as a closed-loop freshwater system in both seasons, and sample measurements of salinity (in March 2015, at the end of the dry season) show that the system works well. Within these systems, rice agriculture fields are located. Sample interviews with farmers show that there are rice harvests twice a year. Fresh water ponds for fish farming are also used. Also many banana and coconut trees grow in this area.

Canal erosion and pollution

Two important things were observed during fieldwork that were not found before in literature study: the first one was the extensive visible erosion in the inland canal system of Ca Mau, and the second one was the amount of waste pollution in inland water bodies. Regarding the canal erosion, there are fragmented protection measures at places such as wooden palls, concrete revetments or palls, but these are taken by individual house owners, are not integrated and only work partially. In many cases, the erosion is undermining these constructions as well, resulting in river bank erosion again. Canal erosion can be attributed mainly to motor boat activity, which has significantly increased in the last years. Regarding pollution, severe waste management issues were found in many areas of Ca Mau, dictating that more work should be done on raising awareness about proper waste management.

Land use and its relation to water

A lot of different land uses were observed in the area, linked to the primary sector. In all cases, these land uses were shaped by the issue of dealing with freshwater shortage in the dry periods. The following land uses were identified:

Rice farming

Sample visits in rice farms were performed as part of the fieldwork, in the closed loop systems (see Figure 75). In such a visit, the farmer harvested rice two times per year, while also having the fresh water pond for fish farming in the remaining time. The rainfall in the wet season is enough to provide sufficient fresh water. The farmer, in this case, doesn't make use of groundwater, for domestic uses he relies on the water tower built under a project of UNICEF.

Shrimp/rice alteration

Farmers who do extensive shrimp/rice farming harvest rice and shrimp once per year correspondingly. During interviews, they stated that they don't use any extra products to improve the water quality. The shrimp are usually obtained from the brackish water in the canal, and sometimes there is a need to buy shrimp spawn. It takes approximately 2-3 months for the shrimp to grow, and after these months 35 kg/day of shrimp is harvested. Similarly to the rice farmers, some farmers that were interviewed also had fresh water ponds to grow catfish.

Shrimp/mangrove farming

During the fourth field visit (Figure 72), the practice of mixed mangrove-shrimp land use was study. The visit included an eco-tourism shrimp farm, where low tourism uses (restaurant) were combined with shrimp and crab farming. The interviewed farmer, in this case, grows shrimp the whole year round, and harvests 2 times a month. In total there were over 200 shrimp-mangrove farmers in the Nam Can district according to the shrimp farmer. With regards to the balance between mangrove and shrimp, the farm consists of 50% mangrove and 50% shrimp. The mangrove, generally, was stated during the interview to have positive influence on the water quality; its leaves are providing food for aquaculture, and there is shadow which makes it easier for the shrimp to grow. The water in the pond is refreshed under the tidal difference (tidal range of about 1,5m), but in the wet season it is more difficult to drain the water to sea due to the canal limited drainage capacity, leading to a lower harvest. It was also stated that the farmers help each other increasing the productivity through sharing expertise, but there is a lack of an official network between shrimp farmers. Knowledge and training, in this instance, could increase the capacity of shrimp harvests.

Intensive shrimp farming and results about aquaculture

An example of intensive shrimp farming was also seen during field visits. In this case, the intensive shrimp farmer buys shrimp swan, as well as chemical production aids (e.g. limestone to negate the acidic soils).The shrimp was fed four times, and the water quality (salinity level regulation) was maintained by adding groundwater, using an aerator rotator; lime stone was also used, to prevent high acidity in the water due to the soil. After 4 months the harvest can be up to 12 ton of shrimp in total. This farmer in this visit had 7 shrimp ponds, of which 4 were operative, and 3 were closed due to cleaning.

From the afore-mentioned interviews, it seems that local people prefer to cultivate shrimp all year round (mostly extensively because they don't have the money to invest in intensive shrimp farming, see below) because it is more profitable. But, this is a vulnerable operation, because the harvests are vulnerable to shrimp and the production is highly variable. The practice of extensive shrimp farming is currently unsustainable, with shrimp ponds being opened at the cost of mangrove land and being deserted after a few years, due to a series of bad harvests.

