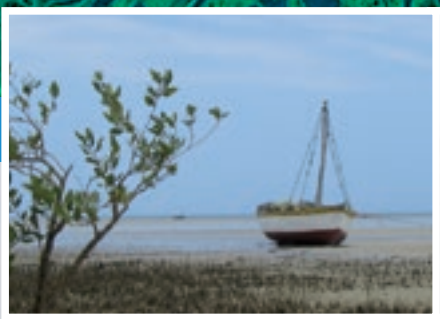
DeltAlliance



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Deltares
Enabling Delta Life

ALTERRA
WAGENINGEN UR

UNESCO-IHE
Institute for Water Education

TU Delft

Knowledge for Climate

Comparative assessment of the vulnerability and resilience of deltas

Extended version with 14 deltas

synthesis report

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Internet

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

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Comparative assessment of the vulnerability and resilience of deltas

Extended version with 14 deltas

synthesis report

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Introduction

Chapter 1

Rationale

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. This is being addressed by the Delta Alliance, an international knowledge driven network organization with the mission to improve the resilience of deltas worldwide.

This report is an extended version of the Comparative assessment of the vulnerability and resilience of 10 deltas, published by the Delta Alliance in December 2010 (available at www.delta-alliance.org). In this extended version four additional deltas, the Ayeyarwady, Parana, Tana and Zambezi delta, are elaborated in the same way as in the earlier version, by means of score cards and (summarized) delta descriptions. However the overall synthesis and conclusions chapters in this report involve all 14 deltas.
The paragraphs below are summarizing the framework of delta assessment, pragmatic choice of deltas and delineation, elements of delta descriptions and target groups.
For details about the approach and for the descriptions and score cards of the other 10 deltas is referred to the earlier version of 2010, available at www.delta-alliance.org. The current report is also available at this website as well as a separate working document with the full version of the four additional delta descriptions

Framework for delta assessment – an integrated approach

In this collaborative project of the Delta Alliance a framework for delta assessment is applied, combining a DPSIR approach with a Spatial Layer model. This Integrated Approach takes into account long term and short term drivers and pressures (a.o. climate change and socio-economiic developments) the impacts in tthree spatial planning layers of the delta system and the governance regarding organisation and institutional aspects of adaptive responses. The three physical planning layers are 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.

Introduction

Chapter 1

Pragmatic choice of deltas and delineation

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 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 score card. 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.
This report provides a comprehensive overview of the current and future state of the following 14 deltas (with additional deltas in green):

Elements of delta descriptions

For each delta an 'indicative' score card gives an impression of the current and future state of the different layers and governance issues, summarized in an overall Resilience and Sustainability Index. 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. Besides the current situation two development scenarios are recognized: 1) Scenario1, moderate perspective 2050 with medium economic growth and related medium technological developments, combined with medium climate change and sea level rise, 2) Scenario2, extreme perspective 2050 with high economic growth and related high technological developments, combined with high climate change and sea level rise.

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 score cards are presented, based on above mentioned 'framework for delta assessment'. The score cards need further development and elaboration, which is envisaged in near future.

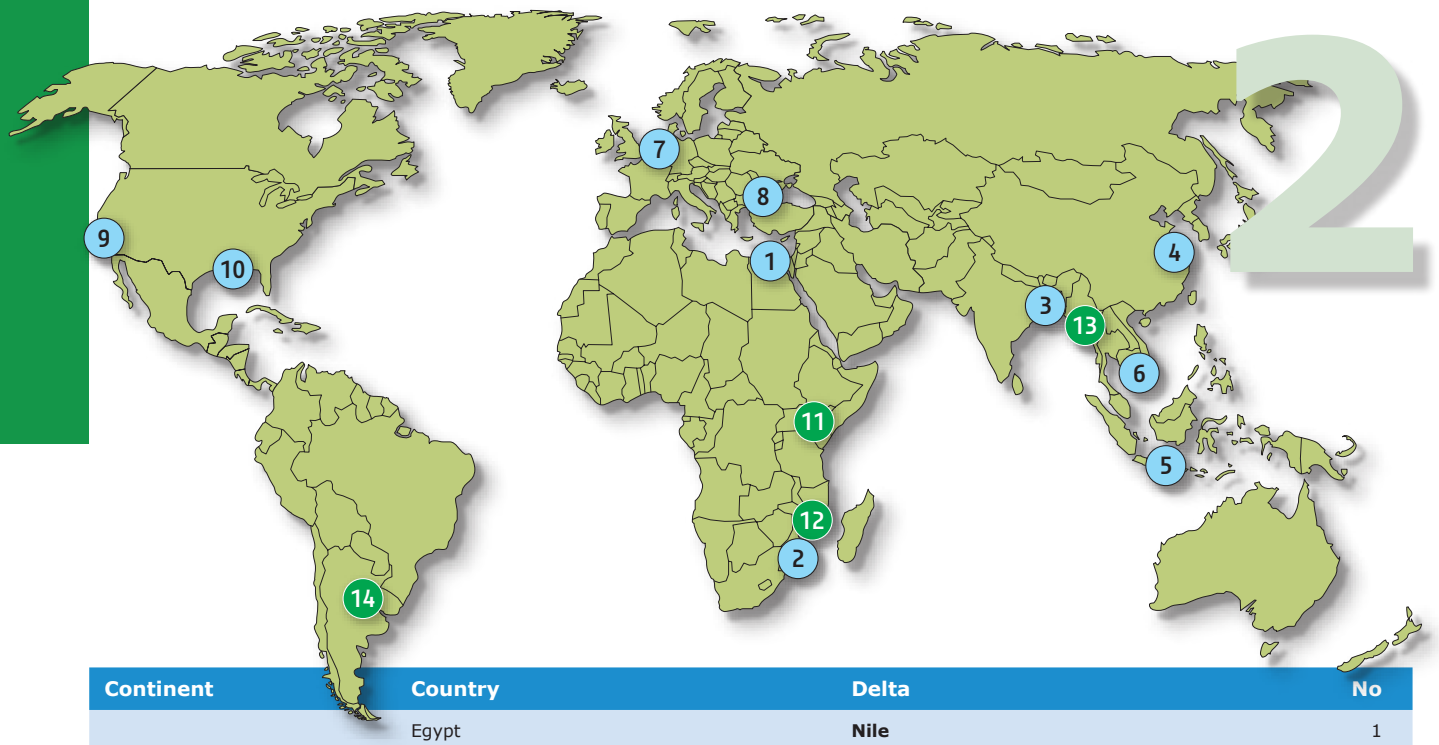
Moreover for each delta a brief overview is given regarding currently applied adaptive measures and technical methods and tools to support delta management. Also an overview of research gaps and opportunities for collaboration is presented in order to contribute to the development of collaborative research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

Target groups

The proposed framework for delta assessment and especially the score cards 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.

Overview
of Delta Scorecards

Chapter 2

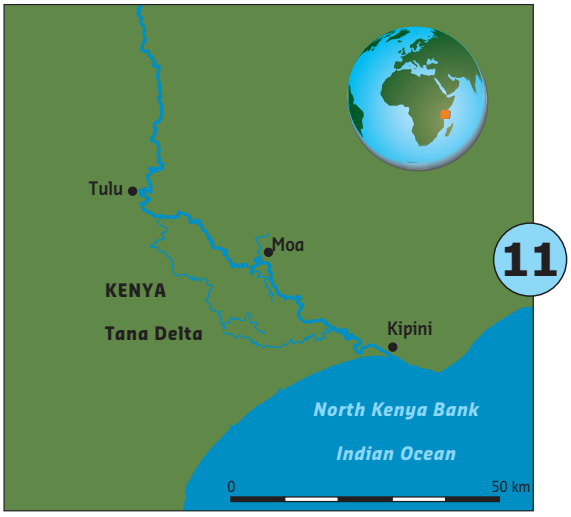


Continent	Country	Delta	No
Africa	Egypt	**Nile**	1
	Kenya	**Tana**	11
	Mozambique	**Incomati**	2
	Mozambique	**Zambezi**	12
Asia	Bangladesh	**Ganges-Brahmaputra-Meghna**	3
	China	**Yangtze**	4
	Indonesia	**Ciliwung**	5
	Myanmar	**Ayeyarwady**	13
	Vietnam	**Mekong**	6
Europe	The Netherlands	**Rhine-Meuse**	7
	Romania	**Danube**	8
N-America	United States of America	**California Bay-Delta**	9
	United States of America	**Mississippi River Delta**	10
Z-America	Argentina	**Parana**	14

The map and table above give an overview of all 14 deltas with in green the four additional deltas elaborated in this synthesis report.

The Delta Assessment approach as described in chapter 1 is applied for each delta, by the elaboration of delta descriptions. In the following paragraphs for each of the additional four deltas the scorecards and some clarification notes on the scorecards are mentioned. The main items of the delta descriptions are summarized in the Appendix and the full delta descriptions (of the 14 deltas) are available in separate 'Working documents' at www.delta-alliance.org

Tana



Scorecard

Tana 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	––	0	––	–	––

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

Concluding remarks on score card

The current situation in the delta can be described as moderate to low in terms of sustainability. Land and water use is high, infrastructure is poor and natural resources are dwindling. The pressures on the occupation layer and the base layer are likely to increase due to significant economic development combined with higher dependence on ecosystem goods and services supporting the livelihoods of the communities in the delta.

The anticipated changes in climate change, sea level rise and upstream hydropower engineering are likely to worsen the situation for all layers with unpredictable and uncontrolled erosion patterns in the delta and at the coast. Many legal frameworks are in place but mainly uncoordinated. Attuning and implementation is needed for assuring the sustainability of the delta and its resources.

Tana, due to its richness, has to cope with very high land and water demands due to high population pressures, which combined with a moderate to inadequate infrastructure lead to significant problems. Furthermore, due to engineering, flood hazards can decrease but due to community behavior and lack of protection systems flood vulnerability remains high.

It is unlikely that the projected improvements of the network layer following the Lapsset/ Lamu corridor developments will outweigh the current rapid and negative developments of the occupation and base layers of the Tana delta, leading to an overall decrease of sustainability of the Tana delta.

Zambezi

Scorecard

Zambezi 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	–	+	**–**

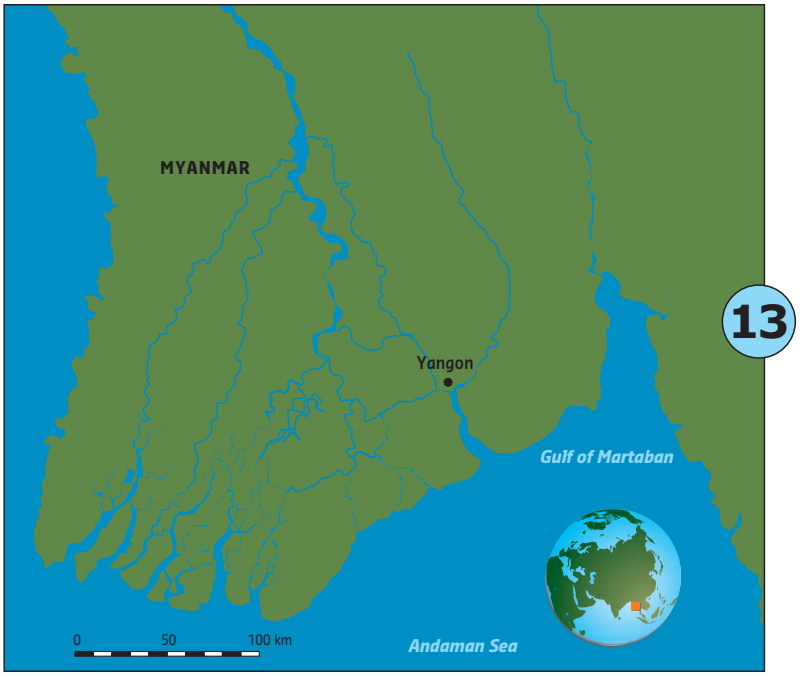
resilience/sustainability: *++ (very good), + (good), 0 (medium), – (low), –– (very low)*

Concluding remarks on score card

Pressure on land and water use (occupation layer) is considered good due to the low population density. The delta has very good natural resources (base layer) as it has abundant water, little pollution and natural delta processes with respect to sedimentation and erosion. However it is worth to note that the delta area, flow regime and ecosystem have changed considerably due to the construction of Kariba dam (1958) and Cahora Bassa dam (1974). For the future scenarios the pressures on the land and water use and natural resources are expected to increase due to the economic growth in the country and the river basins specific developments such as expansion of irrigated agriculture, impacts of upstream mining activities and effects of climate change and sea level rise. Frequency of floods and droughts may increase and with sea-level rise salinity intrusion problems may arise. The infrastructure (network layer) is scored low at present as the population has limited access to safe drinking water, no sanitation and mainly secondary roads and dikes. With the strategy plans for science, technology and innovation put in place and with the economic development the situation is expected to improve with time. The governance in Mozambique is transforming to a decentralised administration that is still following vertical channels of communication leading to fragmented actions to deal with natural resources management. There are also weaknesses in term of absence of the necessary cooperation with the private sector and in involving stakeholders and citizens. It is however in its early stages and process is going slowly due to low technical, human and financial capacity.

