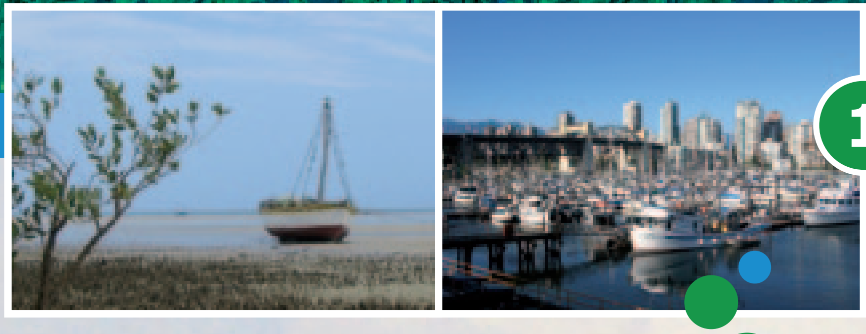
DeltAlliance



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Comparative assessment of the vulnerability and resilience of 10 deltas

synthesis report

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In addition the World Wide Fund for Nature contributed to the delta descriptions of the Ganges-Brahmaputra-Meghna, Ciliwung and Mekong

Internet

For more information about the Delta Alliance and to download this Synthesis report and related Work document (with full delta descriptions) go to **www.delta-alliance.org**

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Comparative assessment of the vulnerability and resilience of 10 deltas

synthesis report

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Table of contents

The full delta descriptions are available in a separate 'Working document' (see **www.delta-alliance.org** or CD on the back cover of this report).

Executive Summary


www.BeeldbankVenW.nl, Rijkswaterstaat

Worldwide, deltas host dense populations and are important centres of agricultural and industrial production, and economic activity. Many deltas are areas of great ecological importance as well, featuring wetlands of high and unique biodiversity. Deltas are vulnerable to changes by natural forces and human activities. Major drivers of change are population growth, economic development, climate change and subsidence.

Framework for delta assessment

In this collaborative project of the Delta Alliance a framework for delta assessment is proposed, building on the work done for the Aquaterra 2009 conference in Amsterdam and elaborating recent recommendations of the World Estuary Alliance conference (hosted by WWF in Shanghai, June 2010) regarding the development of a worldwide assessment of estuaries by means of 'scorecards'. This framework links the DPSIR approach with a Layer model for a delta, which should be seen as a first step towards a more elaborated framework, to be developed in due time with relevant stakeholders. The integrated approach takes into account the different 'layers' of the delta system and related governance issues. Three physical planning layers are recognized: the Occupation layer (land and water use), the Network layer (infrastructure), and the Base layer (natural resources), each with different but interrelated temporal dynamics and public-private involvement.

The advantage of this approach is that it is sufficiently generic which makes it applicable for all deltas. The framework provides relatively easy linkage with governance issues and with the different actors and agencies involved in delta management.

Executive Summary

Pragmatic choice of 10 deltas

The framework is used for describing deltas in a uniform format in order to make a comparative overview and analysis easier. Building on the contacts of the Delta Alliance (and World Estuary Alliance) each delta description is prepared by a Delta Wing Coordinator of the Delta Alliance (or another main contact person), in most cases in cooperation with several (sectoral) experts.

For pragmatic reasons the delta wing coordinators themselves were free to choose the appropriate definition for their delta description, to decide which (sectoral) experts should be involved and to determine the score in the scorecard. We are confident that this does not significantly influence our overall conclusions, as long as due attention is given to referencing to the area of interest wherever quantitative indicators are used.

The following table gives an overview of the 10 deltas studied

Continent	Country	Delta	No
Africa	Egypt	**Nile**	1
	Mozambique	**Incomati**	2
Asia	Bangladesh	**Ganges-Brahmaputra-Meghna**	3
	China	**Yangtze**	4
	Indonesia	**Ciliwung**	5
	Vietnam	**Mekong**	6
Europe	The Netherlands	**Rhine-Meuse**	7
	Romania	**Danube**	8
N-America	United States of America	**California Bay-Delta**	9
	United States of America	**Mississippi River Delta**	10

This report provides a comprehensive overview of the current and future state of these deltas, based on the delta descriptions. The main items of the delta descriptions are summarized in Appendix A and the full delta descriptions are available in a separate 'Working document' (see **www.delta-alliance.org** or CD on the back cover of this report).

Elements of delta descriptions

For each delta an 'indicative' scorecard gives an impression of the current and future state of the different layers and governance issues, summarized in an overall Resilience and Sustainability Index. Two scenarios of future change are considered. The rationale of the resilience and sustainability indicator is that sustainable development of a delta depends on a combination of the status of the three layers. Resilience and sustainability is good if the provision of goods and services equals the demand, without deterioration of the base layer. The scorecards are based on an analysis of drivers of change and pressures on the different layers of each delta and governance issues, based on, as much as possible, quantitative indicators. It is emphasized that in this report first versions of delta scorecards are presented, based on above mentioned 'framework for delta assessment'. The scorecards need further development and elaboration, which is envisaged in the follow-up of this project.

Moreover for each delta a brief overview is given regarding currently applied adaptive measures and technical methods and tools to support delta management. Also an overview of research gaps and opportunities for collaboration is presented in order to contribute to the development of collaborative research projects across deltas.

The proposed framework for delta assessment and especially the scorecards are intended to enhance awareness raising, discussion and prioritization on most relevant delta issues, in each delta but also in comparison with other deltas. This should lead to more efficient and effective (multi-sectoral) policy formulation, management design and implementation, in concrete Delta plans, pilot-projects and (research) programmes. The target groups are all stakeholders who are involved in delta management at different levels and with different interests (government, private companies, NGOs, public), and who wish to contribute to the resilience of their own delta and other deltas worldwide.

Comparative analysis of delta scorecards

Comparison of the scorecards for the different deltas clearly shows that current overall sustainability is not satisfactory for most of them. Many are in the danger zone (orange), which means that they are very vulnerable to adverse drivers of change. The Ganges-Brahmaputra-Meghna (Ganges-Brahmaputra-Meghna delta) and Ciliwung deltas are in a critical state and scores lowest (red), because they have major problems for all layers and also governance has not yet been capable to improve this situation.

For the deltas that are in or beyond the danger zone the reasons for this position differ. The Ciliwung delta, Ganges-Brahmaputra-Meghna delta and Nile delta are examples of deltas that have to cope with very high land and water demands due to high population pressures, which combined with a moderate (Nile) to inadequate (Ciliwung and Ganges-Brahmaputra-Meghna delta) infrastructure lead to significant problems. The California Bay and Mississippi River deltas have moderate land and water pressures, but their major problem lies in the rapid declining nature values (e.g. ongoing wetland loss in Louisiana). Furthermore, their current flood vulnerability in combination with the weak flood protection system results in relatively high flood risks. Also the Incomati combines a moderate land and water pressure with degrading natural resources and an insufficient infrastructure.

Positive exceptions are the Yangtze, Mekong, Rhine-Meuse and Danube deltas. The Rhine-Meuse delta can currently be considered to have a relatively good sustainability, mainly because of the high score for infrastructure, moderate land and water use and relatively good governance. The Danube delta scores positive on the status of all three layers, which is not a surprise considering the very low population density of around 5 inhabitants per km^2. The Yangtze delta (and maybe the Mekong delta) seem to be in a transition zone: currently the demands on land and water use can be balanced by the infrastructure. But the natural resources are in decline and land and water use are on the rise, which in due time could affect sustainability negatively. (N.B. See page 57 for extensive explanation regarding Table A).

Based on the aggregated scorecards we may conclude that for most of the deltas current resilience and sustainability is not satisfactory. The reasons for this vary from delta to delta, but the following general mechanisms seem to be prevalent (see Table A):

- An imbalance between demands and supply with regard to land and water use.
- An inadequate or ageing infrastructure.
- Disruption of the natural delta processes.
- Inadequate governance to address problems and implement solutions.

Drivers of change

The most important driver in the deltas studied is climate change, which is expected to have medium to severe impacts in seven out of ten deltas. This involves among others

- sea level rise, resulting in higher flood risk, salt water intrusion, salinisation and coastal erosion,
- more extreme weather events, especially in tropical areas and
- change in distribution and extent of ecosystems/habitats.

Often already existing problems in deltas will be exacerbated by the impacts of climate change. In half of the deltas studied economic development is an important driver with medium to severe impacts on the natural system. In many deltas considerable subsidence is caused by human activities.

Table A
Comparative overview of the scorecards of the 10 deltas studied

	Land and water use (occupation layer)	Infra–structure (network layer)	Natural Resources (base layer)	Governance	Resilience & Sustainability Indicator		
					Current	Moderate Scenario	Extreme scenario
Nile delta	––	0	–	0	–	–	––
Incomati delta	0	–	–	–	–	–	––
Ganges-Brahmaputra-Meghna delta	––	––	––	0	––	–	––
Yangtze delta	–	+	–	0	0	0	––
Ciliwung delta	––	––	––	–	––	––	–
Mekong delta	0	0	–	0	0	+	0
Rhine–Meuse delta	+	++	0	+	+	0	–
Danube delta	+	+	+	0	+	0	0
California Bay–Delta	0	–	–	0	–	0	–
Mississippi River Delta	0	0	–	0	–	0	–

resilience/sustainability: *++(very good), + (good), 0 (medium), – (low), –– (very low)*

Many deltas are heavily affected by developments taking place upstream. For example, new reservoirs may trap sediments that are needed to prevent coastal erosion. Changes in land use and measures in the catchment will influence water and sediment fluxes to the delta (e.g. higher peak discharges because of reduced storage in the basin or loss of discharge due to irrigation) Also, water and sediment quality in the delta is largely influenced by upstream developments. In the envisaged follow-up of this project upstream developments will get more attention.

Governance and comprehensive delta plans

The need to tackle the problems at all physical planning layers poses a major challenge to the governance of a delta. Better interaction between the three layers necessitates a reorientation on the tasks and responsibilities between public and private actors. This new role division may require a change in governance style. Government services, citizens and other stakeholders need to cooperate with respect to integrated (multi-sectoral) policy formulation, management design and implementation, resulting in Delta plans and programmes, and better management upstream.

For a number of deltas the challenge is defining a comprehensive (multi-sectoral) delta plan, i.e. a delta-specific framework for future delta management and development, incorporating a common perception (vision) for all delta stakeholders at national and sub-national levels. Comprehensive delta plans exist for few deltas. However, there is a growing number of collaboration structures within (and across) deltas, which are needed to develop such plans. At the level of legal instruments, designed to support sustainable delta management and development, much work still needs to be done for most deltas.

Adaptive measures, methods and tools

Various types of adaptive measures can be proposed to improve resilience and sustainability of deltas. The types distinguished in this study are: technical, ecological, economic and institutional measures. In general the adaptive measures proposed for the deltas studied tend to be technical and ecological, rather than economic or institutional.

The inventory of available methods and tools yielded that there are many delta-specific process models, decision support systems and integrated assessment and management tools. Collaborative efforts in tool development should focus on adapting existing tools for new situations rather than on developing completely new ones for each delta. Working with common tools will facilitate research collaboration and inter-delta data exchange.

Comparative analysis of research gaps

In Table B an overview is presented of issues for which research gaps have been identified in various deltas. The most prominent field of potential inter-delta research cooperation concerns various base-layer issues, ranging from monitoring and predicting changes, through understanding cause-and-effect relationships and ecosystem functioning, to natural safety and 'building with nature'. As to governance, the major issues identified for cooperation are 'governmental roles and arrangements' and 'integrated delta management'. The most important occupation and network layer issues relate to socio-economic scenarios, freshwater management and treatment, and innovative dikes and dams. In addition, the following general remarks can be made:

- Recent research on delta issues tends to be problem-oriented and mainly focused on the base-layer. There are opportunities for solution-oriented research following the multi-layer approach used in this study.
- Common delta research gaps have been identified in this study especially for base-layer issues. However, an integrated approach remains important because of relationships between the different layers and governance issues.
- Although the problems in deltas may be very specific and need tailor-made solutions, collaborative research across deltas may result in a change of perspective and innovative solutions.

Although new research is necessary, it should be remembered that optimizing the use of existing research results also deserves attention. Inter-delta collaboration is not only a way to reach joint research objectives, but may also facilitate sharing of existing research results for application in management and policy development. An inter-delta supply-and-demand inventory of research results was beyond the scope of this study but could be a fruitful exercise in a follow-up comparative delta study.

Table B
Comparative overview of research gaps. Between brackets for each issue the number of deltas for which this issue is identified as a research gap

	Nile	Incomati	Ganges-Brahmaputra-Meghna	Yangtze	Ciliwung	Mekong	Rhine-Meuse	Danube	California Bay-delta	Mississippi River delta
Occupation layer										
Socio-economic scenarios (6)	●	●		●	●			●		●
Water use and treatment (5)	●	●	●		●		●			
Integrated spatial planning (5)	●	●	●		●		●			
Ecosystem services (5)	●			●	●		●	●		
Land-use change modelling (4)	●		●		●				●	
Adaptation to salinisation (2)	●		●							
Network layer										
Freshwater management (7)	●	●	●		●	●	●		●	
Dikes and dams (5)	●		●		●		●		●	
Transport (3)	●	●			●					
Flood forecasting/early warning systems (1)			●							
Base layer										
Effects of changes/ eco-system functioning (9)	●	●	●	●	●		●	●	●	●
Building with nature and natural safety (8)	●		●	●	●	●	●	●		●
Monitoring changes (7)	●		●	●	●	●	●		●	
Predicting changes (7)	●		●		●	●	●	●	●	
Base-layer data management (3)			●		●					●
Governance										
Governmental roles and arrangements (6)	●				●	●	●		●	●
Integrated delta management (6)	●	●	●	●	●			●		
Communication/capacity building (4)	●	●	●		●					
Financial arrangements (4)			●		●		●		●	
River basin cooperation (2)		●	●							
Policy impact studies (1)					●					

Follow-up in next phase

The combined layer and DPSIR model approach has proven to be useful, workable and practical. However delta comparisons could become more robust if for at least a minimum set of indicators quantitative data is provided and a transparent scoring method is developed (to be elaborated in the follow-up of this project). This set of indicators will necessarily be a compromise between completeness, practicality and availability. Accepting that the data availability and quality will vary somewhat among the deltas under study, the challenge is to identify the key indicators that provide a maximum of information on delta sustainability with minimum data. In further work on the scorecards scenario details and ranking methods need to be clarified.

In the next phase of the Delta Alliance it is envisaged to support a follow-up of this current comparative overview of deltas. In this research the delta assessment approach will be further developed and more deltas will be involved (a.o. Rhone, Po, Thames, Elbe, …)
Moreover concrete collaborative research ideas across deltas will be elaborated and better implementation of existing research will be encouraged.

Introduction

Chapter 1

Rationale

The objective of this project is to provide a first step towards a comprehensive overview of the current and future state of deltas. This involves climate change impacted (policy) sectors, identifying main indicators for main drivers of change and application of 'scorecards', taking into account different socioeconomic and climate change scenarios. The reason behind this objective is twofold:

- it enables an overview of the main challenges, (potential) problems and opportunities of deltas worldwide, contributing to a sense of (inter)national awareness, need for knowledge exchange on policy and research issues, and to encourage collaborative (research) projects.
- when repeated from time to time it enables monitoring of changes in the status of delta developments, showing trends and policy impacts.

Although there already exists a large body of knowledge on the characteristics and functioning of many deltas, most of this information is of a mono-disciplinary nature. There is relatively little knowledge that enables a comparative overview of delta management in which both the natural scientific, social and managerial knowledge is integrated. This study is meant to provide a framework to start collecting and arranging data and information in such a way that the interaction between climate change, the biophysical and socioeconomic development of deltas can be made visible.

Introduction

Chapter 1

Definition of delta

Deltas are formed from the deposition of the sediment carried by the river as the flow leaves the mouth of the river. A delta may be therefore defined as a landform that is created at the mouth of a river where that river flows into an ocean, sea, lake or flat arid area. More precise definitions are given by scientists from various backgrounds and focus on their respective discipline. For instance:

- the seaward prograding land area that has accumulated since 6,000 years, when global sea level stabilized within a few meters of the present level (Amorosi & Milli, 2001),
- the seaward area of a river valley after the main stem of a river splits into distributary channels (Syvitski & Saito, 2007),
- the area of a river valley underlain by Holocene marine sediments (Kubo et al., 2006),
- accumulated river sediment that has variably been subjected to fluvial, wave, and tidal influences (Overeem et al., 2005),
- the area drained by river distributary channels that are under the influence of tides, or
- any combination of these definitions (Syvitski, 2008).

The aerial extent of a particular river delta varies depending on the definition and it is therefore difficult to define exactly what area of coastal lowlands is incorporated by a delta (Syvitski, 2008). Also the seaward boundary is a matter of definition. Reker et al. (2008) define the delta front, where river and marine processes are both important, and the pro-delta, where marine processes dominate. With the delta plain, where river processes dominate, these three environments together constitute a delta.

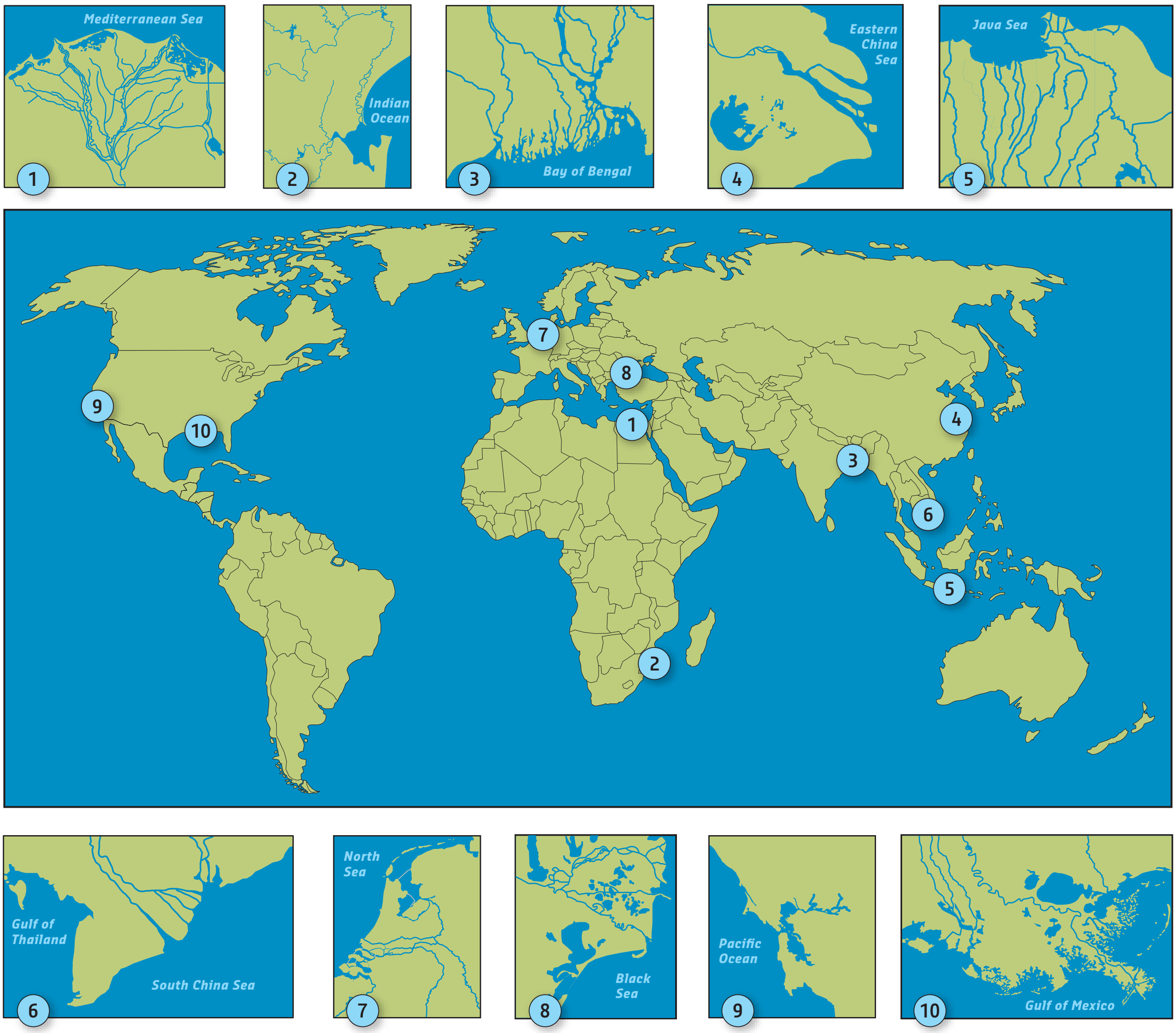
For some deltas the landward delineation is quite straightforward. The Nile delta is probably the best example: its apex can be located near Cairo where the river splits in several distributaries, and the accumulated river sediments are clearly visible on satellite images as they contrast with the surrounding desert. For others, such as the Yangtze or Rhine-Meuse delta, it is more difficult to delineate the landward boundary.

In this study a broad interpretation of deltas is adopted, which includes deltas proper, estuaries and the adjacent coastal zone. We are aware of the fact that this poses a methodological problem. Especially when one considers that often the geomorphological definition does not match the administrative or commonly used naming. For instance, in China there are three main methods to define the Yangtze delta administratively: the Shanghai region, 16 cities, Shanghai and two provinces. From a geological viewpoint, the Yangtze delta has its apex at the city of Zhenjiang, more than 160 km from Shanghai. Problems occur when key characteristics of deltas are given, such as the total area, the number of inhabitants or population densities. A clear definition of the delta area would solve this problem. However, a new problem arises: which definition to choose? Based on its geomorphology or administrative boundaries? Besides, most socioeconomic data is available for administrative units rather than geomorphological units. Hence, defining where the delta starts largely depends on the disciplinary domain. But since this comparative overview intends to provide an integrated, interdisciplinary picture of deltas, we cannot single out one discipline on which to base our definition. In the framework of this comparative overview of deltas, we therefore decided not to choose one particular definition of a delta. Hence, the delta wing coordinators themselves were free to choose the appropriate definition for their delta description. We are confident that this does not significantly influence our overall conclusions, as long as due attention is given to referencing to the area of interest wherever quantitative indicators are used.

Deltas studied and main characteristics

The following 10 deltas are studied (see map below):

Continent	Country	Delta	No
Africa	Egypt	**Nile**	1
	Mozambique	**Incomati**	2
Asia	Bangladesh	**Ganges-Brahmaputra-Meghna**	3
	China	**Yangtze**	4
	Indonesia	**Ciliwung**	5
	Vietnam	**Mekong**	6
Europe	The Netherlands	**Rhine-Meuse**	7
	Romania	**Danube**	8
N-America	United States of America	**California Bay-Delta**	9
	United States of America	**Mississippi River Delta**	10



Overview of some salient features of the deltas:

Continent	Delta	Salient features
Africa	**Nile**	The Nile delta ranks among the world's most fertile farming areas and is surrounded by a highly arid environment with related water scarcity issues. With half of Egypt's population of 80 million living in the delta, its relevance for the national economy can hardly be underestimated.
	Incomati	The Incomati delta is part of the fastest growing socio-economic areas in the Southern African region, due to rapid developments along the Johannesburg-Maputo international axis of economic development. Maputo Bay is considered a hotspot for conservation of wetlands.
Asia	**Ganges-Brahmaputra-Meghna**	With a surface area of some 100,000 km², the delta formed by the three rivers Ganges, Brahmaputra and Meghna is the largest in the world. It is also one of the most densely populated regions on earth. Floods from river and sea are a permanent threat.
	Yangtze	The Yangtze delta shows a fast urbanization trend fuelled by the economic growth of Shanghai, China. The city is serving as the financial and logistic centre of China and has the world's largest cargo port. Water quality and water supply is facing serious challenges.
	Ciliwung	In the Ciliwung delta Jakarta is situated. This mega-city is the fourth largest urban area in the world and of major importance to the national eoconomy. It is still rapidly developing, although some part of the metropolitan city is already below sea level and is still subsiding.
	Mekong	For two-third the Mekong delta is situated in southern Vietnam and for one third in Cambodia. It is one of the most productive and intensively cultivated areas in Asia ('Rice Bowl') and a priority area for economic development. Floods are a common feature to which the people have learned to cope with.
Europe	**Rhine-Meuse**	Together, the Rhine and Meuse rivers have formed a delta that constitutes roughly two third of the Netherlands. With Rotterdam harbour being one of the worlds largest sea ports, the delta is highly developed. Most of the area is below sea level, but also has one of the highest safety standards against flooding.
	Danube	At the mouth of the Danube, the largest river in Europe, a delta has formed partly in Romania and for the other part in the Ukraine. With an average density of 5 inhabitants per km² the delta is sparsely populated. The entire Romanian part of the delta has been declared a Biosphere Reserve because of its outstanding natural values.
N-America	**California Bay-Delta**	The California Bay-Delta consists of an inland delta formed by the Sacramento-San Joaquin river and a densely populated, but low-lying urban area around San Francisco Bay. The delta is exceptionally rich in natural values and agricultural production, and is a vital source of fresh water for California's trillion dollar economy.
	Mississippi River Delta	The Mississippi River Delta hosts a highly productive area of fish and wildlife, although it continues to loose wetlands at an alarming rate. The city of New Orleans was severely struck by Hurricane Katrina. Its port is one of the key centres of maritime and petrochemical industry in the USA.

Brief introduction on report structure

In **Chapter 2** the approach of the proposed framework for delta assessment is elaborated. This involves explanation of the DPSIR approach and Layer model, governance issues, the use of indicators and the delta 'scorecard'. In **Chapter 3** for each delta the scorecard and some clarification notes on the scorecard are mentioned. The main items of the delta descriptions are summarized in the Appendix. **Chapter 4** is the synthesis and main part of this report. A comparative overview of the deltas is presented and discussed, regarding drivers of change, pressures (for the three layers), governance, scorecards, adaptive measures, technical methods and tools, and research gaps and opportunities for exchange and collaboration. In **Chapter 5** some main conclusions are drawn, lessons learned are summarized and recommendations are made on the way forward. The full delta descriptions are available in a separate 'Working document' (see **www.delta-alliance.org** or CD on the back cover of this report).

Approach

Chapter

2

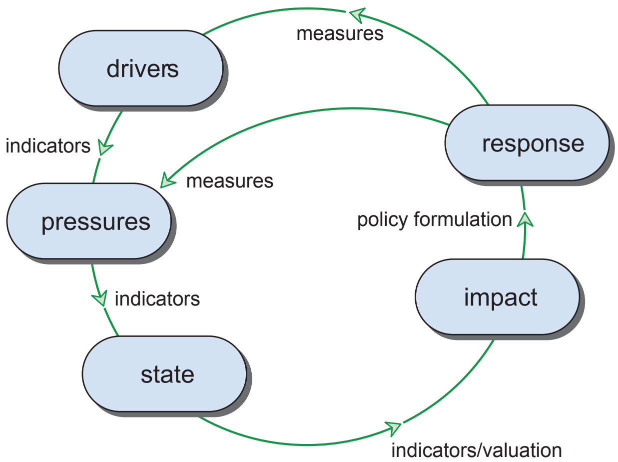
The proposed framework for delta assessment builds on the work done for the Aquaterra 2009 conference in Amsterdam (Van der Most et al., 2009) and elaborates recent recommendations of the World Estuary Alliance conference (Shanghai, June 2010) regarding the development of a worldwide assessment of estuaries by means of 'scorecards'. The proposed framework links the DPSIR approach (OECD, 1993) with a layer model for a delta. This should be seen as first step towards a more elaborated framework, to be developed in due time with relevant stakeholders. The advantage of this approach is that it is sufficiently generic which makes it applicable for all deltas. As will be explained later, the framework provides easy linkage with governance issues and with the different actors and agencies involved in delta management.

Approach

Chapter 2

The framework is used for describing deltas in a uniform format in order to make a comparative overview and analysis more easy. Building on the contacts of the Delta Alliance (and World Estuary Alliance) each delta description was prepared by a Delta Wing Coordinator of the Delta Alliance (or another main contact person), in most cases in cooperation with several (sectoral) experts. Summaries of these descriptions can be found in Chapter 3 of this report. All delta descriptions end with a scorecard, which summarizes the overall status

Figure 1
The DPSIR approach



and outlook regarding delta sustainability. Based on these descriptions and scorecards a synthesis has been prepared by the authors that has been commented upon by the Wing Coordinators (and related experts).

As mentioned already in the introduction, the definition and delineation of a delta poses a methodological problem, especially with respect to data collection and interpretation. We decided to take a pragmatic approach and did not prescribe a strict definition. Instead, the delta wing coordinators themselves were free to choose the appropriate definition for their delta description, to decide which (sectoral) experts should be involved and to determine the score in the scorecard. This also implied that the Wing coordinators are responsible for using as much as possible scientific or reliable data and information for their descriptions. It has to be borne in mind that this is a daunting task because of the interdisciplinary nature of the approach. Since it is the first time that such a wide ranging comparative overview is prepared it is inevitable that we come across many difficulties in this respect. Therefore, the descriptions and scorecards should be regarded as a foundation on which to build improvements and elaborations for future comparisons.

DPSIR approach

The Driver, Pressures, State, Impact Response (DPSIR) approach has been developed by the OECD (OECD, 1993) to analyse environmental problems. The DPSIR framework helps in finding the root causes of problems, the so-called drivers. These are mostly found in the broader societal context (e.g. population growth is a major driver of many environmental problems). But also natural phenomena could act as important drivers. Also global environmental and economic developments, such as climate change and international oil and commodities markets are important drivers for change.

Drivers fuel changes that result in pressures on the actual state of a delta. These pressures can be identified as problems that affect the current state of the delta. Adverse changes in this state will have an impact on the perceived values and objectives of a society. For instance, water pollution is a pressure on the state of the environment, which leads to adverse impacts on the health of people but also on the biodiversity of the aquatic system, on the fishery production etc. When these adverse impacts are serious, they should lead to a response, in terms of a policy formulation and subsequent measures to improve the situation. These measures could be directed either to reducing the root causes of the problem or to reduce the pressure directly (see figure 1).

Drivers for delta development

Population growth, economic development, climate change and subsidence are the main drivers for change in deltas. These developments pose extensive demands on the available natural resources. But also technological development can be seen as a driver for change: it may provide opportunities for more cost efficient infrastructure or exploitation of previously untapped natural resources. In the box below a general description of the main drivers for change is provided.

In addition to these (external) drivers, there is a number of societal trends which affect the organization and outcome of delta planning and development. Of these trends decentralization and privatization may be viewed as autonomous developments. The challenge is to utilize the advantages of both trends, while minimizing their undeniable drawbacks. This calls for a selective enhancement of governance structures, reflecting the regional scale, integrated nature and long term perspective of more resilience and sustainable delta development.