Use of Ground water

One of the major concerns of this study was whether there is extensive use of groundwater supplies for human uses in the province. A number of questions in interviews, therefore, targeted this specific unsustainable water practice. It was found out that groundwater pumping is considered expensive, so it was limited for usual farming (rice and shrimp/rice) only to relatively small domestic uses. In some areas, there is alternative infrastructure for domestic uses (UNICEF has built water towers), which leads to people not using any groundwater at all. The exception in this practice is intensive shrimp monoculture, which uses groundwater on a daily basis to regulate salinity levels. Apart from this, it was seen that in settlements there is industrial activity that uses groundwater as cooling water, even for smaller industrial units; groundwater extraction is therefore concentrated on intensive uses, such as shrimp-farming, industry and urban clusters.

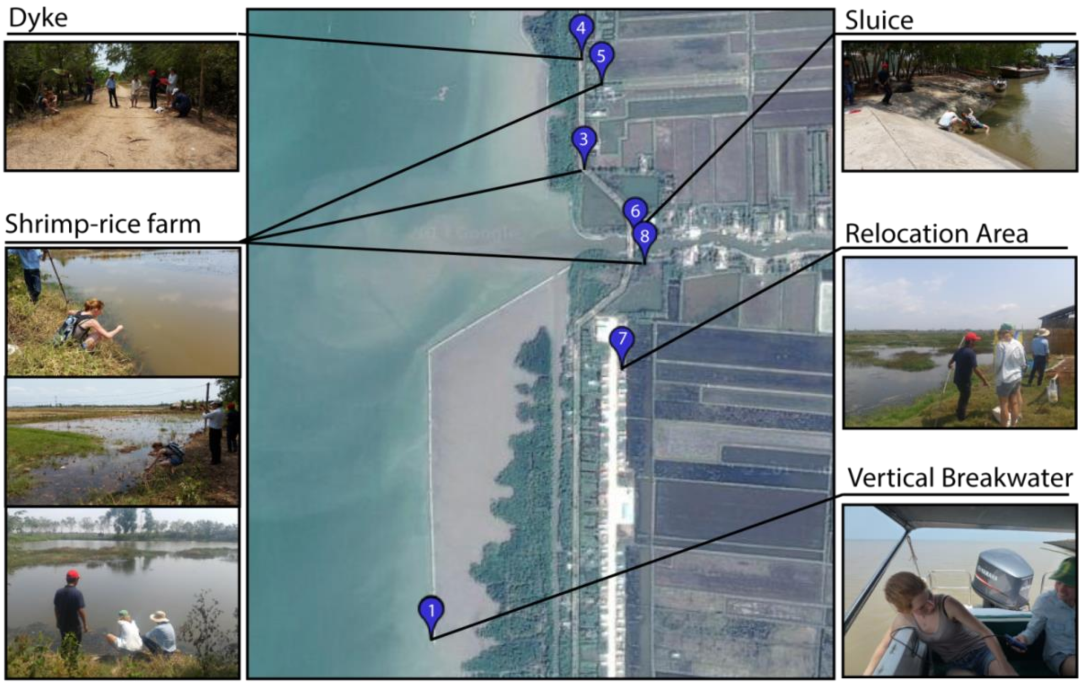


Figure 73: Detailed overview field visit #1

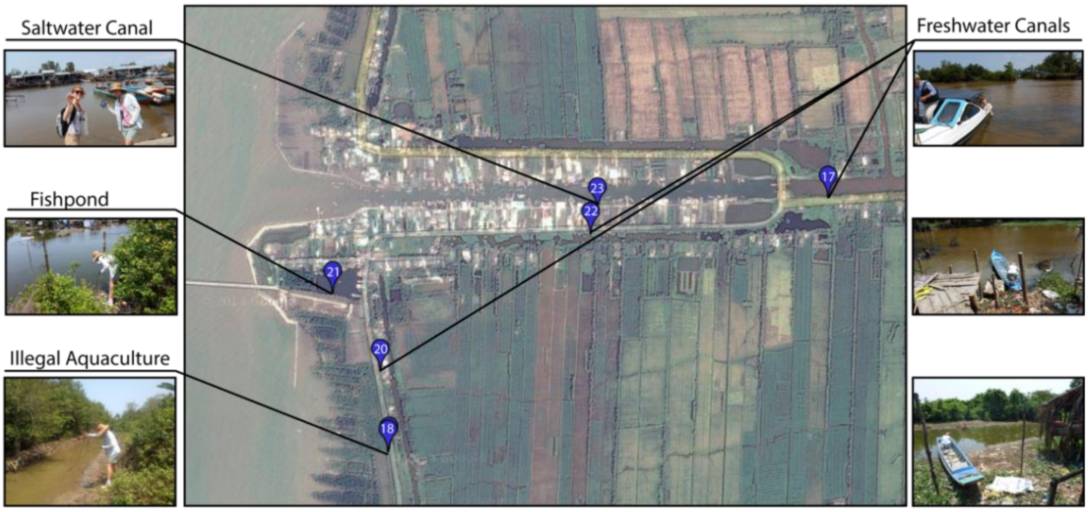


Figure 74: Detailed overview field visit #2

Figure 75: Detailed map of field visit #3

Main conclusions

In general, many parallel processes and pressures were observed in the coastal zone, with aquaculture, the mangrove ecosystem, various types of coastal protection, a separate sea dike system and small human settlements co-existing. This makes it difficult to integrate and manage the system, while keeping all these functions in the same zone. Relocation policies should be therefore considered, but multiple incentives have to be given and efficient spatial measures have to take place. The efficiency of policy, in this case, is crucial to create a sustainable, habitable coastal zone; fragmented measures will only target parts of the problem, but will not be able to evolve on an integrated level.

For the existing coastal works, while existing works are efficient, a more cost-effective and sustainable solution has to be studied and employed in an integrated manner. The lifespan of existing constructions is questionable, and due to the high costs of these constructions, these can only be applied on several short pieces of coastline. Existing structures thus solve problems locally, but also will increase erosion downdrift at the coast.