Mozambique has one of the fastest growing economies in Africa which is very encouraging. However, socio-economic development, infrastructure and governance still largely depend on donors. But even with the development of technology, awareness about the importance of the environment and good governance the pressure in the occupation and base layer is expected to increase so the overall resilience and sustainability will decrease proportionally in time.

Ayeyarwady delta



Scorecard

Ayeyarwady 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	+	–	0	0
Scenario 2 extreme 2050	–	–	––	0	–

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

Concluding remarks on score card

The population density is relatively low compared to the one of the Mekong or the Ganges-Brahmaputra-Meghna Deltas, but yet 3 to 4 times as high as the country's average. The pressure on space is not that high. The demand for fresh water and the flood vulnerability score high. It is expected that through economic development the livelihood conditions might improve under the moderate scenario.

The current infrastructure concerning transport is badly developed. Many works have been done with regard to river embankments, construction of polders and irrigation systems, of which the maintenance could be improved. In the moderate scenario it is expected that important investments will be done to upgrade the road and other infrastructure. It is expected that the area of irrigated agriculture will increase.
The delta is and will always be very vulnerable in view of the risk of (increasing) extreme events such as storm surges, cyclones and extreme rainfall. Also salinization will be a continuous threat for mainly the Lower and Middle Delta.
The governance of the delta is currently at a rather low level. There are opportunities for the application of more integrated and participatory approaches.

Parana delta

Scorecard

Parana 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
Scenario 2 extreme 2050	–	+	0	+	–

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

Concluding remarks on score card

Even though the pressure on land use and the negatives impacts of human activities are high in some sectors of the delta, they are concentrated mainly in the lower delta, which represents 43% of the total area of the region. In both scenarios (moderate and intensive), the pressures on land use and natural resources are expected to increase due to the growth of Buenos Aires Metropolitan Area and other big cities located in the margins of the delta-together with the introduction of "continental" residential typologies into the islands-, as well as a result of the expansion of production activities, especially large-scale agriculture and forestry. In terms of infrastructure, only under an extreme scenario the implementation of innovative technologies for sustainable development is expected because nowadays it is not considered a priority by the governments. On the contrary, the delta is still being underestimated regarding its values and potentialities. In terms of governance, an improvement is expected resulting from the implementation of the integrated plan of PIECAS and the coordination of actions among the different jurisdictions that share the region. Besides, the increasing mobilization and participation of citizens and Civil Society Organizations (CSOs) would contribute to enhance governance through increased adaptive capacity.

Overview of Delta Scorecards

Chapter 2

Synthesis
Current and future state of deltas

Chapter 3

Drivers of change

Based on the delta descriptions an inventory of the drivers of change impacting delta areas has been prepared. Table 1 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 1
Overview of drivers of change in the studied deltas. In green the additional four deltas

Continent	Country	Delta	Demographic trends	Economic developments	Technological developments	Climate change	Subsidence
Africa	Egypt	Nile	•••	••	••	•••	••
	Kenya	Tana	•••	••	•	••	unknown
	Mozambique	Incomati	•	••••	••	•••	•
	Mozambique	Zambezi	•	•••	••	•••	unknown
Asia	Bangladesh	Ganges-Brahmaputra-Meghna delta	••	•••	••	••••	••
	China	Yangtze	•••	••••	••	••	••
	Indonesia	Ciliwung	••••	•••	••	•••	••••
	Myanmar	Ayeyarwady	••	•••	••	••••	•••
	Vietnam	Mekong	••	••••	••	•••	••
Europe	Netherlands	Rhine-Meuse	•	••	•••	••	••
	Romania	Danube	•	•	•	••	•
N-America	USA	California Bay-Delta	••	••	••	•••	••••
	USA	Mississippi River Delta	•	••	•••	•••	•••
Z-America	Argentina	Parana	••	•••	••	••	•••

- • *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 2). 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.

Other deltas have a very low population density (Danube, Parana, Zambezi, Tana) and population is located in villages or rural settlements that are randomly located often in the vicinity of the river.

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 2 Overview of delta population (number, density) and growth rate. In green the additional four deltas

	Population number (in million)	Population density (inhabitants/km)	Growth rate (%)
Nile	35	1000	2,0
Tana	0.1	74	3,2-3,4
Incomati	2,5	44	0.4
Zambezi	0.3	35	2.2 - 4.1
Ganges-Brahmaputra-Meghna delta	156 - 200	1200	1,3
Yangtze	20-85[1]	>1000	0,3 - 2,0
Ciliwung	23	>1000	3,6
Ayeyarwady	8	230	1.52
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[2]	<100	minor
Parana	0,024[3]	1[4]	1,3[5]

1 *The total number of population depends on the definition of the delta*
2 *Two-thirds of the population is living in New Orleans*
3 *The delta itself has 24000 inhabitants with a surface of 17500 square km. The delta and the surrounding urban cores of the provinces of Entre Ríos, Santa Fe and Buenos Aires (including the Buenos Aires Metropolitan Area) have around 16 million inhabitants.*
4 *The delta area has a density of 1 inhabitant/km² and the Buenos Aires Metropolitan Area has a density of 5400 inhabitant/ km².*
5 *According to the INDEC (National Institute of Statistics and Census, 2010) the growth rate of the population of the Buenos Aires Metropolitan Area (including the city of Buenos Aires) was 11,7% in the period 2001-2010.*

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, GBM). 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, GBM and Ayeyarwady 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.

In the less densely populated deltas, Tana, Zambezi and Parana the economic activities are farming, fishing and livestock but this is often mostly for subsistence use. Plans for large scale agriculture do exist in most of these deltas, which will have many effects. The Tana delta is also much used in the dry season by livestock emanating from neighboring counties. Also the Parana delta has an important regional function as commercial route connecting Chile and Brazil.

Technological developments

In many deltas technological developments focus on water management issues, e.g. in the Mekong for boosting rice production and in the California 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, GBM, 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.

The Ayeyarwady, Parana, Tana and Zambezi deltas have low scale technological developments such as roads, bridges, information and communication around the villages, irrigation canals and embankments. In several basins large dams have been constructed posing a threat to the ecological integrity and flow regime downstream. In the Ayeyarwady large polders, incl embankments, storage and drainage canals, have been created to prevent salt water intrusion and enable paddy cultivation.

Satellite image of the Ayeryarwady delta

Climate change

Another important driver in the deltas studied is climate change, which is expected to have medium to severe impacts in nine out of fourteen 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.
- 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 (e.g. Zambezi) 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. GBM and Ayeryarwady), 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, GBM, 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

consolida¬tion 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).

The Parana and Ayeyarwady deltas are having a higher subsidence rate than the forecasts of sea-level rise, exacerbating the risks of flooding. Not much knowledge or observation data exists on subsidence of the Tana and Zambezi 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 3 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, GBM 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.

In contrast, the Zambezi Delta is an almost pristine delta with a very low population density, e.g. in the Marromeu district only 6.8% has human occupation. There is however a large interest to have agricultural development in the delta.

Development of large scale agricultural production-processes are also observed in the Tana Delta (export crops, biofuels, next to mineral exploitation) and the Parana Delta (soybean, livestock production and forestry). The pressure on space In the Parana delta is moderate which is also associated with the nearby urban conurbation of the Buenos Aires Metropolitan Area.

Although the population density in the Ayeyarwady Delta is three to four times as high as the country's average, it is still relatively low compared to many other Asian deltas. Pressure is expected in the urban area around Yangon.

In almost all tropical deltas there is a pressure on the mangrove forests, by wood extraction (for charcoal) and the development of aquaculture.

Table 3: overview of status of land and water use in the studied deltas. *In green the additional four deltas*

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

- • *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 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, GBM). 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).

Increasing salinity intrusion in the Ayeyarwady Delta is a major threat for fresh water supply for drinking water (combined with the arsenic pollution of the groundwater) as well as for agriculture purposes, especially in the Lower and Middle Delta during the dry season.

In the pristine Zambezi delta there is no fresh water shortage. The large percentage of the population without access to safe water is due to lack of infrastructure.

In the Tana delta there is an increasing water shortage due to use upstream and irrigation projects.

In the Parana Delta the urbanization of rural urban areas, the increment of the number of dwellings and the increase of the scale of agricultural production cause an important pressure on the fresh water availability: Buenos Aires needs more than 5 million m^3/day.

Flood vulnerability

In ten out of fourteen deltas the flood vulnerability is moderate to severe. In the Incomati and GBM deltas floods are a permanent threat. Most of GBM 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.

Floods (caused by upstream rainfall) do occur in the Tana Delta. Normally under natural circumstances they are seen as a blessing for farmers and fishermen and also benefit the connected wetlands and riverine forests. However, similar to the Zambezi delta, the timing is changed and the extend is reduced by the construction of large dams and reservoirs. Occasional floods do occur amongst others due to 'uncontrolled' spilling of the reservoir water or extreme rainfall patterns and consequently river discharge. Despite discouragement from the government, people continue to live in the flood prone areas.

The flood vulnerability in the Ayeyarwady Delta is high. The delta is still active with unstable river branches and occurrence of flash floods (mainly in the Upper Delta). The Lower delta is prone to tropical cyclones with high storm surges. Cyclone Nargis in 2008 killed almost 140.000 people.

In the Parana Delta the vulnerability to flood differs between the islands and the coastal area along the delta. Flooding and subsequent negative impacts occur when high river discharges coincide in time and space with elevated water level in the Rio de la Plata due to strong South Eastern winds coming from the Atlantic Ocean.

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 3 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 8 out of the 14 studied deltas flood protection is not adequate. Upgrading of the flood safety is urgently needed for the Ciliwung, Incomati, GBM, Ayeyarwady, 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, and 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 (GBM) 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.

The Ayeyarwady delta is facing an ageing Infrastructure which needs to be maintained and upgraded. The maintenance of embankments, polder sluices, drainage canals and irrigation systems is a recurrent problem. There is a challenge to improve the flood protection due to the threat of cyclones, sea level rise and upstream floodings.

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.

In the Parana delta flood protection is mainly restricted to isolated polders which create suitable conditions for agricultural production and residential purposes. In the last three years, the polder surface increased around 16.5%, reaching 240.748 ha of polders. The intervention by dikes and ditches alters the regime of the wetland.

In the Zambezi Delta upstream dams and dikes give people sufficient protection against flooding. Railways and roads built in the flood plains also act as flood protection.

In the Tana delta five major reservoirs have been built in the upper basin over the past fifty years. This led to a 20% decrease in the peak flows of May. However these measures have significantly modified the hydrological regime of the river, the flood characteristics of the wetlands and the availability of flood water for riverbank farming downstream.

Table 4: overview of status of major infrastructure in the studied deltas. In green the additional four deltas.

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

In the Parana delta drainage is mainly linked to creating polders and to the use of islands for large-scale livestock farming, commercial forestry systems and agriculture systems (Soybean crops). The interventions and economic activities depress water table levels, gives soil changes and lead eventually to compaction and subsidence.

In the Zambezi delta area only the SENA Sugar Estate has an irrigated agricultural field. The rest of the agricultural land owned by smallholders is rain-fed.

Maintenance of the water infrastructure is urgently needed for the Ayeyarwady delta This includes improvement of embankments, drainage canals, irrigation systems and dredging of blocked waterways for navigation.

The large scale interventions upstream of the Tana River limit the flooding of floodplains and banks downstream. This reduces the possibilities for floodplain and riverbank agriculture significantly. Farmers will become more dependent on rainfall and expansion of irrigation systems is likely.

Aerial view of part of the Tana delta

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.

The islands of the Parana delta have no water supply or sanitation network. The cities along the borders of the delta have an average coverage of the water supply network of around 50% and 20% of sewage system. The main source of water is the Rio de la Plata and two aquifers. There are two big water capture and treatment plants for the Buenos Aires Metropolitan Area and the lower delta.

In the Zambezi delta the water supply and sanitation infrastructure is limited to the main villages only. In general, the percentage of population without access to safe drinking water is high (around 50 to 60%) and sanitation services coverage is even lower.
For the Ayeyarwady delta the need for drinking water supply and waste water treatment plants is also high. Salt intrusion and contamination with arsenic create additional challenges to safe water supply.

Local people in the Tana delta depend on water abstracted directly from the Tana River which makes them vulnerable to water-borne diseases. This is due to inadequate investments in water infrastructures downstream.

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.

The Parana delta is well connected to the Buenos Aires Metropolitan Area and other urban areas along the deltas by railways and highways. This infrastructure is also integrated with the port system located along the delta, which is the most important fluvial network of the country. Public investment in highways encouraged the integration of the delta into the dynamics of the metropolitan expansion from the basis of private transportation but has also led to urban sprawl and daily commuting to Buenos Aires.

In the Zambezi delta the road network has secondary and tertiary earth roads with good to reasonable conditions. However road maintenance is poor and after long periods of rainfall it is almost impossible to drive these roads.

In Mayanmar the government has taken steps to develop new ports and maintain the existing ones. Still, poor infrastructure, such as the lack of proper roads, electricity, limited

telephone networks and dependency on traditional river transport limits the economic development of the The Ayeyarwady Delta. The Tana delta is not well networked in terms of transport infrastructure. The development of Lamu Port could stimulate other infrastructure developments.