Pressures and state of the delta: the Layer model

In order to understand how the drivers lead to changes in the pressures and state of the delta, a multitude of relations between human activities, physical and ecological delta conditions need to be accounted for. To provide insight in this complex system, it is proposed to apply a simplified structure in the form of a Layer model. This Layer model recognizes three physical planning layers (figure 2): the Base layer (water and soil), the Network layer (infrastructure) and the Occupation layer (zoning of land use functions), each with different but interrelated temporal dynamics and public-private involvement (VROM, 2001). The model indicates a physical hierarchy in the sense that the Base layer influences the other layers through both enabling and constraining factors. For instance, the soil type determines to a large extent the type of agriculture that can be performed in the occupation layer.

Drivers of change

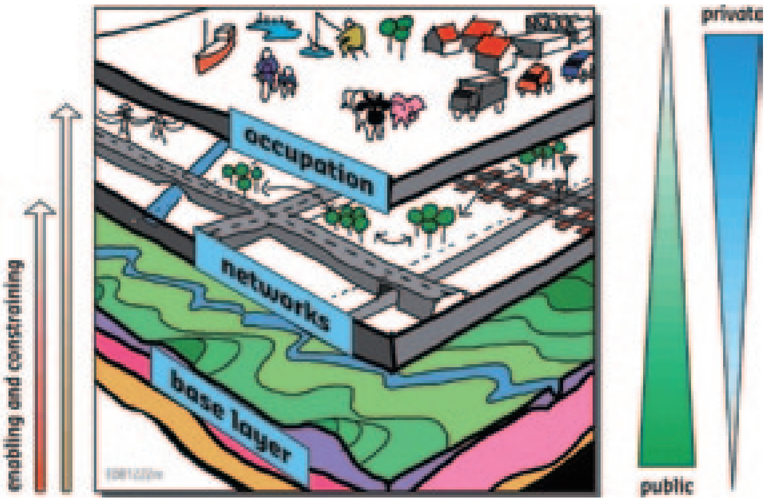
Population growth: the global population still grows with some 2% per year, although there are distinct regional differences. The migration of people towards coastal urban areas often yields in a greater than average growth of the population in delta areas. The number of people to be served and to be protected against natural hazards will increase.

Economic development: despite the current financial crisis, economic growth may be expected over longer periods of time, resulting in larger demands to be met, higher values to protect, more energy to be generated and more goods to be transported. This may also lead to upstream developments (dams etc.), which are also recognized as important drivers of change for deltas.

Climate change: although the extent of climate change may be subject of debate, there is general consensus that the rise of global temperature is inevitable, with its associated (local) impacts on sea level rise and the hydrological cycle (larger and more frequent droughts and floods).

Subsidence: most deltas are subjected to the natural geological process of long-term subsidence. Additionally, extraction of groundwater and fossil fuels, may cause significant lowering of the delta surface on the short term. Other short-term processes leading to delta surface lowering at a more local scale are shallow compaction and oxidation of organic sediments, which may also result from human activities.

Technological development: innovations may open opportunities to enhance the functionality of infrastructure solutions, to extent the life time of infrastructure and/or to develop more cost efficient designs.



occupation
speed of change
10 - 25 years

networks
speed of change
25 - 100 years

base layer
speed of change
50 - 500 years

Figure 2
The Layer model

Unfavourable conditions (constraints) posed by the Base layer can to a certain extent be mitigated through adaptations in the Network layer or occupation layer. For example, farmers can use agrochemicals to improve soil conditions. And dykes can be constructed to protect low lying land from flooding. But these adaptations to the original physical geography of an area require investments and need to be managed.

The essence of the Layer model is the difference in dynamics and vulnerability between the layers, which results in a logical order in planning the various layers. The layers enable and/or constrain activities in another layer. Besides the physical interactions between the layer, the model is also useful in positioning the roles of different actors, such as government agencies, private entrepreneurs and stakeholders. The development and maintenance of infrastructure in the network layer is traditionally the responsibility of the government. The government also has a main role in the protection and management of the base layer. Moving towards the occupation layer the role and influence of the government becomes more restricted and the influences of private parties and citizen's interests become more dominant. The Layer model is largely compatible with other well known approaches, such as the ecosystem functions approach (De Groot, 1992; De Groot, 1994; De Groot et al., 2002). The base layer provides the enabling conditions for humans, which can be split into function categories, such as regulation, habitat, production, information and carrier functions. An important advantage of the layer model is that it explicitly takes into account human alterations to the natural ecosystem. Indeed, many deltas are no longer in a pristine state and should be described as modified or highly modified ecosystems. The layer model describes these modified ecosystems in terms of the base layer and the network layer.

One of the principal challenges in the study of human–environment systems is to understand the interactions between phenomena that occur at different temporal and spatial scales (Newell et al., 2005). For this the Layer model is excellently suited, since it combines the spatial scale of each of the layer with the vertical differentiation in temporal dynamics. Each of the layers can be represented in map form, or as overlays in a GIS, enabling spatial analyses.

As with time and space, an analogous approach can be used to articulate scales of human decision making in similar terms: 'agent' and 'domain'. The agent captures the concept of who makes decisions, and the domain describes the specific institutional and geographic context in which the agent acts (Agarwal et al., 2002). The Layer model makes it possible to distinguish different types of agents for each of the three layers. When combining the model with the institutional layer model of Williamson, the matrix thus constructed becomes even more powerful to link human-environment systems with different modes of decision making (Marchand & Ruijgh–Van der Ploeg, 2009).

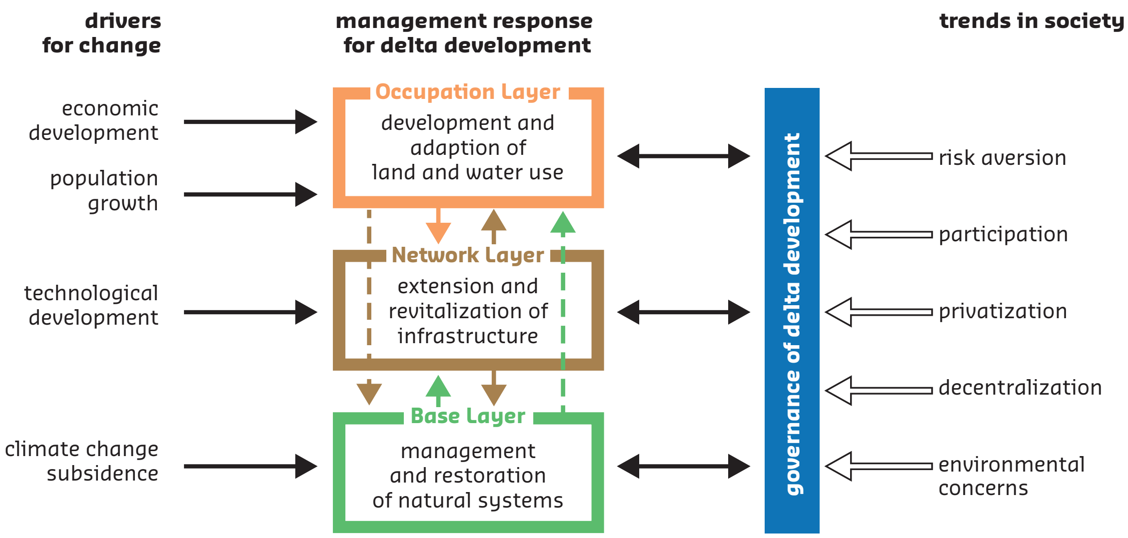
Delta management responses and governance

To promote more resilience and sustainable development of deltas a clear vision has to be developed on how to respond to the various drivers of change as well as on how to play along with the trends in society. Using the Layer model as a starting point, it becomes clear that there are three main response themes on which delta management could focus, i.e. the development and adaptation of land and water use (occupation layer), the extension and revitalization of infrastructure (network layer) and the management and restoration of natural systems (base layer). Regarding the base layer it should be noted that in deltas especially the sediment dynamics (balance) between sea, river and hinterland is important. Many deltas suffer from a sediment deficit, because sediments from the catchment are trapped in reservoirs upstream. Often embankments along the delta distributaries prevent flooding and vertical accretion of the delta plain. The disturbance of natural delta sediment dynamics (i.e. lack of sediment) leads to land loss and increased flood vulnerability.

The governance required for these management challenges extends over all three layers and is characterized by a mix of government responsibility and private or non-governmental actor roles. In figure 3 a conceptual picture is given that links the management response themes to the drivers of change and trends in society. This concept provides the framework for the assessment of delta development and management responses and will be used for the comparative overview of deltas.

In the past few decades the development and management of deltas has become increasingly complex and often an issue of societal debate. As depicted in Figure 3 the management needed to implement the responses to both physical and societal drivers of change extends over the three spatial planning layers. The term 'governance' is used here because management is not only a responsibility of the government, but also of stakeholders in the broadest sense. The government can be described as an institutional structure (administration) that society uses to translate politics into policies, legislation and implementation. Governance is the outcome of the interaction of the government, the public service and citizens throughout the political process, policy development, program design and service delivery.

Figure 3
Framework for delta assessment



In the layer model the management responsibilities of the Base and Network layers are traditionally allocated to government institutions and agencies. The Network layer which consists of infrastructure of all sorts, such as electricity grids, roads, canals and dykes, is managed by public work departments, water boards and utility companies. The Base layer is managed somewhat differently, often through legislation with respect to resource use (e.g. mining concessions, fishing quota, environmental impact assessments etc.). The distribution of tasks and responsibilities amongst public and private entities in relation to spatial planning varies among countries. In general, the role of public government is more limited in the Occupation layer than in the other layers because of the rights that are associated with land ownership.

Privatization, participation and decentralization are trends in many societies that affect the role and position of the government. For instance, the traditionally strong role of government agencies in public networks is changing because of a privatization trend. Public-private partnerships are becoming more and more the modus operandi for new infrastructural projects. Utility sectors, such as railways, electricity and drinking water have been privatized in many countries. Increased efficiency of tax payer's money is a key motive for this development. But that does not mean that there is no role left for the central government. Indeed, in order to safeguard public values in the liberalized utility sectors, authorities are installed that oversee quality and guaranteed delivery of goods and services.

Decentralization of planning and management is also a noteworthy trend in many countries. There are different reasons for downscaling management and planning to more regional and local levels: e.g. reduction of government bureaucracy, increased empowerment and participation of local stakeholders, state budget constraints and political motivations. However the need to cope with the negative side-effects of decentralization constitutes a major trigger for the strengthening of the governance structure through multi-level and multi-sectoral governance.

Deltas are mostly governed by multiple (and often sectoral) governing layers at local and regional level. Only in some cases there is an authority or agency trusted specifically for the management of a delta. Furthermore, there is a need for a stronger involvement with river basin management because of the important linkage between river and delta. In many cases this even requires international cooperation because of the transboundary character of many rivers.

In some countries interest groups and citizens have a stronger voice in development. They are able to delay or deter developments if these harm their interests. Involvement of stakeholders and citizens is important to promote societal support for development projects. If the success of proposed measures depends on the active co-operation of stakeholders and/or citizens their participation is a precondition for a sustainable development.
Development of deltas is faced with many uncertainties, among these the speed and extent of climate change. This explains a growing interest in risk management and other approaches for dealing with risk and uncertainty in a structured and systematic way.
It is clear that governance has many dimensions: political, organizational, social and economic. And societal trends may be viewed as autonomous developments influencing all these dimensions. The challenge for delta areas is to develop governance structures, reflecting the regional and local scale, integrated nature and long term perspective of delta development. In other words, to create the proper conditions for a sustainable development of deltas.

The governance structure of deltas may be strengthened through different ways:

- Promoting a better co-operation between different levels and sectors of government taking into account trends of decentralization and the need for (national) coordination.
- Facilitating the cooperation between government and the private sector taking into account trends of privatization but also the need to safeguard the public interest.
- Better involving stakeholders and citizens in development and management issues to promote the societal acceptance of development projects as well the long term sustainability of development projects (arrangements and incentives for maintenance).
- Creating arrangements for dealing with uncertainties and sharing of risks (insurance).

An example of a multi-sectoral approach is 'Rotterdam Mainport Development' (PMR). This project has two main objectives:

1. expansion of Rotterdam harbour for economic development and
2. promotion of nature areas and well-being.

Besides compensation of nature, the project also envisages 750 hectares of new nature and recreation areas around the city. Hence, it is more than just an economic harbour project, but aims at integrated development in which shipping, industry, nature and environment will benefit. Currently work on both the land reclamation for the harbour extension and for nature development is in progress.

Towards indicators of change

Now that we have formulated a generic framework for delta assessment, indicators are proposed for the main drivers, pressures and governance issues. First we will look at the indicators that can be used to describe the current and future state of the delta and through which we can fill in a scorecard for each delta. At a later stage the framework will be used for illustrating adaptive measures and the knowledge agenda of the Delta Alliance. In figure 4 below a first elaboration is given of the drivers, pressures, governance issues and responses, which are relevant for most deltas in one way or another. This list is by no means exhaustive and can be extended or modified for a specific delta.

Figure 4
Interaction in deltas between Drivers, Pressures, Governance and Responses

DRIVERS	PRESSURES/IMPACTS	GOVERNANCE	RESPONSES
Demographic trends • population in delta • migration	**Land and water use (Occupation layer)** • pressure on space • shift in land use/urbanization • water demand • flood vulnerability	**Multi-level and multi-sectoral cooperation**	**Development and adaptation of land and water use** • multifunctional land use • land use zoning • water saving • flood preparedness
Economic developments • status of economy • sectoral developments • upstream development	**Infrastructure (network layer)** • flood protection system • irrigation and drainage • water supply & sanitation • roads, railways & ports	**Public-private partnerships**	**Extension/revitalization of infrastructure** • land reclamation • multifunctional use of infrastructure • building with nature
Technological developments • food / agricultural • civil engineering • ICT • energy generation	**Natural resources (Base layer)** • freshwater shortage • salinity intrusion • water pollution • flood hazard • coastal/fluvial erosion • loss of biodiversity and wetlands • sediment supply • mobility of delta distributaries	**Involvement of stakeholders and citizens**	**Management and restoration of ecosystems** • protected areas management • habitat restoration • ecological engineering • environmental flows • multiple use of wetlands • ecosystem approach
Climate change • temp./evaporation • sea level rise • precipit./discharge		**Approaches for dealing with risks and uncertainties**	
Subsidence • natural and human induced subsidence			

Table 1

Preliminary list of indicators for drivers, pressures and governance

DRIVERS	Main indicators
Demographic trends • population in delta • migration	• number of people and growth rate • migration trend in delta (annual percentage in/out)
Economic developments • status of (total) economy • sectoral developments • upstream development	• per capita GDP, growth rate, % contribution by delta • main sectors, growth rate • unemployment rate • (planned) dams in main tributaries in the catchment
Technological developments • food / agricultural • civil engineering • ITC • energy generation	• Percentage of GDP spent on innovation and research in each sector
Climate change • temperature / evaporation • sea level rise • precipitation / discharge	*(Downscaling of global IPCC scenarios)* • change of temperature / evaporation • change of sea level (mm/year) • change of precipitation (mm/year) or river discharge (M^3/sec)
Subsidence • natural and human induced subsidence	• cause of subsidence (e.g. geologic, grond water extraction or oil exploration) • rate of subsidence (mm/year)
PRESSURES/IMPACTS	**Main indicators**
Land and water use • pressure on space • shift in land use / urbanization • water demand • flood vulnerability	• number of inhabitants, population density, change in land value • % urban area, urbanization rate • water deficit / number of days with interrupted water supply • % area vulnerable for flooding / number of vulnerable people / value of vulnerable assets
Network / infrastructure • flood protection system • irrigation and drainage • water supply & sanitation • roads, railways and ports	• flood risk (safety level), % of delta protected (high-medium-low) • % of delta under irrigation • % of infrastructure which needs to be upgraded • number of floods or flooding days per year • % people with access to water supply, % untreated waste water • water sanitation risk index* • density of infrastructure, number of ports (+ volume of goods)
Natural resources • freshwater shortage / salinity intrusion • pollution • flood hazard • coastal erosion / wetland loss • biodiversity loss • sediment supply • mobility of delta distributaries	• number of droughts or drought days per year / % of delta with salinity problems • % of polluted areas (water, soil, air) • frequency of storms (storm surge) / frequency of extreme river discharge, flood hazard level (high-medium-low) • annual loss of land (km^2/year) / average erosion rate (m/year) • total area of wetlands / % of wetlands protected by treaties • biodiversity index (e.g. LPI)** • soil erosion in catchment (Mton/year) • fluvial sediment transport (Mton/year) • river discharge (peak/low and variability) • % of sediment trapped in reservoirs • existence of dykes/embankments along delta distributaries
GOVERNANCE	**Main indicators**
• multi-level and multi-sectoral cooperation	• existence of integrated plans (delta plan, national adaptation plan etc.) • existence of inter-ministerial committees, multi scale level committee etc.
• public-private partnerships	• number of PPP's • scale of PPP's (geographic, budget, time span)
• involvement of stakeholders and citizens	• existence of legal instruments for participation (e.g. spatial planning instruments) • number of NGO's involved in planning and decision making
• approaches for dealing with risks and uncertainties	• existence of adaptive management , adaptation strategies etc. (long term) • existence of risk management, emergency systems etc. (short term)

* *average of fraction of population without treatment of discharge water and fraction of population without public water supply*

** *LPI (Living Planet Index). The LPI is an indicator of the state of global biological diversity, based on trends in vertebrate populations of species from around the world. Unclear if the data used for the LPI is sufficiently detailed to produce an index on the scale of a single delta. WWF uses this LPI for their estuaries report.*

Indicators for drivers, pressures and governance

For this delta assessment many different indicators may be used (table 1). Ideally, these indicators are quantitative and based on reliable data. In practice it may be quite difficult to produce such indicators, since data may be incomplete, scattered or unreliable. We will encounter both temporal and spatial problems: data may be incomplete, heterogeneous and inconsistent. For instance, subsidence rates may show large spatial differentiation within one delta. Should we then take the maximum values or an average for the entire delta? This may be especially difficult if only a few data points are available.

Preferably indicators should be indicative of the (potential) problem that it describes. However in many cases a problem can only be identified by combining the results of several indicators. In other words an (integrated) problem analysis is needed.

The opportunities for collecting data for indicators differ from country to country. Usually one can make use of the activities of the government statistical office, which often produces a wealth of data. However, it always remains a challenge to downscale national data into data that are applicable for the delta in question. Often a delta is not regarded as one administrative unit, which implies that data for several units, such as provinces or districts needs to be combined and/or split up. In addition, for many indicators the existing data can not be used directly, but requires additional data processing. Therefore, this list of indicators should be regarded as indicative only (see also appendix for elaborated draft overview for deltas).

In each delta description the main elements of drivers, pressures (for the three layers) and governance are briefly described in 'summary tables' using most appropriate indicators (to be determined by the expert). Based on these 'summary tables', the scorecard for the delta will be filled in.

The relation between indicators, performance criteria and scores for a delta is illustrated in figure 5 below. This needs to be further elaborated in the follow-up of this project.

Figure 5
Relation between indicators, performance criteria and scores for a delta. Each score is a combination of performance criteria which on their turn are based on indicators.

	Land and water use (occupation layer)	Infra–structure (network layer)	Natural Resources (base layer)	Governance	Resilience & Sustainability Indicator		
					Current	Moderate Scenario	Extreme scenario
Delta	+	++	0	+	+	0	–

Performance criteria (Occupation Layer)		
Pressure on space	Water demand	Flood vulnerability
••	•	••

Main indicators: Pressures

Land and water use (occupation layer)

• Population density	• 500/km^2
• Urbanization	• High

Scorecard

The idea behind a scorecard is to present a highly aggregated evaluation of the state of the delta, without the need to delve into background data and analyses. The current version should be considered as a first step towards a more elaborated scorecard, to be developed in due time with relevant stakeholders.

It is an executive summary in the form of a table (preferably followed by some concluding remarks). Below an example of such a scorecard is presented (Table 2). Of course such a representation provides only a very rough indication of the status of a delta and is based on an interpretation of both qualitative and quantitative sources of information as mentioned in the summary tables for each item. Each item is scored on a 5 point scale, related to resilience and sustainability (from very good till very low).

Besides the current situation two development scenarios are recognized:

- Scenario 1, moderate perspective 2050: medium economic growth (1.2 %, Regional Communities-scenario) and related medium technological developments, combined with medium climate change and sea level rise (to be determined by expert)
- Scenario 2, extreme perspective 2050: high economic growth (1.7%, e.g. Transatlantic Market–scenario) and related high technological developments, combined with high climate change and sea level rise (to be determined by expert)

Table 2
Scorecard for delta assessment and some clarification notes (example of the Rhine-Meuse delta)

Rhine-Meuse delta	Land and water use (occupation layer)	Infrastructure (network layer)	Natural resources (base layer)	Governance	Overall resilience & sustainability indicator
Current situation 2010	+	++	0	+	+
Scenario 1 moderate 2050	0	++	0	+	0
Scenario 2 extreme 2050	–	++	–	+	–

resilience/sustainability: *++(very good), + (good), 0 (medium), – (low), –– (very low)*

Clarification notes on scorecard (example of the rhine-meuse delta)
The pressure on the occupation layer and the base layer will increase in time by economic development, climate change and relative sea level rise. Most critical issues will be related to drought and salinisation. Although economic development may also lead to more innovative technical solutions to critical issues, this might not be enough to safeguard sustainable development. Currently the estuarine natural value is low because hard infrastructure limits natural dynamics such as tides and natural brackish zones. The infrastructure will be maintained under all scenarios because of legal arrangements. Also the governance aspects and mechanisms are expected to be the same in time. In both scenarios the overall resilience and sustainability indicator will decrease, a bit more in the extreme scenario.

The rationale of the resilience and sustainability indicator is that sustainable development of a delta depends on a combination of the status of the three layers. Resilience and sustainability is good if the provision of goods and services equals the demand, without deterioration of the base layer. Hence a high demand from land and water use (high population density, large agricultural sector etc.) in itself does not necessarily lead to problems if the base layer, combined with infrastructure can meet this demand. Development is not sustainable if the base layer is deteriorated. A highly efficient and effective infrastructure could compensate the deficits, although long term sustainability (including biodiversity) is often not guaranteed. A combination of high demands with a poor functioning infrastructure and deteriorated base layer certainly indicates a critical (unsustainable) situation. On the other hand, when land and water use pressures are low, resilience and sustainability is easier obtained, even if infrastructure performance is poor.

With the scorecard some general conclusions can be drawn on the overall resilience and sustainable development of the delta.

Levee failure in California Bay-Delta

In the following paragraphs the reference status (more or less) of the layers and the governance issues are briefly described for the different scores.

Reference for Land and water use (occupation layer)

Good or very good: Sparsely populated delta, abundance of fresh water. Population density < 200 inhabitants/km^2. Example: Danube delta.
Medium: a medium intensity of land and water use. Population density between 200 and 500 inhabitants/km^2. Example: Mekong delta
Low or very low: denotes a high intensity of land and water use. This usually coincides with a high population density (> 500 inhabitants/km^2), existence of one or more large cities (high urbanization rate) and water-intensive agriculture. Example: Ganges-Brahmaputra-Meghna delta.

Reference for Infrastructure (network layer)

Good or very good: Modern up-to-date infrastructure with respect to land and water management and transport. High standard of flood protection, well maintained dikes or levees, storm surge barriers etc. Efficient and effective irrigation and drainage system. Extended road, railway and port infrastructure. Example: Rhine-Meuse delta
Medium: Land and water infrastructure is existent, but of mediocre quality, problems with maintenance. Transport infrastructure insufficient to cope with the transport demand. Example: Ciliwung, Indonesia.
Low or very low: Land and water infrastructure far below desirable state, or non-existent. Many problems with maintenance. Transport infrastructure is a major bottleneck for development. Example: Ganges-Brahmaputra-Meghna delta

Reference for Natural resources (base layer)

Good or very good: The delta is in a healthy condition, water, soil and air are of good quality, high biodiversity. Natural delta processes (e.g. sedimentation, soil development, natural purification, biomass production) are such as one expects from a natural delta. Freshwater is abundant and biological stocks are underexploited. High biodiversity. Example: Danube delta.
Medium: The delta is in average condition, water, soil and air are slightly polluted. Limited expression of natural delta processes. Freshwater and biological resources are exploited to or

over the maximum sustainable yield. Moderate biodiversity. Example: Mekong delta.
Low or very low: The delta is under large stress, water, soil and air are highly polluted. Natural delta processes have come to a complete standstill. Freshwater and biological resources are heavily overexploited. Low biodiversity. Example: Ciliwung delta.

Reference for Governance

Good or very good: The management of the delta is coordinated by a delta agency who is responsible for the implementation of an integrated delta plan that is based on an explicit delta vision or policy. In this vision or policy there is explicit attention towards uncertainties, e.g. in relation to climate change. Adaptation measures as well as emergency systems are proposed or being implemented. Stakeholders are intensively involved through a participation process that is framed in legal instruments. For the implementation of measures public-private partnerships, covenants and other management agreements are extensively being used. The Rhine delta may be given as an example where good governance more or less exists.
Medium: There is a general awareness that the management of the delta should be improved and first initiatives or ideas for a delta-wide governance structure exist. Discussions are being held among stakeholders on an ad hoc basis, experiments are conducted with public-private partnerships. Studies are on-going with respect to the impact of climate change on the sustainability of deltas. The California Bay-Delta is an example in this category.
Low or very low: Deltas that score low with respect to most of the indicators for governance may be considered to fall in this category. No delta-wide governance structure exists, administrative institutions are fragmented, there is hardly any multi-level and multi-sectoral cooperation. Stakeholders and citizens are generally not involved and awareness is still in an embryonic phase. The Incomati delta (Mozambique) may be considered to fall in this category.

Rotterdam, the economic heart of the Rhine-Meuse delta

Overview
of Delta Scorecards

Chapter 3

The Delta Assessment approach as described above is applied for each delta, using the delta descriptions as delivered by the Delta Alliance Wing coordinators and their teams. In the following paragraphs for each delta the scorecard and some clarification notes on the scorecard are mentioned. The main items of the delta descriptions are summarized in the Appendix and the full delta descriptions are available in a separate 'Working document' (see www.delta-alliance.org or CD on the back cover of this report).

Nile delta

Scorecard

Nile delta	Land and water use (occupation layer)	Infrastructure (network layer)	Natural resources (base layer)	Governance	Overall resilience & sustainability indicator
Current situation 2010	––	0	–	0	–
Scenario 1 moderate 2050	–	0	–	0	–
Scenario 2 extreme 2050	––	–	––	0	––

resilience/sustainability: *++ (very good), + (good), 0 (medium), – (low), –– (very low)*

Clarification notes on the scorecard:

The current situation in the Nile delta can be described as close to moderate rather than low. The pressures on the occupation layer and the base layer will increase due to population growth and economic development in the country. Furthermore, climate change and sea level rise will make the situation worse unless mitigation measures will be deployed and adaptation strategies planed.

The most critical issues will be related to increased salinisation in coastal areas, and droughts in the Nile Basin. Unless technological developments and Governance aspects do not significantly improve, the overall resilience and sustainability indicate will significantly decrease in the future.

Incomati delta

Scorecard

Incomati delta	Land and water use (occupation layer)	Infrastructure (network layer)	Natural resources (base layer)	Governance	Overall resilience & sustainability indicator
Current situation 2010	0	–	–	–	–
Scenario 1 moderate 2050	–	–	0	–	–
Scenario 2 extreme 2050	–	–	0	–	––

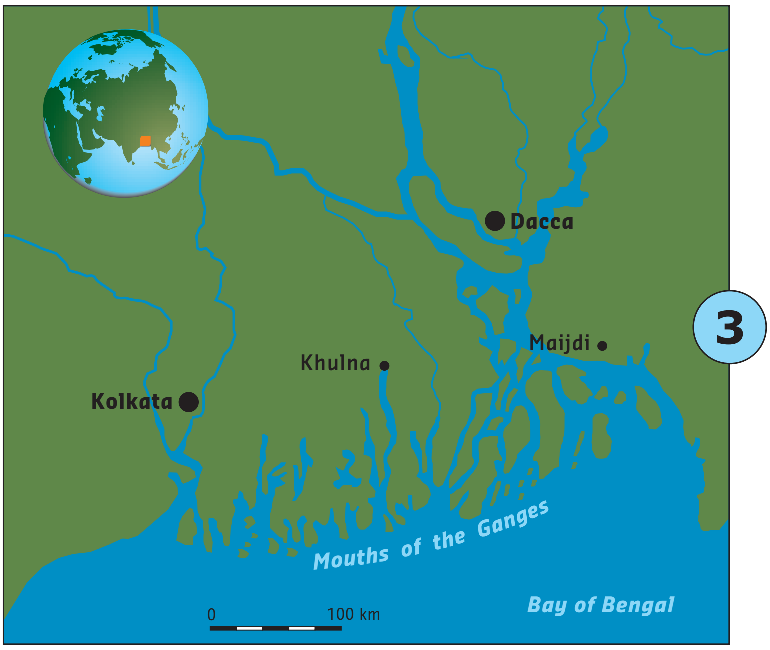
resilience/sustainability: *++ (very good), + (good), 0 (medium), – (low), –– (very low)*

Clarification notes on the scorecard:

The pressure on the occupation layer and the base layer will increase in time by socio-economic development, climate change and sea level rise. Most critical issues will be extremes in floods and droughts, but also the higher frequency of tropical storms.

In land use planning and development of infrastructure and technology there is increased awareness on environmental issues. This would reduce the negative impacts on the natural resources and ecosystems, but by far not enough to guarantee sustainable use of the natural resources. It is expected that the population pressure will lead to overexploitation and degradation of the resources, even if innovative technologies and integrated planning will be applied. Governance is increasing in power by improvement of integrated and participatory approaches. Although the country's economy is one of the fastest growing in Africa, economic development, technical infrastructure and governance are still largely dependent on donors. This affects the overall resilience and sustainability. The situation will worsen in case of more extreme scenarios.