In terms of water management, freshwater closed loop systems were deemed to be well-managed. However, it is questionable if these systems can be maintained in the future, because of the high maintenance costs and the climatic pressures on the system. Together with the people, DARD and the PPC should make a plan to come up with a sustainable solution, either of structural adjustment to embrace aquaculture or of high maintenance to preserve freshwater levels. These plans are reflected on the next chapters about the scenarios and strategies.

Concerning land use changes, shrimp-rice appears to be the most profitable option, but it is currently unsustainable and features a degrading quality, due to a lack of proper practice, as well as water quality issues. The conflict in water uses, where extensive shrimp-rice farmers use water that has been polluted from other uses, might increase in the future, thus imposing a restraining factor to an otherwise profitable activity for Ca Mau. Other than this, changes regarding the conveyance of channels and their operation with regards to salinity are needed to fully embrace aquaculture for Ca

Mau. Sustainability issues (such as the right balance between mangrove and shrimp ponds) need to be studied as well, to provide options that are more viable in the long-term.

Two problems that were underestimated or not considered before, during the System Dynamics modeling approach, were observed: the first one is severe erosion in the canals due to the high navigation activity, which is counteracted on an individual user level, with local wooden and concrete constructions that suffer from design and maintenance problems. The other one is the lack of proper waste management, and the subsequent pollution problem. These problems formed the basis of certain research proposals in the following Chapters.

8

Measures

- Introduction
- Strategy of each scenario
- Measure packages
- Conclusion

Introduction

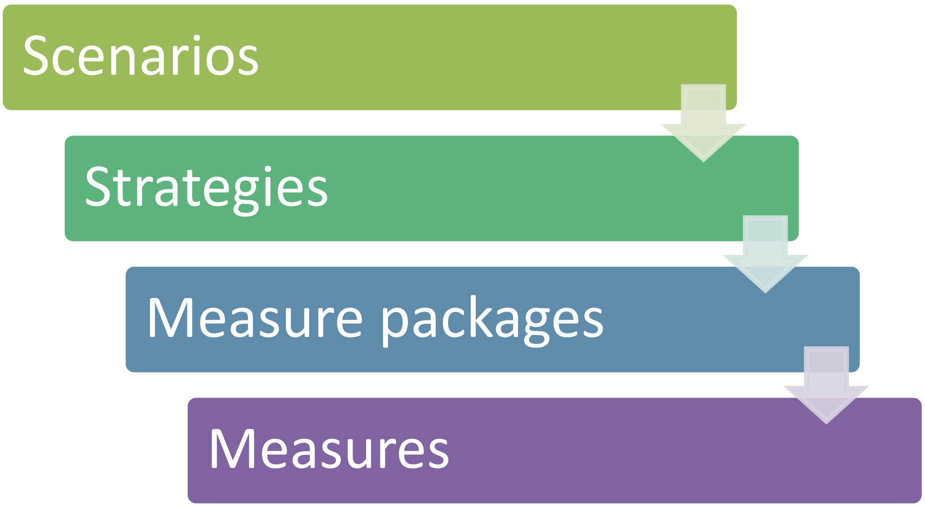


Figure 76
Structure: Scenario to measures

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.

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. At the first sight some strategies are very similar, this is logical because the transformation strategies will also contain elements from the prevent collapse strategies. In the chapter scenarios, different possible futures are predicted and within the chapter measures it is described how to reach or avoid these possible futures. 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.