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 5 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 5 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 5: overview of base-layer pressures in the studied deltas. In green the additional four deltas

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

• = *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 still a lesser problem in some other deltas (e.g., Yangtze, Mekong, Zambezi, Tana 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. Significant erosion also takes place in the Ayeyarwady River delta caused mainly by mangrove destruction and decreased sediment load due to dam construction upstream. With strong growing populations in the Tana Delta's flooding-sensitive river banks and erosion-sensitive mangrove coasts, as well as the planned upstream construction of more large dams, this delta is most likely to witness increased erosion as well. Also, in the Nile delta, coastal erosion is a large-scale problem due to fluvial sediment trapping upstream. Several coastal protection measures are taken but are hampered by the strong sediment deficit at the coastline.

The Parana River discharges 160 million ton/year of sediments into the estuary Rio de la Plata. This results in the Delta extending in size (increased surface of ca. 617 km^2/yr) and is expected to reach Buenos Aires city's coast in about 110 years. Nevertheless there is localised coastal erosion.

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 and Ayeyarwady deltas riverbank erosion is a serious problem. In the somewhat smaller and pristine delta systems (e.g. Tana and Zambezi) the river morphodynamics can cause local damage and loss of life for especially farming communities that settled in fertile floodplains. This is partly due to dam construction upstream, tempering the natural morphodynamics, allowing people to move closer to the Delta Rivers. Consequently, with high precipitation amounts in the basin, these Delta communities are caught by surprise by the now unpredictable river bank erosion or even river course changes (Tana delta).

Hydrological pressures

With flooding being a fundamental natural process in all deltas, the different scores in Table 5 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 and the Ayeyarwady deltas partly reflects the vulnerability of these areas for cyclone- or storm-induced surges.

For the latter delta, also high precipitation in surrounding mountains, exacerbated by deforestation, can cause detrimental flash floods in the lower delta regions.

For the Parana delta, with intermediate score, periodic persistent south easterly winds pushing up Rio de la Plata levels, may exacerbate flooding when combined with high precipitation or discharge.

The Mississippi River Delta and Yangtze delta may also be affected by hurricanes, but have better flood protection systems, which explain their intermediate scores. The Rhine-Meuse delta is less prone to flooding than many other deltas, partly because of an well-developed flood protection system, but also because it is located in the temperate climatic zone where extreme storm and precipitation events are much less common than in the tropics.

Flood plain in the Zambezi delta

In some cases also the perception of the delta population partly determines whether flooding should be considered as a pressure. In the Mekong, Zambezi and Tana deltas, for example, the notion that river floods bring benefits for agriculture and nature is acknowledged. Of course, such a perception strongly depends on land use in the delta.
In some deltas (Yangtze, Nile, Zambezi, Tana), upstream engineering (dams and reservoirs) moderate river peak flows, causing lower probability of river flooding.
However, for the Tana and Zambezi, the occasional extreme and rather unpredictable flooding events, caused by emergency dam spilling and high precipitation upstream, may cause significant damage to the communities that moved into the floodplains.

Increased salinisation and freshwater shortage is a problem in most deltas, but is most pronounced in deltas in arid climates, such as the Nile, Tana, Zambezi and the Sacramento-San Joaquin deltas. In these systems river water use has increased considerably (urban development or large-scale irrigation upstream), and salinisation of soils is enhanced by high evaporation.

In the Ganges-Brahmaputra-Meghna and Ayeyarwady deltas 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, agriculture and drinking water supply.

Salinisation seems a minor problem in the Mississippi and Parana River delta relative to other pressures, such as coastal wetland loss due to subsidence or eutrophication.

For the Tana and Zambezi deltas, proposed developments in the lower regions or in offshore areas adjacent to delta mouths, will likely lead to increased seawater intrusion and consequently further pressures from increased salinity or sodicity of soils, floodplains and groundwater especially in the lower delta.

Ecological/environmental pressures

Increasing water and soil pollution is a major problem in nearly 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 and industrial output of pollutants has strongly reduced following implementation of strict legislation. However, in most deltas rapid urbanization, industrial development, agricultural intensification or mining activities strongly compromise water and soil quality. In the Mississippi and Zambezi River deltas for example, eutrophication of surface waters is a real 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 most deltas. An example of native habitat loss is found in the Parana Deltas islands where the rate of wetland loss due to polderization has been estimated to around 10.500 ha/year.

An increased loss of wetlands and unique riverine remnant forests has been reported for the Tana River delta. The Tana River delta has been added to the RAMSAR list since 2012 for this reason.

Comparable to the Tana delta, the distributaries of the Zambezi River delta have become disconnected due to construction of flood protection embankments and upstream dam construction. The subsequent lack of flooding changes vegetation patterns in the delta region and leads to a decrease in mangrove area. As in the Ayeyarwady, these kinds of developments allow people to move safer into these areas and as a result the remaining forests and wetlands are degrading further due to increased pressures from encroachment, uncontrolled resource exploitation and coastal development (paddy fields and shrimp ponds).

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, floodplains and wetlands and constitutes a threat to all life in the delta 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 including biodiversity is lost due to pollution, changing hydrological conditions, invasion of exotic species, and extinction of species due to loss of habitat or overexploitation. In fact the state of ecosystems is influenced by most of the pressures on deltas described above, and as such 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 communities, which are jeopardized by further delta deterioration. Therefore, loss of wetlands, riverine and mangrove forests and biodiversity also represents a significant pressure on the functioning and resilience of the delta system.

The mangrove forests in several deltas suffer from overexploitation (e.g., GBM, Ayeyarwady, Zambezi and Tana). For the Sundarban mangrove in Bangladesh this also means a decrease in capacity to buffer cyclonic storm surges.

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 6 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 US where there is a dense governance framework, with dynamic interplay between local governments, state and federal agencies, this has led to surprisingly little result.

The 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.

Table 6: overview of status of governance in the studied deltas. In green the additional four 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
Tana	••	••	••	•	–
Incomati	••	••	••	•	–
Zambezi	••	•	••	••	–
Ganges-Brahmaputra-Meghna delta	••	••	••	•••	0
Yangtze	••	•••	••	••	0
Ciliwung	••	•	••	••	–
Ayeyarwady	••	•	•	••	–
Mekong	••	••	•••	••	0
Rhine-Meuse	•••	•••	•••	•••	+
Danube	•••	•	••	••	0
California Bay-Delta	••	•••	•••	••	0
Mississippi River Delta	••	••	••	••	0
Parana	••	••	•••	•	0

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

resilience/sustainability:

++(very good), + (good), 0 (medium), – (low), –– (very low)

In the Netherlands a Delta Programme was established, which involves integration of land use planning, flood risk management, fresh water supply and urban restructuring. This Dutch Delta Approach consists of involving all relevant stakeholders (multi-governance), joint fact-finding and an integrated (multi-sectoral) approach. The progress of the Delta Program and cooperation between stakeholders is monitored and supported by a politically independent Delta Commissioner.

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

In the Parana delta there is a complex network of institutions that have the competence to decide on the Parana Delta region. The diversity of functional authorities, complex institutional arrangements and conflicting visions on the delta, converge in making the design and implementation of policies and measures, including water management and land use strategies, a difficult task.

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 Mozambican Water Policy created in 1995 pushes toward decentralized administration, where decisions are taken at local/regional levels whereas the government responsibility changes from direct implementation to a more facilitative role. The coordination between different sectors of the government is carried out by technical steering groups which act as advisors to the higher level institutions (the ministries).

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.

Myanmar counts many ministries which are often working in quite a sectorial way. There is a lack of coordination and collaboration between the different institutions, including a lack of sharing of data and information. Different departments have different acts, proclamations and laws.

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 are 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[1]. 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. The implementation of the Water policy also led to more involvement of the private sector. The government transferred its administration responsibility for some infrastructures (irrigation, water supply systems, etc.) to the private sector and changed to playing a more facilitative role.

Although the private sector is looking into opportunities in Myanmar with great interest, it should be noted that only about 30% of the transactions is successful. This is mainly due to the lack of knowledge and legislation in Myanmar, e.g. in the specific field of Public Private Partnerships.

In the Tana delta government institutions and the private sector have had little constructive dialogue about the future of the Delta. The situation is currently exacerbated by a multitude of large-scale, potentially conflicting development proposals.

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.

The civil society is strongly involved in the Parana Delta, either through research institutions and local groups who fight for the fulfilment of environmental rights and the protection of the region. Today there are more than 35 civil society organizations that focus their work on the Parana Delta and the surrounding area.

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 the Myanmar stakeholder involvement is in a very early stage. Stakeholder consultation at the planning and implementation phase of a project in different parts of the country needs to be further encouraged.

1 Statement from Delta Conference, Rotterdam

Aerial view of the islands of the Parana delta and the urban area of Buenos Aires (Verónica Zagare, 2014)

Local communities in the Tana delta are not well represented in governance processes affecting the Delta.and their views on development proposals do not have formal recognition within to the decision-making process.

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.

In Mozambique regular committee meetings are held at basin level and all interested or affected people are invited to join and to express their point of view and get clarifications about important decisions at basin level.

In Argentina the decision making processes is influenced by the regime on Free Access to Public Environmental Information, which seeks to guarantee the right of access to information that is under the state domain, either at national, provincial or municipal level. In addition, the Environmental Public Hearing process provides the community and organizations with the opportunity to learn about the works, activities or projects that are being (or are going to be) developed, and the positive or negative impacts that they may have on the Delta.
The Land Use Plan for the Tana delta is supposed to guide the involvement of all stakeholders in the Tana Delta.

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.

In the Parana delta the level of participation has increased. Also, an increase in the participation of NGOs in the design of public policies and monitoring processes of territorial planning is observed.

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 being conducted regarding flood vulnerability and climate change impacts. 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.

The Danube Delta Biosphere Reserve Authority develops management plans which are discussed and adapted to new situations every few years.

The government of Mozambique adopts a precautious attitude to deal with risks. For instance, the National institute for disaster management, which has the responsibility for coordinating disaster risk management at national, provincial and community levels, organizes campaigns to disseminate information about flood risks prior to flooding season and also advises people to move their settlements to higher/safer grounds.

In the Parana delta there are currently no approaches to deal with risks and uncertainties in terms of processes and policy, however it is expected that this will be developed in near future.

In the delta and coastal areas of Myanmar an early warning system for cyclonic storm surge is operational and Disaster Reduction Plans have been developed for all districts, in the aftermath of the devastating Nargis cyclone.

A typical deltaic country such as The Netherlands is 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 focus on more resilient flood risk management strategies, early warning and recovery programs (pro-action). To safeguard the Dutch Delta for future flooding and to prepare the country for future droughts and water scarcity, a Delta Programme was established to assess impacts of climate change scenarios and socio economic developments and to explore policy options. Based on that an adaptive delta management plan is being elaborated taking into account uncertainties up to 100 year in the future.

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 and currently a Bangladesh Delta Plan is being developed.

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 7 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 7 shows that adaptive measures in general tend to be technical and ecological, rather than economic or institutional. In the Rhine-Meuse, Ganges-Brahmaputra-Meghna, Zambezi and Ayeyarwady 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,

Table 7
Comparative overview of the types of adaptive measures proposed for the studied deltas. In green the additional four deltas.

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

- • *none or few*
- •• *some*
- ••• *many*

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.

Technical measures for increased water supply are planned in the Ayeyarwayd, Tana and Zambezi delta, eg tube-wells or reservoir. Data dissemination and early warning systems is a technology that is developing rapidly and with interest from the Ayeyarwady, Parana, Tana and Zambezi delta.

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

The Rhine-Meuse delta from space

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.

Plans do exist for sustainable delta management that include measures such as restoration and reforestation (Ayeyarwady), creation of protected areas (Ayeyarwady and Parana) and environmental flows (Tana, Zambezi).

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: (1) adapted forms of building and construction, (2) financial instruments to support/promote 'delta-friendly' economic activities, (3) 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.

Institutional measures

Many institutional measures are being implemented in the Rhine-Meuse delta referring to the Dutch Delta plan and Dutch Delta Approach, which focuses on involving all relevant parties (multi-governance), joint factfinding and an integrated (multi-sectoral) approach.. Others examples 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).

The different additional four deltas have undertaken interesting economic and institutional measures, such as community programs on health, flood and/or sustainable land use (Ayeyarwady, Zambezi), establishment of river basin committees for improved governance at basin level (Zambezi), stakeholder participation (Tana) or multisectoral dialogue (Parana), management plan for the delta (Parana) or forest management plan (Ayeyarwady).

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 and the Ayeyarwady, 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 (Sacramento-San Joaquin and Mississippi River deltas), 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

Regarding adaptive delta management in the Netherlands several tools are applied to support decision making, such as scenario analyses, and adaptive tipping points and pathways approach. 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). 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.

In Myanmar RIBASIM is applied, a generic model package developed by Deltares for simulating the behaviour of river basins under various hydrological conditions,. The model package is a comprehensive and flexible tool which links the hydrological water inputs at various locations with the specific water-users in the basin. Also WFlow is used, a distributed hydrological modelling platform generating rainfall-runoff for all major river basins and serves as input for RIBASIM and SOBEK.