Ganges-Brahmaputra-Meghna delta



Scorecard

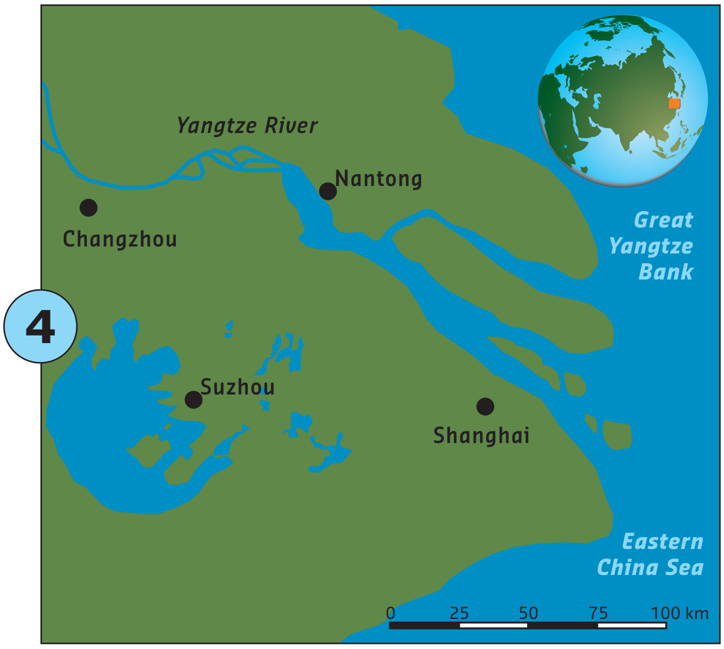
Ganges-Brahmaputra-Meghna delta	Land and water use (occupation layer)	Infrastructure (network layer)	Natural resources (base layer)	Governance	Overall resilience & sustainability indicator
Current situation 2010	––	– –	– –	0	– –
Scenario 1 moderate 2050	– –	–	–	–	–
Scenario 2 extreme 2050	––	– –	––	–	––

resilience/sustainability: *++ (very good), + (good), 0 (medium), – (low), –– (very low)*

Clarification notes on the scorecard:

The current situation in the delta can be described as unsustainable. The pressures on the occupation layer and the base layer will increase due to population growth and economic development in the country. Furthermore, climate change and sea level rise will make the situation worse. The most critical issues will be related to increased river and coastal flooding, salinisation in coastal areas, and droughts in northwest region. Unless technological developments and Governance aspects do not significantly improve, the overall resilience and sustainability will significantly decrease in the future.

Yangtze delta



Scorecard

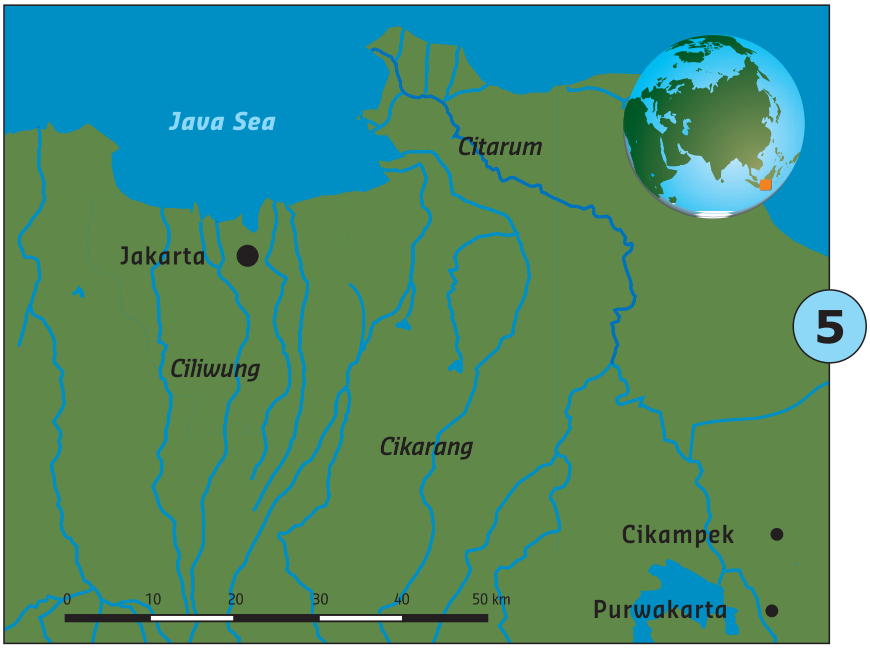
Yangtze delta	Land and water use (occupation layer)	Infrastructure (network layer)	Natural resources (base layer)	Governance	Overall resilience & sustainability indicator
Current situation 2010	–	+	–	0	0
Scenario 1 moderate 2050	–	+	–	+	0
Scenario 2 extreme 2050	––	0	––	+	––

resilience/sustainability: *++ (very good), + (good), 0 (medium), – (low), –– (very low)*

Clarification notes on the scorecard:

Currently, the overall resilience of the delta is medium, thanks to the rather good status of the network layer compensating for the high land and water use. However, in the extreme scenario the resilience may deteriorate as land and water pressures will increase and the natural resources will further degrade.

Ciliwung delta



Scorecard

Ciliwung delta	Land and water use (occupation layer)	Infrastructure (network layer)	Natural resources (base layer)	Governance	Overall resilience & sustainability indicator
Current situation 2010	––	––	––	–	––
Scenario 1 moderate 2050	––	––	––	0	––
Scenario 2 extreme 2050	––	–	––	0	–

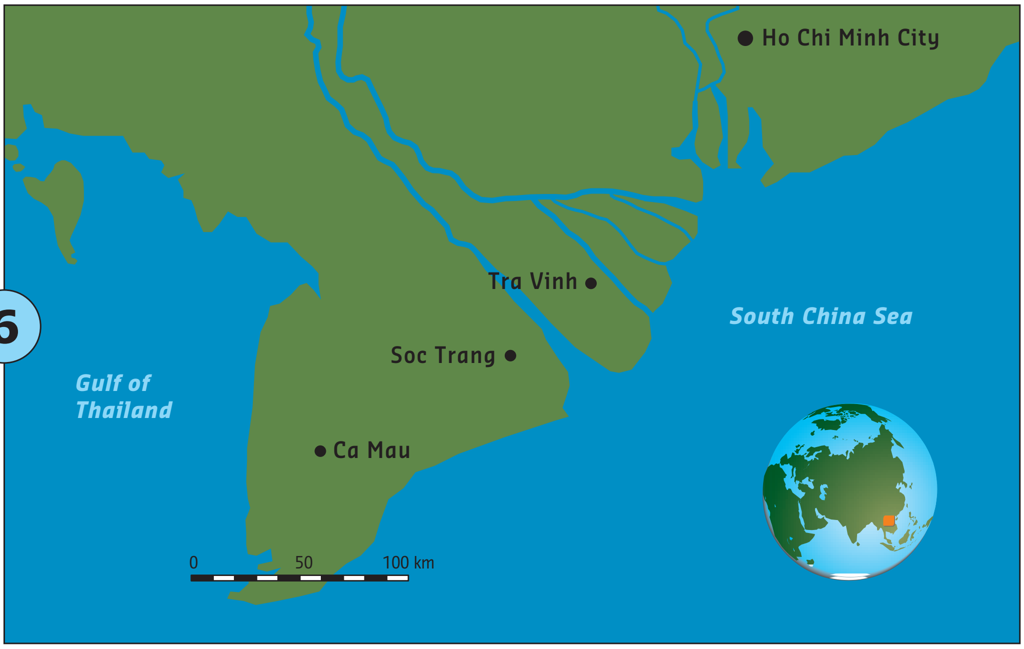
resilience/sustainability: *++ (very good), + (good), 0 (medium), – (low), –– (very low)*

Clarification notes on the scorecard:

The pressure on the occupation layer will remain high unless urbanization rate and population growth rate can be controlled. Climate change is expected to further increase the pressure on space. Economic development may not be enough to achieve a sustainable development. Unless the development is well distributed over the whole country, high economic dominance of Jakarta will in fact make Jakarta and the country in general more vulnerable. The infrastructure development may be accelerated under high economic growth, but could be insufficient to offset the high population growth and high level of poverty. The governance aspect is expected to improve with increasing need of better coordination among government institutions, and larger involvement of private sectors and NGOs in the decision making processes.

Mekong delta

6



Scorecard

Mekong delta	Land and water use (occupation layer)	Infrastructure (network layer)	Natural resources (base layer)	Governance	Overall resilience & sustainability indicator
Current situation 2010	0	0	–	0	0
Scenario 1 moderate 2050	–	+	+	+	+
Scenario 2 extreme 2050	–	+	–	+	0

resilience/sustainability: *++ (very good), + (good), 0 (medium), – (low), –– (very low)*

Clarification notes on the scorecard:

The pressure on land use and consequently on water demand will be higher and higher for agriculture development, especially rice crops and aquaculture. At the same time, fast expansion of industrial zones and urbanization will put more pressure to land availability. Upstream dam construction might make water scarcity in dry season more severe. However, infrastructure development in the Mekong delta can help to diminish the problems. Several projects addressing shortage of fresh water in dry season and other projects aiming to reduce flood (by discharging flood water to the Gulf of Thailand) start to show effects. The key issues in water and governance in the Mekong delta are "integrated planning" and collaboration between provinces in the delta and collaboration between the countries in the region. These issues seem to develop more positive because of the awareness of local people and authorities.

Rhine-Meuse delta

Scorecard

Rhine-Meuse delta	Land and water use (occupation layer)	Infrastructure (network layer)	Natural resources (base layer)	Governance	Overall resilience & sustainability indicator
Current situation 2010	+	++	0	+	+
Scenario 1 moderate 2050	0	++	0	+	0
Scenario 2 extreme 2050	–	++	–	+	–

resilience/sustainability: *++ (very good), + (good), 0 (medium), – (low), –– (very low)*

Clarification notes on the scorecard:

The pressure on the occupation layer and the base layer will increase in time by economic development, climate change and relative sea level rise. Most critical issues will be related to drought and salinisation. Although economic development may also lead to more innovative technical solutions to critical issues, this might not be enough to safeguard sustainable development. Currently the estuarine natural value is low because hard infrastructure limits natural dynamics such as tides and natural brackish zones. In the fluvial part of the delta, however, water quality has much improved over the past decades and many river restoration projects are ongoing in the embanked floodplains. The infrastructure will be maintained under all scenarios because of legal arrangements. Also the Governance aspects and mechanisms are expected to be the same in time. In both scenarios the overall resilience and sustainability indicator will decrease, a bit more in the extreme scenario.

Danube delta

Scorecard

Danube delta	Land and water use (occupation layer)	Infrastructure (network layer)	Natural resources (base layer)	Governance	Overall resilience & sustainability indicator
Current situation 2010	+	+	+	0	+
Scenario 1 moderate 2050	0	0	0	+	0
Scenario 2 extreme 2050	–	0	–	+	0

resilience/sustainability: *++ (very good), + (good), 0 (medium), – (low), –– (very low)*

Clarification notes on the scorecard:

The Danube delta position as a Nature Reserve creates a diverse situation when compared to many of the other deltas worldwide. The management strategy aims at obtaining sustainability in a territory with a very low population density, with no industry, few other human activities, and a very rich biodiversity. Because of human interventions and increasing pressures around the borders of the Danube delta Nature Reserve in the future (some) degradation is expected in all layers, resulting in a slightly reduced overall resilience.

California Bay-Delta

Scorecard

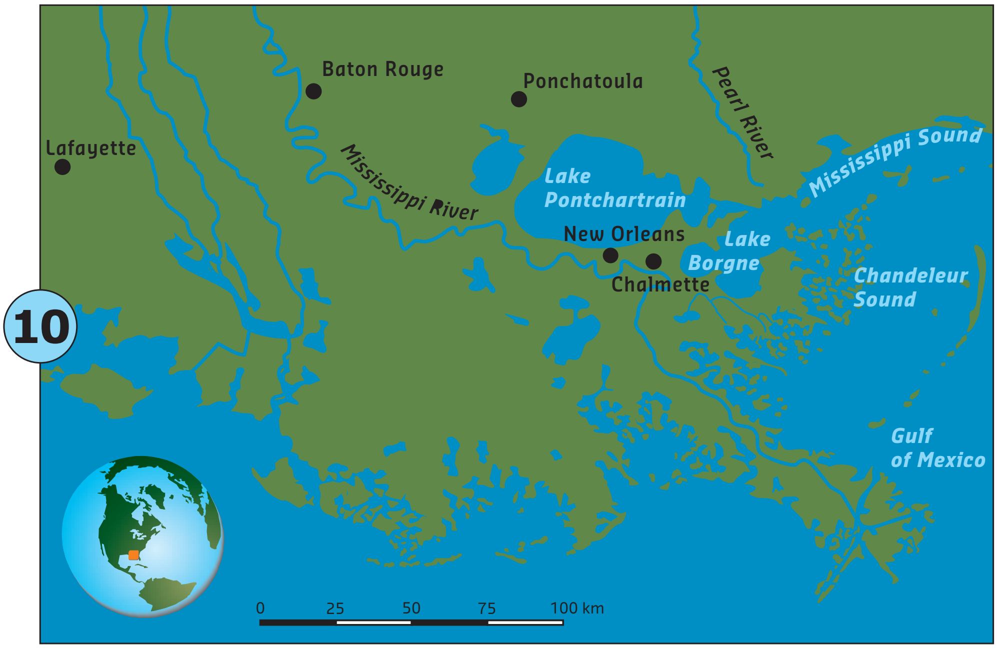
California Bay-Delta	Land and water use (occupation layer)	Infrastructure (network layer)	Natural resources (base layer)	Governance	Overall resilience & sustainability indicator
Current situation 2010	0	–	–	0	–
Scenario 1 moderate 2050	+	0	0	0	0
Scenario 2 extreme 2050	–	–	–	0	–

resilience/sustainability: *++ (very good), + (good), 0 (medium), – (low), –– (very low)*

Clarification notes on the scorecard:

The ecosystem of the Bay-Delta is in continued decline and on the verge of a total collapse. There are many stressors that have contributed to the state this system is in today. Through various planning efforts, initiated by the state in cooperation with other levels of government and stakeholders, California is trying to address these challenges and make the Bay and Delta more resilient to future change. If successful, this will enhance and restore the ecosystem, improve flood management and provide a more reliable water supply. However climate change is putting additional stress on the system and could hold back recovery.

Mississippi River delta



Scorecard

Mississippi River delta	**Land and water use** (occupation layer)	**Infrastructure** (network layer)	**Natural resources** (base layer)	**Governance**	**Overall resilience & sustainability indicator**
Current situation 2010	0	0	–	0	–
Scenario 1 moderate 2050	–	0	–	+	0
Scenario 2 extreme 2050	–	+	––	+	–

resilience/sustainability: *++ (very good), + (good), 0 (medium), – (low), –– (very low)*

Clarification notes on the scorecard:

Given the extreme condition of land loss, the situation has been and continues to exist in a critical state. The pressures on the occupation layer and the base layer will increase due to land loss and other environmental changes. Furthermore, climate change and sea level rise will make the situation worse. The most critical challenges will be concerned with the transformation of wetlands over the next 50 years. This will entail various changes to the landscape, including shifting from salt water to fresh water in many areas.

It is critical that the state of Louisiana adopt various technological developments in the form of flexible infrastructure. These changes could help regenerate the devastated wetlands and help increase the biodiversity of the region. In both scenarios, it is critical that Governance is significantly improved in order to ensure that the overall resilience and sustainability of the region will increase.

Overview of Delta Scorecards

Chapter 3

Synthesis

Current and future state of deltas

Chapter 4

Drivers of change

Based on the delta descriptions an inventory of the drivers of change impacting delta areas has been prepared. Table 3a shows an overview of this inventory. The qualifications should be regarded as an expert judgment at a fairly aggregated level. It enables to draw some general conclusions that are formulated below.

Table 3a
Comparative overview of drivers of change in the studied deltas

	Demographic trends	Economic developments	Technological developments	Climate change	Subsidence
Nile	•••	••	••	•••	••
Incomati	•	••••	••	•••	•
Ganges-Brahmaputra-Meghna delta	••	•••	••	••••	••
Yangtze	•••	••••	••	••	••
Ciliwung	••••	•••	••	•••	••••
Mekong	••	••••	••	•••	••
Rhine-Meuse	•	••	•••	••	••
Danube	•	•	•	••	•
California Bay-Delta	••	••	••	•••	••••
Mississippi River Delta	•	••	•••	•••	•••

• *minimal impacts, now and in the near future (around 10 years)*
•• *small impacts*
••• *medium impacts*
•••• *severe impacts*

Demographic trends

Most deltas studied are densely populated, especially all Asian deltas (Ganges-Brahmaputra-Meghna delta, Yangtze, Ciliwung, Mekong) and the Nile delta (see table 3b). In these deltas urban development has led to mega-cities and some of them are still growing at a very high pace (Ciliwung, Nile and Yangtze delta). In the Yangtze delta the official growth rate is minor, however the population is actually growing fast because of (not registered) large number of migrants. In the Incomati delta urban development is limited to greater Maputo.

In some deltas there is a clear distinction between a stable or increasing urban area and a rural area with relatively few inhabitants (California Bay-Delta, Mississippi River Delta). The Danube delta is a biosphere reserve with only rural settlements and a small town.

Table 3b
Comparative overview of delta population (number, density) and growth rate

	Population number (in million)	Population density (inhabitants/km)	Growth rate (%)
Nile	35	1000	2,0
Incomati	2,5	44	0.4
Ganges-Brahmaputra-Meghna delta	156 - 200	1200	1,3
Yangtze	20-85*	>1000	0,3 - 2,0
Ciliwung	23	>1000	3,6
Mekong	17	425	0,6
Rhine-Meuse	6,5	500	minor
Danube	0,01	5	minor
California Bay-Delta	0,5 – 7,0	?	?
Mississippi River Delta	1,5**	<100	minor

**   the total number of population depends on the definition of the delta*
*** 2/3 of the population is living in New Orleans*

Economic developments

In half of the deltas economic development is an important driver with medium to severe impacts. This especially pertains to the Asian deltas (Yangtze, Mekong, Ciliwung, Ganges-Brahmaputra-Meghna delta).

The highly urbanised deltas of the Rhine-Meuse, Ciliwung and Yangtze are of high national economic importance with most people employed in services and industry. In the Ciliwung delta the capital of Indonesia, Jakarta, is located. It's economic development is rapidly shifting from the industrial and manufacturing sector to the services sector. In the Yangtze delta Shanghai is the financial and logistics center of China, with an annual economic growth rate of around 8%.

The agriculturally dominated deltas are the Mekong and Ganges-Brahmaputra-Meghna deltas, with mainly rice, aquaculture (shrimps, catfish) and related industries. The Mekong delta is a national economic priority area with a target growth of 8% per year for the production of food, commodities and consumer goods. A substantial part of the industry in the California Bay-Delta is also related to agriculture.

In the Nile delta the economic conditions have improved considerably over the years. The tourism, industry, agriculture, and service sectors are significant contributors to Egypt's economy. Also in the Incomati delta the economic development is rapidly increasing. The

Incomati catchment is one of the fastest growing socio-economic regions in the SADC region (Southern African Development Community).

For over two centuries agriculture has been a key part of the Mississippi River delta economy. But now offshore oil and natural gas production, along with all its related service industries and the Port of New Orleans dominate the state's coastal economy. Recently eco-tourism is beginning to emerge. In the Danube delta economic development is strictly regulated. Only traditional activities and eco-tourism are permitted.

Technological developments

In many deltas technological developments focus on water management issues, e.g. in the Mekong for boosting rice production and in the Calfornia Bay-Delta for increased efficiency in water use and conveyance on the water supply side. Several deltas have also developments in infrastructure and related (geo-engineering) modelling or ICT services (Ciliwung, Ganges-Brahmaputra-Meghna delta, Mississippi River Delta). In the Yangtze delta there is a focus on environmental compensation measures especially regarding infrastructure. In the Incomati delta a strategy for development of science and technology aims at increasing poverty alleviation. A 'Millennium Village' is established in the delta to improve the development and adoption of technology. Research programs (partly) funded by the government and public-private partnerships are stimulating innovative developments in the Nile and Rhine-Meuse deltas.

Climate change

The most important driver in the deltas studied is climate change, which is expected to have medium to severe impacts in seven out of ten deltas. Often already existing problems in the deltas will be exacerbated by the impacts of climate change. The following impacts, with regional differences, are to be expected:

- **Sea level rise**, resulting in higher flood risk, salt water intrusion, salinisation and coastal erosion. The Mekong delta for example is very vulnerable to sea level rise, since around 40% may be submerged by one meter of sea level rise.

Maeslant Storm Surge Barrier in the Rhine-Meuse delta

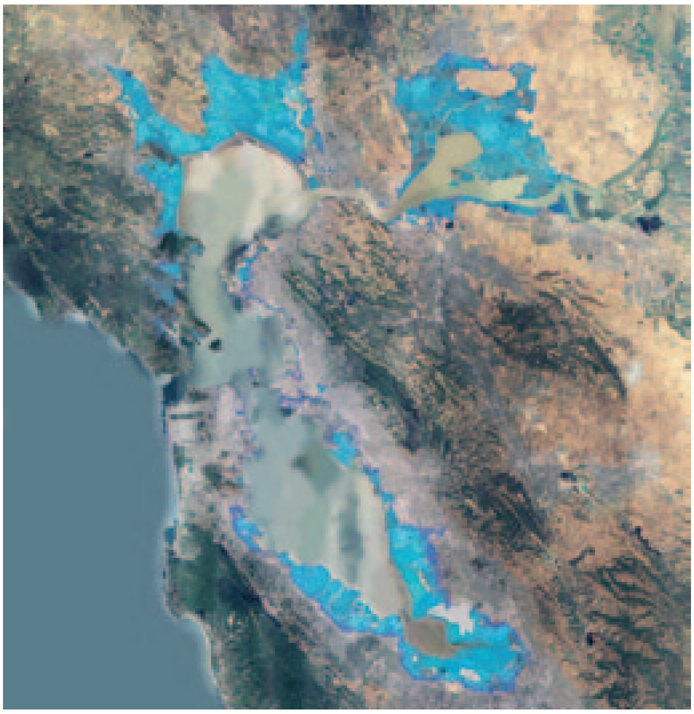
- **More extreme weather events**, especially in tropical areas. This involves changes in length and intensity of the rainy season, which may result in more severe floods, longer droughts and higher temperatures (e.g. Ciliwung). The frequency and strength of cyclones and related floods seem to be on the rise, especially in the Asian deltas (e.g. Ganges-Brahmaputra-Meghna delta), but also in the Mississippi River delta. But also at temperate latitude, in the Rhine-Meuse and Danube deltas, higher peak flows and lower water levels are expected. The climate of the California Bay-Delta is already unusual in its extreme variability and in the Yangtze delta the average temperature is increasing. This resulted in a change in timing and spatial distribution of precipitation and resultant water flow.
- **Change in distribution and extent of ecosystems/habitats** in many deltas, among others in the Danube delta.

Subsidence

In many deltas considerable subsidence is caused by human activities. This involves drainage, (ground) water extraction and soil compaction (Nile, Ganges-Brahmaputra-Meghna delta, Rhine-Meuse, California Bay-Delta, Mississippi River Delta), but also oil and gas production (Nile and Mississippi River Delta).

In the Ciliwung delta subsidence of 10-250 mm/yr is a serious threat, especially in the north of Jakarta, caused by a combination of groundwater extraction, load of constructions, natural consolidation and tectonic subsidence. Subsidence is also a major issue in the California Bay-Delta, because reclaimed wetlands were converted into housing and agricultural or commercial areas. Some delta islands (polders) have experienced over 9 meters of subsidence in the last 160 years, primarily due to ground water pumping and wind erosion. The entire Mississippi River Delta is subsiding largely because since the early 20th century the Mississippi river has been canalized for flood control and navigation. Consequently water and sediment flow to the wetlands has been denied. Shortage of sediment supply can also be caused by lower river discharge and dam construction upstream, which adds to the problem of subsidence (Mekong and Nile).

Areas (in blue) that are vulnerable for sea level rise in the California Bay-Delta



Pressures

Occupation layer (land and water use)

Based on the delta descriptions an inventory of the present condition and problems regarding the land and water use has been prepared. Table 4 shows an overview of this inventory. The qualifications should be regarded as an expert judgment at a fairly aggregated level. It enables to draw some general conclusions that are formulated below.

Pressure on space

In almost all deltas limited space is a problem, but this is especially the case in deltas with mega-cities and increasing urban development. In the Nile, Ganges-Brahmaputra-Meghna delta and Yangtze deltas urban development results in moderate pressure on space and in the Ciliwung delta even in severe pressure. The core problem for the Ciliwung delta is the out-of-control urbanization of Jakarta, involving among others occupation of floodplains and shortcomings in infrastructure. In California Bay-Delta the pressure on space is high in the Bay area but minor in the Sacramento-San Joaquin delta. Also in the Mississippi River Delta and the Danube delta the pressure on space is minor.

In the Mekong delta pressure on space will increase in future, especially influenced by flood protection measures, agricultural and aquacultural expansion and intensification. In the Yangtze delta land reclamation of wetlands is important for Shanghai to cope with the fast urbanization.

Table 4

Comparative overview of status of land and water use in the studied deltas

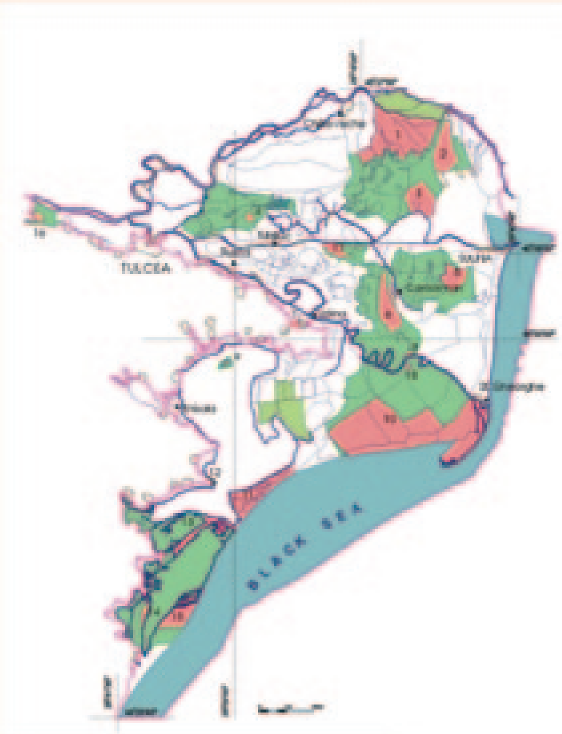
	Pressure on space (including urbanization)	Water demand/Fresh water shortage	Flood vulnerability	Overall Score
Nile	•••	•••	•••	--
Incomati	••	•••	••••	0
Ganges-Brahmaputra-Meghna delta	•••	••	••••	--
Yangtze	•••	••••	••	-
Ciliwung	••••	••••	••••	--
Mekong	••	••	•••	0
Rhine-Meuse	••	••	••	+
Danube	•	•	•	+
California Bay-Delta	••	•••	••••	0
Mississippi River Delta	•	•	•••	0

• *no (additional) pressure, now and in the near future (around 10 years)*
•• *some pressure*
••• *moderate pressure*
•••• *severe pressure*

resilience/sustainability:
++(very good), + (good), 0 (medium), – (low), –– (very low)

Water demand / Fresh water shortage

Water demand is a main and increasing issue in some highly urbanized deltas (Nile, Yangtze, Ciliwung). In the Ciliwung delta land conversion from forest to agriculture and urban areas, results in water shortages during the dry season. A major breakthrough will be necessary to manage the present situation, both with regard to management of the existing water resources, and with regard to demand reduction. Fresh water shortage is a continuous threat in the Yangtze delta especially by increasing water demand in Shanghai. Water supply mainly comes from upstream and reservoirs. In the California Bay-Delta fresh water shortage is becoming a serious issue as opportunities for increasing supply to satisfy growing demand



Spatial planning in the Danube Delta Biosphere Reserve

Pink/red: strictly protected areas (nature sanctuaries)

Green: buffer zones

White: traditional economic use areas (for fisheries, reed harvesting, ecological tourism, etc.)

Light green: areas in need of ecological reconstruction

(Source: see website DDBR Administration)

are limited and California is experiencing severe droughts. During low river discharge the increase of salinity intrusion in coastal areas is making existing water supply sources as well as agriculture and freshwater ecosystems vulnerable (Incomati, Mekong, Ganges-Brahmaputra-Meghna delta). In the Rhine-Meuse delta occasionally dry years occur during which serious water shortages are experienced, which affect agriculture, energy (cooling water) and shipping (lower navigation depths).

Flood vulnerability

In seven out of ten deltas the flood vulnerability is moderate to severe. In the Incomati and Ganges-Brahmaputra-Meghna deltas floods are a permanent threat. Most of Ganges-Brahmaputra-Meghna delta is still active with very unstable river branches and the delta is prone to tropical cyclones with high storm surges. In the Ciliwung delta almost half of the area is below sea level resulting in some 6 million inhabitants vulnerable to flooding, especially in the northern part of Jakarta. Most of the California Bay-Delta is below or just above sea level and large scale flooding could have immense consequences for the entire state as it would disrupt water supply for an extended period.

In the densely urbanised Nile delta the vulnerability is high, but river floods are minimized by the Aswan Dam. In the Mekong delta moderate floods occur regularly, bringing sediments and nutrients essential to food security (agriculture and fish production) and biodiversity (sustainance of the fresh water ecosystems). However, extreme flood events can be destructive. Hurricanes are a 'way of life' in the Mississippi River delta. The recent hurricanes Katrina and Rita resulted in devastating floods, which triggered intensive flood protection measures. In the Rhine-Meuse delta flood protection standards are among the highest in the world. Although the flood risk is quite small, potential consequences of a flood are high.

Network layer (Infrastructure)

Living in deltas has always required human intervention. Infrastructure was and is developed to adapt the natural systems to create more favourable conditions for living and working in deltas. Historically, the infrastructure network used the natural patterns of river channels for transportation and levees on which dikes and roads were built. Evidence can still be seen in the road/railway network in Bangladesh that often runs parallel to major river branches. Ferries are used to cross the many open watercourses. Construction of new roads and bridges requires considerable investment, but can greatly contribute to the economic development of delta areas.

Based on the delta descriptions an inventory of the present condition and problems regarding the major infrastructure categories has been prepared. Table 5 shows an overview of this inventory. The qualifications should be regarded as an expert judgment at a fairly aggregated level. It enables to draw some general conclusions that are formulated below. Note that 'Adequate' does not mean that everything is in order, but that there are relatively minor problems within the network layer. Networks are constantly being adapted to the changing demands, for instance deepening of navigation channels for larger ships. In many countries this is an on-going process of expansion and adaptation. If this goes without many problems, it is scored as 'adequate'.