The measures can be divided into three categories. The first category are the policy driven measures, these are measures that stimulate certain activities by creating convenient legislations. Secondly there are physical measures that contain tangible measures in the water system. Finally there are measures that still need more research, these are further mentioned in the chapter research proposals.

Strategy of each scenario:

Status Quo

As described in the chapter Scenario's the current situation will not be influenced. Therefor there is not a strategy nor a package of measures required to reach the scenario.

Prevent collapse

Like described previously a collapse can occur fast or gradual. The strategies may vary to prevent fast and gradual collapse and are elaborated below.

Prevent fast collapse

In the chapter Scenario's, one can find in Figure 67 that an economic damage or a natural disaster like a flood is the trigger for this collapse. The strategy to prevent a flooding differs from prevention from an economic damage. Both should be implemented to be well prepared. Although these kind of impacts can't be prevented for 100%, 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. Resilience is defined as the ability of a system to absorb and utilize or even benefit from a perturbation and changes that attain it and so persist without a qualitative change in the system's structure (Beatley, 2012).

From the figure 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. Mangrove degradation is enforced by coastal erosion, coastal aquaculture and deforestation. A proper land use plan, supervision and rehabilitation can protect and strengthen the mangrove belt. The RSLR can be prevented/ reduced by abandoning groundwater extraction. Thinking of resilience, the negative consequences of a flood can be decreased by increasing the discharge in the channels and adapt your life style to the fact that a flood might occur. The strategy to prevent or be more resilient to a flooding contains:

- Integrated water and land use plan
- Coastal erosion package
- Rehabilitate/ increase mangrove belt
- Improvement coastal defense system
- Canal erosion and inland flood protection package
- Groundwater extraction package

Considering a flood, a proper water- and land use plan is not directly necessary. Currently some dyke reinforcement is taking place (as seen during the fieldwork) without thinking into account consequences and needs of the inhabitants. Inhabitants don't support this strategy and even sabotage the works (pierce dykes). Therefor it is recommended to create an integrated water and land use plan.

Prevention gradual collapse

The trigger who leads to a gradual collapse, as discussed in the chapter Scenarios, has a socio-economic background (low economic growth). The result is that political legislations and or changes are serious delayed causing severe negative effects on different elements within the system. Whatever measure is taken, due to poor and delayed execution, it will not reach its goal. The consequences in the field of water and coastal management cannot be prevented by measure packages specifically for these topics. First of all a strategy is needed to prevent the economic relapse and the political issues have to be solved before adequately other measures can be implemented. The low economic growth on itself can only be changed by the implementation of drastic economical reformations. 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. Measures of the economic growth packages, fresh or saline, can be adapted to stimulate the economy. The legislation and policy package will have the highest priority. In the chapter Research proposal the subject is elaborated further.

- Legislation and policy package
- Economic growth package

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.

Transformation packages

Saline adaptation

Saline adaption is a strategy that embraces the salt water intrusion and the strategy exploits the benefits that come with it. From Figure 69 it can be seen that high economic growth and effective legislation and policy are driving forces for the transition. From these drivers follow effective measures against flooding and erosion. Also the transition from fresh to saline water is key for this strategy, the irrigation system 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. This can be done by coastal protection, mangrove rehabilitation, reduction of canal erosion and water quality measures. Furthermore fresh water is needed for domestic use and for balancing the salinity in the aquaculture ponds. Currently ground water is used for this, but alternatives are needed to prevent further subsidence.

The following measure packages can be assigned to this strategy to achieve the described goals:

- 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 system
- Canal erosion and inland flood protection package
- Pollution package
- Groundwater extraction package

Maintaining fresh water

This strategy aims at maintaining the fresh water ecosystems in the districts that still have them. The districts that have become brackish will keep the focus on high yield aquaculture, but combined with the fresh water districts the industry can be diversified making it a more sustainable and reliable sector. Again the high economic growth and effective legislation and policy are key drivers of change and influence the effectiveness of the measures Figure 70. 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 guarantying the quality of land and water resources also are important in this strategy. Thus coastal protection, rehabilitation of mangroves, reduced canal erosion and water quality improvement are included in the strategy.

The measure packages for this transition scenario seem very similar to the ones described in the saline adaptation strategy. The essential difference lies in diversification of industry versus specialization of industry and how this influences the adjustments that have to be made on the irrigation system.

- 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 system
- Canal erosion and inland flood protection package.
- Pollution package
- Groundwater extraction package

Measure packages

The measure packages which are necessary to support the strategies for each scenario are elaborated below.