In Mozambique several tools for hydrological modeling, integrated water resources management and flood protection are applied (DRIFT, HEC, VIC, MIKE Flood ARA, WEAP, HUGO and WRSM2000 Zambezi).

In the Parana delta many methods and tools are applied for assessment of ecosystem functions, socio-economic valuation of ecosystem services (including sustainability indicators), scenario analyses regarding urban and environmental impacts, mapping and GIS analyses.

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.

Conclusions
and the way forward

Chapter 4

Comparison of delta score cards

Comparing the score cards of the deltas produces a 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. 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.

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 GBM 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, GBM 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 GBM) 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. The Ayeyarwady delta faces a similar situation with underdeveloped infrastructure and high vulnerability to extreme events such as cyclones, storm surges and extreme rainfall. Also the Incomati and the Tana delta combine a moderate land and water pressure with degrading natural resources and an insufficient infrastructure.

Positive exceptions are the Yangtze, Mekong, Rhine-Meuse, Danube, Zambezi and Parana 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.

In the Zambezi delta the pressure on land and water use is considered low due to low population density and the delta has good and sufficient natural resources. However, the flow regime and ecosystem has changed considerably due to the construction of upstream dams.
The average land and water use in the Parana delta is still estimated to be sustainable but in the lower delta the pressure is increasing because of the growth of the Buenos Aires Metropolitan Area with expected negative impacts.

Table 8: Comparative overview of the score cards of 14 deltas studied. In green the additional four deltas.

Current situation	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	–	–	––
Tana	–	–	0	–	–	–	––
Incomati delta	0	–	–	–	–	–	––
Zambezi	+	–	+	–	0	0	–
Ganges-Brahmaputra-Meghna delta	––	––	––	0	––	–	––
Yangtze delta	–	+	–	0	0	0	––
Ciliwung delta	––	––	––	–	––	––	–
Ayeyarwady	–	––	––	–	–	0	–
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	–
Parana	+	0	–	0	+	0	–

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

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 also negative impacts of growth by increased pressure on land use and natural resources, and climate change (including extreme events) impacting the natural systems and their resources (base layer), which reduces the enabling conditions for continuing working and living in a delta.
The challenge is to have a socio-economic development that will be sustainable, also contributing to improved resilience of deltas.

For several deltas (e.g. the GBM, Mekong, California Bay-Delta, Mississippi River and Ayeyarwady deltas) there is slight optimism that with a moderate economic and 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.

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.

Chapter 4

Research gaps and opportunities for knowledge exchange and collaboration

An inventory of research gaps has been carried out based on the delta descriptions. Table 9 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 the table. 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 the table the issues have been ranked per category (spatial layers and governance) based on the number of deltas for which related research gaps were mentioned.

	Nile	Tana	Incomati	Zambezi	Ganges-Brahmaputra-Meghna
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', which involves risk based approaches and dealing with uncertainties.

Of course, the mere identification of shared problems and issues for further research is no guarantee for successful collaboration. Especially, geographical variation among deltas

Table 9: Inventory of issues for which research gaps have been identified in various deltas. Between brackets for each issue the number of deltas for which this issue is identified as a research gap. In green the additional four deltas.

Yangtze	Ciliwung	Ayeyarwady	Mekong	Rhine-Meuse	Danube	California Bay-delta	Mississippi River delta	Parana
•	•	•			•		•	•
	•	•		•				•
	•	•		•				•
•	•	•		•	•			•
	•	•				•		•
		•						
	•	•	•	•		•		•
	•	•		•		•		
	•	•						
		•						•
•	•	•		•	•	•	•	•
•	•	•	•	•	•		•	
•	•	•	•	•		•		•
	•	•	•	•	•	•		•
	•	•					•	•
	•	•	•	•		•	•	•
•	•	•			•			•
	•	•						
	•	•		•		•		
		•						
	•	•						

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.

Satellite image of the Ganges-Brahmaputra delta in India and Bangladesh

Opportunities for follow-up

This current report can be considered as a starting point for further research and knowledge exchange on the current and future state of deltas. The tables above make very clear that deltas deserve attention and (innovative) solutions and best practices are very much needed. For this we can build on already available knowledge and expertise available in many deltas. Latest delta technologies can be tapped from highly developed deltas , but also indigenous knowledge should be mobilised in order to account for diversity in natural and socio-cultural environments.

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 processes in the base layer and their interactions with the network and occupation layer. But the governance and planning processes will play a vital role in sustainable development. In other words delta management needs an integrated approach covering governance and all three layers, and

thus delta knowledge development ideally needs a similar balance. This means also that a good dialogue is needed between all 'delta stakeholders': government, knowledge institutes, private companies, NGOs and the delta society.

Some additional questions which require attention are:

- Which solution oriented Best Practices are available that can be of use for other deltas?
- Which deltas are in lack of monitoring data to assess what is going on?
- Which issues are most relevant in urbanised deltas and which in rural deltas?

Envisaged role of Delta Alliance

Delta Alliance is an international knowledge-driven network organization for deltas worldwide, a vehicle for increased cooperation between many parties involved in delta management. The Delta Alliance was initiated in 2010 by the Netherlands addressing the need for more international knowledge exchange for improving the resilience of deltas worldwide, building on the own long term experiences in the Dutch delta. Its mission is to improve the resilience of deltas through more integrated and effective efforts, building on scientific research and knowledge exchange. It aims at disclosure of knowledge for application by a wide audience of end-users from the knowledge, public and private sectors, as well as to identifying upcoming research agendas.

With increasing pressure from population growth, industrialization and a changing climate, it is more important than ever that these valuable and vulnerable locations increase their resilience to changing conditions. Delta Alliance brings stakeholders involved in delta management together in order to benefit from each other's knowledge and experience and as such contribute to an increased resilience of their delta region.

When talking about delta knowledge, it's meant knowledge for an integrated approach. Apart from the water sector this includes among others socio economic aspects, ecosystems, land use and relevant governance aspects. Advocating and applying an integrated delta approach is part of the mission of the Delta Alliance.

Delta Alliance has currently ten network wings where activities are focused: California Bay (USA), Ciliwung and Mahakam (Indonesia), Mekong (Vietnam), Rhine-Meuse (the Netherlands), Nile (Egypt), Pantanal (Brazil), Ganges-Brahmaputra (Bangladesh), Mississippi (USA), Yangtze (China) and Parana (Argentina). Some other 10 deltas have shown keen interest to join the Delta Alliance network, notably from Ghana, Taiwan, Senegal, Kenya, Ghana, Benin, Rumania, Myanmar, Italy, Spain.

Delta Alliance will continue to implement its resilience strategy by:

- Assessing and monitoring the resilience of deltas to climate change and other pressures (including a regular update of the current and future state of deltas)
- Creating pressure, awareness and momentum for improved resilience through knowledge sharing and capacity building activities.
- Providing knowledge generating activities for improved resilience of deltas to climate change and other impacts.
- Showcasing best practices and lessons learned from across deltas for both preparedness and
- Response building on examples in the Delta Alliance wings
- Hosting Delta Alliance wing sessions in during regular events or conferences, which include practitioners and experts from deltas around the world
- Hosting an internet platform with information about deltas, including a toolbox for Adaptive Delta Management with overview of methods and tools, examples of their applications and best practices (www.delta-alliance.org)

Conclusions and the way forward

Chapter 4

Cooperation with other networks and programs

Research and investment in addressing the unique challenges of river delta regions are happening in many projects and programs around the world. Delta Alliance provides a framework to support the symbiosis of these countless on-going activities in delta regions, reducing unnecessary overlap and identifying gaps in efforts.

The Delta Alliance has currently many linkages with other delta related networks and initiatives such as the Global Water Partnership strategy 2014-2018, the Belmont Forum Deltas project, the GEF Transboundary Waters Assessment Programme, the Alliance for Global Water Adaptation, and the SIWI/UNEP initiated From Source to Sea partnership.
Delta Alliance is also involved in the network and knowledge sharing activities envisaged in the Sustainable Delta 2015 initiative endorsed by ICSU.

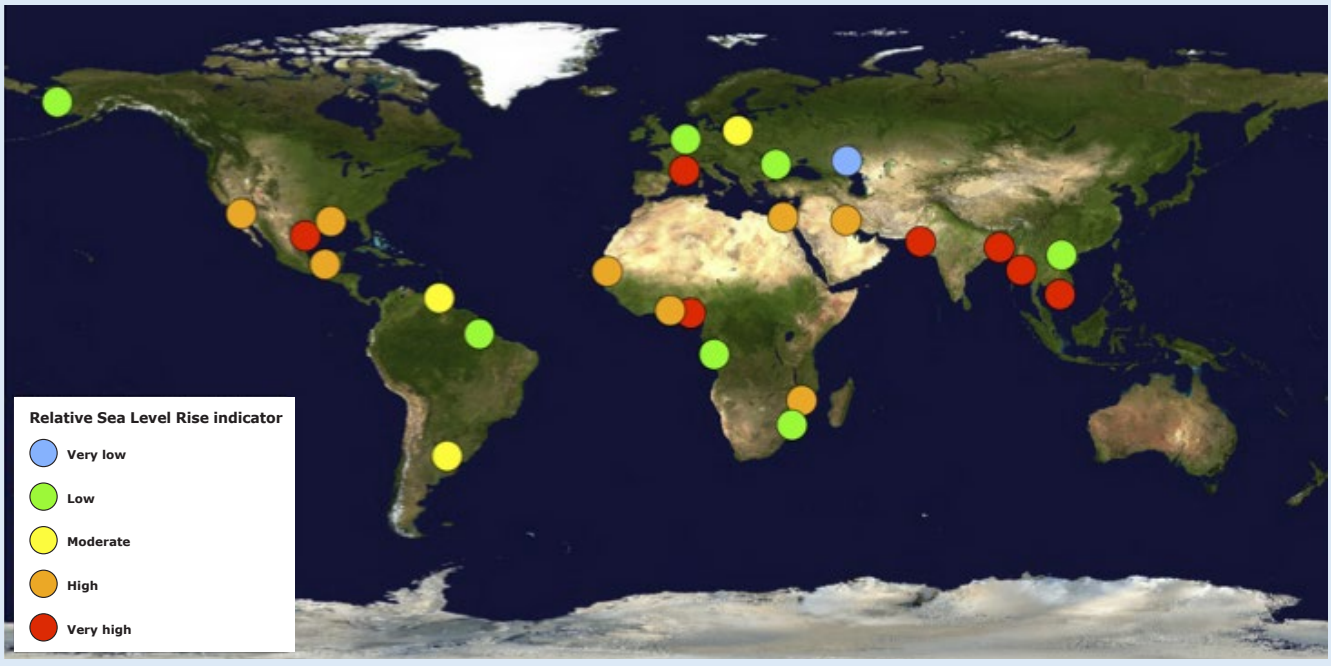
TWAP delta vulnerability assessment of 26 deltas

The results of the TWAP delta vulnerability assessment are elaborated on the basis of a risk categorisation for four indicators: relative sea level rise, population pressure, wetland ecological threat and governance, building on already existing information. The results of the relative sea level rise indicator are illustrated below.

For the TWAP assessment aggradation, subsidence and sea level rise is assessed for each delta, with a transboundary river basin, from published data (Syvitski et al 2009 and Ericson et al 2006). Based on the available quantitative data, each delta is assigned to one of five relative sea level rise (RSLR) categories, largely following Ericson (2006), with category 1 representing no RSLR (<= 0 mm/yr) and category 5 representing high RSLR (>5 mm/yr).

From the 26 deltas assessed the most at highest risk are in Asia (Ganges, Indus, Irrawaddy and Mekong). In Africa and America also a considerable number of deltas are at (high) risk, especially the Niger and Rio Grande. Europe has the least transboundary deltas with only the Rhone at high risk.

One of the important factors for the RSLR is increasing population in delta (mega) cities, especially in Asia. This results often in less delta aggregation and increased human induced (accelerated) land subsidence caused by severe ground water extraction in order to comply with high(er) water demand.



Global map with relative risk categories for Relative Sea Level Rise for the selected deltas (see table 10 for detailed data)

Global Water Partnership and Delta Alliance have started in 2012 with the support of the Netherlands International Development Program – DGIS – a cooperation program that aims at developing a joint Global Program of Action on Deltas titled the 'Enabling Delta Life Initiative'. The general objective of the program is to strengthen the management of deltas. Four main work packages are envisaged about Capacity Development, Demonstration projects, Knowledge and awareness and Governance and Fundraising.