Many deltas still have a high flood risk

In the majority of the studied deltas flood protection is not adequate. Upgrading of the flood safety is urgently needed for the Ciliwung, Incomati, Ganges-Brahmaputra-Meghna delta, California Bay and Mississippi River deltas. Jakarta has only 25% of its area protected by embankments, leaving some 6 million inhabitants vulnerable to flooding. For the Incomati, flooding occurs in the lower basin at irregular intervals with impacts on agriculture, natural habitats, damage to infrastructure and loss of life. The most devastating flood occurred in the year 2000. There is no flood protection along the river. In Bangladesh (Ganges-Brahmaputra-Meghna delta) about every ten years more than 50% of the area is flooded when discharges reach extreme values. Earthquakes threaten the Sacramento-San Joaquin delta levees. There is a 60% change that the Bay Area will experience a large-magnitude earthquake before 2032, which could cause multiple levee failures, causing thousands of homes and farms to be flooded. As a result of Hurricane Katrina, restoration of damaged infrastructure in the Mississippi River delta is still an important issue. Reconstructions are now underway.

For the other deltas the flood protection system currently does not require urgent measures, although improvements are of course always desirable. The Rhine-Meuse delta has one of the highest safety standards and only needs upgrading on a longer term in view of sea level rise and economic developments.

Table 5
Comparative overview of status of major infrastructure in the studied deltas

	Flood protection	Irrigation & drainage	Water supply & sanitation	Roads, railways, ports & navigation channels	Overall Score
Nile	••	•	••••	•••	0
Incomati	••••	•••	•••	•••	–
Ganges-Brahmaputra-Meghna delta	••••	•••	••••	••••	––
Yangtze	•	••	•	•	+
Ciliwung	••••	••••	••••	•••	––
Mekong	••	••	•••	•••	0
Rhine-Meuse	••	••	•	•	++
Danube	•	•	••	•	+
California Bay-Delta	••••	••	•••	•	–
Mississippi River Delta	••••	••	•	•	0

- • *Adequate, now and in the near future (around 10 years)*
- •• *Adequate, but adaptation needed in view of climate change (long term)*
- ••• *Improvements are desirable in view of economic development (medium term)*
- •••• *Rehabilitation or upgrading urgently needed*

resilience/sustainability:
++(very good), + (good), 0 (medium), – (low), –– (very low)

Irrigation and drainage systems need adaptation to changing demands

Most delta land use is or was agriculturally dominated, evidences of which can be found in sometimes age-old irrigation and drainage systems. The Nile delta is a good example of this historical development that led to high water productivity in agriculture. The extensive irrigation system is stretched to its limits; there is a constant need for efficiency improvement. Further improvements cannot therefore be found in better water infrastructure, but require innovations in farming systems, water pricing and water management. In Bangladesh already hundreds of large, medium and small-scale irrigation and drainage projects have been implemented, often in conjunction with flood protection. Nowadays also non-structural measures are being introduced, with policies to encourage small-scale irrigation using treadle pumps and small diesel or electric pumps. For the Incomati especially the upstream extension of irrigation poses significant problems in the delta downstream. There are plans to increase the irrigated areas in all three riparian countries. Population growth and expansion of urban areas and industry demand more water than the river can supply, consequently more dams are being constructed and water from the Incomati is transferred to other basins.

Increasingly deltas are becoming urbanized, which lead to a change in hydrological characteristics (e.g. increased rainfall run-off). This poses new challenges to the water system because the dimensions of the irrigation and drainage network which originally was designed for agricultural purposes may no longer be appropriate. For instance, rapid urbanization of the Ciliwung floodplain led to solid waste disposal in drains that reduce their discharge and as a consequence aggravate flooding problems.

Water supply and sanitation still a major challenge for developing deltas

Most highly developed deltas have a more or less adequate water supply and sanitation infrastructure. In striking contrast are the deltas in countries in transition or lesser developed countries. In these deltas, large parts of the population lack safe water supply and sanitation systems. Drinking water production for many of the urban areas in the deltas is sometimes insufficient, as is for instance the case for greater Maputo area (Incomati). The consequences could directly impact on public health, but also indirectly on other parts of the delta system. For instance, inadequate infrastructure for piped water supply influences the flooding problem in Jakarta. Less than half of Jakarta's households have access to piped water supply which results in both households and commercial establishments extracting groundwater for their basic water needs, adding to land subsidence.

The major features of California's water supply system were built between the 1920s and the 1970s. Back then it was supposed to support about half of the population California has today. This infrastructure is now aging and requires updating and maintenance. It is a pressing issue because millions of people in the south are now dependent on fresh water from the delta.

Roads, railways and ports are constantly expanding

Some of the deltas, such as the Rhine-Meuse, Mississippi River, and Yangtze deltas have a highly developed infrastructure centred around a major harbour and city. River and sea transport has historically been the prime factor for economic development. For instance the US has long utilized the Mississippi river as a major transportation corridor for shipping goods to international markets, as well as supplying goods to the interior of the country. Therefore, ports and navigation channels have been well developed in the delta. Road infrastructure in the Mississippi River delta is concentrated near the city of New Orleans. Downriver from the city the road network is not very well developed as it mainly serves local transport. In the Netherlands, the harbour of Rotterdam is continuously expanding and currently new port facilities are created by reclaiming land from the sea. Along the Yangtze it is the rapidly expanding city of Shanghai and its port that constantly demands an expansion of the infrastructure. The Yangtze estuary deepwater navigation channel project that started in 1998 has now succeeded in reaching a water depth of 12.5 metres.

Road/railway infrastructure in the deltas of the Ciliwung and Ganges-Brahmaputra-Meghna and to a lesser extent of the Mekong and Nile rivers are currently inadequate in the sense that they hinder economic development. The rapid urbanization of Jakarta results in severe shortcomings in the provision of infrastructure. The development of road infrastructure is lagging behind the growth of traffic, resulting in severe traffic jams during almost the entire day. Infrastructure for transport in Bangladesh is rather poorly developed. The infrastructure in the Johannesburg-Maputo international socio-economic axis of development is rapidly improving.

Base layer (Natural resources)

Pressures on the base layer of deltas can be subdivided into geological, hydrological and ecological/environmental pressures. Geological pressures are coastal erosion and river morphodynamics, which may lead to loss of land and infrastructure. Hydrological pressures include flooding, salinisation, and freshwater shortage, of which the latter two are strongly related, and therefore taken together in this study. The category of ecological/environmental pressures includes water and soil pollution, and wetland and biodiversity loss.

Based on the delta descriptions an inventory of the base-layer pressures has been prepared. Table 6 shows an overview of this inventory. Note that the scores mainly indicate whether the pressure presently is a problem, which partly depends on land use and population density. Base-layer pressures in the Danube delta, for example, generally score low in Table 6 because this delta is largely in a natural state and uninhabited. Adequate measures may also mitigate pressures. For example, coastal erosion in the Rhine-Meuse delta could be a severe problem, but at present is well under control due to extensive sand nourishments. It is also important to remember that not all pressures are caused by human interference in the delta system. Especially river morphodynamics (channel migration and distributary shifting) and flooding are natural delta processes that, to some extent, are needed to maintain a healthy natural delta system. In a delta occupation perspective, however, they can be classified as pressures. The scores should be regarded as an expert judgment at a fairly aggregated level. Below, the different pressures and the scores are briefly discussed with some examples from the deltas studied.

Table 6
Comparative overview of base-layer pressures in the studied deltas.

	Coastal erosion	River morpho-dynamics	Flooding	Salinisation/ freshwater shortage	Water and soil pollution	Wetland and biodiversity loss	Overall Score
Nile	••	•	•	•••	•••	••	–
Incomati	••	••	••	••	••	•••	–
Ganges-Brahmaputra-Meghna delta	••	•••	•••	•••	•••	•••	– –
Yangtze	•	•	••	••	•••	•••	–
Ciliwung	••	•	•••	••	•••	•••	– –
Mekong	•	••	••	••	•••	••	–
Rhine-Meuse	•	•	•	••	•	••	0
Danube	••	•	•	•	•	•	+
California Bay-Delta	•	•	•	•••	••	••	–
Mississippi River Delta	•••	•	••	•	•••	•••	–

• *minor and/or well controlled*
•• *intermediate and/or partly controlled*
••• *major and largely uncontrolled*

resilience/sustainability:
++(very good), + (good), 0 (medium), – (low), –– (very low)

Geological pressures

While coastal erosion is a potential threat that is well controlled by effective measures in the Rhine-Meuse delta, it is a minor problem in some other deltas (Yangtze, Mekong and Ganges-Brahmaputra-Meghna) due to sufficient sediment supply by the rivers, which compensates for the marine erosion forces. Severe coastal erosion in the Mississippi River delta is a result of subsidence, recurrent severe storms, and fixed embanked delta distributaries routing fluvial sediments across the continental shelf, where it is trapped in deep waters outside the coastal zone. In the Nile delta coastal erosion is a large-scale problem due to fluvial sediment trapping upstream. Some 120 million tons of sediment is trapped each year in Lake Nasser behind the Aswan dam. Coastal protection measures are taken but are hampered by the strong sediment deficit at the coastline.

In most deltas river morphodynamics are not a problem due to effective engineering measures. In very large rivers, however, the standard technical solutions may be insufficient or too expensive for implementation. In the Ganges-Brahmaputra-Meghna delta riverbank erosion is a serious problem and may amount to 800 m in one year.

Incomati floodplain at Marracuene near Maputo Bay, with in de far background some dunes near the Indian Ocean.

Hydrological pressures

With flooding being a fundamental natural process in all deltas, the different scores in Table 6 reflect different natural conditions, but, inevitably, also partly the effectiveness of flood protection measures. The high score for the Ciliwung delta results from inadequate urban water management in combination with strong subsidence, whereas the high score for the Ganges-Brahmaputra-Meghna delta partly reflects the vulnerability of this area for cyclone-induced surges. The Mississippi River Delta and Yangtze delta may also be affected by hurricanes, but have better flood protection systems, which explain their intermediate scores. In some deltas (Yangtze, Nile), large upstream reservoirs moderate river peak flows, causing lower probability of river flooding. The Rhine-Meuse delta is much less prone to flooding than many other deltas, partly because of an excellent flood protection system, but also because of much more favourable natural conditions, being located in the temperate climatic zone where extreme storm and precipitation events are much less common than in the tropics. In some cases also the perception of the delta population partly determines whether flooding should be considered as a pressure. In the Mekong delta, for example, the notion that river floods bring benefits for agriculture and nature begins to be widely acknowledged. Of course, such a perception strongly depends on land use in the delta.

Salinisation and freshwater shortage is a problem in most deltas, but is most pronounced in deltas in arid climates, such as the Nile delta and the Sacramento-San Joaquin delta. In these systems river water is used for large-scale irrigation, and salinisation of soils is enhanced by high evaporation. In the Ganges-Brahmaputra-Meghna delta saline water intrusion is highly seasonal, due to a strongly seasonal monsoonal climate. Salinity and its seasonal variation in this system are a dominant factor for the coastal ecosystem, fisheries and agriculture. Salinisation seems a minor problem in the Mississippi River delta relative to other pressures, such as coastal wetland loss due to subsidence and eutrophication.

Ecological/environmental pressures

Water and soil pollution is a major problem in almost all deltas studied. The Rhine-Meuse delta is a positive exception, where, for example, due to international cooperation in the whole river basin, the quality of river water has much improved since the 1970s. Also, agricultural output of pollutants has strongly reduced following implementation of strict legislation. However, in most deltas rapid urbanization, industrial development and intensification of agriculture strongly compromise water and soil quality. In the Mississippi River delta for example, is eutrophication of surface waters is a main issue. The sources of nutrients are inadequately treated sewage and agricultural and urban runoff. The reduction of the wetland area has aggravated the problem in the Mississippi River delta. The load of pollutants in delta waters and soils generally reflect developments in the whole river basin. A dramatic example is the Yangtze delta. Every year, 25 billion tons of sewage and industrial waste is discharged into the Yangtze representing 42 % of China's total sewage and 45 % of the industrial discharge. This severe pollution strongly exceeds the self-purifying capacity of the river, and constitutes a threat to all life in the river and public health.

Natural delta ecosystems generally deteriorate in two dimensions: (1) area is lost due to urbanization, expansion of agricultural lands and coastal erosion, (2) ecosystem quality/biodiversity is lost due to pollution, changing hydrological conditions, invasion of exotic species, and extinction of species due to loss of habitat. In fact the state of ecosystems is influenced by most of the pressures on deltas described above, and as such the ecosystem health can be considered an indicator of the summed effect of multiple pressures on the delta. On the other hand, healthy delta ecosystems provide many services to the delta population, which are jeopardized with their deterioration. Therefore loss of wetlands and biodiversity also represents a pressure on the delta system. In Bangladesh the Sundarban mangrove forest suffers from overexploitation. With shrinkage of the forest its capacity to buffer cyclonic storm surges diminishes. In the Mississippi River delta the conservation of wetlands, as a shield against hurricane impact, is a main issue. About one third of the delta is protected against inundation and part of this area has been converted to dry land. From the 1930s some 4,000 km^2 of coastal wetland has been converted to open water. A number of factors have been linked to this land loss, including construction of flood control levees along the Mississippi river, a reduction in the amount of suspended sediment load of the Mississippi river due to structures upriver such as dams, oil and gas extraction under the delta, altered wetland hydrology due to canal construction, salt water intrusion, wave erosion along exposed shoreline, sea level rise, and compaction of the relatively young subsoil of the delta.

Governance

Based on the delta descriptions an inventory of the present condition and problems regarding governance issues has been prepared. Table 7 shows an overview of this inventory. The qualifications should be regarded as an expert judgment at a fairly aggregated level. It enables to draw some general conclusions that are formulated below.

Cooperation between government agencies is a major challenge

Although there is a growing awareness of the importance of good cooperation between different echelons and departments within the government, satisfactory results are still scarce. Even in the situation of the California Bay-Delta where there is a dense governance framework, with dynamic interplay between local governments, state and federal agencies, this has led to surprisingly little result. In a recent report of the Delta Vision Task Force it was concluded that decades of study and discussion has failed to solve political deadlock (Blue Ribbon Task Force, 2008). The Task Force states that a new governance structure is needed to achieve the goals set out in the Vision document. In another example from the USA, we see a similar problem where governance activities in the Mississippi River delta are carried out by a combination of Federal, State and local agencies, which could not prevent the rather dramatic developments of the past decade. For instance, the task force of 5 federal agencies and the state of Louisiana to develop a 'comprehensive approach to restore and prevent the loss of coastal wetlands in Louisiana' did not result as yet in a significant reduction of the ongoing loss of wetlands.

In the Netherlands the recent establishment of a Delta Commissioner and Delta Programme initiated the development of integrated planning for flood risk management and freshwater supply. This Delta Programme has the potential to break through the existing horizontal and vertical task divisions within the government, but still has to prove itself.

The Danube delta provides a good example for having an organization specifically responsible for management of almost the entire delta. The Danube Delta Biosphere Reserve Administration coordinates the activities and environmental protection programme in the Danube Delta Biosphere Reserve. The cooperation of the Administration with other ministries

Table 7
Comparative overview of status of governance in the studied deltas

	Cooperation between levels and sectors of government	Cooperation between government and private sector	Involvement of stakeholders and citizens	Approaches for dealing with risks and uncertainties	Overall Score
Nile	••	••	••	••	0
Incomati	••	••	••	•	–
Ganges-Brahmaputra-Meghna delta	••	••	••	•••	0
Yangtze	••	•••	••	••	0
Ciliwung	••	•	••	••	–
Mekong	••	••	•••	••	0
Rhine-Meuse	•••	•••	•••	•••	+
Danube	•••	•	••	••	0
California Bay-Delta	••	•••	•••	••	0
Mississippi River Delta	••	••	••	••	0

• *Practically non-existent, unknown*
•• *First initiatives*
••• *Developing, mixed results*
•••• *Fully developed, satisfactory results*

resilience/sustainability:
++(very good), + (good), 0 (medium), – (low), –– (very low)

View on the Danube river

and departments is well regulated by laws. Nevertheless sometimes gaps in communication and disputes in case of conflicting interests may appear.

Encouraging developments to improve delta governance can be found in those countries that are in the process of administrative decentralization, such as Indonesia, Mozambique and (less pronounced) Bangladesh. Main challenges in this decentralization process are to prevent that governance becomes ineffective and to build sufficient capacity at the regional and local level. Although in Bangladesh most decisions are taken at the centre, even for local matters, efforts are underway to improve governance systems. In Vietnam, provinces already have a considerable autonomy. The government of Mozambique is implementing a decentralized administration by which the decisions are taken at district level, or a bottom up approach. There are regional river basin management units coordinated by water department.

The Chinese government has a typical centralized authority. Cooperation between different government sectors in the Yangtze estuary is 'not easy or efficient enough, but it is improving'.

Egypt is subdivided into 26 Governorates, of which 12 are (partly) in the Nile delta. Each Ministry is represented in the governorates by a local authority. The Governor takes the responsibility of the management between all these units and offices to serve the general work-plan of his governorate.

Comprehensive delta plans

In some deltas, comprehensive plans for delta development exist, providing guidelines for adaptation and development. Such plans effectively are frameworks of boundary conditions within which concrete solutions for delta issues need to be worked out. An example is the final report of the Delta Commission in the Netherlands published in 2008, which sketches the future of the Rhine-Meuse delta until 2100 for different sectors of the society, including a crude idea of necessary adaptation measures and a research agenda. For the California Bay-Delta a comprehensive delta plan is being developed by the state of California. At the same time, the Bay Delta Conservation Plan (BDCP) is being prepared through a collaboration of state, federal, and local water agencies, state and federal fish agencies, environmental organizations, and other interested parties. Also of importance for this delta is the California Water Plan, which provides a framework for water managers, legislators, and the public to consider options and make decisions regarding California's water future. In the Ganges-Brahmaputra-Meghna delta, the government has formulated the Bangladesh Climate Change

Strategy and Action Plan, and limited resources have been mobilized to implement the action plan partly. In the Ciliwung delta, the current lack of a common perception (vision) for all delta stakeholders at national and sub-national levels (i.e., a comprehensive delta plan) is considered an important obstacle for improvements in delta management and development.

Platforms for collaboration and international context

Effective delta management and development is supported by platforms for collaboration. In the Mekong delta, the Government Steering Committee for the South-western Region coordinates the efforts of various ministries that are involved in the management of the Mekong delta in Vietnam. The Mekong River Commission (MRC) is the platform for international collaboration. For the California Bay-Delta a new state agency was established, the Delta Stewardship Council, to facilitate the cooperation of local governments, state and federal agencies in the Delta and Bay area. In the Netherlands, inter-sectoral cooperation needed for implementation of the comprehensive delta plan proposed by the governmental Delta Commission occurs in the Delta Programme, in which various sectors of the government are represented. A different type of regional collaboration occurs in the Urban Economic Coordination Alliance of the Yangtze delta. This alliance was established in 1992 and has 16 member cities. The main purpose is to coordinate regional economic development.

A special issue regarding government cooperation is the international river basin dimension. The rivers of several deltas cross one or more country boundaries: Incomati, Rhine/Meuse, Mekong, Ganges-Brahmaputra-Meghna and Nile. Cross-border river management has been institutionalized in various stages of implementation through international river commissions, such as the Mekong River Commission, the International Rhine Commission and Lower Nile Basin Initiative. There is high level interaction between India and Bangladesh regarding shared river basins, although this has not been institutionalized formally. With respect to the Incomati the establishment in 1983 of the Tripartite Permanent Technical Committee (TPTC) by the Governments of South Africa, Swaziland and Mozambique is worth mentioning. More recently initiatives were taken to implement minimum in-stream flows and further cooperation for the Incomati river basin.

Wild ducks near a riverbank

Regarding the international context of delta management, the implementation of several international conventions and treaties should be taken into account, such as the Convention on Biodiversity (CBD), the UN Framework Convention on Climate Change (UNFCCC), the Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities (UNEP-GPA), and for Europe several EU Directives (Water Framework Directive, Flood Directive, Bird and Habitat Directives, etc.).

Legal instruments

A proper legal framework will strongly contribute to effective implementation of comprehensive delta plans and related measures. For the Rhine-Meuse delta a new Delta Act is being prepared, which will safeguard financial means for implementation of the measures proposed by the Delta Programme in the future. In the Netherlands flood safety standards, determining dike heights, are also legally embedded. Examples of legal arrangements for delta management in the USA are coastal Wetlands Planning, Protection and Restoration Act of 1990 (Mississippi River delta) and the Delta Reform Act of 2009 (California Bay-Delta). The former created a task force of five federal agencies and the state of Louisiana to develop a "comprehensive approach to restore and prevent the loss of coastal wetlands in Louisiana", whereas the latter put the co-equal goals of a restored delta ecosystem and a more reliable water supply into law.

Cooperation between government and private sector should be balanced

There is a great variety in how the private sector can cooperate with the government. Privatization is a trend that can be found in many countries. For instance, in Bangladesh the privatization of the public sector industries has proceeded at a moderate pace. In roads, irrigation and power sectors there is good cooperation between the government and the private sector. Increasing public-private partnerships is a major policy of the Bangladesh government. In Vietnam cooperation between government and the private sector in environmental and climate change issues has just started to develop. In the Danube delta private initiative is not well developed and where it exists it is resumed mainly to agri-tourism and other small fishery, tourism, subsistence business. In the Nile delta financial systems for projects are changing towards PPP. For instance the PPP West Delta is a new project paid totally by farmers. In Mozambique the water sector is undergoing major changes towards less centralised water management, more involvement of private sector and more acceptance economic value of water. Some of the water use infrastructures such as irrigation systems and water supply for domestic use in the rural areas are let to private management.

Finding the right balance between government and private sector interests is important in this respect. In the Mississippi River delta, the shipping and petroleum industries seem to have the ability to steer the government too much in the delta. While the government may have restorative priorities, in the name of the economy destructive industrial projects will be permitted. A further complicating problem of wetland management in the delta is land ownership. A mosaic of private and public properties exists that rarely coincides with natural drainage basin characteristics. Thus management plans are most often formulated for administrative units instead of natural landscape units.

Involvement of stakeholders and citizens is gaining momentum

Involvement of stakeholders and citizens is important to promote societal support for development projects. Such participation is a precondition for sustainable development if the success of the proposed measures depends on the active co-operation of stakeholders and citizens. In all studied deltas this awareness has taken roots, resulting in many different ways and stages of implementation. In California there is a very strong bottom-up approach to decision making about large infrastructural investments. Public participation is strong through workshops and community meetings. In the Mississippi River delta citizens have had a little more involvement in coastal planning issues since the 2005 hurricanes. However, the gap between the engineers/scientists and the citizens creates communication problems. In the Danube Delta Biosphere Reserve area a number of environmental NGOs are very active. Nevertheless, a lot still has to be done to improve both communication and integration of local views. In Mozambique the associations of farmers have a sit in the irrigation management board; the ICZM steering committee involves private as well as individuals; WWF, IUCN and local NGO are active in supporting integrated water management.

In many countries public participation is regulated by law. In the Netherlands several laws and legal instruments are in place to procure involvement of stakeholders and citizens. In Vietnam all issues, policies and projects related to community development, including environmental protection and climate change must be discussed and agreed by representatives of the communities, according to the 'Ordinance of Grass Root Democracy' issued in 2007. In Bangladesh existing policy and guidelines require public consultations in all development projects. Stakeholder consultation at planning and implementation phase is therefore already practiced.

Non-governmental organizations often play an important role in public participation processes. In The Netherlands many NGOs are influencing policy and implementation of plans at national and local level. In the Yangtze Estuary the World Wide Fund for Nature is active in water resource restoration, wetland and biodiversity conservation, low carbon economy development as well as overall policy recommendations.

Approaches for dealing with risks and uncertainties: new initiatives

Development of deltas is faced with many uncertainties. This explains a growing interest in risk management and other approaches for dealing with risk and uncertainty in a structured and systematic way. In most of the deltas these approaches are still in an early stage of thinking or implementation. New initiatives are taken with respect to studies and policies. For instance, recently the Delta Initiative was launched, being a multi-year research and planning effort at the University of California – Berkeley focusing on the multiple risks of river floods, earthquakes and climate change that pose a threat to the California Bay-Delta. For the Mekong delta in Vietnam several studies are underway regarding flood vulnerability and climate change impacts. There is a National Target Programme to respond to Climate Change running from 2011-2015 aiming mainly at awareness raising. There are several policies helping local people to deal with risks, such as the Living-together-with-floods National Program, the National Disaster Reduction Program and Central Committee for Flood and Storm Control.

For the Nile delta an adaptation framework for climate change impacts within ICZM plans are needed as well as monitoring and observation systems. The Danube Delta Biosphere Reserve Authority develops management plans which are discussed and adapted to new situations every few years.

Typical deltaic countries such as the Netherlands and Bangladesh are in the forefront in flood risk management, due to their long history of floods. The Netherlands has chosen a flood defense strategy centuries ago, but there is a growing attention for more resilient flood risk management strategies, early warning and recovery programs. Furthermore, the recently established Delta Programme intends to identify strategic decisions in view of long term climate change. Bangladesh also focuses on the development of flood forecasting and early warning systems, which has been practiced for many years already for coastal storms surges. The existing National Water Management Plan and Coastal Zone Policy for Bangladesh show explicit attention to long term sustainability goals.

Scorecards

Comparing the scorecards of the deltas produces an broad picture regarding the problems and sustainability of the major deltas in the world (table 8). It also has the advantage that it identifies in what way deltas resemble or differ from each other. Scores for each of the deltas are based on indicators as well as interpretation of the extended descriptions, which can be found in a separate working document. Table 9 provides an overview of the main indicators for drivers, pressures and governance, used for the comparison (see appendix for a first elaboration of the main indicators for the selected deltas). This is a selection of the indicators that were mentioned in table 1. For some indicators quantitative data are available. For other indicators these data are lacking, incomplete or only available in qualitative format.

The combined scorecard, below, should therefore be used with care. It will certainly lead to discussions and questions why a certain delta has a higher score than another delta. But this should not be seen as a weakness, but as an intended spin-off of this scorecard: only by such discussions better insight can be gained regarding the interpretation of concepts such as resilience and sustainability, which are difficult to define and quantify. And they may eventually lead to an update of the scorecard altogether.

Table 8
Comparative overview of the scorecards of the 10 deltas studied

	Land and water use (occupation layer)	Infra–structure (network layer)	Natural Resources (base layer)	Governance	Resilience & Sustainability Indicator		
					Current	Moderate Scenario	Extreme scenario
Nile delta	––	0	–	0	–	–	––
Incomati delta	0	–	–	–	–	–	––
Ganges-Brahmaputra-Meghna delta	––	––	––	0	––	–	––
Yangtze delta	–	+	–	0	0	0	––
Ciliwung delta	––	––	––	–	––	––	–
Mekong delta	0	0	–	0	0	+	0
Rhine–Meuse delta	+	++	0	+	+	0	–
Danube delta	+	+	+	0	+	0	0
California Bay–Delta	0	–	–	0	–	0	–
Mississippi River Delta	0	0	–	0	–	0	–

resilience/sustainability: *++(very good), + (good), 0 (medium), – (low), –– (very low)*

Comparison of the scorecards for the different deltas clearly shows that current overall sustainability (column 6 in table 8) is not satisfactory for most of them. Many are in the danger zone (orange), which means that they are very vulnerable to adverse drivers of change. The Ganges-Brahmaputra-Meghna delta and the Ciliwung deltas are in a critical state and score lowest (red), because they have major problems for all layers and also governance has not yet been capable to improve this situation.

For the deltas that are in or beyond the danger zone the reasons for this position differ. The Ciliwung delta, Ganges-Brahmaputra-Meghna delta and Nile delta are examples of deltas that have to cope with very high land and water demands due to high population pressures, which combined with a moderate (Nile) to inadequate (Ciliwung and Ganges-Brahmaputra-Meghna delta) infrastructure lead to significant problems. The California Bay-Delta and Mississippi River delta have moderate land and water pressures, but their major problem lies in the rapid declining nature values (e.g. ongoing wetland loss in Louisiana). Furthermore, their current flood vulnerability in combination with the weak flood protection system results in relatively high flood risks. Also the Incomati combines a moderate land and water pressure with degrading natural resources and an insufficient infrastructure.

Positive exceptions are the Yangtze, Mekong, Rhine-Meuse and Danube deltas. The Rhine-Meuse delta can currently be considered to have a relatively good sustainability, mainly because of the high score for infrastructure, moderate land and water use and relatively good governance. The Danube delta scores positive on the status of all three layers, which is not a surprise considering the very low population density of around 5 inhabitants per km^2. The Yangtze delta (and maybe the Mekong delta) seems to be in a transition zone: currently the demands on land and water use can be balanced by the infrastructure. But the natural resources are in decline and land and water use are on the rise, which in due time could affect sustainability negatively.

With regard to the developments on the medium term (2050), we can distinguish two counteracting drivers of change: on the one hand there is the expectation that with economic growth, technological improvements and improved governance, the current problems stemming from inadequate infrastructure and poverty can be ameliorated. On the other hand we find climate change impacting the natural systems and their resources (base layer), which reduces the enabling conditions for continuing working and living in a delta. For several deltas (e.g., the Ganges-Brahmaputra-Meghna delta, Mekong, California Bay-Delta and Mississippi River deltas) there is slight optimism that with a moderate climate change scenario the improvements in infrastructure will outweigh the adverse effects of climate change, resulting in better sustainability. However, in a more extreme scenario it is expected that the balance will tilt to the negative side, leading to an overall reduction of sustainability.

Table 9
Main indicators for drivers, pressures and governance used for the comparison

Main indicators: Drivers	Main indicators: Pressures	Main Indicators: Governance
Demographic trends • Growth of delta population	**Land and water use (occ. layer)** • Population density • Urbanization • Fresh water demands • Flood vulnerability	**Multi-level and multi-sectoral cooperation** • Existence of integrated plans • Existence of multi sectoral / multi-level committees
Economic developments • GDP/capita • GDP av. growth	**Infrastructure (network layer)** • Flood protection standards • Irrigation and drainage • Water supply & sanitation • Road, railways and ports	**Public-private partnerships** • Number of PPPs • Scale of PPPs (geogr/finan)
Technological developments • Research and development • Knowledge-intensive industry	**Natural resources (base layer)** • Storm surges • Coastal / fluvial erosion • Ecosystem health • Biodiversity loss • Water quality • Freshwater shortage / salinity intrusion	**Involvement of stakeholders and citizens** • Existence of Legal instruments for participation • Number of NGOs involved
Climate change • Mean temperature change in 2050 • Mean precipitation change in 2050 • Increase of river peak discharge • Sea level rise		**Approaches for dealing with risks and uncertainties** • Existence of adaptive management (strategies) • Existence of risk management and emergency systems
Subsidence • Tectonic subsidence • Surface-lowering in peaty areas • Overall subsidence		

Golden Gate Bridge near San Francisco Bay

For all the other deltas it is expected that both scenarios make it a lot more difficult to maintain the present resilience and sustainability status, leading to lower scores in 2050 for most of them.