Integrated water and land use plan

An integrated water and land use plan including the coastal zone and inland. Based on this plan well considered decisions can be made reducing the chance of conflicting decisions. As example; the built or replacement of dykes can be in an area where residents of the province life. These people have to be relocated to a suitable location.

- For the coastal zone GIZ, cooperates with the government to establish an Integrated Coastal Area Management. Their goal is to define a coastal zone management plan for the whole coast of Ca Mau.
- For the inland water management and land use, a plan specifically for Ca Mau must be created. Taking into account the policy in neighboring provinces and on a national level. Basis for this can be the Mekong Delta Plan.
- Both plans have to be adjusted to each other.

Coastal erosion package

The coastal erosion is induced by different factors as described in the chapter Current state. The following measures are suggested:

- The RSLR induced by climate change and land subsidence due to groundwater extraction can only be influenced by a reduction of the groundwater extraction. Possible measures for the last topic are defined in the package Groundwater extraction package.
- Built of sustainable and cost-effective hydraulic structures to reduce the wave impact and trap sediment along the coast. There is a wide range of measures used in Ca Mau (see chapter Measures). Not all perform equally well or are less beneficial. A research is recommended to investigate which (implemented) measures are suitable along the West coast of Ca Mau.
- Measures that increase the available sediment like beach nourishment.
- The dredging of the inland channels can be combined with the nourishment of the coast. This integrated measure requests further research to state weather the material properties, grain size and pollution rate, are suitable.
- The mangrove squeeze and deforestation increases the coastal erosion as well. The needed measures are described in the package Rehabilitation and increase of the mangrove belt.

Due to the fact that there are research gabs in exact hydraulic processes, the topic is included in the research proposal.

Rehabilitation and increase of the mangrove belt

The mangrove belt is a natural defense system of the coast to protect against flooding and erosion. Increasing the width of the mangrove belt and also the density of the belt increases the strength and health of the mangrove belt. The following measures are suggested:

- Instead of squeeze more space should be given to the mangrove belt for the existence of the belt and the safety of the people. This can be done by
  - Placement of the dykes more land inward. One should take into account the people have to be relocated. This influences the land use.
  - Accretion of the coast and extending the belt towards the sea. Coastal stability and accretion is necessary for this measure. The wave energy and current velocity has to be low and if necessary reduced (Coastal erosion package).
- To increase of the density of the mangrove belt the following two measures are recommended:
  - A policy measure which defines a maximum ratio of shrimp/ mangrove within a farm, preferably 40%/60% respectively.
  - Old abandoned shrimp fields within the mangrove belt are gabs without a use. These ponds can be converted back into mangrove forest with the right care.
- The success of mangrove cultivation is highly dependent on the plantation of the right species and location. Research is suggested to the correlation between the two factors along the coast of Ca Mau.

Improvement coastal defense system

- The height of the dyke is not sufficient at every part of the province. The local authorities are aware of the problem. The heightening of the current dyke system must be included in the integrated coastal management plan, mentioned above.
- A maintenance and inspection plan for the dyke system in cooperation with the SIWRP and DARD to secure the status of the dyke in the future (pro-active policy).
- Repair of damaged spots within the dyke system in cooperation with the DARD authorities on district level. The repair works are location depend but examples can be:
  - Rebuilt of the dyke with material as used before.
  - Use of soil bags; in which (experimentally) mangrove can grow.
- Connection of the dyke system with the culverts near the coastal inlets to create a closed system.
- Dredged materials of the canal system might be to heighten dykes along the rivers and canals or use the material for coastal protection.

Canal erosion and inland flood protection package

Canal erosion and inland flood protection go hand in hand because well maintained canals prevent flooding. If the canals are not eroded or full of sediments they have a better water conveying capacity. This enables the canals to drain storm water better and reduce foods. There are three categories of measures in this package: policy based measures, physical measures and further research on measures.

- Speed limit for boats in the canals to reduce the wave action on the banks.
- Policy to encourage the local population to plant protective vegetation, like water coconut trees, along the canal banks. These plants reduce the wave action and improve the soil structure of the canal bank.
- Policy on training the local farmers to build small scale interventions against bank erosion like wooden fences.