Delta Alliance has been asked to participate in **GEF funded Transboundary Water Assessment Programme** (TWAP-Rivers) for the vulnerability assessment of 26 deltas, coordinated by the UNEP-DHI Centre. The overall objective of TWAP is to undertake the first global assessment of transboundary water bodies, through a formalized consortium of partners, that will assist GEF and other international organisations to have a base line,

		Relative risk category	RSLR (mm/year)	Source
America	Amazon	2	0 - 1.5	Ericson
	Colorado	4	2- 5	Syvitski
	Grijalva	4	3 - 5	Ericson
	Mississippi	4	2 - 5	Syvitski
	Orinoco	3	0.8 - 3	Syvitski
	Parana (La Plata)	3	2 - 3	Syvitski
	Rio Grande	5	5 - 7	Ericson
	Yukon	2	0 - 1.5	Ericson
Europe	Danube	2	1.2	Syvitski
	Rhine-Meuse	2	0 - 1.5	Ericson
	Rhone	5	2 - 6	Syvitski
	Volga	1	0	Li et al
	Wisla	3	1.8	Syvitski
Asia	Ganges-Brahmaputra-Meghna	5	8 - 18	Syvitski
	Hong (Red)	2	0 - 1.5	Ericson
	Indus	5	> 11	Syvitski
	Irrawaddy (Ayeyarwady)	5	3.4 - 6	Syvitski
	Mekong	5	6	Syvitski
	Shatt-al-Arab	4	4 - 5	Syvitski
Africa	Congo	2	?	Syvitski
	Limpopo	2	0.3	Syvitski
	Niger	5	7 - 32	Syvitski
	Nile	4	4.8	Syvitski
	Senegal	4	3 - 5	Ericson
	Volta	4	3 - 5	Ericson
	Zambezi	4	5	IPCC

Table 10: Relative risk categories for Relative Sea Level Rise for the selected deltas (in blue the deltas studied in the Delta Alliance Comparative assessment of 14 deltas)

Legend

RSLR (mm/year)	*Relative Risk Category*
<=0	*1 Very low*
>0 - 1.5	*2 Low*
1.5 - 3	*3 Moderate*
3 - 5	*4 High*
> 5	*5 Very high*

Source of map and table: TWAP FSP River Basins Component – Vulnerability Assessment of Deltas in Transboundary River Basins, final draft report July 2014, Delta Alliance, UNEP-DHI

to improve the setting of priorities for funding and to formalize the partnership with key institutions aimed at incorporating trans boundary conditions into regular assessments programs. It is anticipated that this baseline will serve to assist international funding agencies in tracking the impacts of their interventions in terms of changes in state of the aquatic environments under consideration.

References

This synthesis report is based on the working documents with 14 delta descriptions, referring to many literature. For this (very) long list of literature please see the reference sections in the working documents available at www.delta-alliance.org

Appendix

Summary of delta descriptions

In the following paragraphs the main issues of the additional four 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 (of all 14 deltas) are available in separate 'Working documents' at www.delta-alliance.org

11 Tana delta

Summary of drivers of change

Demographic trends: The Tana Delta has ca. 100,000 residents. With the total number of households of 12,457, and a mean household size of ca. 7 persons, the Delta population is growing at an estimated 3,62% a year. Over the past decade, conflicts have been increasing in the Tana River Delta as a result of increasing population, the majority of whom (over 90%) live in the rural areas

Economic developments: The main economic activities are farming, livestock keeping (pastoralism) and fishing. The settlement patterns are random but are concentrated close to the river. The Tana Delta a dry season grazing area for livestock emanating from other Counties. Fuel wood is derived from forests and woodlands located in the delta. Other products include medicinal herbs, honey and eco-tourism, including several lodges and a wildlife conservancy. Strong developments are expected in the delta due to the implementation of the Lamu Port Southern Sudan-Ethiopia Transport (LAPSSET) Corridor (see 1.1.4 for more information).

Climate change: Wide fluctuations in climatic conditions including pronounced flooding and droughts are experienced. In the next 20 years rainfall may be more prolonged, bimodal erratic, unreliable, and consequently cause more flooding events (although these may be counteracted by the building of the High Grand Falls Dam, see). In the next 40 years a possible increase of 15-25 cm in mean sea level could significantly reduce the scope of farming on those parts of the lower floodplain lying within 20 to 30 km of the coast.

Subsidence: Unknown due to lack of data. However, human induced subsidence is likely to occur when downstream sediment supply decreases due to upstream dams and reservoirs, promoting the net change in sea level rise at the coast. Subsidence due to tectonic activity or by compacting organic layers is assumed to be small.

Technological developments: The technological developments in the delta are currently limited in comparison to dams and reservoirs for power and irrigation upstream. However, the planned LAPSSET foresees major development push in infrastructure, large scale agriculture, logistics, and energy and water production.

Research gaps

Research is required in the development of impact assessment tools for various climatic impacts on delta health and functioning. The complete impact of climate change and the planned developments on delta morphology is unknown.

Summary of pressures in Occupation layer

Pressure on space: Space in the delta is currently under threat as government, corporations and foreign agencies are implementing large-scale land acquisitions (LSLA). Nomadic pastoralists as well as communities engaging in small-scale subsistence farming will be affected more with current Delta development plans. Driven by high population growth and densification of settlement the pressure on space is likely to increase further.

Vulnerability to flood: Floods have become less frequent and predictable due to dam and reservoir construction upstream. With the further development in the delta the vulnerability to flooding will increase especially at moments when dam regulation in the upper catchment fails and emergency spilling surprise growing floodplain communities with flashfloods.

Water demand / freshwater shortage: Water availability per capita in Tana Delta is today ca. 22% of the amount it was 50 years ago. The whole catchment is classified as 'water scarce' mainly as the result of a growing number of farming or pastoralist communities and increasing number of commercial irrigation schemes. With projected socioeconomic developments, water demand will increase leading to prolonged fresh water shortages in time and space throughout the whole Tana delta.

Appendix

Research gaps

- *There is need to expand the hydromet services for the delta; currently, only KENWEB appears to do substantive work on continuous data collection.*
- *In 2007, Tana River changed course near Mnadzini; it is not fully known what are the determinants of course change; hence it cannot be predicted.*
- *Food and water demand in the delta is not clearly known.*
- *With projected land use changes a detailed water balance of the delta is required.*

Summary of pressures in Network layer

Flood protection: There is iimproved upstream land use. Also, five major reservoirs have been built in the upper basin that have significantly modified the hydrological regime of the river, with a 20% decrease in the peak flows of May.

Irrigation and drainage: Upstream dams and the biofuel and large irrigation schemes impact downstream flooding processes by diminishing the possibilities for floodplain agriculture and limiting scheme cropping to the riverbanks. Generally, irrigation and drainage infrastructure are limited and poorly developed.

Water supply and sanitation: Due to inadequate investment in water infrastructure, the locals depend on surface water taken directly from the Tana River, making them vulnerable to water-borne diseases. Currently supply and sanitation are worsening and little infrastructure is implemented.

Roads, railways, ports and navigation channels: The delta is not well networked in terms of infrastructure. Although roads and power supplies do connect the major towns in and just outside the delta, the structure is aging and insufficient. With the projected plans in the delta, large infrastructural investments are expected for industrial and urban developments.

Research gaps

- *Sustainable water engineering is required for allowing full development of the Delta's limited resources now and in the future.*
- *Knowledge on implementing waste water treatment is lacking.*
- *A detailed allocation assessment, including a comprehensive water quantity and quality balance, is needed.*

Summary of pressures in Base layer

Coastal erosion: With increased pressure on the lower biotopes (forests, mangroves and reef) and a disturbed sediment and water discharge it is expected that structural integrity of the lower regions of the delta will decrease and consequently coastal erosion to increase.

River morphodynamics: A rapid analysis of river discharges at Garsen shows that peak discharge rates are largely attenuated and smoothed out between the two stations, with an average decrease in transiting volume of 76%.

Flooding (flood hazard): The flooding characteristics of wetlands, particularly the flood extent, timing, frequency, duration and flood peaks, have decreased (ca. 20%) but are more irregular.

Salinisation/salt intrusion: Salinity and sodicity problems are common in the Tana Delta where they have naturally formed under the prevailing climatic conditions and due to high rates of evapotranspiration and lack of leaching water. Land degradation by salinization is on the increase in irrigated deltaic areas where irrigation of unsuitable soils or use of poor quality irrigation water is a common practice.

Water and soil pollution: Pollutants from agriculture sector are relatively high due to lack of standards implementation. Nutrient run-off can cause eutrophication locally with possible algal blooms (including toxic blue green algae) and lowered oxygen content.

Wetland and biodiversity loss: Biodiversity loss, environmental degradation and poverty is high, resulting from increased human pressures on available delta resources and the disturbance of the (natural) structural functioning of the delta.

Research gaps

Lack of hydrological, climate and topographical data hampers the characterization of the flood events. Commonly, water fluxes are un-gauged and models too course with little predictive power.

Summary of governance issues

Cooperation between (scale) levels and sectors of government: Although 14 government institutions are currently involved in the management of the Delta and significant legislation and policy are in place at the national level to guide sectorial developments e.g. water, agriculture and mineral resources policies, the development agenda in the Delta remains largely uncoordinated.

Cooperation between government and private sector: The Physical Planning (PPA) Act mandates Local Authorities (LA) to regulate development within their areas of jurisdiction to foster orderly and sustainable development. However, government institutions and the private sector have had little constructive dialogue about the future of the Delta. The situation is currently exacerbated by a multitude of large-scale, potentially conflicting development proposals.

Involvement of stakeholders and citizens: Local communities are not well represented in governance processes affecting the Delta. The communities are largely unorganised; especially the most isolated and marginalised and their views on development proposals do not have formal recognition within to the decision-making process.

Approaches for dealing with risks and uncertainties: The Land Use Plan (LUP) for the Tana River Delta is supposed to guide the involvement of all stakeholders in the Tana Delta. The LUP framework will guide strategic Planning in the Delta to lower risks and uncertainties, and specifically addresses resource conflicts between local agriculturalists, pastoralists and large-scale agricultural schemes

Research gaps

- *Uncoordinated research and monitoring programmes that do not adequately inform the management of Delta resources on issues affecting them.*
- *A lack of adequate mechanisms to address risk management issues affecting the Delta such climate change, drought, floods and tsunami and storm surges.*
- *Inadequate partnership and cooperation between government and non-governmental organizations.*
- *Lack of coordinated institutional governance of natural resources and development.*

12 Zambezi delta

Summary of drivers of change

Demographic trends: Although Mozambique has currently a high economic growth (GDP is 14.59 billion USD with an economic growth rate of 7 %), it is considered one of the poorest countries in the world. A large part of the population lives below the poverty line, with huge disparities between rich and poor, in income between urban and rural population. Around 328,000 inhabitants (1.4% of the total population of Mozambique) live in the Zambezi delta region. The average population growth rate for the main village is around 4.1 %/year, whereas the average growth rate in Mozambique is 3 %/year.

Economic developments: Agriculture is the largest water consumer after hydropower (open water evaporation losses). The main economical developments in the delta region are the SENA Sugar Estates and the shrimp industry. The main highway connecting the South and North of Mozambique also crosses the delta at Caia together with the railway linking the Tete coal mining hub to Beira port further south. More upstream, in the Tete Province there are huge economical developments, mainly hydropower and coal mining which has consequences for the delta.

Climate change: According to the IPCC (Intergovernmental Panel on Climate Change) prognosis the Zambezi River Basin exhibits the worst potential effects of climate change among the eleven major African river basins, mainly due to the combined effect of temperature increase (order of 0.3 - 0.6 °C) and rainfall decrease (order of 10 - 15 %). The climate changes forecasts for Africa also predict that the risk of extreme events like droughts and floods will increase including inundation due to sea-level rise in coastal areas. Estimates suggest that the Lower Zambezi runoff will decrease by 13 - 14 % and sea level is expected to rise as well. The World Bank study (2010) shows that the impact of climate change on the Zambezi delta (mainly the increase in temperature) could lead to an irrigation deficit of 27% and a reduction of basin yield of 13% by 2030.

Subsidence: A topical area in many delta's in the world. Land subsidence has not been reported for the Zambezi Delta so far. Although more than 50% of the population uses groundwater as source of water, mainly from shallow open wells or wells equipped with hand-pump, groundwater exploration is still low in the region so land subsidence due to excessive groundwater abstraction and consequent soil compaction is very unlikely

Technological developments: The Zambezi delta is developing slowly in terms of technological developments. Small scale farmers and fishermen use old fashioned technology and electricity supply is very limited. Solar panel technology for electricity supply is being promoted. Telecommunications with 3G network and access to internet is available around the main villages. There is a railway branch to Marromeu sugar plantation connected to the SENA railway. Plans for expansion of hydropower also exist with construction of Mphanda Nkuwa and expansion of Cahora Bassa by including turbines on the North Bank.

Research gaps

- *There is a need for the development of the monitoring network (eg. river discharge, reliability of rating curves, monitoring of discharge through distributaries, etc.);*
- *Monitoring of water quality to assess impacts of small scale and large scale agricultural developments, as well*

as the impacts of the large mining ventures taking place upstream;
- *Research to understand the combined river and coastal dynamics and roles of flow regime changes in these dynamics, and monitoring of sediment transport;*
- *Assessment of potential threats related to delta subsidence;*
- *Research for diagnosis and economic valuation of ecosystems as well as identification of sound management measures to protect it;*
- *There is a need to develop integrated urbanization plans taking into account flood hazard and other aspects.*

Summary of pressures in Occupation layer

Pressure on space: Pressure on space is in general low due to low population density. Nevertheless, illegal hunting and wood cutting on mangroves pose some pressure in direct vicinity of the main villages. There is large interest to have agriculture development in the delta area which can lead to significant water abstractions and subsidence.