Adaptive measures

Various types of adaptive measures can be proposed to improve resilience and sustainability of deltas. The types distinguished in this study are: technical, ecological, economic and institutional measures. Technical measures comprise all 'hard' adaptations of the physical environment and infrastructure in the delta. Ecological measures are 'soft' adaptations, designed to support, restore or strengthen the natural delta processes that lead to resilience. Economic measures include financial or legal arrangements that can be made to support and promote activities that contribute to delta resilience and sustainability, and, on the other hand, to restrict activities that counteract sustainable delta development. Institutional measures involve adaptations at the level of governance and society.

Based on the delta descriptions an inventory of adaptive measures has been prepared. Table 10 shows an overview of this inventory. The scores should be regarded as an expert judgment at a fairly aggregated level, giving a crude indication of the approach followed/ proposed in the various deltas. Below, the different adaptive measures and the scores are briefly discussed with some examples from the deltas studied.

Table 10 shows that adaptive measures in general tend to be technical and ecological, rather than economic or institutional. In the Rhine-Meuse and Ganges-Brahmaputra-Meghna deltas, there is a relatively strong focus on technical measures, whereas in the California Bay-Delta and Yangtze delta preferentially ecological measures are proposed. For other deltas the picture is more balanced. In the Danube delta, which is largely a nature reserve with very low population density, very few adaptive measures are taken.

Technical measures

The most important technical measure in the Rhine-Meuse delta is re-enforcement of dikes and dams to bring these up-to-date with legal safety levels. Higher safety levels are proposed and will demand further measures. Other technical measures proposed in the Rhine-Meuse delta include land reclamation, by extensive sand nourishments or construction of polders, and compartmentalisation, which involves the realization of extra infrastructure behind the dikes to reduce the flooded area in case of dike-breach event. A slightly different, but equally technical, approach is followed in the Ganges-Brahmaputra-Meghna delta, with investments in flood shelters, early warning systems and floating houses and facilities, as well as further embankments and dams.

Table 10
Comparative overview of the types of adaptive measures proposed for the studied deltas.

	Technical	Ecological	Economic	Institutional
Nile	••	•	•	•
Incomati	•	••	•	••
Ganges-Brahmaputra-Meghna delta	•••	•	•	•
Yangtze	•	•••	•	•
Ciliwung	••	••	•	••
Mekong	••	••	•	••
Rhine-Meuse	•••	••	••	••
Danube	•	•	•	•
California Bay-Delta	•	•••	•	•
Mississippi River Delta	••	••	•	•

• none or few
•• some
••• many

Ecological measures

A number of adaptive measures proposed for the Yangtze delta aim at restoring and using the natural wetlands to improve resilience. Examples include: green dredging, i.e., using dredged sediments to create new wetlands, enhancing sediment trapping in wetlands, and storing rainwater in wetlands for natural purification. Along with these measures control of invasive species and reintroduction of large mammals to increase biodiversity is proposed. Currently, the Yangtze delta wetlands are under high pressure of strong urbanization and extensive water and soil pollution. Therefore, the measures are urgently needed, although it can be expected that they will need to be supplemented by short-term technical flood-protection measures. A different situation exists in the Sacramento-San Joaquin Delta, where the delta population is smaller and rural. Many plans exist for restoration of wetlands in this delta and in San Francisco Bay, including measures to enhance peat growth on delta islands to reverse subsidence. Important ecological adaptive measures in the Rhine-Meuse delta are taken in the Room for the River project, which involves the creation of extra flow and storage capacity for river floodwaters, along with floodplain ecosystem rehabilitation.

Economic and institutional measures

Hardly any economic measures are proposed in the studied deltas. For the Rhine-Meuse delta a few measures are considered that, at least partly, relate to economic activities:

- adapted forms of building and construction,
- financial instruments to support/promote 'delta-friendly' economic activities,
- risk-based allocation policy, in which economic activities (land use) are dependent on agreed safety levels and related zoning.

Currently, these measures need elaboration and are far from large-scale implementation. Slightly better is the status of some institutional measures proposed in the Rhine-Meuse delta. One is to set up new institutional alliances to enhance multi-sectoral cooperation

Example of long term vision on Rhine-Meuse delta in which re-establishing sediment dynamics prevails above shortening the coastline by 'hard measures' (source: WWF, 2008)

and implementation of effective measures. Others are educational programs on hazards, vulnerability and risk management, and insurance products for damage due to storms and floods. Especially the latter two need further development. In the Ciliwung and Mekong deltas programs for public awareness-raising and disaster-preparedness are proposed as institutional adaptation measures, along with initiatives for integrated coastal zone (Ciliwung) and trans-boundary river basin management (Mekong).

Technical methods and tools

Technical methods and tools supporting delta management and development reported from the deltas studied can be subdivided into two categories:

1. process models that describe physical processes in the base layer of the delta system;
2. decision support systems and integrated assessment and management tools that use, often rule-based, process information from the three layers of the delta system for scenario analysis of future developments.

Below, the two categories will be illustrated with examples from various deltas.

Process models

A suite of advanced process models is available for the Ganges-Brahmaputra-Meghna delta. Examples for the river system include the 2D HD and 1D HD models of hydrodynamic and morphological processes in key rivers in the delta. Coastal/marine process models are the Bay of Bengal (BoB) model, which includes a storm-surge prediction tool, and the SAL model, which is a salinity model for the near-coastal river system. All these models have been developed by the Institute of Water Modelling in Bangladesh. In the Rhine-Meuse delta, Delft3D, developed by Deltares, is the leading modelling system to investigate hydrodynamics, sediment transport and morphology and water quality for fluvial, estuarine and coastal environments. For the river system, SOBEK and WAQUA are alternatives for, respectively, 1D and 2DH studies. In the USA (California Bay-Delta and Mississippi River Delta), HEC-RAS of the US Army Corps of Engineers is the standard model for one-dimensional flow and sediment transport computations, and water temperature modelling. A different kind of process model is a geological delta evolution model. The National Center for Earth Surface Dynamics in the USA has developed a theoretical framework for the quantification of the response of deltaic systems to the effects of subsidence and rising sea level. In addition, NCED has developed a numerical model that can quantitatively predict land-building by means of river diversions in the Mississippi River delta.

Decision support systems/ integrated assessment and management tools

The Institute of Water Modelling in Bangladesh has issued a range of decision support systems (DSSs) for water resources management, reservoir operation and coastal zone management. In the Netherlands, the river basin model STREAM was developed by the Institute for Environmental Management (IVM-Free University of Amsterdam). STREAM is a spatial hydrological model that allows for assessing hydrological impacts due to changes in climate and socio-economic drivers in river basins. STREAM has been applied to various rivers basins in the world, including the Rhine-Meuse, Ganges-Brahmaputra-Meghna, Yangtze, Nile and Incomati basins. A different type of tool is ARK Routeplanner, which constitutes a framework for assessment and cost-benefit analysis of climate adaptation options, developed by Wageningen University and Research Centre in the Netherlands.

The Rhine-Meuse delta from space

Research gaps and opportunities for knowledge exchange and collaboration

An inventory of research gaps has been carried out based on the delta descriptions. Table 11 provides an overview of the issues that have been identified for further research. The specific knowledge gaps/research questions raised in the delta descriptions were aggregated in the broader issues presented in Table 11. This process inevitably goes with some information loss, but on the other hand facilitates comparison and identification of potential opportunities for collaboration. Opportunities for collaboration concern the issues that were put forward as research gaps in multiple delta descriptions. In Table 11 the issues have been ranked per category (layers and governance) based on the number of deltas for which related research gaps were mentioned.

Table 11
Comparative overview of research gaps. Between brackets for each issue the number of deltas for which this issue is identified as a research gap

	Nile	Incomati	Ganges-Brahmaputra-Meghna	Yangtze	Ciliwung	Mekong	Rhine-Meuse	Danube	California Bay-delta	Mississippi River delta
Occupation layer										
Socio-economic scenarios (6)	●	●		●	●			●		●
Water use and treatment (5)	●	●	●		●		●			
Integrated spatial planning (5)	●	●	●		●		●			
Ecosystem services (5)	●			●	●		●	●		
Land-use change modelling (4)	●		●		●				●	
Adaptation to salinisation (2)	●		●							
Network layer										
Freshwater management (7)	●	●	●		●	●	●		●	
Dikes and dams (5)	●		●		●		●		●	
Transport (3)	●	●			●					
Flood forecasting/early warning systems (1)			●							
Base layer										
Effects of changes/ eco-system functioning (9)	●	●	●	●	●		●	●	●	●
Building with nature and natural safety (8)	●		●	●	●	●	●	●		●
Monitoring changes (7)	●		●	●	●	●	●		●	
Predicting changes (7)	●		●		●	●	●	●	●	
Base-layer data management (3)			●		●					●
Governance										
Governmental roles and arrangements (6)	●				●	●	●		●	●
Integrated delta management (6)	●	●	●	●	●			●		
Communication/capacity building (4)	●	●	●		●					
Financial arrangements (4)			●		●		●		●	
River basin cooperation (2)		●	●							
Policy impact studies (1)					●					

Important issues for knowledge exchange and collaboration obviously are 'socio-economic scenarios', 'water use and treatment' and 'integrated spatial planning' (occupation layer), as well as 'freshwater management' and 'dikes and dams' (network layer). The most prominent field of potential inter-delta research cooperation concerns various base-layer issues, ranging from monitoring and predicting changes, through understanding cause-and-effect relationships and ecosystem functioning, to natural safety and 'building with nature'. As to governance, the major issues identified for cooperation are 'governmental roles and arrangements' and 'integrated delta management'.

Of course, the mere identification of shared problems and issues for further research is no guarantee for successful collaboration. Especially, geographical variation among deltas needs to be taken into account. Developed solutions, for one issue in a certain delta need not to be applicable to the same issue in another delta. For example, dikes and dams designed for the temperate-zone storm surges in the Rhine-Meuse delta may not be able to withstand the tropical cyclone-induced storm surges in the Ganges-Brahmaputra-Meghna delta. Conditions of salinisation in arid environments with a high evaporation (e.g., the Nile delta) may be very different from those in a temperate humid environment (e.g., the Rhine-Meuse delta), and this will certainly affect management solutions. Also, ecosystem-functioning in deltas varies widely as a function of geographical location. As to governance, socio-cultural differences between deltas will be reflected in different governmental styles. It seems that especially base layer and governance features are highly delta-specific, which needs to be acknowledged in inter-delta knowledge exchange and research collaboration.

In conclusion, although the problems in deltas need tailor-made solutions, a change of perspective, by inter-delta comparison and cooperation, can lead to new and unexpected opportunities. Acknowledging differences between deltas will help to better single out the key points of shared interest and focus research cooperation. There are major opportunities for knowledge exchange and collaboration at the level of understanding the base layer. It should be remembered, however, that delta management needs an integrated approach covering governance and all three layers, and thus delta knowledge development ideally needs a similar balance.

Conclusions
and the way forward

Chapter 5

Conclusions

General conclusions and lessons learned on the resilience and sustainability of deltas

Based on the aggregated scorecards (see page 57) we may conclude that for most of the deltas current resilience and sustainability is not satisfactory. We saw that the reasons for these rather disappointing scores differ from delta to delta, but the following general mechanisms seem to be prevalent:

- An imbalance between demands and supply with regard to land and water use;
- An inadequate or ageing infrastructure in the delta;
- Disruption of the natural delta processes;
- Inadequate governance to address problems and implement solutions.

In many deltas the high pressure from land and water use combined with inadequate infrastructure leads to high flood risks, (potential) overexploitation and degradation of the natural resources and environment and possible economic stagnation. Major infrastructure works to comply with the increasing demands are often sought for, but can on their turn disrupt the natural delta processes. The modification of the natural delta patterns and processes through major infrastructure works has often resulted in new problems for which additional technological interventions were needed. Often these solutions are ad hoc and lack an integrated approach ignoring the constraining and enabling conditions of the base layer. Examples are the disruption of the natural sedimentation processes and the increase of flood risk and salinity intrusion through the construction of deep navigation canals. Most of the plausible future changes in delta boundary conditions, both on the seaward side and on the landward side through the river catchment, are likely to aggravate rather than mitigate these problems.

Hence delta management faces an important dilemma: accommodating more people and more activities than the base layer of a delta can support requires new or upgraded infrastructure, which on their turn could lead to a further reduction of the natural carrying capacity of the basis layer. Solutions for this dilemma include innovative technological breakthroughs, multifunctional land use and building with nature. More importantly, however, solutions should be looked into that take account of all three layers and their interactions. It is highly unlikely that unregulated autonomous development of the occupation layer can be accommodated solely through more and bigger infrastructure. In other words: Delta governance should be focused on optimizing the land occupation and activities of the population, on better managing the infrastructure and on the restoration of natural systems and processes.

The need to tackle the problems at all physical planning layers poses a major challenge to the governance of a delta. The reason for this is that the institutional arrangements for each of these layers differ: each layer has different temporal dynamics and public-private involvement. Better interaction between the three layers necessitates a reorientation on the tasks and responsibilities between public and private actors. This new role division may require a change in governance style. Government services, citizens and other stakeholders need to cooperate with respect to integrated (multi-sectoral) policy formulation, management design and implementation, resulting in Delta plans and programmes. Our analysis on governance shows that there is a general awareness on this issue, that many deltas are experimenting with new role models and arrangements, albeit often with mixed results.

It may be of relevance to underline that our inventory results supports the observation (e.g. from M. Parry at the Rotterdam Conference) that many deltas are already highly vulnerable to flood risk and weather extremes, even without climate change. And that this vulnerability is likely to increase due to human activity, leading to decreased accretion,

increased subsidence and a fast growing exposed population. Climate change will add to this vulnerability through accelerated sea level rise, intensified weather extremes, altered regional run-off, impacts on ecosystems and freshwater availability.

Delta plans

For a number of deltas the challenge is defining a comprehensive (multi-sectoral) delta plan, i.e., a delta-specific framework for future delta management and development, incorporating a common perception (vision) for all delta stakeholders at national and sub-national levels. Such plans have been elaborated for the Rhine-Meuse, California Bay-Delta, and Ganges-Brahmaputra-Meghna deltas.
Elaboration of a comprehensive delta plan into concrete measures should be facilitated by a coherent system of process models, decision support systems, and integrated assessment and management tools.

Whereas model and tool development requires inter-delta research collaboration, setting up and implementing comprehensive delta plans predominantly needs appropriate intra-delta governance structures. The latter refers to inter-sectoral and interregional/international governmental collaboration. Platforms for collaboration at both levels have been established, the Delta Alliance being an example of stimulating collaboration across deltas and within deltas (by the Wing structure). However in most deltas the development of effective intra-delta (and often intra-governmental) collaboration structures needs more attention.

Next to strong collaboration structures, effective and sustainable delta management also needs strong legal arrangements. In some deltas, legal instruments have been designed especially to support sustainable development. Ideally, such legal instruments should be rooted in a comprehensive delta plan and warrant implementation of adaptation measures and sufficient financial means for future sustainable development.

Various types of adaptive measures can be proposed to improve resilience and sustainability of deltas. The types distinguished in this study are: technical, ecological, economic and institutional measures. In general the adaptive measures proposed for the deltas studied tend to be technical and ecological, rather than economic or institutional. In the Rhine-Meuse and Ganges-Brahmaputra-Meghna deltas, there is a relatively strong focus on technical measures, whereas in the California Bay-Delta and Yangtze delta preferentially ecological measures are proposed. For other deltas the picture is more balanced.

Methods and tools

From our evaluation of technical methods and tools (see page 61) it can be concluded that, nowadays, there are many advanced delta process models available for many base layer features. The same holds for decision support systems and integrated assessment and management tools. Especially for the Ganges-Brahmaputra-Meghna and Rhine-Meuse deltas a variety of such tools has been developed. Tools at this level tend to be rather generic and therefore can be, or already have been, applied to multiple deltas and river basins. Collaborative efforts in tool development should focus on adapting existing tools for new situations rather than on developing completely new ones for each delta. Working with common tools will facilitate research collaboration and inter-delta data exchange.

Conclusions and the way forward

Chapter 5

The way forward

Discussion on the method for comparative overview

The combined layer and DPSIR model approach has proven to be useful, workable and practical. The approach was discussed during the Rotterdam Conference and most Delta Alliance Wing coordinators were enthusiastic about it. But there were critical comments as well. The following remarks were made:

- The model is good from a communication perspective. It facilitates dialogue.
- Using the model and filling in the scorecard is a very useful exercise.
- The layer model does not take into account the sometimes highly dynamic nature of a delta (e.g. seasonal cycles).
- Preparing and updating a scorecard is often too expensive or time consuming (experience from California Bay-Delta).
- The scorecard is a starting point, or status-check. It can be used to mobilize more involvement, not for the sake of making a better scorecard but for the process behind it.
- Scorecards should help to identify where the 'hot' projects are and to attract funds.

Short-timescale delta dynamics (third remark above) can be taken into account in our approach by proper definition of indicators of delta dynamics (e.g., mean annual river flood, maximal storm surge height). Another problem is that the layer model does not capture long-term geological delta dynamics, such as shifting of delta distributaries and associated coastal progradation and retreat. However, this was not a major problem in this study, because of the relatively short, at least in a geological perspective, timescales involved.

Feedback on the approach in the EBR-session (see Appendix) indicated that catchment developments should be included as an extra driver of change. Many deltas are heavily affected by **developments taking place upstream**. For example, new reservoirs may trap sediments that are needed to prevent coastal erosion. Changes in land use and measures in the catchment will influence water and sediment fluxes to the delta (e.g. higher peak discharges because of reduced storage in the basin or loss of discharge due to irrigation) Also, water and sediment quality in the delta is largely influenced by upstream developments.

Indicators are a useful means of obtaining comparable information from deltas. However, as we have seen earlier (table 8 in synthesis scorecard), for many indicators quantitative data are unfortunately lacking (see also Appendix). Delta comparisons could become more robust if for at least a minimum set of indicators quantitative data is provided and a transparent scoring method is developed (to be elaborated in the follow-up of this project). This set of indicators will necessarily be a compromise between completeness, practicality and availability. Accepting that the data availability and quality will vary somewhat among the deltas under study, the challenge is to identify the key indicators that provide a maximum of information on delta sustainability with minimum data. In further work on the scorecards scenario details and ranking methods need to be clarified.

Research gaps and opportunities for collaboration

Traditionally, much research on deltas focused on the base layer. Especially since the hurricane Katrina disaster in the Mississippi River delta a considerable number of articles about delta processes, degradation and threats have been published in the leading international scientific journals. This concerns peer-reviewed fundamental research papers (e.g., Syvitsky et al., 2009; Blum & Roberts, 2009; Nicholls & Cazenave, 2010), but also commentary and news items (e.g. Service, 2007; Kabat et al., 2009; Bohannon, 2010) reflecting increased awareness of delta vulnerability. Recently, Vörösmarty et al. (2010) performed a global study of threats to human water security and river biodiversity in river basins. With deltas being the exits of river basins, the threats addressed by them represent urgent problems for many deltas. However, a vast majority of the many recent articles on delta issues almost exclusively focuses on the environmental problems, not on solutions or strategies for the future.

Whereas a thorough understanding of the base layer remains crucial, in our view sustainable solutions can only be found when the research focus is shifted to encompass all three layers of the delta system and governance aspects, because solutions for problems in the base layer commonly require adaptations of the other layers and/or governance. Our inventory of issues for which research gaps have been identified in various deltas (see page 63) showed that most shared research gaps exist for base layer and governance issues, which therefore provide many opportunities for collaboration across deltas, leading to a new perspective on delta problems, and to innovative solutions. In identifying research themes, however, we should acknowledge the many relationships between the three layers and governance aspects and strive for well-balanced research programs. Naturally, there are many differences between deltas and problems can be delta-specific, but acknowledging these differences will help to better single out the key points of shared interest and focus research cooperation.

Although new research is necessary, it should be remembered that optimizing the use of existing research results also deserves attention. Inter-delta collaboration in not only a way to reach joint research objectives, but may also facilitate sharing of existing research results for application in management and policy development. An inter-delta supply-and-demand inventory of research results was beyond the scope of this study but could be a fruitful exercise in a follow-up comparative delta study.

Follow-up of comparative overview of deltas

In the next phase of the Delta Alliance it is envisaged to support a follow-up of this current comparative overview of deltas. In this research the delta assessment approach will be further developed and more deltas will be involved (a.o. Rhone, Po, Thames, Elbe, …)
Moreover concrete collaborative research ideas across deltas will be elaborated and better implementation of existing research will be encouraged.

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References

Agarwal, C., G.M. Green, J.M. Grove, T.P. Evans & C.M. Schweik, 2002, *A review and assessment of land-use change models: dynamics of space, time, and human choice. Gen. Tech. Rep. NE-297. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 61 p.*

Amorosi A. & S. Milli, 2001, *Late Quaternary depositional architecture of Po and Tevere River deltas (Italy) and worldwide comparison with coeval deltaic successions. Sedimentary Geology 144:357–375*

Blue Ribbon Task Force, 2008, *Delta Vision Strategic Plan. State of California Resources Agency. Sacramento, CA.*

Blum, M.D. & H.H. Roberts, 2009, *Drowning of the Mississippi Delta due to insufficient sediment supply and global sea-level rise. Nature Geoscience 2, pp. 488-491.*

Bohannon, J., 2010, *The Nile Delta's sinking future. Science 327, pp. 1444-1447.*

De Groot, R.S., 1992, *Functions of Nature. Wolters-Noordhoff, Groningen.*

De Groot, R.S., 1994, *Evaluation of environmental functions as a tool in planning, management and decision making. PhD Thesis. Wageningen.*

De Groot, R.S., M.A. Wilson & R.M.J. Bouwmans, 2002, *A typology for the classification, description and valuation of ecosystem functions, goods and services. Ecological Economics 41, pp. 393-408.*

Kabat, P., L.O. Fresco, M.J.F. Stive, C.P. Veerman, J.S.L.J. van Alphen, B.W.A.H. Parmet, W. Hazeleger & C.A. Katsman, 2009, *Dutch coasts in transition. Nature Geoscience 2, pp. 450-452.*

Kubo Y., J.P.M. Syvitski, E.W.H. Hutton & A.J. Kettner, 2006, *Inverse modeling of post Last Glacial Maximum transgressive sedimentation using 2D-SedFlux: application to the northern Adriatic Sea. Marine Geology 234, pp. 233–243.*

Marchand, M. & T. Ruijgh – van der Ploeg, 2009, *Reframing integrated water management for urbanized deltas: a combined approach of spatial planning and governance to analysis and design. Paper presented at the Conference People and the Sea, (V): living with uncertainty and adapting to change July 9th- 11th 2009, Amsterdam.*

Newell, B., C.L. Crumley, N. Hassan, E.F. Lambin, C. Pahl-Wostl, A. Underdal & R. Wasson, 2005, *A conceptual template for integrative human–environment research. Global Environmental Change 15, pp. 299-307*

Nicholls, R.J. & A. Cazenave, 2010, *Sea-level rise and its impact on coastal zones. Science 328, pp. 1517-1520.*

OECD, 1993, *OECD core set of indicators for environmental performance reviews: a synthesis report by the Group on the State of the Environment. Organisation for Economic Co-operation and Development OECD, Paris, France.*

Overeem I., J.P.M. Syvitski, E.W.H. Hutton, 2005, *Three-dimensional numerical modeling of deltas. In: Giosan L., Bhattacharya J.P. (eds) River deltas—concepts, models, and examples. SEPM Special Publication No. 83, pp 13–30.*

References

Reker, J., J. Vermaat, A. van Winden, M. Eleveld, R. Janssen, W. Braakhekke, N. de Reus & N. Omzigt, 2006, *Deltas on the move. Making deltas cope with the effects of climate change. National Research Programme Climate changes Spatial Planning.*

Service, R.F., 2007, *Delta blues, California style. Science 317, pp. 442-445.*

Syvitski, J.P.M., 2008, *Deltas at risk. Sustainability Science 3(1), pp. 23-32.*

Syvitski J.P.M. & Y. Saito, 2007, *Morphodynamics of deltas under the influence of humans. Global and Planetary Change 57, pp. 261–282.*

Syvitsky, J.P.M., A.J. Kettner, I. Overeem, E.W.H. Hutton, M.T. Hannon, G.R. Brakenridge, J. Day, C. Vörösmarty, Y. Saito, L. Giosan & R.J. Nicholls, 2009, *Sinking deltas due to human activities. Nature Geoscience 2, pp. 681-686.*

Van der Most, M., M. Marchand, T. Bucx, T. Nauta & M. van Staveren, 2009, *Towards sustainable development of deltas, estuaries and coastal zones – trends and responses (in the framework of the Aquaterra 2009 conference in Amsterdam).*

Vörösmarty, C.J., P.B. McIntyre, M.O. Gessner, D. Dudgeon, A. Prusevich, P. Green, S. Glidden, S.E. Bunn, C.A. Sullivan, C. Reidy Liermann & P.M. Davies, 2010, *Global threats to human water security and river biodiversity. Nature 467, pp. 555-561.*

VROM, 2001, *Het belang van een goede ondergrond. Ruimtelijke Verkenningen 2000. Den Haag. [in Dutch]*

Appendices

Summary of delta descriptions

In the following paragraphs the main issues of the delta descriptions are summarized. This involves drivers of change, pressures (in occupation layer, network layer and base layer), governance and related research gaps. The full delta descriptions are available in a separate 'Working document' (see www.delta-alliance.org or CD on the back cover of this report).

❶ Nile delta

Summary of drivers of change

Demographic trends: about 35 million inhabitants are living in the nile delta. The population density is about 1000 inhabitants/km^2 with a growth rate of 2% per year.

Economic developments: economic conditions in Egypt have improved considerably over the years. In 1990-91, real gdp growth rate was 3.7%. By the end of fiscal year 1998, the growth rate reached 5%, fuelled primarily by private sector investment through continued rapid privatization and institution building (Egypt inc). Results of the economic and financial performance indicated a great improvement during fy 2006/2007 and first quarter of fy 2007/2008. Egypt's economy achieved a growth rate of 7.1% Which is the highest growth rate in the preceding 10-year period.
The tourism, industry, agriculture, and service sectors are significant contributors to Egypt's economy. Tourism currently represents 11.3% Of gdp, 40% of the total Egypt's non-commodity exports and 19.3% Of Egypt's foreign currency revenues. The industrial sector's contribution to the gdp in 2006/07 was around 17.2%. The agriculture sector accounts for roughly 14.8 % Of gdp. Also, agriculture contributes about 30% to Egypt's commodity exports, which makes it a major revenue-generator. And, of Egypt's overall labour force, 40% works in the agricultural sector, mostly in the nile delta and nile valley.
The economic importance of the nile delta comprises industrial centres, commercial and fishing harbours, large urban areas, tourism centres, agriculture activities, gas and oil production, and fisheries.

Climate change: climate change is expected to exacerbate the current problems through a combination of many aspects like changes in long term average nile flows, higher consumptive water use, rising sea level, salt water intrusion leading to problems with soil and water salinisation, erosion and accretion, and changes in wave and current patterns.

Subsidence: land subsidence in the coastal zones of the nile delta has resulted from the shortage of sediment supply by the nile river, oil and gas production, soil compaction, and (fault) tectonics. The coastal zone of the nile delta is tilting eastward at rates varying from 0.5 To 4.0 Mm/year.

Technological developments: in the field of hydraulic engineering, coastal engineering, hydrodynamics, and water management many research programs of nwrc, research institutions and universities have been carried out.

Research gaps

- *Multi-disciplinary research to study climate change impacts and resilience across the different layers and sectors of the delta.*
- *Socio-economic impacts of the climate changes, especially to the most vulnerable communities and sectors.*
- *Impacts of sea-level rise on soil and water salinity, agriculture, wetlands ecosystems and fisheries, patterns of waves and currents, and drainage infrastructure.*
- *Impacts of climate changes on water resources, water requirements, and agriculture.*

Summary of pressures in Occupation layer

Pressure on space: With half of Egypt's population of 80 million living in the delta and a population growth rate of nearly 2% pressure on available space is the main issue of the Nile delta.

Vulnerability to flood: River floods are minimized through the High Dam and coastal storms are rather mild.

Freshwater shortage: The entire country is dependent on Nile water inflow. As demands continue to rise, freshwater shortage will increase in the future.

Research gaps

- ***Land-use and land-cover change models****: There is a need for models to predict land-use and land-cover changes,* *urban and rural land-use change, and agricultural land-use change. Models need to be appropriate for sea-level rise as well as climate change and ecosystem projects, including vegetation changes and loss of ground surface to permanent seawater flooding.*

- ***Spatial planning**: How can we optimally integrate the water management and sea flooding safety infrastructure into spatial planning concepts?*
- ***Water use and treatment in industry, domestic and agriculture**: Which innovations are needed in industry, domestic and agriculture for treatment and more efficient water use?*
- ***Ecosystems, agriculture and salinisation**: What are opportunities for using natural protectorates areas for water retention in salinating areas? Could wetlands function as blockades against salinisation of groundwater and salt water intrusion? There is a need to develop saline agriculture (including fish and algae) or cultivation of more salt-tolerant crops (e.g. sugar beet).*
- ***Ecological flow requirements**: Which ecological flow is required to maintain soil salinity in the Nile delta at acceptable levels for agriculture and in the coastal lakes for fisheries and biodiversity (and also control sea water intrusion)?*

Summary of pressures in Network layer

Ageing infrastructure: The extensive irrigation system is stretched to its limits; there is a constant need for efficiency improvement.

Research gaps

- *Water efficiency improvement in times of climate change. Nile water share for Egypt is limited and water requirements will be increased. Egypt might be enforced to reuse more agricultural drainage water as well as groundwater, but both will suffer from sea-level rise. In this context, modification of drainage system and hydraulic conveyance infrastructure is needed to potentially meet water demands.*
- *How to improve water harvesting techniques to maximize the sustainable returns of rainfed agriculture.*
- *Rehabilitation of water and drainage control/pumping structures.*
- *How to develop more environmental friendly constructions for coastal protection infrastructure?*
- *What are opportunities for recharging drainage water into coastal groundwater aquifers to minimize sea water intrusion?*
- *Rehabilitation and improvement of irrigation canals for inland transportation.*

Summary of pressures in Base layer

Coastal erosion: Due to Aswan dam most of the Nile sediments are trapped in Lake Nasser. Sediment balance at the coast is disturbed, leading to coastal erosion.

Loss of biodiversity: As the bird-rich coastal lagoons are at the end of the system, their water quality is threatened by salinisation and pollution.

Loss of soil fertility: A higher inputs of fertilizers is required to compensate for loss of soil fertility. Leaching of these leads to groundwater contamination.