- Currently the erosion measures placed along the canals are in poor state. Policy on increasing the maintenance of bank erosion measures would improve this situation.
- Dredging of canals to improve the water conveying capacity. This increased the drainage during floods and it decreases the velocity of the water and thus the eroding capability of the flow.
- Use the dredged material from the canals to heighten the dykes along the canals. This prevents flooding and improves the bank strength.
- Implementation of pilot projects to find new erosion measures like using water plants to stop erosion (Chapter Research proposals).
- Finding the weak spots in the current dyke system and doing local maintenance or dyke improvements at these locations. It can save a lot of money to only fix the broken parts instead of renewing the whole dike. (find weak links in the dike system Chapter Research proposals)

Economic growth package

Economic growth is one of the driving forces in the system and it is a complex process to influence it. Furthermore it is behind the scope of this report to discuss the improvement of economic growth in detail. Here the measures are restricted to the field of water management.

- The farmers in Ca Mau share knowledge on farming techniques and support each other in the process of innovation. It would be very rewarding to invest in training several farmers in sustainable intensive shrimp farming techniques. Thus boosting the local production of shrimp.
- Similar as for shrimp farming other farming techniques and innovations should be shared with the farmers in Ca Mau. Knowledge of producing certain rice varieties with a limited amount of water could increase the yields in Ca Mau significantly.
- Reduce the bottlenecks in the shrimp industry chain, by reducing the middle man and promoting certain branches (see Economy part), this will yield a larger income for the local inhabitants of Ca Mau.
- Once the production of export products starts to improve infrastructure can be a limiting factor. This is why it is important to improve the infrastructure and export possibilities like ports.
- Many farmers produce shrimp in an ecological way but sell it for normal prices because they are not certified. Improving certification of bio-products of aquaculture, provide incentives to farmers to farm bio- products and increase their value per product.
- For a stable economic growth it is helpful to have a diverse industry. Within the scenario where fresh water production areas are maintained it is important to encourage the diversification of the different sectors in the industry.

Legislation and policy package

All the measures discussed in this report are all influenced by policy a legislation. If the government is not able to implement measures in an effective way none of the measures will resolve in a better situation. The following measures will help to improve the effectiveness of policies and legislation.

- Because of the complex government structure related to water management, there is a lack of communication between the different ministries and departments. More effective communication between these parties is necessary.
- The transfer from public and governmental awareness into effective policies is a slow and tedious process. It is important to look into possibilities to shorten the timescale of this process.
- Unnecessary bureaucracy reduces the effectiveness of measures because it creates a lag between the output from the system and the reactive interventions. Improving the level of bureaucracy will reduce this lag.
- Reducing corruption, this will help to select measures that are best for the water system as a whole and not just for certain individuals.
- More empowerment for the government to enforce their policies.
- The points mentioned above only describe problems and there causes. For translating these points into measures more research and expert knowledge on the topic is needed. (see Research proposals)

Sluices and irrigation package (fresh)

This package is essential for the fresh water transition strategy. Maintaining the fresh water areas will include large investments in the sluices and the irrigation system. It is the question if the benefits of fresh water areas outweigh the investment costs.

- Currently there is only one district that has a proper functioning closed loop system. Other districts also have the infrastructure to create a closed loop system but the infrastructure is in bad shape and needs to be renovated.
- To avoid the irrigation system from degrading into an insufficient state again, a regular maintenance plan has to be created and implemented.
- The changing rainfall patterns create the need to look into methods of rain water harvesting. Currently the rainwater is stored in the canal system, but the storage capacity can be increased by construction RWH reservoirs.
- Instead of constructing large reservoirs looking into alternative RWH techniques like described in the chapter (Research proposals) can be beneficial. For effective measures it is important to select a RWH technique that is supported by the local community.
- Investigating the possibility to introduce new rice cultivation techniques and varieties that require less water like NERICA.

Sluices and irrigation package (saline)

For this package the current sluices and irrigation system have to be drastically redesigned. Sluices will be removed and canals have to be dredged. This seems like a large investment, but the new system will require less maintenance on structures.

- Redesign the fresh water irrigation to fit the needs of the new land use (aquaculture). This includes removing the old sluice structures, and increasing the conveyance capacity of the canals by dredging.
- Even though the saline water intrusion is embraced in this strategy, fresh water is still needed for domestic use and for keeping an optimal salt balance in the aquaculture ponds.

To obtain this fresh water RWH reservoirs have to be constructed. An alternative is to do research on new RWH techniques (Research proposals).

- Spatial planning: promote ecological mangrove aquaculture near the coastal areas (behind the protected zone), this will form a second coastal protection barrier and it will improve the water quality of the area.

Groundwater extraction package

It is impossible to forbid the extraction of ground water because it is an essential source of fresh water for industry, domestic use and intensive shrimp culture. The only way to cope with this problem is to investigate in alternative sources of fresh water like described in the Research proposals. In the meantime training could be given on waster saving strategies to industries, farmers and domestic users.