Vulnerability to flood: After the construction of the Kariba and Cahora Bassa dams the floods became less frequent and timing is less predictable. As a consequence population felt safer and moved their settlements to the fertile floodplains and are sometimes caught by surprise during years with high floods resulting in damage and loss of lives. This encroachment results in high exposure of the community and reduced reaction time to flood waves therefore increasing the vulnerability of the population. Cyclons do occur quite frequently in the Mozambican coast. Over the last 75 years before 2005, the Zambezi Delta was hit by 9 to 15 cyclones (MICOA, 2005). But the flooding events recorded in the Delta region were mainly due to high flows in the Zambezi River coming from upstream. Flooding from sea has not been reported to affect the local communities of infrastructure so far.

Water demand / freshwater shortage: At the moment water demand is very low compared to the Zambezi average discharge and there is no freshwater shortage in the delta area. Water abstractions are regulated by ARA Zambezi. Water is abstracted from the aquifers in small urban areas but due to limited infrastructure only a small part of the population is covered by the water supply systems and this water abstraction can be considered low. Water for domestic use and farming small areas (less than 1ha) is free of charge

Research gaps
- *There is a need for improved planning to control the development of settlements in inappropriate locations such as low lying lands prone to flooding;*
- *There is a need to develop flood hazard maps to assist in the development of population settlement planning;*
- *There is a need to develop a flood forecasting model for flood management.*

Summary of pressures in Network layer

Flood protection: Flood protection dikes where built around 1893 to protect sugar fields in Mopeia, Marromeu and Luabo. Railway and roads built in the floodplains also act as flood protection. Two large dams (Kariba and Cahora Bassa) were built for flood protection, in addition to hydropower.

Irrigation and drainage: In the delta area only the SENA Sugar Estate has an irrigated agricultural field. The rest of the agricultural land owned by smallholders is rain-fed.

Water supply and sanitation: Water supply and sanitation infrastructure is limited to the main village only. In general, the percentage of population without access to safe drinking water is high (around 50 to 60 %) and sanitation services coverage is even lower.

Roads, railways, ports and navigation channels: The road network has 630 km of secondary (earth) roads with good to reasonable conditions and 330 km of tertiary roads in reasonable conditions. Road maintenance is poor. There is a 88 km railway that links with the greater SENA railway. A new railway line between Tete and Macuze in Zambeze province north of Chinde is under development by a Thai enterprise. The railway will cross the northern margin of the delta with a crossing in Shire river at a point called Shire batelão. There are three small airports and barges to transport people and goods from/to Chinde and Marromeu.

Research gaps
- Research to assess low cost water supply and sanitation alternatives;
- Research to study the effects of the flood protection measures in terms of flood risk reduction and impacts to the environment;
- Research to investigate the effect of the new proposed embankments associated with the new Macuze line over the flooding in the delta;
- Feasibility studies for the development of infrastructure in the delta region.

Summary of pressures in Base layer

Coastal erosion: Recent studies carried out during the preparation of the environmental impact assessment for the navigation of the Zambezi River have shown that the

mouth of the Zambezi is very dynamic in terms of sediment transport.

River morphodynamics: The Zambezi river is a braided to anabranched sand bed river with high sediment transport dynamics, and presenting migrating bars. Sediment trapping at Cahora Bassa dam impacts on the river morphology resulting in a colonizing and stabilizing river bed.

Flooding (flood hazard): Flooding in the Zambezi delta became less frequent and timing is less predictable after the construction of the large dams upstream. Off-season flooding associated with dam operation has been reported in the Zambezi. The floods were mostly associated with spilling in preparation for the rain season or to accommodate higher than normal flows into the reservoir. The dam releases when done without proper notification to local communities often resultin in loses of agriculture produce by farmers along the flood plain.

Salinisation/salt intrusion: Salinisation of soils has been reported. The annual floods that became less frequent had an important function of flushing accumulated salts on floodplain soils.

Water and soil pollution: The cities along the Lower Zambezi river release sewage water without adequate treatment which leads to eutrophication of the river and spreading of water related diseases. Car washing near river banks is also contributing to pollution of the river. With a low population, a low water supply coverage and a high dilution potential from the Zambezi discharge, the problems are however still small.

Wetland and biodiversity loss: Tributaries of the Zambezi river have become disconnected due to construction of flood protection embankments and change in flow regime has contributed to changes in vegetation patterns in the delta region, including decrease in mangrove area and wildlife numbers. Praagman etal 2013 report that near-coast and riverine fishery have replaced floodplain fishery, although industrial prawn catch has also reduced due to decreasing numbers of prawn. The natural reserve of Marromeu experienced reductions in numbers of waterbirds and wildlife, some of which are already classified as endangered species (Beilfuss 2012). Biodiversity lose as a result of the changes in the extent of the wetland areas have been reported in the Zambezi delta. For the entire Zambezi delta the biggest landuse is grassland (50 - 60 %) and mangroves contribute about 3 %. The mangrove cover was reduced by 24 % with a recovery of 18 % for the 1972 - 1979 period and during the 1989 - 2013 the decline was at 14% and recovery at 26%. However the reduction takes place with different rates and in different periods for the different parts of the Zambezi Delta and is not a continuous process in all areas of the delta. Poacher activities cause uncontrolled and devastating forest fires.

Research gaps

- Data collection (sediment characteristics, sediment transport, coastal erosion, salinity intrusion, improved discharge monitoring network, including development of more accurate rating-curves and accurate topographic and bathymetric surveys to produce a digital elevation model) to support analysis, model calibration and validation;
- Community programs to disseminate information about importance of ecosystem services and to tackle issues of illegal hunting and wood extraction as well as water pollution;
- Development of an integrated morphological model (for river and coastal dynamics) to study the main drivers of morphological changes and predict impacts of proposed activities and proposed environmental flows;
- Development of a salinity intrusion model to study the main drivers affecting the salinity intrusion and impacts of proposed flow regimes, other proposed activities and sea level rise including impacts on estuary vegetation and fisheries;
- Research on status of the environment, especially the biodiversity;
- Research on the quantification and importance of ecosystem services benefiting the population livelihoods and economy of the delta region;
- Topographical monitoring for land subsidence evaluation.

Summary of governance issues

Cooperation between (scale) levels and sectors of government: The Water Policy created in 1995 pushes toward decentralized administration, where decisions are taken at local/regional levels whereas the government responsibility changes from direct implementation to a more facilitative role. The coordination between different sectors of the government is carried out by technical steering groups which act as advisors to the higher level institutions (the ministries).

Cooperation between government and private sector: The implementation of the Water policy also led to more involvement of the private sector. The government transferred its administration responsibility for some infrastructures (irrigation, water supply systems, etc.) to the private sector and changed to playing a more facilitative role.

Involvement of stakeholders and citizens: Stakeholders, interested citizens in general and national and international NGO's can get involved and participate in the definition of

policies and decision making process in different ways, such as in basin committees where activities at basin level are discussed.

Approaches for dealing with risks and uncertainties: The INGC (National institute for disaster management) is an autonomous government institution with the responsibility for coordinating disaster risk management at national, provincial, district and even community levels. The government adopts a precautious attitude to deal with uncertainties.

Research gaps

- *Study of adaptive management alternatives for better implementation of the decentralization;*
- *Research on better institutional structures and capacity building for the government lower levels to enable direct implementation of the administration tasks with success;*
- *Development of integrated policies (cross-sectoral integration) and integrated master plans for basin level development activities including programs to improve living standards of rural populations;*
- *Integrated river and coastal management approach;*

13 Ayeyarwady delta

Summary of drivers of change

Demographic trends: Population of the country was estimated at 58.38 million during the census of 2008-2009. Taking into account a growth rate of 1.52 percent the actual population will be approximately 62 million. Ayeyarwady Region, covering a large part of the Ayeyarwady Delta has a population of 8,041,084 on an area of 35,032 km^2, hence a population density of 230 inhabitants/km^2. With 250 inhabitants/km^2 the delta is one of the most densely populated regions in Myanmar. This population density in Ayeyarwady Region is e.g. relatively low compared to the one of the Mekong Delta (approx. 500 inhabitants/km^2, excluding Ho Chi Minh City) and the Ganges-Brahmaputra-Meghna Delta (more than 1200 inhabitants/km^2), (Driel and Nauta, 2013).

Economic developments: The country is one of the poorest nations in Southeast Asia, 37% of the population is unemployed and 26% live in poverty. Myanmar's economy is one of the least developed in the world. In the past, GDP growth has been relatively slow averaging ~2.9% annually. A change of government in 2011, however, induced a number of policy reforms that increased GDP growth to 7.8% per annum. In 2011, Agriculture contributed ~43% to GDP, services ~36.6% and industry ~20.5% (CIA, 2011). Agriculture, forestry, and fisheries constitute the largest contribution to the economy. Approximately 75% of the rural population rely on the agriculture, livestock and fisheries sectors for their livelihoods. Other major livelihood activities in Myanmar utilise the following major products: i) wood and wood products (amongst others through destructive mangrove exploitation for charcoal); ii) copper; iii) tin; iv) tungsten; v) iron; vi) cement; vii) construction materials; viii) pharmaceuticals; ix) fertilizer; x) natural gas; xi) garments; xii) jade; and xiii) gems (Hadden, R. L. 2008). The GDP growth will be around 6.8% (2013) being the GDP per capita $1,700 (CIA, 2013; Ministry of Transport - NAPA, 2012).

Climate change: The Myanmar's National Adaptation Programme of Action (NAPA) to Climate Change (Ministry of Transport, 2012) includes the climate change predictions as presented in Table 1.

Table 1 Climate change predictions (Source: NAPA)

Climate change predictions for 2001-2020 include:

Climate change predictions for 2001-2020 include:	Climate change predictions (compared to 2001) for 2021-2050 include:	Climate change predictions (compared to 2001) for 2051-2100 include:
• an increase in temperature of ~ 0.7 ºC in the Ayeyarwady region • an increase in clear sky days in Northern and Central Myanmar exacerbating drought events • highly variable rainfall changes throughout the country with however only small increase in the Ayeyarwady region • an increase in floods and droughts resulting from variable rainfall conditions	• an increase in temperature of 1.4 ºC in the Ayeyarwady region • an increase in rainfall of approx. 250 mm in Ayeyarwady Delta • periods of heavier rains • longer dry spells	• an increase in temperature of 3.5 ºC in Ayeyarwady region • an increase of approx. 450 mm of rainfall in Ayeyarwady region • a weakened monsoon climate supported by decreased cloud coverage • an increase in drought periods across most of Myanmar

In Slangen et al. (2013) updated projections for twenty-first century regional sea-level changes are given for two sea level change scenarios (A and B) based on the IPCC-RCP climate scenarios 4.5 and 8.5 with a temperature increase

of 1.2°C–2.7°C and 2.7°C–5.4°C, respectively, between 1986–2005 and 2081–2100.

In total scenario A yields a net global mean sea-level rise of 0.52±0.19 m (mean±1σ) between 1986–2005 and 2081–2100, while scenario B yields a net global mean sea level rise of 0.70±0.26 m for the same period.

According to the Asian Development Bank (ADB), "many more people" in Southeast Asia died as a result of natural disasters between 2001 and 2010 than during the previous decade, primarily due to the 2004 India Ocean tsunami and 2008's Cyclone Nargis, whose aftermath showcased the Myanmar government's inability to respond to extreme weather. Although not directly to be related to climate change, the devastating Cyclone Nargis hit Myanmar with resulting waves of more than 6 meters in May 2008, the strongest ever (U Nyan Win, 2010) killing 138,373 people and leaving about 2.4 million affected. Total damage and loss was estimated at approximately 11.7 trillion Kyats, i.e. 4.1 billion US$ (Ministry of Social Welfare, Relief and Resettlement, 2012).

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 such as ground water pumping for drinking water supply of fish and shrimp ponds. However, so far, no real field observation data have been found on subsidence in the Ayeyarwady delta. Syvitski et al (2009) estimated a Relative Sea Level Rise (= Sea level rise plus compaction/subsidence minus delta aggradation trough sedimentation) of 3.4 – 6 mm/year, and categorised herewith the Ayeyarwady Delta as a delta in peril: 'reduction in aggradation plus accelerated compaction overwhelming rates of global sea-level rise'.

Technological developments: Myanmar´s science and technology infrastructure is mainly focussing on agriculture research, due to the importance of the agriculture sector for the national development. It includes the development of agricultural products and methods as well as sustainable forestry. Many dams have been built in the mountainous areas around the Upper Delta and more upstream in the Ayeyarwady basin, mainly for irrigation purposes. It is expected that the existing irrigation systems and the polders (to protect the agricultural land from salt water intrusion) will be upgraded and extended. The annual rice production of Ayeyarwady Region of about 6 million tons accounts for 30 percent of the total production in Myanmar of about 22 million tons annually (FAO, 2001/2002). This situation is mainly due to the increase of farmland area, with a rapid 25 percent increase between 1990 and 1994.