Research gaps

- *How can we use natural processes for land reclamation and sustainable delta management?*
- *Which morphological and ecological changes are currently occurring in the delta and are their rates changing?*
- *A detailed picture of future climate-change related changes (sea-level rise, wave and current patterns) is needed for planning adaptation of infrastructure. Especially levels of uncertainty in predictions need to be quantified.*
- *Rate of erosion and measures for coastline protection.*
- *An ecological model needs to be developed to observe the change in wetlands bio-diversity due to human intervention.*
- *A well calibrated and validated salinity model of sea water intrusion should be developed to understand the existing situation and to analyze the impact of climate change and sea level rise on salinity and its consequences on agriculture, fisheries, drinking water and biodiversity.*
- *Climate change impacts on the Nile delta. Information is needed by coastal managers to adapt to climate change, including inland, coastal and near-shore water quality, inland flooding, coastal erosion and patterns, wave and current patterns, saltwater intrusion, wetland loss and beach loss, and socio-economic impacts.*
- *Liquefaction, groundwater level rise impacts, subsidence due to pumping, instability of foundations with water level rises, and sea defences failure.*
- *More interdisciplinary research needs to be done into the loss/change of biodiversity and the relationship between lack of sediment and land subsidence and coastal erosion.*
- *Digital Elevation Model is highly needed for the whole Nile delta.*
- *Periodical soil surveys as a basis to establish fertilizer rates, continued restoration and maintenance of agricultural drainage systems, as well as for installing new drainage systems where needed.*
- *Development of community programs to turn these waste materials into inputs (fertilizers, water, energy), possibly combining it with agricultural waste, for local reuse (cradle to cradle).*

Summary of governance issues

Cooperation between (scale) levels and sectors of government: Highly centralized government with a strong administrative culture exists. The Egyptian Government is currently in a decentralization process. The main challenge in the decentralization process is to prevent decentralized processes from becoming ineffective. Efforts are underway to improve core governance systems and to improve sectoral governance.

Integrated Coastal Zone management is badly needed. This will require a further development of the institutional situation with regard to the mandate of national and local authorities to control and manage coastal developments.

Cooperation between government and private sector: The privatization of public sector industries has proceeded at a moderate scale. Also many major public industries have been privatized. Increasing private public participation (PPP's) is one of the policies of the Government.

Involvement of stakeholders and citizens: Although the Government of Egypt has realized the importance of stakeholders and citizens involvement in decision making process to increase public acceptability, it is still limited. The involvement of stakeholders and citizens is relatively higher at local level, whereas at the provincial and national levels are less. A new master plan for the coastal zones is still far from community participation.

Approaches for dealing with risks and uncertainties: To reduce loss of lives and land, Egyptian Government has implemented a comprehensive plan to manage the shoreline of the Nile delta.
There is a growing attention for awareness rising on climate changes impacts. Vulnerability of coastal zones to inundation due to sea level rise has been studied and many observation systems have been practiced.

Research gaps

- *A linked management approach that sees the river basin and coastal area as one interdependent system should be developed.*
- *Salinity is an important factor for agriculture, drinking water and fisheries. Salinity forecast system needs to be developed for the coastal area as sea level rise impacts threaten soil and groundwater quality.*
- *Adaptive management techniques need to be improved through better education and legal instrumentations.*
- *Data collection, monitoring and evaluation system requires improvement. Work on integrating policies and initiations of National plans are required.*
- *Water pollution is a challenge for sustainable development plans in the Nile delta as well as the coastal wetlands due to insufficient roles and laws.*
- *Improve the accuracy of climate changes impacts prediction.*
- *Measures to reduce risks: local knowledge and awareness.*
- *Enhance roles of provincial and local authority/officials.*
- *Legal reform and institutional setup are needed.*
- *Integrated Coastal Zone Management Plan needs to be initiated.*
- *Development of programs to improve the living standards of the rural inhabitants, and reducing poverty rates in the rural areas.*

❷ Incomati delta

Summary of drivers of change

Demographic trends: About 2,5 million inhabitants are living in the (urban) delta zone between Maputo Bay (Maputo) and the border of South Africa. The population is continuously growing (0.42%). Water demand in the basin is growing fast and has surpassed the water available in the basin. Currently, 50% of the water, generated in the basin, is being withdrawn.

Economic developments: The Incomati catchment is one of the fastest growing socio-economic regions in the SADC region, due to rapid developments along the Johannesburg-Maputo international axis of economic development, which is mainly situated in the catchment. Currently, 50% of the water, generated in the basin, is being withdrawn. Upstream, part of the water is being transferred to drier river basins in South Africa.
In South Africa, the Incomati catchment is one of the most stressed in the country. Reason why this catchment is the first to develop into a Catchment Management Agency (CMA) according to the new Water Law. The main economic sectors in Mozambique are: agriculture (23.6% of GDP), transport and communication, and trade (12.1 % of GDP). Mining is important in South Africa. In the Incomati catchment water is used for irrigation agriculture (sugar cane), forestry, mining, industrial and household use. The river is strategically important for its location in the south of Mozambique, near the capital, which is the most important economic area of the country. It is a major source of freshwater for Maputo City. Together with the Umbezuli and Maputo rivers it feeds Maputo Bay with its fresh- and brackish to salt water ecosystems. They are crucial for the economically important shrimp and other fish species. The Bay is under considerable environmental stress. NEPAD and WWF have identified Maputo Bay as one of the 10 hotspots for wetland conservation on the east African continent.

Climate change: Climate change is expected to exacerbate the current problems through a combination of rising sea level and extreme river discharges (floods and droughts). Effects of climate change will influence the Incomati basin strongly. A recent study for example, indicates that in the near future (up to 50 years) an increasing frequency of cyclones together with sea level rise and associated salt intrusion, will have impact on the coastal floodplains. It will have serious effects on livelihood conditions (agriculture, subsistence harvesting) and on environmental aspects. This also stresses the issue of safety and how to protect against floods, as well as the operation rules for the dams that are in the basin.

Subsidence: There are no evidences of subsidence in the delta, but it is believed that due to freshwater shortage and heavy extraction of ground water observed in the lower Incomati river basin, subsidence is likely to occur in the delta. On the other hand, there are evidences of accretion in the mouth. Aerial photography analysis over the period 1965 to 1991 showed that the Macaneta Spit, located at the mouth of the Incomati river, has been building up sediments. In addition, the spit was displaced, pushed and stretched south-east wards by an area of about 0.3147 km^2, during the period 1965 to 1982, and by about was 0.0899 km^2, during the period 1982 to 1991. The observed displacement seems to be the result of an accretion process.

Technological developments: The Science, Technology and Innovation Strategic Development Plan of Mozambique aims at the development of science and technology, including traditional knowledge, to increase the production of goods and services which will contribute to the poverty alleviation, economic development of the country and to the wellbeing of Mozambicans.
Solar energy is being promoted for pumping water to supply villagers for domestic use, and there are plan for applying on irrigation of the small scale farms. The technology used in agriculture is old-fashioned still, with exception of the sugar cane production which is mechanized. There are research on the production and improvement of draught resistant crops mainly for the villagers. There are no major building constructions in the delta; the government encourages the use of local material for the building of touristic lodges. There are plans to build large commercial aquaculture farms in the delta, which may bring technology development. The Ministry of Science and Technology promotes and encourages the use of ICT, so the internet and cellular phones are accessible throughout the delta. Further, the Ministry established a Millennium Village in the delta, which is an incubator of science and technology; this would improve the development and adoption of technologies.

Research gaps

- *There is a need to understand the coupled river basin and coastal system to contribute to the establishment of an Environmental River Flow Requirements for the health and integrity of the delta and coastal ecosystems.*
- *There is a need to understand the main drivers of ecological, hydrodynamics and morphodynamic changes in the delta.*
- *There is a need to identify alternative livelihood to reduce pressure on the natural resources and ecosystems in the delta.*
- *There is a need to conduct research on the environmentally sound land and water use practices to reduce wastage and degradation of resources and ecosystems.*
- *There is need to understand the socio-economic drivers of the development in the delta (such as the demography and socio economic activities) and their linkages.*
- *There is a need to conduct research for defining wise practices for reducing and/or solving conflicts in the resource uses and users in the delta and coastal areas.*
- *There is a need to develop an integrated land use occupation plan which should include settlements, agriculture, industry, tourism and transports.*
- *There is a need to conduct studies for the development of environmentally sound infrastructures in the delta, this should include access roads, settlement, industries and tourism resorts.*
- *There is a need to develop coupled environmental and socio-economic models to support management and decision making.*
- *There is a need to conduct assessment and gap analysis on the institutional and legal framework governing the delta and river basin management in general.*

Summary of pressures in Occupation layer

Pressure on space: Apart from greater Maputo (near Maputo Bay and Nylstroom, the basin has no major urban developments. But landuse in the form of agriculture and forestry will increase.

Vulnerability to flood: Flooding occurs in the lower basin at irregular intervals, with impacts on agriculture, natural habitats, damage to infrastructure and loss of life. The most devastating flood occurred in the year 2000. In Manhiça, located at the lower Incomati, alone about 17,000 ha of cultivated land were flooded and 20,000 families were affected while 18 deaths were reported. There are no flood protections along the river.

Freshwater shortage: More than 50% of the water resources are being withdrawn at the moment, mainly in the upstream parts. The two overriding issues in the Incomati River Basin are the modification of stream flow leading to draught and flood situations and water shortages. These are caused mainly by dams and reservoirs, water abstraction from these and inter-basin transfers to meet the increased demand for agriculture, urban and industrial developments. Rising sea levels will increase the problem of salt water intrusion, affecting agriculture and drinking water production in the lower Incomati basin.

Research gaps

- *There is a need to understand the main drivers of ecological, hydrodynamics and morphodynamic changes in the delta.*
- *There is a need to identify alternative livelihood to reduce pressure on the natural resources and ecosystems in the delta.*
- *There is a need to conduct research on the environmentally sound land and water use practices to reduce wastage and degradation of resources and ecosystems.*
- *There is need to understand the socio-economic drivers of the development in the delta (such as the demography and socio economic activities) and their linkages.*
- *There is a need to conduct research for defining wise practices for reducing and/or solving conflicts in the resource uses and users in the delta and coastal areas.*

Summary of pressures in Network layer

Ageing infrastructure: There is a lack of structured spatial planning, especially in the flood plain areas of the Basin including greater Maputo. Many new buildings in the outskirts of Maputo are (being) build on flood prone and erosion prone land near the Bay of Maputo and will be more at risk as a result of climate change. The infrastructure in the Johannesburg-Maputo international socio-economic axis of development is rapidly growing.

Research gaps

- *There is a need to develop an integrated land use occupation plan which should include settlements, agriculture, industry, tourism and transports.*
- *There is a need to conduct studies for the development of environmentally sound infrastructures in the delta, this should include access roads, settlement, industries and tourism resorts.*

Summary of pressures in Base layer

Coastal erosion: Coastal erosion occurs near the mouth of the Incomati and in the Bay of Maputo. In the 60's, the Dutch have constructed some coastal defence in the Bay, but this is now insufficient, since erosion is ongoing.

Loss of biodiversity: The health of estuarine and coastal ecosystems is compromised by pollution and reduced hydrodynamics. There is a serious loss of biodiversity in the Bay as a result of changing river discharges, cutting of mangroves and increasing water pollution, but this is not properly documented. WWF has placed Maputo Bay as one of the ten hotspots for conservation of wetlands in the whole of East Africa.

Research gaps

- *Studies into the causes of erosion and of decline of ecosystem values in the river and especially in the delta.*
- *Studies to improve ecosystem quality and reduce erosion.*
- *There is a need to understand the coupled river basin and coastal system to contribute to the establishment of an Environmental River Flow Requirements for the heath and integrity of the delta and coastal ecosystems.*
- *There is a need to understand the main drivers of ecological, hydrodynamics and morphodynamic changes in the delta. This should include the linkages between river runoff and salt intrusion, sediment fluxes, erosion, fisheries productivity and mangrove health.*

Summary of governance issues

Cooperation between (scale) levels and sectors of government: The government of Mozambique is implementing a decentralized administration by which the decisions are taken at district level, or a bottom up approach. A cross sectoral coordination which may lead to a mainstreaming of development plans is assured by the technical steering groups which act as advisors to the board ministers. At much higher level there are ministerial task groups which are set to deal with particular development aspects.

There are regional river basin management units coordinated by water depart. These units are the main responsible for the management of water with involvement of the stakeholder in the area under their jurisdiction.

Cooperation between government and private sector: The water sector in Mozambique is undergoing major changes towards less centralised water management, more involvement of private sector and more acceptance to economic value of water. These changes were formally established in 1991 in the Water Law that incorporated the basic principles and policies of water management. Under the implementation of this Law some of the water use infrastructures such as irrigation systems and water supply for domestic use in the rural areas were let to private management.

Involvement of stakeholders and citizens: There are different ways by which the larger stakeholders including individual citizens participate in the definition of policies for water use and the management of water. The associations of farmers have a sit in the irrigation management board; the ICZM steering committee involves private as well as individuals; WWF, IUCN and local NGO are active in supporting integrated water management.

Approaches for dealing with risks and uncertainties: In the light of the uncertainties the government privileged the precautionary measures, for instance the government urges people to build their house in high grounds safe from flooding; the catches are limited to a minimum allowable catch set base on precautionary approach; cutting of mangroves is prohibited, minimum allowable flow is applied to accommodate for the environmental flow.

Research gaps

- *A linked management approach that sees the river basin and coastal area as one interdependent system.*
- *There is a need to develop coupled environmental and socio-economic models to support management and decision making.*
- *There is a need to conduct assessment and gap analysis on the institutional and legal framework governing the delta and river basin management in general.*

❸ Ganges-Brahmaputra-Meghna delta

Summary of drivers of change

Demographic trends: Some 156 million people live in in Bangladesh and about another 44 million in West Bengal part of this delta, with 1226 inhabitants per km² and an annual growth rate of 1.292%.

Economic developments: One of the world's poorest countries with a predominantly labour-intensive agricultural economy and weak industrial base. Underemployment is a serious problem, so finding alternative sources of employment will continue to be a challenge. The GDP growth over the next 5 years will be about 6.0%. The per capita GDP is about US$ 400/yr.

Climate change: Currently the country is already vulnerable to water extremes. With additional climate change the effects will be: increase in cyclones and storm surges, sea level rise, salinity intrusion, water logging. With a sea level rise of 1.5m effects will be: permanently flooded area of 16% with population of 22 million, north east and central region will cope with river floods, north-west increased drought. Especially agricultural sector will be affected and coastal inhabitants. However, here climate change may lead to a spin-off by increased fisheries.

Subsidence: The lower deltaic area of Bangladesh is located on two active troughs, Faridpur Trough and Hatiya Trough. Although most of the Bengal Basin is slowly subsiding, the troughs are subsiding more rapidly. The area shows evidence of three different types of subsidence: tectonic, anthropogenic, and that resulting from the compaction of peat layer.

Technological developments: The need for faster technological development is increasingly felt in Bangladesh. Development plans of Bangladesh have emphasized science and technological research to develop technologies through adoption of imported technology as well as development of indigenous technologies. New crop varieties have been introduced to increase yields and improve resistance to pests, salinity, etc. Also, new irrigation technologies have been introduced to improve water efficiency and to expand irrigation areas. ICT sector is rapidly developing even in rural communities. Basic infrastructure development is still slow and energy is a major constraint to technological developments. A suite of tools (process models) for predication of the impacts of climate change on floods, salinity intrusion in groundwater water and rivers, morpho-dynamics, storm surges have been developed and are being routinely used. A National Science and Technology Policy has been formulated and adopted by the Government. It has laid down the directions for S and T activities and research, institutional and manpower development, dissemination and documentation facilities.

Research gaps

- *Need to know the exact increase in sea level change in the coastal area in near future.*
- *There is need for more research on subsidence for the whole delta. Uncertainties in climate change predictions need to be reduced. Reliable methods for downscaling from GCMs and RCMs required. New research is required in the development of tools for assessment of impacts on various sectors based on the predictions from process models. Research on various adaptation measures like, salinity and flood resilient crop varieties, guidelines on climate proofing of infrastructure, reduction of GHG emission. Comprehensive database on climatic, natural resources and socio-economic parameters is necessary to support various research and development initiatives. Impact of climate change on coastal morphology and storm surge.*

Summary of pressures in Occupation layer

Pressure on space: With some 1226 inhabitants/km^2 the delta is one of the most densely populated regions on earth.

* *No significant encroachment of mangrove forests on the Indian side since 1943.*

Vulnerability to flood: Most of the delta is still active with very unstable river branches and the delta is prone to tropical cyclones with high storm surges. Floods are a permanent threat; in a normal year 20% of the country is inundated by river spills and drainage congestions.

Freshwater shortage: Due to upstream developments and climate change, critical low flow conditions of rivers are likely to increase. Increase of salinity intrusion in coastal areas is making existing water supply sources and freshwater ecosystem vulnerable.

Research gaps

- *Need to develop an automated process to know the up to date status on number of population, population growth rate, migration rate, food demand, food intake per person, etc.*
- *Need to develop a suitable numerical model to determine the shortage of fresh water in the present situation and in the near future. Reliable methods for downscaling from GCMs and RCMs required. Improvement in 7-10 day flood forecasting is required. Hydromet system needs to be expanded into the Bay of Bengal. Prediction and management of river bank erosion needs to be improved. Further research on cyclone forecasting and tracking required. Sediment transport processes in major rivers and estuary need to be studied.*

Summary of pressures in Network layer

Ageing infrastructure: Management of embankments and irrigation system is a recurrent problem. Infrastructure to support transportation, communications, and power supply is rather poorly developed.

Research gaps

- *Research required in river bed level management in embanked rivers. Research into improved Polder Management necessary. Advanced tools that simulate the interactions between the infrastructure (network) and natural resources (base) layers required.*

Summary of pressures in Base layer

Coastal erosion: Riverbank and island erosion is one of the major issues. Erosion is a bigger problem than flooding. The average annual pace of net accretion in the Meghna Estuary is about 18.8 km^2 over the last 30 years.

Loss of biodiversity: Especially the mangrove forests (Sundarbans) are highly valuable but also under high pressure from encroachment* and exploitation. It is also vulnerable to accelerated climate change and sea level rise.

Salinity Intrusion: Saline water intrusion is highly seasonal in Bangladesh. Salinity and its seasonal variation are dominant factor for coastal echo-system, fisheries and agriculture. Therefore, any changes on present spatial and temporal variation of salinity will affect the biophysical system of coastal area.

Cyclonic storm surge: Due to its geophysical setting Bangladesh is frequently visited by the cyclone-induced storm surge and during the last 48 years nineteen (19) major cyclones devastated the coastal area. A cyclone in 1970 resulted in close to 300,000 deaths, and another, in 1991 led to the loss of 138,000 lives. Nevertheless, the potential for economic and infrastructural damage remains very significant.

Research gaps

- *A well calibrated and validated morphological model of river, estuary and sea need to be developed to calculate the bank erosion and land reclamation more accurately in present and future condition.*
- *An ecological model needs to be developed to observe the change in bio-diversity due to human intervention. Quantification of ecosystem services and estimation of benefits to livelihoods and the economy are required.*
- *A well calibrated and validated salinity model of river, estuary and sea should be developed to understand the existing situation and to analyze the impact of climate change and sea level rise on salinity and its consequences on agriculture, fisheries, drinking water and biodiversity.*

Summary of governance issues

Cooperation between (scale) levels and sectors of government: Highly centralized government with a strong administrative culture. Decisions are taken at the centre, even for local matters. Efforts are underway to improve core governance systems and to improve sectoral governance.

Cooperation between government and private sector: The privatization of public sector industries has proceeded at a moderate pace. In roads, irrigation, and power sectors there has been good cooperation between government and the private sector. Also many major public industries have been privatized. Increasing PPP's is a major policy of the Government.

Involvement of stakeholders and citizens: Existing policy and guidelines require public consultations in all development projects. Therefore, stakeholder consultation at planning and implementation phase of a project in different parts of the country is already practiced.

Approaches for dealing with risks and uncertainties: To reduce loss of lives and property, Bangladesh focuses on the development of flood forecasting and warning systems. Coastal area has already been practiced the early warning system for cyclonic storm surge and got the benefit. Bangladesh Water Development Board has a separate unit for flood forecasting and they can forecast with 3 days lead time.

Research gaps

- *Salinity is an important factor for agriculture, drinking water and fisheries. A salinity forecast system needs to be developed for the coastal area. Adaptive management techniques need to be improved through better education. Data collection, monitoring and evaluation system requires improvement. Work on integrating policies and updating existing National plans required. Storm Surge tool available but needs to be made operational for storm surge inundation forecasting at community level.*

❹ Yangtze delta

Summary of drivers of change

Demographic trends: The population of Yangtze delta (Shanghai) is 20 million, (this number could be 85.37 million if talking about the entire Yangtze delta region including the other two provinces, 16 cities in total). Population growth rate for permanent residents(registered in government system) was 0.27% in 2009.

Economic developments: Yangtze delta (Shanghai) is the financial and logistics centre of China, with a total GDP of 219 billion USD in 2009, the annual growth rate is 8.2%. Talking about the entire Yangtze delta region with 16 cities, the GDP is 700 billion USD in 2009.

Climate change: The average temperature is increasing. The precipitation and water flow to the estuary had been changed in timing and spatial distribution. Climate change is affecting Yangtze delta from both upstream and the sea.
Subsidence: Yangtze delta subsided 7 mm in 2007 and 5 mm in 2009, the sinking rate is decreasing as the government is implementing several methods to prevent subsidence.

Technological developments: Technological developments involve environmental compensation measures, especially regarding infrastructure, e.g. aquatic life release activity in the estuary, artificial oyster reef construction on the jetties of the deep water navigation channel and formation of new estuary wetlands by dredged sand.

Research gaps

- *Climate change impacts on the Yangtze delta and relevant solutions development.*
- *A sustainable and wise pattern for demographic and economic development.*
- *How to achieve sustainable and low carbon development?*
- *How to balance conservation and development or even make them mutual beneficial.*

Summary of pressures in Occupation layer

Pressure on space: Reclamation is an important method for Shanghai to increase its land, and now it is facing the serious fact that land consuming rate is faster than the natural wetland growth rate, leading to net loss of coastal wetlands.

Vulnerability to flood: Flood risk is increasing in the Yangtze delta because of the subsidence, coastal wetlands degradation and climate change.

Freshwater shortage: Shanghai is a typical water quality-induced water shortage city, freshwater supply is facing serious challenge with two key factors: pollution and salt-water intrusion.

Research gaps

- *A sustainable mode of land reclamation based on sufficient coastal wetland conservation.*
- *Risk assessment of sea level rise based on urban spatial pattern assessment.*
- *Ratio/area of wetland we should maintain as a buffering zone to safeguard Shanghai between city and sea.*
- *Urban hydro-environmental improvement.*

Summary of pressures in Network layer

Infrastructure: Shanghai is among the most advanced cities in China, and serving as the economic centre and logistics centre with the world largest port. Yangtze estuary deepwater channel and the Yangshan Deepwater Port are two projects need to be emphasized. A dike system was built to protect Shanghai from storms, isolating sea and land along the coastal line. Urban development, or urban sprawl in some area, had driven the demand of new land and infrastructures. EXPO has pushed the infrastructure of Shanghai to a higher status.

Research gaps

- *How to minimum the negative impacts on the nature and environment during the infrastructure construction and management.*
- *How to compensate the above impacts of infrastructures.*

- *How to develop a more environmental friendly way for construction and management. of infrastructure.*
- *How to adopt natural solutions.*

Summary of pressures in Base layer

Coastal erosion: Drastic drop of the Yangtze River's sediment load is slowing down the growth of coastal wetland, mainly caused by upstream dams and partially compensated by bank erosion along the middle and lower reaches. Under the condition of sea level rise and reclamation, coastal erosion may happen in some sections of shoreline.

Loss of biodiversity: Water quality is a major issue as many upstream domestic and industrial waste water is discharged untreated. Habitat loss and aquaculture are causing biodiversity loss.

Research gaps
- *Trends of land use change.*
- *The distribution of nature resources and their interactive relationship with human activities.*
- *Recommendation on future natural resources conservation and utilization.*

Summary of governance issues

Cooperation between (scale) levels and sectors of government: Cooperation between different government sectors is not easy or efficient enough, but it's improving.
Shanghai is relatively more open than most other parts of the country, NGO, private companies and public are having more influences.
Existing relevant governmental organizations are:
- Tai lake basin management bureau
- Yangtze delta mayor forum
- Yangtze delta information sharing platform

Cooperation between government and private sector: Shanghai had widely developed its international cooperation network.

Involvement of stakeholders and citizens: WWF is active in water resource restoration, wetland and bio-diversity conservation, low carbon development as well as overall policy recommendations.

Approaches for dealing with risks and uncertainties: Shanghai recognizes the increasing importance of sustainable development of water resources in dealing with floods and droughts. Risk assessment and coping strategies are being made by the government.

Research gaps
- *How to achieve integrated management by bringing different sectors to one platform.*
- *How to strengthen the legal system to better safeguard the estuary/delta safety.*
- *How to develop a long-term and short-term integrated management mode.*

❺ Ciliwung delta

Summary of drivers of change

Demographic trends: the population of greater jakarta is estimated at 23 million, making it the fourth largest urban area in the world. Jakarta's population growth rate remained at 3.6% Per year.

Economic developments: the indonesian economy and politics are rapidly developing. In 2007 the annual income per capita was some us $ 2000,- and gdp growth amounted to 6.3%. Jakarta alone contributes to about 25% of the national gdp.

Climate change: The effects of climate change may be strong. Changes in length and intensity of the rainy season are likely to continue, which could result in longer dry seasons and shorter but more intense wet seasons. Changing rainfall patterns will have a large impact on food production, thus affecting food security.
The mean sea level in the Jakarta Bay will increase as high as 0.57 centimetres (cm) per year. This coupled with subsidence as high as 0.8 cm per year, as observed in the Jakarta Bay, can have a large impact on flood risk, urban productivity and infrastructure.

Subsidence: Land subsidence is a serious threat in Jakarta. The rate varies temporarily and spatially, with estimates about 1 – 15 cm/year, but in the northern city the rate could be up to 20 – 25 cm/year. These rates are a combination of various causes, such as groundwater extraction, load of constructions, natural consolidation of alluvial soil, and tectonic processes.

Technological developments: Percentage of GDP spent on innovation and research in technology development sectors is not known. However, in 2005, Jakarta contributed to about 26.4% of the national GDP in the construction sector, 20.1% in transportation and communication, and 19.3% in services.

Research gaps
- ***Downscaled multi-ensembles climate change scenario analysis:*** *Even though climate scenarios for Jakarta were*

reported based on one or several climate models, an analysis focusing on the statistical probability of extreme weather events (extreme precipitation intensity, abnormal long wet season duration, frequency of droughts, etc) is lacking. This statistical information is necessary to assess the capacity of existing infrastructures to cope with the extremes and to decide if infrastructure upgrading is required.

- ***Socio-economic development projections:*** *the growth of jakarta metropolitan and other surrounding urban centers (bogor, depok, tangerang, bekasi) along with their economic growth is inevitable. A set of socio-economic development projections based on current trends and existing city development plans (e.G. Mass transport system, land allocations for trade and service centres, etc.) Will be helpful for exploring and anticipating future pressures and ecological and socio-economical risks.*

Summary of pressures in Occupation layer

Pressure on space: Jakarta is the fourth largest urban area in the world (23 million inhabitants). The core problem for the Ciliwung delta is the out-of-control urbanization of Jakarta.

Vulnerability to flood: Currently some 6 million inhabitants are vulnerable to flooding. Some part of the metropolitan city is already below sea level and is still subsiding (at least another meter over the next 20 years). Especially the northern part of the city is prone to inundation due to excessive rainfall and flash floods and impact of rising sea water level on the flood extent is expected to increase. Occupation of floodplains, groundwater withdrawal for water supply and solid waste disposal exacerbate the flooding problem in Jakarta.

Freshwater shortage: Land conversion from forest to agriculture and urban area results in water shortages during the dry season. A major breakthrough will be necessary to manage the present situation, both with regard to management of the existing water resources, and with regard to demand reduction.

Research gaps

- ***Spatial Plan in Jakarta:*** *At present the special autonomy of Jakarta is developing the Jakarta Spatial Plan for 2010-2020. However the spatial plan process lacks community participation and it is unclear how the plan will address the hydrology functions in Jakarta. The spatial plan as government policy should be based on sustainable delta and watershed ecosystem management.*
- ***Scenario based risk assessment of natural and social hazards:*** *In accommodating high economic growth and in providing better services to the community, the Metropolitan of Jakarta will require all efforts to be more resilient to disasters. An integrated scenario based risk assessment of natural and social hazards could help in shaping city development and urban planning. The assessment should include ecosystem valuation, especially addressing linkages of ecosystem services with disaster risk reductions, existing and planned infrastructure and water supply development.*
- ***Water Footprint Study:*** *Over-use of ground water in Jakarta by hotels, industries and households have been reduced significantly the amount of ground water. This is increasing the vulnerability of Jakarta by salt water intrusion, sea level rise and land subsidence. Land-use changes in upstream and coastal areas of Jakarta resulted in significant reduction of forests, lakes, rivers and mangroves areas surrounding Jakarta. This situation has decreased the hydrology functions in the Jakarta's delta.*

Summary of pressures in Network layer

Ageing infrastructure: The rapid urbanization of Jakarta results in severe shortcomings in infrastructure. Although much of the infrastructure is relatively recent, rehabilitation is needed, especially with respect to drainage systems. Inadequate infrastructure for piped water supply result in groundwater extraction and related land subsidence, influencing negatively the flooding problem.

Research gaps

- ***Ecosystem based planning:*** *The whole spatial development plan should be integrated with river basin and coastal management (water front city vision) and water supply-demand management, and should consider ecosystem service benefits for climate change adaptation and mitigation, DRR, pollution control, etc. Moreover this should be combined with the on-going development of a mass-and-rapid transport system.*
- ***Impact studies:*** *Some policies, especially for economic development might lead to unintended negative impacts. For example, dumping waste into a river can create negative impacts for downstream people. This situation has already happened in Jakarta's delta.*
- ***Infrastructure development*** *as part of Spatial Plan in Jakarta (see also above in 'Summary of pressures in Occupation layer').*

Summary of pressures in Base layer

Coastal erosion: Locally there is coastal erosion due to natural and man-made factors. Islands in the Bay are disappearing as a result of coral reef destruction.

Loss of biodiversity: Water quality is a major issue as many upstream domestic and industrial waste water is discharged

* General Statistics Office, Statistical Yearbook of Vietnam 2009

untreated. Moreover the quality of the ground water is threatened by salinisation. Consequently the whole physical, biological and ecological system in the Ciliwung basin as well as in the coastal wetlands is at stake. Unless remedial action is taken the system is in clear jeopardy.