Pollution package

Pollution is a serious threat to the socio-economic state of Ca Mau. Industrial waste and other sources of pollution can cause large reductions in the production from agriculture and aquaculture.

- Promotion and training in small scale local waste water treatment. There are lots of small scale waste water treatment options but it is best to select measures that fit the local environment. More research on this topic would be useful in finding the best suitable solution.
- Introducing stricter policies against pollution from the industrial sector. The stricter policies have to be combined with regular monitoring to be effective.
- Stimulate waste collection along the households in Ca Mau. The collected waste can possibly even be recycled (plastics, paper and metals).
- A number of cleaning campaigns, targeted specifically at waste hot-spots. Again, local communities could play a vital role in collecting, re-cycling waste and cleaning these areas.
- The introduction, in parallel to road collection, of a “pontoon and boat” garbage collecting system. In this measure, households are advised to place stuff in pontoons, while boats collect them at regular time intervals and lead them to more suitable, designated wastelands.
- Construct wastewater treatment facilities for the households and the industry in Ca Mau city.

Conclusion

Below an overview is given of the chosen strategies (and packages of measures). The Status quo scenario is not included because no strategy is needed as explained above.

Package		Fast Collapse	Gradual Collapse	Maintaining Saline water	Adaption to fresh water
I.	Integrated water and land use plan				
II.	Coastal erosion				
III.	Rehabilitation/ increase of mangrove belt				
IV.	Improvement coastal defense system				
V.	Canal erosion and inland flood protection package				
VI.	Economic growth package				
VII.	Legislation and policy package				
VIII.	Sluices and irrigation package(fresh)				
IX.	Sluices and irrigation package(saline)				
X.	Groundwater extraction package				
XI.	Pollution package				

The purpose of this table is to have an overview and determine if there are measures which are required for more than one scenario.

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. They are independent of which future scenario is desired. 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 transform the system; effective policy and economic growth is requested. Besides there are packages specific for the desired scenario.

For the current situation of the province of Ca Mau, it is important the 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) efficient or cannot be finances. 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 and get the highest priority.

If a certain strategy is chosen, the planning of the execution of the measures will play a roll. Some measures can be executes 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. As example we take the fast collapse scenario. The protection of the coast by mangroves will take five years or longer before the mangroves are planted, grown and able to capture sediment. The built of a bamboo sediment trap structure can be done within one year (depending on the size of the structure). Although the rehabilitation is necessary to prevent coastal erosion, it is not the most effective measure for the short term in which a flood might occur. These time scales influence the priority of the measures that will be taken.

9

Research Proposals

- Thematic Area A: Human Land and Water use
- Thematic Area B: The Coastal Zone
- Thematic Area C: River and Inland Canal Management
- Thematic Area D: Policy and Institutions

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 a catalysis for further research in this area. The format of the research proposals will be as shown in Figure 77.

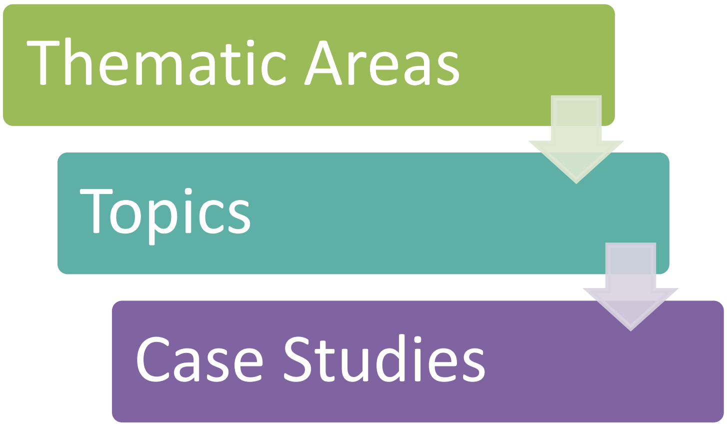


Figure 77: Format of the chapter Research Proposals

There will also be hints in the research proposals which describe the group's own judgement. This is not directly related to the research proposal, but may help on the assessment of it.

Thematic Area A: Human Land and water use

Topic A.1. Balance between freshwater and saltwater

Figure 78: Freshwater canal in Tran van Thoi (left), Saltwater channels near U Minh (right) (Fieldwork Study).

Case Study A.1.1 – 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.

Hints:

Having these areas is good for reasons of product diversification for the province.

At the moment people living in fresh water areas prefer fresh water above saline/brackish water (source: SIWRP)

Areas currently work well (see salinity measurements), no need to immediately abandon or adjust them.