Other research focuses are set on biotechnology, renewable energy, health, internet technology and marine science and technology.[1]

According to the World Energy Council, in 2007, Myanmar had coal resources estimated at around 2 million tons, 447.7 TCF of natural gas and 206.9 million barrels of oil. The hydropower potential of Myanmar's four main rivers is estimated at 40,000 megawatts, of which only a small portion has been harnessed. The Myanmar government is undertaking ventures to exploit these energy resources, both as a basis for accelerated overall economic development and for direct social benefit to their residents[2], (Driel and Nauta, 2013).

Research gaps

- *Apart from statistical data on for instance agricultural production there is not much recent information available on the Ayeyarwady delta, mainly due to the fact that in the last 20 years not much research has been done and most of the monitoring programs have been halted. Therefore research gaps exist for all drivers of change.*
- *The recently performed census 2013 will give new data on the population in the Delta: population number, density, composition, growth rates, etc.*
- *It is expected (and the first signs are clearly visible) that the recent opening of the country will also create new rapid economic developments. Not much information has been found on the expected developments. To stimulate economic development and foreign investments so-called 'special economic zones' are and will be created in the neighbourhood in Yangon, however outside the Ayeyarwady Delta. The special economic zones and other business developments will likely on the urban infrastructure and the availability of fresh water.*
- *In face of climate change developing countries are facing different weather patterns than in the past. They cannot rely on 200 years of past data to prepare for the following years. Bringing a new kind of uncertainty: dry areas get much drier, wetter areas get much wetter, and there is greater unpredictability of rainfall. More knowledge has to be developed on how e.g. hydrological systems will change. New infrastructure needs to be planned accordingly. Apart from the NAPA (Ministry of Transport, 2012) study not much research has been done on the extent and impacts of climate change.*

1 Facts on Science, Technology and Innovation. South Asia and European Union. (SEA-EU-NET) http://www.sea-eu.net/facts/sea/myanmar

2 http://www.myanmarenergyinvestmentsummit.com; http://www.worldenergy.org/documents/ser2007_final_online_version_1.pdf

- *Moreover, investments in research and development are needed in the agricultural sector, being the most important contributors to the GDP (World Bank, 2005). During three Delta Alliance workshops held in respectively Pathein, Hinthada and Yangon in June 2014 the key issue 'knowledge development and innovation' scored among the participants second highest (after flooding) out of 8 key issues for the delta.*

Summary of pressures in Occupation layer

Pressure on space: The delta is one of the most densely populated regions in Myanmar. Ayeyarwady Region, covering a large part of the Ayeyarwady Delta has a population of approximately 8 million on an area of 35,032 km^2, hence a population density of 230 inhabitants/km^2, which is three to four times as high as the country's average.

Vulnerability to flooding and erosion: Most of the delta is still active with unstable river branches and the delta is prone to tropical cyclones with high storm surges. Many people are yearly affected by bank and coastal erosion and also floods are a permanent threat. Floods can be of different nature: floods from the rivers (mainly in the Upper Delta), floods caused by storm surges (mainly in the Lower Delta) and flash floods from the surrounding hilly and mountainous regions.

Agriculture under pressure by climate change, flooding and salinity intrusion: Agricultural production is facing challenges due to increasing risks of flooding and salinity intrusion.

Overfishing: The fishery in the Ayeyarwady Delta encounters the pressure of overexploitation, which has been impacting already the livelihood of rural poor. (MYFish, 2013).

Shift in land use upstream: The effects of the dams are producing a reduction of the sediment supply and therefore erosion of the delta.

Water demand / freshwater shortage: Due to upstream developments, climate change and sea level rise, critical low flow conditions of the Ayeyarwady River tributaries are likely to increase. Increase of salinity intrusion in the coastal areas is making existing water supply sources (domestic and agricultural) and freshwater ecosystem vulnerable.

Need for more livelihood opportunities: For a sustainable development of the (rural) Ayeyarwady Delta there is an urgent need for improvement of the livelihood opportunities for the local population. The majority of the people in the Delta is landless and are therefore placed in a non-voluntary dependent position. Lack of or limited access to credit hampers also the economic development of the rural population. Multi-sectorial development is needed to increase the livelihood of the rural population (MMRD Research Services, 2014).

Impact of climate change on public health (directly derived from the NAPA) Effects of increasing temperatures and erratic precipitation patterns are the spread of infectious diseases, heat stress, heat exhaustion and dehydration. The greatest concern at present is however related to freshwater resources (Lian and Bhullar, 2010).

Research/knowledge gaps

During the Delta Alliance missions in July 2013 (Driel and Nauta, 2013) and June 2014 the following research and knowledge gaps have been observed:

- *Data on population: density, growth rate, current unemployment, projections and current situation.*
- *Migration both into the delta and out of the delta, due to loss of livelihoods, needs to be considered.*
- *More insight needed in fishing rights, not aquaculture alone, but captures fisheries in river, estuary and those on delta dependent on marine fisheries as well.*
- *Inventory of existing (development) plans needed.*
- *There is need of socio-economic and livelihood profiling of the population to understand the actual vulnerability*

Summary of pressures in Network layer

Demand for more transportation facilities (roads, ports and waterways): Road transportation is the most important way of transport in Myanmar, but until rather poorly developed. Most towns and cities are accessible only by land route. Myanmar has 5.099 km of railway, only a few towns and cities are connected by railway lines, but the condition of train services in Myanmar make it too difficult. There are currently no rail links to adjacent countries. Some towns are also reachable by rivers, but river travel is very slow compared to road transportation. Most people have to rely on road transportation to travel in Myanmar. The lack of infrastructure is hampering the economic development.

Maintenance and upgrading of agricultural engineering works

In the last four decades important infrastructure has been constructed for agricultural production: dams, diversion weirs, irrigation systems, and polders. There are plans to further increase agricultural production by the construction of new irrigation systems and the upgrading and repair of existing infrastructure.

Need for embankments against flooding: In order to prevent flooding from the river extensive flood protection embankments have been constructed along several rivers in the Ayeyarwady Delta, mainly in the Upper Delta. Similar embankments have also been constructed in areas that are prone to flash floods. Some of these embankments need maintenance.
More embankments are needed against flooding in the Middle and Upper Delta. Due to the expected more extreme weather events this need will increase the coming decades.

Lack of water supply and sanitation: Only a small percentage of the rural population is connected to a public drinking water supply system. Due to climate change and sea level rise the need for drinking water supply systems will only become more urgent, certainly in the areas that are affected by salinity intrusion and arsenic contamination and waste water treatment plants. Urbanisation and industrial development of Yangon (and some major cities in the Delta like Pathein and Hintada) will articulate the need for proper sanitation facilities, waste water treatment plants and water quality monitoring.

Impact of dams: The constructions of dams pose a threat to the ecological integrity and flow regime of the river basin. Dams also result in adverse impacts to the flow regime of a river with grave implications to the health of floodplains and delta ecosystems and the ecosystem services they provide to local livelihoods

Lack of and ageing infrastructure: Infrastructure to support transportation, water supply, communications, and power supply is generally rather poorly developed. Maintenance of roads, embankments, polder sluices, drainage canals and irrigation systems is a recurrent problem. (Driel and Nauta, 2013).

Research/knowledge gaps
During the Delta Alliance missions in July 2013 (Driel and Nauta, 2013) and June 2014 the following research and knowledge gaps have been observed:
- *Present status and future plans of the transportation sector (Ministry of Public Works).*
- *Current programs and plans, for drinking water supply and sanitation facilities, etc.*
- *Plans for township development (Min. of Border Affairs, DRD).*
- *Cost-efficient and innovative infrastructure*
- *Innovation in agricultural engineering*

Summary of pressures in Base layer

Impact of climate on water resources: Climate change-induced changes to hydrological cycles will deteriorate water quality, quantity, and accessibility. Several sections of the hydrological cycle are vulnerable to climate change: flooding, contamination of water resources, erosion and limited replenishment of waterways, increase of risk of flash floods as well as decrease ground water recharge. Conversely, increases in drought events will increase utilisation pressures on ground water for expanding irrigated agriculture. Rising sea-levels, however, will lead to salt-water intrusion. (NAPA, Ministry of Agriculture and Irrigation, 2012).

Coastal and riverbank erosion: Riverbank and coastal erosion is one of the major issues. River bank erosion takes mainly place in the Upper Delta, where the river geomorphology is still very dynamic. Coastal erosion is mainly due to mangrove destruction and the decrease in sediment load caused by the construction of dams upstream. There is a lack of legislation, regulation and enforcement to avoid the settlement of (mainly fishermen communities on the erosion (and flooding) sensitive coasts and river banks.

River hydrology and hydrodynamics: Given all the projected water uses (hydropower, irrigation, drinking water supply, navigation, industrial and mining abstractions) water allocation priority problems may arise and an impact on the minimum environmental flow requirements may exist. Water balances and allocation studies are necessary to address these future water resources problems.

Flooding (flood hazard): Myanmar is prone to cyclones, mainly during the months April, May, October, November and December. The coastal region such as the Lower Ayeyarwady Delta is also prone to storm surges. During Cyclone Nargis, 90 percent of the 140.000 deaths were caused as a direct consequence of the storm surge.
The Ayeyarwady Delta is a fragile and intricate ecosystem of mangrove swamps and tidal estuaries. Non-saline arable areas are limited and becoming scarce due to the erosion of riverbanks, saltwater intrusion, and increasing soil salinity. Poor water control and drainage works contribute to periodic flooding and crop losses.
The effect of an increase in rainfall and its intensity is the increase in run-off. Deforestation contributes to these processes. Also it can damage vulnerable crop and can create flash floods from the surrounding mountain ranges in the lowland areas of the delta (Hassman, 2013)

Drinking water: quality and quantity: Water scarcity has become a daily challenge in Myanmar's Ayeyarwady Delta in the dry season, especially in the Lower Delta where the river water (and often also the groundwater) is saline. The

delta's inhabitants traditionally source drinking water from rainwater harvesting.
Arsenic contamination of drinking water sources is an emerging public health issue in Myanmar. However, the magnitude of arsenic contamination of groundwater sources in Myanmar is still rather unknown.

Salinization / salt water intrusion: Salinity and its seasonal intrusion gradients are dominant factors for coastal system, fisheries, agriculture and drinking water supply. Therefore, any changes on present spatial and temporal variation of salinity will affect the biophysical system of coastal area.

Water and soil pollution: Agricultural inputs, such as chemical fertilizers and pesticides are increasingly being used. The utilization rate of chemical fertilizers in the delta happens to be the highest among the agricultural regions in Myanmar. This will result in an increasing state of pollution.
Water quality concerns are also being raised with regard to mining activities and the growth of cities and industrial zones. The disposal of untreated domestic wastewater and the increase in industrial and mining activities will further affect the water quality in the delta with a range of additional parameters (heavy metals, organic micro-pollutants and oils).

Mangroves and biodiversity loss: Especially the mangrove forests are highly valuable but also under high pressure from encroachment and exploitation and are largely in a degraded state due to human activities such as wood harvesting (mainly for the production of charcoal) and coastal development (paddy fields and shrimp ponds). Most of the remaining forest is in various stages of regrowth.
Moreover, they are also vulnerable to accelerated climate change and sea level rise, as they pose major new challenges to biodiversity conservation and nature in general.
The root causes of these threats are low conservation awareness, poverty, poor livelihood conditions (lack of alternatives), weak systematic biological monitoring systems, low grassroots support for conservation and weak law enforcement. Environmental conservation in parallel with economic development opportunities is one of the greatest challenges for Myanmar in the 21st century (Wildlife Conservation Society, 2013).

Research/knowledge gaps
During the Delta Alliance missions in July 2013 (Driel and Nauta, 2013) and June 2014 the following research and knowledge gaps have been observed:

- *Need for overview of all hazards and consequences.*
- *Hydrological and monitoring data*
- *Water balances and allocation studies are necessary to address future water resources problems.*
- *Information on Ayeyarwady tributary behaviour and characteristics.*
- *Trends, programs, leading to water quality problems. Baseline conditions.*
- *Knowledge on arsenic contamination of groundwater.*
- *Monitoring system needed for anthropogenic subsidence and groundwater exploitation*
- *Size of loss of wetlands.*
- *Potential impacts of climate change and sea level rise on mangroves and biodiversity conservation.*

Summary of governance issues

Cooperation between (scale) Levels and Sectors of Government: Myanmar counts many ministries which are often working in quite a sectorial way. Efforts are underway to improve core governance systems. In Myanmar land and water are managed by many ministries, agencies and departments. Several departments, under their respective ministries, remain for instance responsible for the supply and management of water for agriculture, industrial, domestic and sanitation purposes. Different departments have different acts, proclamations and laws, but most of them need to be strengthened in order to overcome problems caused by the lack of regulations on land and water. There is also a lack of coordination and collaboration between the different institutions, including a lack of sharing of data and information.

Cooperation between Government and Private Sector: Economic santions on Maynamr prevented western investments and trade for most of the last twenty years). The recent relaxation of sanctions and political change have led to both the Myanmar government and foreign investors seeking to significantly increase investment across economic sectors (Henley, 2014). Although the private sector is looking into opportunities in Myanmar with great interest, it should be noted that only 30 percent of the transactions is successful according to McKinsey (2013). This is mainly due to the lack of knowledge and legislation in Myanmar, e.g. in the specific field of Public Private Partnerships. The privatization of public sector industries need to be further developed

Involvement of Stakeholders and Citizens: Stakeholder consultation at planning and implementation phase of a project in different parts of the country needs to be further encouraged.