Research gaps

- ***Data sharing and interoperability system:*** *Detailed and regularly updated data are necessary to assess existing conditions and trends in the delta, and to enable integrated water resource management and coastal management. Currently data are fragmented, scattered and in various formats at many research and governmental institutions with planners and practitioners. A data sharing and interoperability system will help for trend analysis, scenario development, modelling, and integrated planning.*
- ***Land use changes in upstream areas and coastal areas of Jakarta:*** *Forest, lakes, rivers and mangroves areas surrounding Jakarta have been significantly reduced. This situation has decreased the hydrology functions in the Jakarta's delta.*

Summary of governance issues

Cooperation between (scale) levels and sectors of government: The Indonesian Government is currently in a decentralization process. The main challenge is to prevent decentralized processes from becoming ineffective. Integrated Coastal Zone management is very much needed. This will require a further development of the institutional situation with regard to the mandate of national and local authorities to control and manage coastal developments.

Cooperation between government and private sector: The government has realized the importance of the private sector in development in general. The private sector delivers significant revenues for development, in addition to their direct corporate and social responsibility to the society. The involvement of the private sector in public services is increasing as part of efforts to increase the efficiency and transparency.

Involvement of stakeholders and citizens: The government has realized the importance of stakeholders and citizens involvement in the decision making process for increasing public acceptance. However this is still limited. The involvement of stakeholders and citizens is relatively high at local level by initiatives of NGOs and civil societies, compared to the provincial and national levels. Development of legal public forums at various levels will be useful to balance political interests in decision making.
The new spatial plan process in Jakarta is still far from community participation.

Approaches for dealing with risks and uncertainties: Indonesia recognizes the increasing importance of sustainable development of water resources in dealing with floods and droughts. Rather than avoiding floods completely, the flood and water management is targeted on controlling floods with acceptable risks in line with land use planning, infrastructure development and disaster management under the umbrella of adaptive management.

Research gaps

- ***Communication platforms and tools:*** *Problems of conflicting vertical and horizontal authorities and agencies, accountability and inter-regional transparency in sectors, partial management, weak laws/regulations and weak institutional capacity are still main gaps in governance. Development of a framework for integrated delta management would be required with the objective to setup a good institutional structure and capacity, and a common perception (vision) for all delta stakeholders at national and sub-national levels.*
- ***Sustainable Financing:*** *Until now there are no benefit/ economic sharing schemes based on mutual partnerships between water providers and users. The quality, quantity and flows of water in delta Jakarta has reduced because of mis-management and inappropriate budget to restore, manage and protect sound hydrology functions in Jakarta's delta.*
- ***Credible Watershed Management Body:*** *Because of lack of coordination between governmental organisations, watershed and delta areas in Indonesia, including Jakarta, are not well managed. Based on WWF ID review on water regulations, there are more than 15 regulations in Indonesia about water, with different interests and lack of synergy.*

❻ Mekong delta

Summary of drivers of change

Demographic trends: The number of inhabitants of the delta is some 17 million, the population density is 425 inhabitants/ km^2, with a growth rate of 0.6% per year*.

Economic developments: the Mekong delta is a priority area for economic development; the target is to increase the production of food, commodities and consumer goods by 8% per year.

Climate change: There are 2 important impacts caused by climate change to the Mekong delta; namely sea water rise and extreme climate conditions: more severe and earlier flood and longer period of drought spells.

Subsidence: Subsidence in the Mekong delta might be caused by: shortage of sediment (and nutrients) from upstream, natural process of subsoil under pressure, erosion.

Technological developments: In the past 30 years, many large-scale water resources management projects were implemented in the Mekong delta; namely Reclamation of the Plain of Reeds, Reclamation of Long Xuyen Quadrangular and Flood Water Discharge to West Sea, Fresh Water Supply to Ca Mau Peninsula,…

Research gaps
- *Multi-disciplinary research to study, in one research, multi-layer, multi-aspect, multi-dimension of climate change impacts and resilience.*
- *Impacts of climate change to the most vulnerable communities.*
- *Tendencies of extreme climate and water flow events.*
- *Impacts of large-scale water resources development upstream (hydropower dams in the lower Mekong mainstream).*

Summary of pressures in Occupation layer

Pressure on space: The population density is 425 inhabitants/km^2 and with a growth rate of 0.6% per year, pressure on space will increase in future.

Vulnerability to flood: Floods are a common feature of the delta and society has learned to live with it.

Freshwater shortage: During low flows salinity intrusion is a recurrent problem, likely to increase with sea level rise. Groundwater use is growing.

Research gaps
- *Ground water use potentials and trends.*
- *Benefits bring in by flood: fish, sediment, pest control.*

Summary of pressures in Network layer

Ageing infrastructure: The delta has an extensive canal and embankment system, some of which over 100 years old.
Proposed hydropower dams on the lower Mekong mainstream

Research gaps
- *Conflicts of water-, land- uses in the areas of newly developed projects.*
- *Impacts of the proposed upstream hydropower dams on the ecosystem of the lower Mekong delta which supports agriculture, freshwater fisheries, aquaculture and marine capture fisheries.*

Summary of pressures in Base layer

Coastal erosion: The sediment balance of the Mekong river is, compared to other major deltas, relatively stable. Sand and gravel extraction upstream and in the Mekong delta, result in coastal erosion. The impacts would be even more severe if dams are built on the lower Mekong mainstream and block sediment from flowing downstream.

Loss of biodiversity: The delta has an extremely rich biodiversity which is under pressure due to the rapid economic growth.

Research gaps
- *Rate of erosion and measures for coastline protection.*
- *Mangrove protection.*
- *Sustainable development in the mangrove areas, balancing between poverty reduction and biodiversity.*

Summary of governance issues

Cooperation between (scale) levels and sectors of government: Several ministries are involved in the management of the Mekong delta; coordination by a Government Steering Committee for South-western Region, which is led by a Deputy Prime Minister. Provinces have a considerable autonomy. Peoples Committees represent the central government and control the activities within the area. At the international level is the Mekong River Commission (MRC).

Cooperation between government and private sector: Cooperation between government and private sector in environment and climate change issues has just started to develop recently.

Involvement of stakeholders and citizens: According to the Ordinance of Grass Root Democracy, issued in 2007, all the issues, policies, projects related with community development, including environment protection, climate change, etc. must be discussed and agreed by representatives of the communities. Citizens now are involved more and more.

Approaches for dealing with risks and uncertainties: There are several policies helping local people to deal with risks: the Living-together-with-floods National Program, National Disaster Reduction Program, Central Committee for Flood and Storm Control and the Provincial Committee, etc. are dealing with risks and uncertainties (among others regarding flood risk management / emergency systems)

Research gaps
- *Improve the accuracy of disaster (flood, typhoon,…) prediction.*
- *Measures to reduce risks: local knowledge.*
- *Enhance roles of provincial and local authority/officials.*

❼ Rhine-Meuse delta

Summary of drivers of change

Demographic trends: About 6,5 million inhabitants are living in the (urban) delta zone between Rotterdam and Amsterdam, and between two main harbours Antwerp and Rotterdam. The population is almost stable with a minor growth.

Economic developments: The economic importance of a chain of cities and industrialised areas (a.o. Rotterdam harbour, Schiphol airport) extend far beyond the delta. The Netherlands are a wealthy country. The per capita GDP is close to US$ 30,000. Most people are employed in services and industry. Agriculture and the connected agribusiness contributes significant to the Dutch economy. Agro-related industry and knowledge intensive industry is increasing.

Climate change: Climate change is expected to exacerbate the current problems through a combination of rising sea level and higher flood peaks from the river, and lower water levels leading to problems with salinisation of freshwater intake points.

Subsidence: Long-term historic relative sea-level rise, which largely reflects tectonic subsidence, is about 1 to 2 mm/year. Additionally, as a result of artificial drainage, peat compaction and oxidation have caused ~3-4 m of surface-lowering since the Middle Ages. This process continues today at rates of up to 10 mm/year in areas with a peaty subsoil.

Technological developments: In the field of hydraulic engineering and water management (Delta Technology) many research programs of universities, government and private sector result into innovative developments and actual implementation in case studies world-wide.

Research gaps
- ***Demographic trends:*** *Developing spatial planning concepts for a stable or decreasing population.*
- ***Economic developments and climate change:*** *How to come to a sustainable (low carbon emission) energy future for the Netherlands?*
- ***Subsidence:*** *Which land use and management change is needed to reduce surface-lowering due to peat compaction and oxidation?*

Summary of pressures in Occupation layer

Pressure on space: With a population density of around 500 inhabitants/km^2 the delta is densely populated which implies a high pressure on space.

Vulnerability to flood: Flood protection standards are among the highest in the world. Although the flood risk is quite small, potential consequences of a flood are high. Future sea level rise and growing investments will increase flood risk. Recently a Dutch Delta Plan for sustainable delta management is proposed, which is currently being implemented.

Freshwater shortage: Rising sea levels will increase the problem of salt water seepage and will cause local freshwater shortages.

Research gaps
- ***Spatial planning:*** *How can we optimally integrate the water management and flood safety infrastructure into spatial planning concepts?*
- ***Water use and treatment in industry and agriculture:*** *Which innovations are needed in industry and agriculture for more efficient water use?*
- ***Using natural areas against salinisation:*** *Can natural zones in salinating areas be used for freshwater retention and function as blockades against salinisation of groundwater?*

Summary of pressures in Network layer

Ageing infrastructure: The sophisticated infrastructure will require adaptation to new conditions induced by climate change.

Research gaps
- ***Innovative dike and dam concepts:*** *How should future dikes be designed in order to raise safety standards 10 times? How can dams and storm surge barriers in estuaries and river mouths be designed in order to guarantee safety, while minimally disturbing natural processes and navigation?*
- ***Improvements of freshwater management:*** *What are the possibilities to move freshwater intake points more eastward in the Netherlands? What is the potential of natural water retention upstream the Netherlands to improve freshwater availability in the delta?*

Summary of pressures in Base layer

Coastal erosion: Coastal erosion is well controlled with extensive sand nourishments. Sea level rise will increase the maintenance nourishments needs.

Loss of biodiversity: The health of estuarine and coastal ecosystems is compromised by pollution and reduced hydrodynamics. Plans are underway to improve the situation.

Research gaps
- ***Building with nature:*** *How can we use natural processes for land reclamation and sustainable delta management?*
- ***Monitoring changes:*** *Which morphological and ecological changes are currently occurring in the delta and are their rates changing?*
- ***Magnitude of sea-level rise, and increased peak discharges:*** *A detailed picture of future climate-change related changes is needed for planning adaptation of infrastructure. Especially levels of uncertainty in predictions need to be quantified.*

Summary of governance issues

Cooperation between (scale) levels and sectors of government: The major water bodies in the delta are managed by the national government. Apart from the sectoral management line of responsibility (water management) there is also the administrative line of responsibility.
Recently a high level 'Delta Commission', instituted by the Dutch government, drafted a vision for the long term development of the Dutch Delta. Central to this vision is to partially restore the tidal dynamics and/or to restore the link with the rivers, while maintaining the same level of safety. Currently a delta programme is responsible to prepare the plans and lead them through to implementation from now till 2050.

Cooperation between government and private sector: There are many Public-Private Partnerships in the field of infrastructure, housing and coastal defence, stimulating (innovative) management and development of the Dutch Delta.

Involvement of stakeholders and citizens: Several laws and (legal) instruments are in place to procure involvement of stakeholders and citizens. Moreover many NGOs are influencing policy and implementation plans at national and local level.

Approaches for dealing with risks and uncertainties: There is a growing attention for awareness raising on (flood) risks, implementation of more resilient flood risk management strategies, early warning and recovery programs.

Research gaps
- ***Pricing of water and ecosystem services*** *How should the costs of water and water treatment in future times of scarcity be priced for users? What is the economic value of ecosystem services lost / to be restored?*
- ***Governmental arrangements*** *How should roles and responsibilities for flood protection and water management in the future be organized, in order to guarantee flood safety in the long term in a cost-effective way?*
- ***Financial arrangements*** *Which financial arrangements should be made to guarantee sufficient financial means for future flood protection? Which financial arrangements should be made for compensation of large-scale flood damage?*

❽ Danube delta

Summary of drivers of change

Demographic trends: The total population in the Romanian part of the Danube delta, was estimated at 14,295 inhabitants in 2002 and 12,643 in 2007, showing a decreasing trend (1652 inhabitants lost in 5 years). The average population density is about 5 inhabitants/km^2. There are 23 rural settlements (only 3 have more than 1,000 inhabitants) and only one town - Sulina (4,593 inhabitants in 2007, 4,358 in 2010).

Economic developments: Last 2 decades witnessed the industrial and intensive agriculture failure in the Danube delta Biosphere Reserve territory.
The economic development has been organized by the Danube delta Biosphere Reserve Administration in dedicated areas – as the entire territory is subject to spatial planning. Thus, the area is divided into strictly protected areas (access strictly prohibited, nature sanctuaries), surrounded by buffer zones which separate the prohibited zones from the areas for economic use. In the areas open to economic use there is a strict regulation – only traditional activities being permitted. These include fishing, subsistence agriculture and reed harvesting. To these agri-tourism should also be added.

Climate change: Climate change is a significant driver of change, due to the foreseen variations of the hydrological regime, sea level rise, related impact of increased number of extreme events (more often and bigger storm surges on the coastal zone), oceanographic changes and related impacts (changes in wind directions, delta and sea water temperatures), changes in distributions and widths of ecosystems/ habitats.

Subsidence: At present, the subsidence of the coastal zone nearby the Danube delta is appreciated to 1.5-1.8 mm/yr.

Technological developments: Lots of human interventions were made during the period 1960`s – 1980`s, but all these were stopped when the Danube Delta Biosphere Reserve was established 2 decades ago. Almost no significant intervention has been done since.

Research gaps
- *Detailed studies on subsidence of the Danube delta territory.*
- *Climate change and related impacts on the Danube Delta Biosphere reserve ecosystems and area.*

Summary of pressures in Occupation layer

Pressure on space: Due to the establishment of the Danube Delta Biosphere Reserve and the connected existence of the spatial planning policy, there are no significant conflicting pressures on space. The few cases have strict local causes.

Vulnerability to flood: Being a Biosphere Reserve wetland, even though the area is flood-prone, its vulnerability to floods is minimal, except for the inhabited areas.

Freshwater shortage: Generally not related to quantity but to the obsolete system of water abstraction – distribution – collection – treatment – discharge from settlements. This problem is currently being coped with by the wide programme of rehabilitation / construction of such systems.

Research gaps
- *Studies which should give solutions to retain local communities and maintain their traditional habits.*

Summary of pressures in Network layer

Ageing infrastructure: As Biosphere Reserve, the territory of the Danube delta is mainly lacking infrastructure – on purpose in order to protect it from effects of uncontrolled tourists.
Existing infrastructures are though related to navigation and fisheries (Sulina Canal and other human-cut canals and channels), embankments for agricultural purposes, Sulina – Sf. Gheorghe road (built in the past 2 decades). In order to restore the natural development in the Danube delta, most of these have been let to natural development and evolution. The exception is Sulina Navigation Waterway.

Research gaps
- *"Soft" engineering solutions to restore natural evolution in some parts of the Danube delta – gaps exist also (or mainly) on the evaluation of the environmental impact of such works.*

Summary of pressures in Base layer

Coastal erosion: Coastal erosion is among the most significant pressures affecting the Danube delta Biosphere Reserve territory. Human interventions in the Danube sediment supply and distribution, as well as the building of coastal structures (Sulina jetties) have accelerated the process and widened the areas suffering from coastal erosion.

Loss of biodiversity: Loss of biodiversity has been significant in the past decades of communist regime, both in the Danube delta internal waters, as well as the connected coast. In the past two decades though, since the area has been transformed into a Nature Biosphere Reserve, an improvement has been measured

Research gaps
- *Studies on salt water intrusion in the Danube delta (both salt water wedges and underground salt water intrusions) and related effects.*
- *Modern studies of coastal sea- land interactions at the Danube mouths and neighbouring coasts.*
- *Climate change and related impacts on the Danube Delta Biosphere reserve ecosystems and area.*

Summary of governance issues

Cooperation between (scale) levels and sectors of government: The activities and environmental protection programme in the Danube Delta Biosphere Reserve are under the coordination of the Danube Delta Biosphere Reserve Administration. Other significant institutional players represent the local administration and other activities coordinated by other Romanian Govt. ministries.

Cooperation between government and private sector: Private initiative is not well developed and where it exists it is resumed mainly to agri-tourism and other small fishery, tourism, subsistence business. The activity of private investors and businesses is regulated by the government according to the spatial planning management framework of the Danube Delta Biosphere Reserve Administration.

Involvement of stakeholders and citizens: Local communities are represented by NGOs and professional associations.

Approaches for dealing with risks and uncertainties: The management strategy aims at obtaining sustainable development in the Danube delta territory. The management is multi-sectoral, based on scientific inputs and is adaptive, situation being analysed and discussed every few years.

Research gaps

- *Studies which should give solutions to retain local communities and maintain their traditional habits.*
- *Environmental economics studies to better evaluate and understand the value of the natural goods from the Biosphere Reserve.*
- *Development of Integrated Management plans which should take into account the entire river – delta – sea macro-system, drivers and related pressures acting within the delta from the entire macro-system and means to prevent the negative impacts.*

❾ California Bay-Delta

Summary of drivers of change

Demographic trends: The California Bay-Delta can be divided into two areas. The Sacramento-San Joaquin delta (Delta) and San Francisco Bay. The Delta, an inland delta, constitutes only a relatively small area within the Central Valley. The delta's community is largely rural with a population of about 500,000. The area around San Francisco Bay however is densely populated, with a population of about 7 million people. The delta counties, including the Sacramento area, plus the nine San Francisco Bay Area counties have a combined population of nearly 9 million inhabitants.

Economic developments: The state of California ranks among the most developed areas in the world with per capita income of about US$ 40,000. As a state alone California is the eighth largest economy in the world. The Delta is the hub for California's water supply, moving water from north to south. About 25 million Californians rely on water from the Delta for their drinking water supply and 1.5 million hectares of agricultural land are farmed with irrigation water from the Delta. The San Francisco Bay area is for a large part dependent on its water supply from the Hetch Hetchy project coming from the Sierra Nevada Mountains. The economy here is primarily driven by the financial, IT, agriculture and tourism industries.

Climate change: Climate change will have a significant impact on California. Low lying areas in the Bay Area and the Delta will be more prone to flooding. Changes in precipitation from snowfall to rain will reduce the Sierra Nevada snow pack and will have significant impact on fresh water availability during the summer months. California will also experience higher temperatures and changes in precipitation patterns.

Subsidence: Subsidence is an issue both in the Bay Area and the Delta. Much of the land close to the waterfront is reclaimed wetlands that were converted into housing development or are being used for agriculture or other commercial uses. Some delta islands (polders) have experienced over 9 meters of subsidence in the last 160 years. This is primarily due to ground water pumping and wind erosion.

Technological developments: The technological developments for delta management in California focus on increased efficiency in water use and conveyance on the water supply side. This means the development of better decision support tools and large scale implementation of water conservation measures. In flood protection new concepts for more integrated and robust flood management are being explored outside traditional levee and dam building. As a state California leads the nations in its progressive approach in implementing greenhouse gas emission reduction measures. As a result climate adaptation is also high on the agenda.

Research gaps

- *California is known for its strong research institutes. Amongst others these are UC Berkeley, Stanford, UC Davis, UCLA and Scripps Oceanographic Institute. The high level research that is being conducted provides a lot of input for current delta management as well as future changes. The large uncertainty is climate change and related issues such as subsidence, water supply, flood protection and ecosystem health. More research has to be done on what a sustainable Bay and Delta is. Changes in land uses, large water diversions, fishing and flood management have put a tremendous pressure on the health of the ecosystem and larger infrastructure projects that are being planned. Sound adaptive management plans are needed as well as monitoring plans.*

Summary of pressures in Occupation layer

Pressure on space: Pressure on the available space is currently not a major issue in the Delta. But population growth rates in the Delta are projected to be higher than in the state as a whole. However the pressure to use the Delta for water conveyance and water storage on islands is creating a greater pressure on available space. In the Bay Area there is a large pressure on the available space due to a growing population and a need for affordable housing.

Vulnerability to flood: Most of the Delta is below sea level. Sea level rise, earthquake hazard liquefaction) and subsidence will increase vulnerability. Large scale flooding in the Delta with saline water coming in from San Francisco Bay could have immense consequences for the entire state as it would disrupt water supply for an extended period. In the Bay Area, the parts of the Bay that were filled are just above bay water levels and prone to flooding.

Freshwater shortage: Nearly two-thirds of the state's population depend on the Delta for at least some of their water supply. California is experiencing severe droughts which curtail water export. Due to an already over allocated water system there are limited opportunities to increase supply.

Research gaps
- *In the light of climate change there is a need for land use and land cover change models. There is a need for models to predict land use and land cover changes, urban and rural land use change, agricultural land use change, urbanization, land use models. Model needs to be appropriate for climate change and ecosystem projects, including vegetation changes and loss of ground surface to permanent flooding.*

Summary of pressures in Network layer

Ageing infrastructure: The major features of California's water supply system, dams, pump stations, aqueducts and pipelines, were built between the 1920s and the 1970s. Back then it was supposed to support about half of the population California has today. This infrastructure is now aging and requires updating and maintenance. The flood control infrastructure in the Delta and along the Sacramento and San Joaquin rivers is also aging. Many of the levees were designed to protect agricultural land and provide a 1 in 100 year level of protection at best. It is being believed that Sacramento has the lowest level of flood protection of any city in the United States.

Research gaps
- ***Research needs to be done on hydraulic conveyance and storage infrastructure:*** *In which one looks at alternatives to potentially modify infrastructure to meet water demands and to provide flood control subject to climate change impacts on wet/dry precipitation timing and magnitude.*
- ***Because of climate change California will experience more extreme heat and changes in electricity demands.*** *Research is needed to study atmosphere ocean general circulation models used to evaluate climate change and extreme heat impact on state electricity demands. The linkage to water is the impact on operations of reservoirs in the Sierra Nevada and Coastal Range.*
- ***Hydraulic Conveyance and Storage Infrastructure:*** *Key ideas: need to potentially modify infrastructure to meet water demands and to provide flood control subject to climate change impacts on wet/dry precipitation timing and magnitude.*

Summary of pressures in Base layer

Coastal erosion: The Delta itself does not have a coast as it is an inland delta. In the wider region (San Francisco Bay) several beaches suffer from erosion as well that there is a lot of uncertainty on the response of wetlands to rising bay water levels. The entire California coast has significant erosion problems.

Loss of biodiversity: The Delta is in an ecological tailspin. Invasive species, water pumping facilities urban and agricultural pollution are degrading water quality and threatening multiple fish species with extinction.

Seismic activity: multiple fault lines run through the Bay Area and the Delta. Although many buildings, roads and pipelines are designed to withstand a major earthquake, the big unknown is how levees will perform. Delta levees are likely suspect to liquefaction and levee collapse could lead to major flooding. In which case brackish Bay water would be pulled into the Delta as fresh water outflow is likely to low to keep the salt water out.

Research gaps
- *Research is needed on climate change impacts on California's coastlines. As information is needed by coastal managers to adapt to climate change, including: inland, coastal and near shore water quality, species and habitat protection, inland flooding, coastal erosion, saltwater intrusion, cliff failure, wetland loss and beach loss.*
- *Due to climate variability more research should be done on precipitation modelling. Key ideas for this topic include need for statistical models to accurately model precipitation volatility and extreme precipitation events at individual locations and in micro climates. Need to estimate spatial distributions of precipitation for various applications (e.g., rainfall and runoff models, watershed modelling, surface water modelling, flood control).*
- *Research is also needed on the impacts of earthquakes and other natural disasters on surface and subsurface structures. Liquefaction, groundwater level rise impacts, subsidence due to pumping, instability of foundations with water level rises, levee failure, channel erosion, sedimentation of channels (e.g., need for periodic dredging and channel maintenance).*

Summary of governance issues

Cooperation between (scale) levels and sectors of government: There is a dense governance framework for the Delta and the Bay, with dynamic interplay between local governments, state and federal agencies. The multitude of different governments having some type of jurisdiction over part of the Bay or the Delta has made it very difficult to come to a systems approach for particularly flood management.

Cooperation between government and private sector: The cooperation between government and private sector in California is fairly strong. Many of the federal, state and local resource agencies act as management organizations and use the services of engineering and consultancy firms to support them in executing projects.

Involvement of stakeholders and citizens: There is a very strong bottom up approach to decision making on in California, also on large infrastructure projects. Public participation is very strong through workshops and community meetings, this helps build support and consensus. This is very intensive approach however.

Approaches for dealing with risks and uncertainties: Protection of the area against floods caused by extreme events is a major concern in California. Particularly as it relates to earthquake and flood risk. A major earthquake could cause liquefaction of levees and trigger multiple levee failures, making the Delta an inland sea filled with brackish water and disrupting fresh water supply to Southern California. The existing federal flood protection standard is a 1 in 100 year level of protection. The state of California is currently reviewing this standard and evaluating the possibilities of a higher level of protection.

Research gaps

- *At present California is very interested in how to include climate change projections into policy and guidelines. Information is needed on how institutional changes enable implementation of measures for adaptation to climate change.*

⑩ Mississippi River delta

Summary of drivers of change

Description and demographic trends: The Mississippi River delta region, located in south-eastern Louisiana, USA, consists of alluvium deposited by the Mississippi River over the course of seven thousand years.
A product of fluidity and dynamism, the Mississippi River delta resists clear cartographic delineation as a geographical feature. Some argue that the delta starts at the Old River Control Structure (where bifurcation first occurs, near Simmesport, Louisiana); others use the term "delta" to refer to the entire lower Mississippi River floodplain, which is of course actually a valley. There is also subjectivity in separating the "deltaic plain" from the "Chenier Plain"—that is, the coastal lands of south-western Louisiana formed as river deposits were swept westward by longshore currents—as well as in separating the river's "delta" from its "estuary," the fresh-and-salt-water mixing zone and the outlying barrier islands.
This study views the Mississippi River delta as lying southward of a line between Lafayette and Baton Rouge, which aligns with the historic coastline and marks where the terraces and bluffs forming the southern-most walls of the alluvial valley peter out. Stretching southeastwardly from this line to the present-day mouth of the Mississippi lies the heart of the Mississippi deltaic plain.

The Mississippi River delta is home to roughly 1.5 million inhabitants, two-thirds of whom live in greater New Orleans. The city and region have been gradually losing population for decades, particularly relative to the growing populations of other coastal and Sun Belt cities of the south-eastern United States. Hurricanes Katrina, Rita, Gustav, and Ike, which struck portions of the delta to greater and lesser degrees during 2005 and 2008, punctuated the population decline of this region and New Orleans in particular, but they did not initiate it.

Economic developments: Offshore oil and natural gas production, along with all its related service industries, dominate the state's coastal economy. Louisiana is the third leading state in refineries and petrochemical processing. The Port of New Orleans is one of the largest and busiest ports in the world and the region is a centre of maritime industry. For over two centuries, agriculture has been a key part of the delta economy. Rice, sugar cane, and soybeans are the most important agricultural commodities produced in the region. Louisiana's commercial fishing industry catches about 25 percent of all the seafood in the US. Recreation and tourism are quite significant for the local economy. More recently "ecotourism" is beginning to emerge in the delta.

Climate change: Sea level rose 4 inches in the last 100 years, and it is expected to rise 40 inches in the next 100 years. The frequency of hurricanes in the Atlantic seems to be on the rise with climate change, while research shows that rising sea surface temperatures lead to more powerful hurricanes.

Subsidence: In some urban areas in the delta, where wet/dry zones have been established by perimeter levees in combination with pumping stations that remove natural wetness of the ground from the ground, the elevation of the earth has subsided up to over 10 feet. In those rapidly subsiding areas, the yearly subsidence rate is sometimes over 1cm per year. In general, the entire delta is subsiding largely because since the early 20th century the Mississippi

River has been canalized for flood control and navigation. Consequently water and sediment flow to the wetlands has been denied.

Urban subsidence is exacerbated by municipal drainage, which removes groundwater from the deltaic soils composition of sand, silt, clay, and organic matter, thus opening cavities for compaction and sinkage. As a result, metro New Orleans has artificially subsided below sea level, by anywhere from a few centimetres to four meters. Below-sea-level New Orleans is entirely a manmade condition; levee construction on the Mississippi River and municipal drainage caused New Orleans to drop below sea level throughout the course of the twentieth century.

According to USGS reports, another cause of subsidence on the delta comes from the extraction of gas and oil. A recent report stated "The Gulf Coast Basin is a region where subsidence and fault activation are common around large, mature oil and gas fields even though moderately deep hydrocarbon production has generally been disregarded as the primary cause."

Technological developments: Since the 1930s the delta has been extensively modified by a series of infrastructure projects, including levees, floodwalls, seawalls, surge barriers, pumping stations, floodgates, spillways, floodways, diversions, bifurcations, locks, dams, weirs, sediment pipelines, siphons, etc.

Davis Pond and Caernarvon Freshwater Diversions are recent projects that divert fresh water from the Mississippi River to the surrounding wetlands.

New geo-engineering models are currently being used to investigate delta building dynamics. Other computer modelling is being used for investigating the impacts of climate change on floods, salinity intrusion, and storm surges. New research at LSU is developing the capability of modelling coastal circulation and nearshore surface waves in deltaic sedimentary and hydrodynamic environments in an integrated modelling framework.
(https://www.cct.lsu.edu/site40.php)

Research gaps

- *More research needs to be done on investigating new concepts of flexible infrastructure that is capable of responding to the dynamic conditions of the delta. Research efforts to create various forms of "soft infrastructure" in the delta need to be encouraged. For instance, the idea that wetlands are a type of "living infrastructure" that is more effective than traditional forms of "hard infrastructure" in protecting against storm surge is relatively new. Initiatives to promote living infrastructure projects so far have been piecemeal.*
- *More research needs to be done on the effects of Hurricane Katrina on the delta's population. The catastrophe created a diaspora of the region's population, forcing delta citizens to relocate to other locations in the country. In the five years following the disaster, many citizens have moved back to the delta, but thousands are still in exile.*
- *More research needs to be done on sediment-related infrastructure. While it is widely agreed that sediment is fundamental to wetlands restoration and long-term delta sustainability, there is little consensus on a cost-effective way to move the right sediments in the needed quantities to their target destinations. Transportation options range from siphoning to barging.*
- *Comprehensive database on infrastructure, climate, natural resources and socio-economic conditions is necessary to support various research and development initiatives.*

Summary of pressures in Occupation layer

Pressure on space: The population is not very dense, less than 100 inhabitants/km^2.

Vulnerability to flood: Hurricanes are a way of life in the Mississippi River delta. The hurricane season of 2005 was the most devastating in recent times, triggering intensive improvements and upgrading to the flood protection system of the delta. In the Greater New Orleans area, the main improvement projects include the Inner Harbor Navigation Canal Surge Barrier, new pumping stations at the 17th Street Canal, the Orleans, Avenue Canal, and the London Canal, and a new floodwall in the Lower Ninth Ward.