Can be turned to brackish zone once the external factors (SLR) dictate so. Until then, they operate well. It would be interesting, in this case, to perform a study of actions needed to convert this area from a rice cultivation channel network to a channel network suitable for brackish aquaculture (widening of canals, dredging, culvert operation and adaptation) so that farmers gain the maximum benefit from this transition. This could be also part of Case Study A.1.4.

Case Study A.1.2 – Operational Aspects of Canal Systems/Sluice Gates

Ca Mau is dominated by a complex channel system, which includes both saltwater and freshwater channels (Figure 78) operated by sluices (Figure 79).

Figure 79: Coastal sluice gate in U Minh district (left), a sluice entrance to a closed freshwater system in Tran van Thoi (right) (Fieldwork).

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, 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.1.3 – 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?

Main question: is RWH profitable/desirable for agricultural functions in these areas?

Hints:

GW is proven to be used during the dry period for domestic (household) uses and for intensive shrimp farming.

RWH might not be particularly effective for farming purposes->too much area needed (large m3/day in case of intensive shrimp farming, low-lying area so no depth).

Case Study A.1.4 Spatial planning

Although spatial planning has been part of the master plans created by the ministries for many year there are still questions un answered. 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.

- Overall coastal zone plan/ Plan GIZ ICAM and CCCEP -> coastal plan, possibility to integrate with inland water management.
- 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?

Figure 80: Left: Sulfuric acid soils, right: limestone applied by farmer to reduce the acidity.

Case Study A.1.6 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).

Hints:

Such a network could serve as a basis for a more unified farmer response on pricing and negotiations with middle-men. This would lead to the farmers being able to secure higher prices and thus maximize the net value of their product.

During the field visits Farmers mentioned that a large part of their knowledge comes from other farmers. Exchanging experience and knowledge is essential to them. The existing system of communes could serve as a basis for studies on the structure of this knowledge network, or as a basis for pilot studies.

- 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.

Hints:

On most of the interviews, the shrimp farmers stated that they avoid using expensive chemical products to maximize their yield and that they produce "natural" product. However, the bio-certification system is so complicated that they usually avoid selling it as bio- and just sell it to regular markets. This underlines that there is a 'sink' in the current chain that restricts the potential profit of local farmers.

- 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).

Hints:

Thailand could be used as the model for reforms in the production chain of shrimp (see (Lebel et al., 2002)).

An example to improve the product value chain may come from the Netherlands: CAMPINA farmers: farmers give their share to CAMPINA factory but also have a share with it. One could investigate whether such a structure is feasible for Vietnam (e.g. merger of farmer communes with SE (possibly and joint ventures, or e.g. having one SE being the intermediate (having boats and collecting product so as to give it to processing factories).

Topic A.2. 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 A.2.1 Improving waste management in Ca Mau

Figure 81: Left: Debris entangled in the roots of mangroves in the West Coast of Ca Mau;
Right: waste deposited on canal banks (Fieldwork)

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:

> Hints:
>
> During the fieldwork, a number of boat owners who specialized in collection of certain types of waste (mainly plastic) was discovered. These informal 'recyclers' could form part of a more organized recycling network in the province, in a bottom-up, communal-based recycling campaign.

- 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 A.2.2 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.

> Hints:
>
> This work can be well integrated with the case study of waste management, as there is a direct cause-effect relationship. For example, high microplastic concentrations can be attributed to high concentration of plastic waste within the canals.

Case Study A.2.3 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.

> Hints:
>
> Aquaculture farmers often stated that they often need to innovate shrimp ponds to avoid a decrease in productivity. Their methods of innovation are largely empirical and based on local knowledge, without a supporting network that combines expert knowledge, research and local participation (see Case Study A.2.2). Given this, they do not have a clear view on water quality aspects that may influence their shrimp pond productivity; out of all farmers interviewed, only the intensive shrimp monoculture farmer regularly performed pH measurements.

Case Study A.2.4 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 B.1.1 – 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 B.1.2 – 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 B.1.3 – 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.

Figure 82:left: vertical breakwater U Minh, right: bamboo T-fence Bac Lieu

Case Study B.1.4 – 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 C: 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 C1.1 – 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 C1.2 – 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 C1.3 – 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 the 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.


Figure 83: left: road collapsing due to canal bank erosion, right: canal embankment from dredged material.

Thematic Area D: 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 D1.1 – 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 D1.2 – 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.

10

Discussion & Conclusion

- Discussion
- Conclusion and Recommendations

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-laying 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 analysed, 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.

11

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