Freshwater shortage: As yet there is no serious shortage of freshwater in the delta.

Research gaps

- *The wetlands are disappearing at an alarming rate. The tides and hurricanes of the ocean push saltwater into the wetlands. Before the 20th century, the Mississippi River would flood the delta and push back on the saltwater. However, the same flood protection infrastructure that keeps the Mississippi River from flooding urban territories in the delta also starves the wetlands of their much needed sediment and freshwater. Therefore, the wetlands are disappearing.*

Summary of pressures in Network layer

Ageing infrastructure: There is a high investment need to upgrade the flood protection and navigation (the Mississippi River Gulf Outlet, MRGO) system. As a result of hurricane Katrina, restoration of damaged infrastructure is still an important issue. The improvement of the reliability of flood protection is of importance for resettlement.

The focus on the river's function for navigation has contributed to the accelerating degradation of the delta's environments. While some flood protection and navigation infrastructure should be reinforced, in some areas infrastructure needs to be removed or modified in order to allow the restoration of natural hydrologies.

Research gaps

- *There is a direct correlation between maintaining successful flood protection and waterway navigation infrastructure systems and the inability to promote a healthy and thriving delta landscape with its diverse ecologies of wetlands and marshes. Therefore, research on alternative concepts of "flexible" and "soft" infrastructure is needed in order to secure the delta's safety from floods and protect its waterborne navigation without compromising the mission of restoring the wetlands. New research should consider the natural topography and hydrology of the delta itself as a crucial form of infrastructure. Likewise, the natural biological layers of the delta - from aquatic vegetation to oyster beds - need to be investigated as forms of "living" infrastructure.*

Summary of pressures in Base layer

Coastal erosion: Soil subsidence, construction of flood control levees, canal construction and wave exposure have led to huge land loss. Likely to increase due to sea level rise. The levees along the Mississippi River prevent the natural process of sediment deposits into the wetlands, which is a primary cause of land loss.

Loss of biodiversity: The main issue in the Mississippi River delta is the conservation of some 5,000 km^2 wetlands, which comprise 65% of the Gulf of Mexico's coastal wetlands. However, wetlands are disappearing at an alarming rate since decades, caused by an number of factors (see coastal erosion). The main issue related to water quality in the Mississippi River delta is eutrophication.

Research gaps

- *More interdisciplinary research needs to be done into the loss of biodiversity and the relationship between lack of sediment and land subsidence.*
- *Efforts to establish forms of "ecotourism" in the delta are slowly increasing. Currently there is an untapped potential in ecotourism to become an economic driver in the delta region and to help restore the biodiversity of the region.*

Summary of governance issues

Cooperation between (scale) levels and sectors of government: The governance of activities in the Mississippi River delta is carried out by a combination of Federal, State and local agencies. A relatively new addition to the federal governance arrangement is the coastal Wetlands Planning, Protection and Restoration Act of 1990 which created a task force of 5 federal agencies and the state of Louisiana to develop a "comprehensive approach to restore and prevent the loss of coastal wetlands in Louisiana".

Cooperation between government and private sector: The shipping and petroleum industries seem to have the ability to steer the government too much in the delta. While the government may have restorative priorities, in the name of the economy, destructive industrial projects will be permitted. Restoration projects are a challenge to get off the ground because local citizens and fishermen, as supportive as they are for coastal restoration, do not like their particular fishing areas to experience any change, such as salinity change.

Involvement of stakeholders and citizens: Citizens have had a little more involvement in Coastal Planning issues since the 2005 hurricanes, however the gap between the engineers/scientists and the citizens creates communication problems.

Approaches for dealing with risks and uncertainties: (a.o. regarding flood risk management / emergency systems / adaptive management) Citizens sometimes must build their own levees, or raise their homes. Nevertheless, in a dynamic delta environment, risks and uncertainties still exist.

Research gaps

- *The 1990 Act was a big step, but more cooperation between Federal, State, and local agencies needs to occur soon if the delta wants to keep alive, or go further and revive, its wetlands.*
- *More research needs to be done into the productive potential of private/public initiatives. A historical example of a successful private/public partnership is Eads's jetties in the late 19th century.*
- *In the efforts to restore historical hydrological patterns in the delta, there is a growing debate about whether the government should exercise "imminent domain" to acquire private lands that could be used either as sites of infrastructure or as stewardship areas.*

Minutes of DA-EBR session

Delta Alliance Electronic Board Room Session

(during the Conference 'Deltas in times of climate change', Rotterdam)

When:	Wednesday 29 September 2010, 14:00-17:20
Where:	Blue Room
Attendance:	ca. 25 pp
Chair:	Rob Schoonman, Ministry of Housing Spatial Planning and the Environment, The Netherlands

Welcome (Chair)

Why is the Delta Alliance established?

- Deltas worldwide are facing serious challenges
- Deltas have similar problems (fragmented information)
- Speaking with a united voice (more support)
- International network (share and develop knowledge)

The Alliance network consists: across wings, across disciplines, across sectors.

Announcement of report 'Comparative overview of deltas' (final published in November). The report gives an overview on delta development, management and governance, combining the DPSIR approach (drivers, pressures, state, impact, response) with the 3-layer spatial planning model (base, network and occupation layers).

Objective session: (1) exchange knowledge and
(2) stimulating collaborative (research) projects.

Part 1: Brief presentations of draft Delta descriptions (delta issues, research gaps, needs for knowledge exchange)

Rhine-Meuse

(Dutch Wing coordinator Cees vd Guchte)

- **Drivers of change:** Stable population, economic activity, technology.
- **Natural drivers:** sea level rise, subsidence.
- **Approach:** Base layer, network layer, occupation layer.
- **Pressure (occupation layer):** not enough space, vulnerability of flooding, shortage fresh water.
- **Government issues:** governmental cooperation, public-private partnerships, involving stakeholders, risk-approach.
- **Knowledge gaps:** Spatial planning, efficient water use, use of natural processes, morphological and ecological changes.
- **From governance perspective:** dealing with uncertainties, cost of water treatment, responsibilities in management, financial arrangements.

Ganges-Brahmaputra-Meghna

(Asif Mohammed Zaman)

- **Drivers of change:** high population density, sea level rise (east coast already rising).
- **Pressures:** land water use (critical flow conditions in rivers), ageing infrastructure, natural resources (erosion, biodiversity, salinity, cyclones and storms).
- **Governance:** highly centralized, ppp's increasing, dealing with risks and uncertainties (flood forecasting and cyclone warning).
- **Lessons learned:** adverse climate change impact already being experienced, delta people have indigenous coping measures.
- **Challenge for Delta management:** monitor system, variation in salinity, spatial planning, adapting infrastructure.
- **Gaps:** cheaper methods for portable drink water, research on (soil) salinity, salinity tolerant crops for food production, monitoring system.

Mekong Delta

(Vietnamese Wing coordinator Le Quang Minh)

Population and area similar with NL, but economy grows very fast.

- **Drivers of change:** Population growth (pressure on food demand and land use), urbanization, industrialization.
  ➔ *Upstream development and sea level rise as external pressures on Delta.*
- **Pressures:**
  - **Base layer:** floods (floods do benefit farmers, natural fertility), saline water intrusion, extreme events.
  - **Network layer:** water control projects, changes land-use.
  - **Occupation layer:** increase agriculture activity, de- and reforestation.
- **Government:** lack of regional collaboration, no common strategies and master plans, lack mechanisms from central government to avoid conflicts in policy implementation, lack capacity provinces, weak ppp.
- **Challenge:** poverty reduction and environmental protection.

California Bay-Delta

(California Wing coordinator Peter Wijsman)

Precipitation mainly in the North and fresh water demand in the South (infrastructure solution)

- **System vulnerabilities:** fishing declines, subsidence (due to agriculture), catastrophic events, climate change. Snow into rainfall needs additional reservoirs.
- New housing has taken place in Delta bay and is not high above sea level.
- **Leadership role:** climate change is taken very seriously (governor).
- Alliance California with NL on climate change and adaptation.

Ciliwung Delta

(Indonesian Wing coordinator Jan Sopaheluwakan)

- **Drivers of change:** population and urbanization, economic growth, climate change (intensity raining season), sea level rise, subsidence (ground water extraction), technological developments (contributes economy).
- **Pressures:**
  - **Occupation layer:** out-of-control urbanization, flood vulnerability, fresh water Shortage (requires management).
  - **Network layer:** ageing and inadequate infrastructure.
  - **Base layer:** water quality (salinisation).
- **Governance:** centralization to decentralization, lack of coordination and cooperation between level and sectors of government, increasing cooperation between government and private sector, apply risk assessment, cooperation civil society at local level.
- **Gaps:** Downscale climate change scenarios (make operational), socio-economic development projections, scenario based risk assessment, ecosystem based planning, data sharing, communication government.

Mississippi River delta

(Anthony Fontenot)

- **Technological development:** infrastructure developed after earlier floods, engineering landscape.
- **Man-made changes:** effect on floods and storms, city at risk, natural habitat.
- Alterations increased salt water intrusion, wetlands are disappearing.
- **How to deal with this?**
  - Projects to transfer water from river to wetlands
  - Delta building dynamics (engineering)
  - Complex system (natural and man-made)
- **Economic development:** agriculture, port, recreation/ tourism, gas and oil industry.
  → *Side effect oil industry (making canals is danger for wetlands)*
- **Drivers of change:**
  - **Climate change:** Sea level rise, hurricanes (rising sea temperature)
  - **Climate change** (extraction gas and oil, canalisation of the river).
- **Governance:** coastal wetland planning
- **Lessons learned:** River is vast natural asset, natural dynamic river
- **Research gap:** Soft infrastructure (flexible, dynamic, adaptive), fresh water diversions and sediment related infrastructure, effects on population and economy, database for future planning.

Yangtze Delta

(Wenwei Ren)

- **Drivers of change:** GDP, climate change, subsidence (groundwater extraction)
- **Pressure:**
  - **Occupation layer:** pressure on space (urbanization, reclamation), fresh water shortage
  - **Network layer:** infrastructure
  - **Base layer:** sediment loss and serious erosion (loss of biodiversity and environmental quality
- **Governance:** lack of platform for stakeholders (WWF initiated platform Estuary Partnership)
- **Adaptive measures:** vulnerability report, natural solution water resource, natural solution biodiversity restoration, natural solution for navigation development, low carbon city
- **Lessons learned:**
  (1) knowledge gap between ecologists and engineers
    - environmental awareness of engineers is low, do not have knowledge
    - ecologists want to bring solutions to engineers
  (2) Integrated River Basin Management
    - conscious but not able how to manage

Part 2: EBR session on delta issues and research gaps

(For results see next appendix)

Conclusions

Each delta has given a good comprehensive overview of the problems and challenges the deltas are coping with. The presentations were focusing on delta issues, research gaps and knowledge exchange challenges. Each presentation was structured along the approach taken in the study "comparative overview of deltas", combining the dpsir framework (drivers, pressures, state, impact, response) with the 3-layer spatial planning model (base, network and occupation layer). Using the same structure for all 7 deltas appeared to be a step forward in jointly exploring and identifying common themes of interest, taking into account the respective national socio-economic and cultural contexts.

Evidently, all deltas are facing similar drivers of change, like demographic developments, ever increasing urbanization, economic activities and (envisaged) impacts of climate change.

Common themes of concern in all deltas are sea level rise, floods and droughts, salinisation, fresh water shortages, subsidence and infrastructure problems, be it with varying magnitudes and accents. But there are also clear differences, like the beneficial flooding for farmers in vietnam, or concerns for land slides in western usa.

The speakers, and also the subsequent "electronic board room" session, highlighted the need and mutual interest for exchanging knowledge and experiences in adaptive approaches addressing the themes mentioned above. Innovative, and surely integrated multi-sector and multi-stakeholder approaches are favoured. Lack of capacities, various governance issues and insufficient financing options were regularly indicated as bottlenecks for successful implementation of existing (incl. Indigenous) knowledge.

Some of the suggestions made on remaining challenges included:

- Taking the leadership role in adaptation processes by local/regional government, like the california state governor did
- Champions and/or celebrities may be instrumental in reaching out to the public
- Establish long-term adaptation programming adopted through parliaments, as to overcome the short-term life span of many politicians (ref. Dutch delta programme)
- Provide guidance and transparent communications on risk perception, dealing with uncertainties, and stepwise approaches in adaptive water management (not too little, not too much; not too early, not too late) at various levels of scale and time
- Link national water management adaptation programming to major global agenda's where the use of water is an important factor, such as disaster risk reduction, food security, energy
- Provide local solutions: think globally, act locally

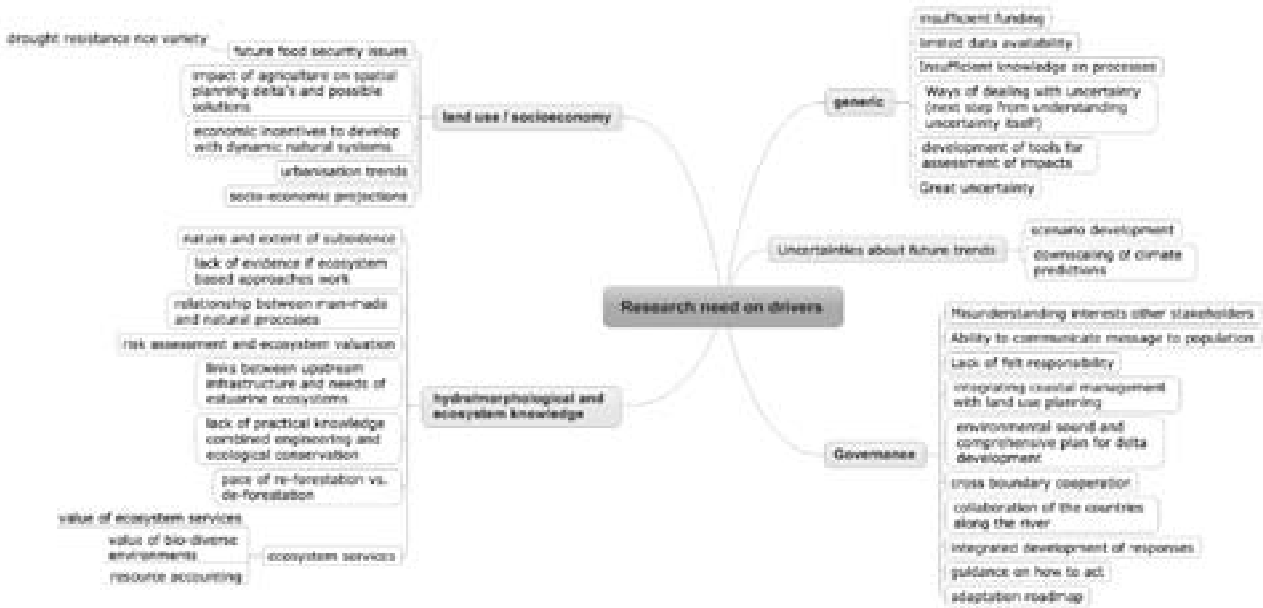
Issues mentioned (much more then summarized above) were prioritized during the electronic board room session, which will be elaborated further during a working session coming friday, october 1st.

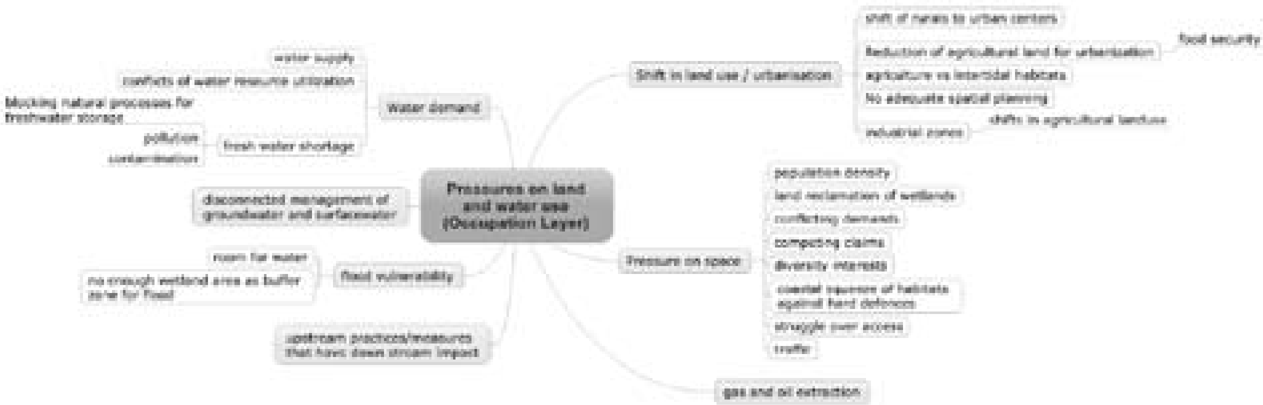
Next to further improve the comparative overview, it is envisaged this joint exercise will provide a common ground for selecting thematic issues to be included in the work programme (knowledge exchange, defining joint projects, etc) for the 3rd phase of the delta alliance. The outcome may also be instrumental in structuring the web-based delta alliance platform.

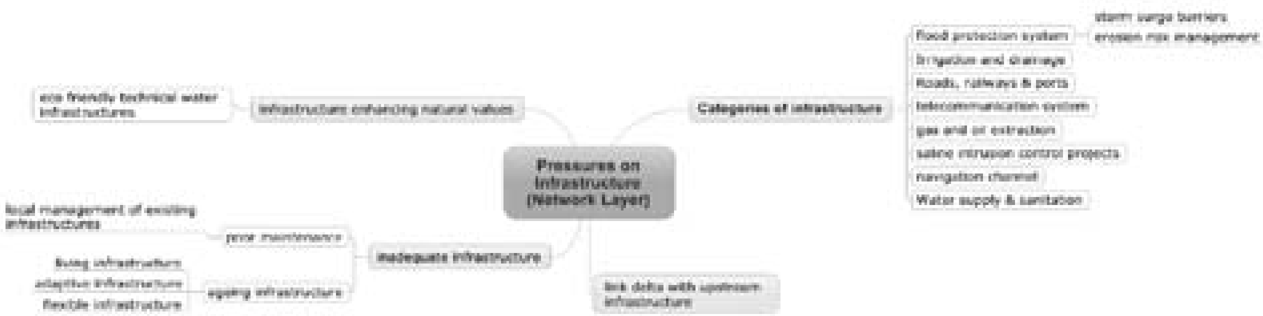
Appendices

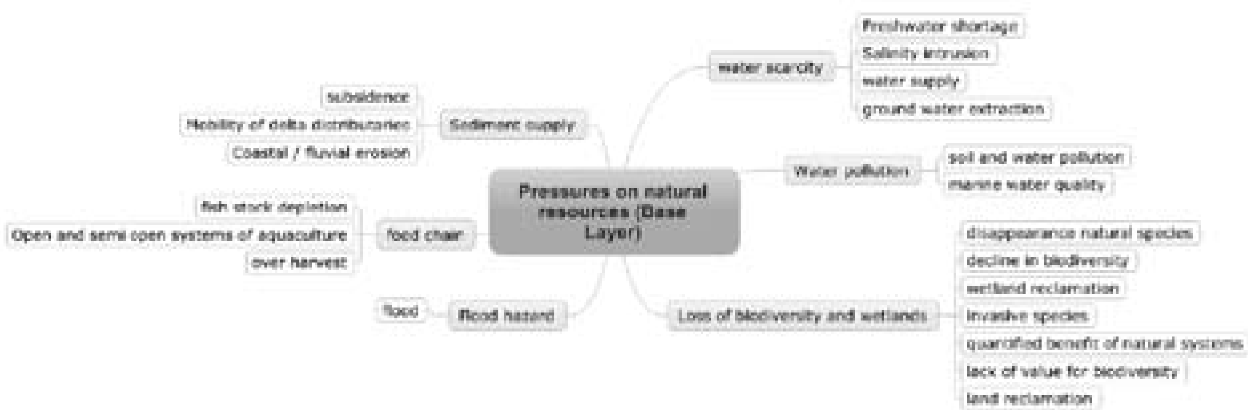
EBR results

During the Electronic Board Room Session on 29 September 2010 at the Rotterdam Conference, the participants were asked to answer a number of questions regarding the drivers of change and pressures in delta regions as well as governance issues concerning delta management. Besides listing these topics the participants were also asked to prioritize them with respect to their perceived importance and to indicate research gaps. Due to time limitations questions regarding Governance could not be answered and prioritization proved difficult. Nevertheless, the resulting output provided a large array of issues and topics that was considered of importance. We have grouped the output for drivers and pressures with Mindjet MindManager software to produce the following mind maps. These maps show the broadness of delta management and as such can provide inspiration for further discussion and research.




Pressures on land and water use (Occupation Layer)
Water demand
water supply
conflicts of water resource utilization
blocking natural processes for freshwater storage
fresh water shortage
pollution
contamination
disconnected management of groundwater and surfacewater
flood vulnerability
room for water
no enough wetland area as buffer zone for flood
upstream practices/measures that have down stream impact
Shift in land use / urbanisation
shift of rurals to urban centers
Reduction of agricultural land for urbanization
food security
agriculture vs intertidal habitats
No adequate spatial planning
industrial zones
shifts in agricultural landuse
Pressure on space
population density
land reclamation of wetlands
conflicting demands
competing claims
diversity interests
coastal squeeze of habitats against hard defences
struggle over access
traffic
gas and oil extraction


Pressures on infrastructure (Network Layer)
infrastructure enhancing natural values
eco friendly technical water infrastructures
inadequate infrastructure
poor maintenance
local management of existing infrastructures
ageing infrastructure
living infrastructure
adaptive infrastructure
flexible infrastructure
Categories of infrastructure
flood protection system
storm surge barriers
erosion risk management
Irrigation and drainage
Roads, railways & ports
telecommunication system
gas and oil extraction
saline intrusion control projects
navigation channel
Water supply & sanitation
link delta with upstream infrastructure


Pressures on natural resources (Base Layer)
Sediment supply
subsidence
Mobility of delta distributaries
Coastal / fluvial erosion
food chain
fish stock depletion
Open and semi open systems of aquaculture
over harvest
Flood hazard
flood
water scarcity
Freshwater shortage
Salinity intrusion
water supply
ground water extraction
Water pollution
soil and water pollution
marine water quality
Loss of biodiversity and wetlands
disappearance natural species
decline in biodiversity
wetland reclamation
invasive species
quantified benefit of natural systems
lack of value for biodiversity
land reclamation

Draft overview of main indicators for deltas

Main indicators: Drivers	Rhine-Meuse delta	California Bay-Delta	Ciliwung / Jakarta delta
Demographic trends			
• Growth of delta population	• Minor	• Minor?	• High (3.6% per year)
Economic developments			
• GDP/capita	• ~30,000 US$	• ~ 40,000 US$	• ~2,000 US$
• GDP av. growth	• Small	• …	• 3.6% per year
Technological developments			
• Research and development	• Research institutes for 'Delta Techno-logy'	• Water use efficiency	• …
• Knowledge-intensive industry	• Expanding	• Front runner in green and clean technologies	• …
Climate change			
• Mean temperature change in 2050	• Winter +0.9 to +2.3 ºC; summer +0.9 to +2.8 ºC	• …	• Shorter rainy season with higher intensity rain, and longer dry season
• Mean precipitation change in 2050	• Winter +4 to +14%; summer -19 to +6 %	• Less snow, more rain	• …
• Increase of river peak discharge	• 3-19%	• …	• …
• Sea level rise	• ≤0.65 to 1.3 m in 2100	• 0.4 cm (2050) to 1.4 m (2100)	• 0.23 - 0.57 cm/year
Subsidence			
• Tectonic subsidence	• ~2 mm/y	• …	• …
• Surface-lowering in peaty areas	• ≤ 10 mm/year	• up to 50 mm/year	• …
• Overall subsidence	• …	• …	• 1 – 250 mm/year
Main indicators: Pressures			
Land and water use (occ. layer)			
• Population density	• 500/ km²	• moderate	• 1000/ km²
• Urbanization	• High	• moderate / high	• Very High
• Fresh water demands	• High	• very high	• High
• Flood vulnerability	• Moderate	• Moderate	• High
Infrastructure (network layer)			
• Flood protection standards	• 1/1250 up to 1/10,000 years	• 1/100 years	• Very low
• Irrigation and drainage	• Adequate	• …	• …
• Water supply & sanitation	• Adequate	• …	• Only 47% HH serviced
• Road, railways and ports	• Adequate / Expanding (ports)	• 3 highways, 3 railroad lines, 5 HV power lines	• …
Natural resources (base layer)			
• Storm surges	• Up to several m	• No storm surges	• No storm surges or seldom
• Coastal / fluvial erosion	• Stable coastline	• Stable coastline	• Local erosion
• Ecosystem health	• Gradual deterioration	• Deteriorating	• Low
• Biodiversity loss	• …	• 31 species threat.	• High
• Water quality	• Average to good	• Concern	• Major problem
• Freshwater shortage / salinity intrusion	• Only during extreme droughts	• Serious concern	• Major problem
Main Indicators: Governance			
Multi-level and multi-sectoral cooperation			
• Existence of integrated plans	• yes…	• Yes	• No
• Existence of multi sectoral / multi-level committees	• yes…	• yes	• no
Public-private partnerships			
• Number of PPPs			
• Scale of PPPs (geogr/finan)			
Involvement of stakeholders and citizens			
• Existence of Legal instruments for participation	• Yes		• no
• Number of NGOs involved	• Considerable		
Approaches for dealing with risks and uncertainties			
• Existence of adaptive management (strategies)	• yes	• yes	
• Existence of risk management and emergency systems			

Main indicators: Drivers	Ganges-Brahmaputra-Meghna	Mekong delta	Mississippi River delta
Demographic trends			
• Growth of delta population	• Moderate (1.3 % per year)	• Moderate (0.6% per year)	• Minor?
Economic developments			
• GDP/capita	• ~ 400 US$	• > 700 US$	• …
• GDP av. growth	• 6 % per year projected over 5 years	• 8.5 % per year (2007)	• …
Technological developments			
• Research and development	• Agro-based, engineering, ICT	• large scale WRM projects	• 'Urban agriculture', sustainable energy, bio fuels etc.
• Knowledge-intensive industry	• …	• …	• …
Climate change			
• Mean temperature change in 2050	• + 0.2 ºC (max) +1.24 ºC (min)	• …	• …
• Mean precipitation change in 2050	• +2.3% (wet season), -4.7% (dry)	• …	• …
• Increase of river peak discharge	• …	• …	• …
• Sea level rise	• 7.8 mm/y (including subsidence etc.)	• …	• 10 mm/y expected
Subsidence			
• Tectonic subsidence	• Significant	• …	• …
• Surface-lowering peat soils	• …	• …	• …
• Overall subsidence	• …	• …	• 4 – 15 mm/year
Main indicators: Pressures			
Land and water use (occ. layer)			
• Population density	• 1200/km^2	• 425/km^2	• <100/km^2
• Urbanization	• Moderate	• Low (85% rural)	• Moderate (50% urban)
• Fresh water demands	• High	• High	• …
• Flood vulnerability	• High	• Moderate / High	• Moderate
Infrastructure (network layer)			
• Flood protection standards	• Low	• Low	• 1/100 years?
• Irrigation and drainage	• Expanding	• Extensive	• Adequate
• Water supply & sanitation	• Insufficient /arsenic problem	• Insufficient	• Adequate
• Road, railways and ports	• Expanding	• Extensive	• Extensive ports
Natural resources (base layer)			
• Storm surges	• Up to > 10 m	• Small (but high tides >3m West)	
• Coastal /fluvial erosion	• Significant (10,000 ha/year loss)	• Minor / local problem Deteriorating	• Major problem
• Ecosystems health	• Deteriorating	• Concern	• Deteriorating
• Biodiversity loss	• Concern	• Increasing problem	• Concern
• Water quality	• Major problem	• Major problem	• Major problem (marine env.)
• Freshwater shortage / salinity intrusion	• Major problem		
Main Indicators: Governance			
Multi-level and multi-sectoral cooperation			
• Existence of integrated plans	• yes		
• Existence of multi sectoral / multi-level committees		• yes	
Public-private partnerships			
• Number of PPPs		• very few	
• Scale of PPPs (geogr/finan)			
Involvement of stakeholders and citizens			
• Existence of Legal instruments for participation			
• Number of NGOs involved			
Approaches for dealing with risks and uncertainties		• yes	• yes
• Existence of adaptive management (strategies)			
• Existence of risk management and emergency systems			

Main indicators: Drivers	Yangtze Estuary	Nile delta	Incomati delta	Danube delta
Demographic trends				
• Growth of delta population	• Low (0.27% per year (2009))	• …		
Economic developments				
• GDP/capita	• ~10,000 USD/capita (in Shanghai)	• …		
• GDP av. growth	• High (8.2 % per year)	• …		
Technological developments				
• Research and development	• …	• …		
• Knowledge-intensive industry	• …	• …		
Climate change				
• Mean temperature change in 2050	• …	• …		
• Mean precipitation change in 2050	• …	• …		
• Increase of river peak discharge	• …	• …		
• Sea level rise	• …	• …		
Subsidence				
• Tectonic subsidence	• …	• …		
• Surface-lowering in peaty areas	• …	• …		
• Overall subsidence	• 1.5 – 10 mm/y	• …		
Main indicators: Pressures				
Land and water use (occ. layer)				
• Population density	• 2800/km^2	• …		
• Urbanization	• High (urban ratio 30%)	• …		
• Fresh water demands	• High	• …		
• Flood vulnerability	• Moderate	• …		
Infrastructure (network layer)				
• Flood protection standards	• ??	• …		
• Irrigation and drainage	• ??	• …		
• Water supply & sanitation	• ??	• …		
• Road, railways and ports	• Rapidly expanding	• …		
Natural resources (base layer)				
• Storm surges	• ??	• …		
• Coastal / fluvial erosion	• Problem in future	• …		
• Ecosystem health	• Rapid decline	• …		
• Biodiversity loss	• Sharp decrease	• …		
• Water quality	• Major problem	• …		
• Freshwater shortage / salinity intrusion	• Major problem	• …		
Main Indicators: Governance				
Multi-level and multi-sectoral cooperation				
• Existence of integrated plans	• limited			
• Existence of multi sectoral / multi-level committees				
Public-private partnerships				
• Number of PPPs				
• Scale of PPPs (geogr/finan)				
Involvement of stakeholders and citizens				
• Existence of Legal instruments for participation				
• Number of NGOs involved				
Approaches for dealing with risks and uncertainties				
• Existence of adaptive management (strategies)				
• Existence of risk management and emergency systems				