Approaches for dealing with Risks and Uncertainties: To reduce loss of lives and property, Myanmar needs to focus 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. Disaster Reduction Plans have been developed for all districts.

Research gaps

- *Lack of knowledge and legislation in Myanmar, e.g. in the specific field of Public Private Partnerships.*
- *Improved land administration by increasing dialogue on land issues with political leaders, by funding technical expertise to assist land administration functions and land governance processes. (Henley, 2014)*

14 Parana delta

Summary of drivers of change

Demographic trends: About 24.000 inhabitants are living in the Delta, resulting in a density of 1 inhabitant per km2. More than half of the population is concentrated in the Lower area, which represents around 43% of the total surface of the delta. The Delta is located near the most populated conurbation of the country, Buenos Aires Metropolitan Area, which has more than 12 million inhabitants with a density of around 5.400 inhabitants per km2.

Economic developments: The Parana Delta is a heterogeneous region with a wide range of resources and, consequently, many production related uses. The main economic activities that characterize the islands of the delta are forestry, cattle raising, beekeeping, fishing, hunting and recreation and tourism. Nowadays, these traditional activities are threatened by new production processes originally designed for terrestrial systems, like large-scale agriculture and particularly soy crop and cattle industry on a large scale. Cattle raising contributes to approximately 85 % of the GVP estimated for the main economic activities carried out in the Delta. But livestock overload gives consequent effects of overgrazing, soil erosion and possible biological and chemical contamination of water resources with negative impact on the ecological integrity of the wetlandsFisheries in the delta involve different modalities: subsistence fishing, commercial/artisanal fishing, commercial/industrial fishing and recreational fishing.The conflicts between them have been exacerbated as a consequence of the increase of industrial fishing for export, dissimilar provincial legislations, presence of new actors and climate change impacts.
Along the borders of the delta, different cities have based their development on industrial or port activities, being the Lower Delta the area which is most influenced by the dynamics of the Buenos Aires Metropolitan Area, essential in Argentina's economic life. This region concentrates most of the industrial and financial activity of the country, contributing with around 55% of the countries' GVP (Gross Value of Production). As illustration the iron and steel industry located in the province of Buenos Aires provides more than 60% of the value generated by this sector. The per capita GDP is USD 16.840 and most people are employed in services and industry.

Climate change: There are observed and future (direct and indirect) impacts of climate change on the Parana Delta, related to the variations in the Parana River discharge and sediment load, changes in the river´s hydrologic regime and streamflow variability might affect the frequency of occurrence of extraordinary floods and droughts. and temperature increases. Streamflow variability primarily affects the Lower Delta and is mainly influenced by the Rio de la Plata and by the climatic events such as the "Sudestada", which consists of persistent South-eastern winds coming from the Atlantic Ocean. Those drivers may accelerate trends in land use change, including extensive conversion to commercial forestry, livestock production and, less frequently, to agricultural uses with extended biodiversity alteration and loss.

Subsidence: At regional level, the Parana River Delta is considered at great risk because the subsidence rate is higher than forecasts of sea-level rise. The rate of surface mineral soil subsidence is 60 mm per year as a result of porosity losses in the top 10 cm of the profile (Ceballos et al. 2013). This finding confirms that wetland soil compaction is an important and intense process in the system, suggesting that profile de-saturation is a key driver (Hadas 2006).

Technological developments: The large scale infrastructural interventions located along the River and its Delta are: five big dams built upstream the river (Ilha Solteira, Jupia, Porto Primavera, Yaciretá and Itaipu), the Parana-Paraguay Waterway, two viaducts (Zárate-Brazo Largo and Rosario-Victoria) and one re-gasification port in Escobar built on the Parana de Las Palmas river. In addition, the construction of the Atucha Nuclear Power Station, located in Zárate in the coasts of Parana de las Palmas River, represents a potential risk to the delta region. Besides large infrastructure works, other low scale technological developments are also developed such as polders and embankments mostly associated with production activities such as agriculture, cattle industry and urban developments. Other heavy engineering works have been realised to expand shipping and spur economic development throughout the region.

Research gaps

- *Need for the development of climate change projections at the Delta and local scales.*

- *Multi- disciplinary assessment of the combined impacts of human activities on the wetland and its resilience capacity in a context of climate change. Generation of future scenarios.*
- *Research on strategies to include climate change projections and impact assessments into policy and guidelines.*

Summary of pressures in Occupation layer

Pressure on space: In the Parana Delta there is a clear trend towards land use. concentration, which consists mainly in land property and use changes from many small producers to just some few big companies. The pressure on space is mostly associated with large-scale production processes, such as cash crops agriculture as Soybean, livestock production and forestry. Nevertheless, it is also related to the influence of the nearby urban conurbation of the Buenos Aires Metropolitan Area, which expansion leads to the introduction of metropolitan patterns in the delta.

Vulnerability to flood: The Parana Delta is a wetland system that is exposed to pulses of floods and droughts. Vulnerability to flood has different implications on the islands and on the continental area of the coasts along the delta, where cities are located. The waterfront of the Upper and Middle Delta usually gets flooded as a result of precipitations and the increase in river discharges, while the Lower Delta is also affected by the Sudestadas, strong South Eastern winds coming from the Atlantic Ocean, which increase the level of the Rio de la Plata blocking the natural drainage of the delta (and the cities located in the coasts). When all these events coincide in time and space, it leads to floods and their negative consequences for areas which should not have been urbanized in the first place. The latter as consequence of unplanned urban growth and the prevalence of the private interests on the urban decision-making. The result is a mosaic of large private (protected?) elevated areas and public (vulnerable) depressed zones.

Water demand / freshwater shortage: Changes in land uses such as the urbanization of rural areas, the increment of the number of dwellings and the increase of the scale of production cause a rise of water demand in the cities. The average water demand of the Metropolitan Area of Buenos Aires in 2003 was estimated in around 4.179.000 m³/day.

Research gaps

- *Comprehensive database on climatic, natural resources and socio-economic parameters in order to support research and development of initiatives. Availability of the information for research purposes.*
- *Study on the effects of the different occupation typologies on the wetland (residential, production, recreation, etc.). Research on innovative solutions to prevent the increase of the terrestrialization trend, finding new ways of occupation according to the context.*
- *Research on innovative solutions for the government to recover its key role on territorial planning and management.*
- *Development of models regarding flooding scenarios in order to integrate them to planning decision-making. Study of the vulnerability to flood of coastal cities.*
- *Production of detailed land use maps*
- *Impact assessment of large-scale cattle raising on wetlands, biodiversity and other local productions like beekeeping.*

Summary of pressures in Network layer

Flood protection: Flood protection is built in the Parana Delta for production and residential purposes. In the last three years, the polder surface increased in around 16.5%, reaching 240.748 ha of polders. Apart from the polders, other used technique is the open ditch system, usually developed in small family production units, which consists in opening small channels or ditches connected with a watercourse to allow runoff from the fields by the action of gravity. Both types of works are developed by privates and alter the regime of the wetland. Thus, some other land movements have been carried on for the construction of residential developments. The topography of the affected islands has been modified to create marinas, clubs and large-scale residential areas, even reaching to a level of 5 m AMSL. These works are a clear consequence of the introduction of the concepts of gated community and consumption areas on the islands, as a product of the metropolitan model of urban growth

Irrigation and drainage: In recent years, the Parana Delta has been a centre of attention due to wetland degradation and the modification of the hydrologic pattern (building of embankments, polders and paths, closure of water courses and streams), to favour large-scale livestock farming, commercial forestry systems and agriculture systems (Soybean crops). In the case of forestry, new technologies are under development to manage water entrance into the polders (with lock-gates) in order to avoid hydric deficit during the periods of droughts.,

Water supply and sanitation: The islands of the Delta have no water supply or sanitation network. On the contrary, the cities along the borders of the Delta (including the Metropolitan Area of Buenos Aires) have an average coverage of the water supply network of around 50% and 20% of sewage system. Water supply captured from surface water courses represents 96% of the total daily production, while the rest 4% comes from yhe underground aquifers.

The main source of surface water is the Rio de la Plata and the underground water sources are the Pampeano and Puelches aquifers.The aquifers are located between 20 and 120 m (lower sea level) and present flows between 3 and 100 m3/h. Regarding sanitation, the system is divided into four areas and the catchment of the North area is treated in a plant located in San Fernando (in the Lower Delta), which has a capacity of treatment of 78.000 m3/day and serves 270.000 dwellings of the departments of San Isidro, San Fernando and Tigre.

Roads, railways, ports and navigation channels: The Parana Delta is connected to the metropolis and other urban areas by railways and highways. At the beginning of the urban expansion, the train had an essential role for the area as transport modality for passengers and freight. During the last decades of last century, public investment on highways encouraged the integration of the Delta into the dynamics of the metropolitan expansion from the basis of private transportation and favoured rapid access through land connections. The mobility network runs along the perimeter of the Delta, only crossing it through two systems of bridges and the routes run parallel to the coasts in the continental area. The terrestrial mobility network of railways and highways has always been deeply integrated with the port system that is located along the delta, which is the most important fluvial network of the country. It is the connection with the Atlantic Ocean and also holds the Parana-Paraguay waterway or ship channel (Hidrovía Parana-Paraguay) that links Nueva Palmira port in Uruguay with Caceres Port, located in Brasil

Research gaps

- *Research on the positive and negative impacts of infrastructure for production purposes on the community and the delta. Innovative solutions to decrease negative effects of infrastructure.*
- *Studies of the consequences / impact of polders and embankments in terms of lost of wetland good and services, using and "accumulated impacts" approach.*
- *Studies on the impacts of the waterway development on the local economy and natural environment.*
- *Introduction and assessment of new approaches like natural infrastructure and hybrid engineering*

Summary of pressures in Base layer

Coastal erosion: Although most coastal erosion existing on the Parana Delta is caused by natural processes, it is also induced by cattle raising, intensive agriculture and navigation.

River morphodynamics: The Parana Delta is a complex estuarine system because, in contrast to other deltas, it does not discharge its sediments directly to the sea, but through the estuary of the Rio de la Plata. The Parana River presents a discharge of 18.000 m3/sec and transports around 160 mill ton/year of sediments (28% clay, 56% mud and 16% sand). The sand which is deposited on the river mouth increases the length of the delta, while the mud influences on incrementing the size through the emergence of banks that become islands. In consequence, the delta has a rate of increased surface of around 617 km2/year and in spite of a slight decrease of the growing rate during the latest decades, the delta front will continue advancing being expected to reach Buenos Aires city's coast in about 110 years.

Flooding (flood hazard): The functioning and structure of the Delta wetlands are conditioned by periodic flooding influenced mainly by the discharges of the Parana river but also, in a lesser degree, by precipitations contributed by the tributaries of the continental margins, tides and the meteorological phenomenon known as "Sudestada". Those consist on persistent South-eastern winds coming from the Atlantic Ocean which increase the level of the Rio de la Plata.

Salinisation/salt intrusion: Even in an extreme condition, the levels of salin ization will not bring any consequence on the water quality for consumption supplied by the Rio de la Plata (surface source) for the Buenos Aires Metropolitan Area. Nevertheless, it could generate local negative effects that will have to be consequently evaluated. The estimated salt concentration is expected to reach 17% by the end of this century. Underground source of water (aquifers) suffers from salinization near the coast of Rio de la Plata and the Lower Delta, and below water courses, which may alter the quality of extracted water.

Water and soil pollution: Water quality in the Parana Delta region is good, however there exists some evidences of organic pollution and eutrophication in some specific areas, mainly caused by te effects of agricultural expansion like livestock waste, pesticides, urban and industrial waste and sewage. The tributaries of the Parana River are examples of the adverse impacts of the anthropic activities due to their high levels of pollution, which exacerbates in the middle and lower sections of the rivers, where the water is not suitable for human consumption and even worse

Wetland and biodiversity loss: The use of natural levees (albardones) that surround the Lower Parana Delta's islands by settlers has resulted in the loss of native woodlands, Besides, the polders and embankments produce a drastic change in the structure and performance of the wetland as it prevents the entry of water into the islands leading to a "terrestrialization" of the area. The rate of wetland lost due to polderization was estimated in around 10.500 ha/year.
The Delta region includes also 25 protected areas of different

size, jurisdiction and degree of implementation, totalling 488.000 ha under protection. Except those of national jurisdiction, the other protected areas lack of management plans or effective control measures.

Research gaps

- *Study the impact on biodiversity and ecosystem services resulting from human intervention and particularly those related to large-scale productions.*
- *Interdisciplinary research on water and soil pollution and their effects on biodiversity and local communities. Particularly studies regarding the impact of agrochemical use in the aquatic biota, fisheries and other traditional production activities, including and assessment of economic losses.*
- *Studies on the invasion and impacts resulting from alien species.*
- *Studies and monitoring of the fish stocks and local fisheries of the Parana Delta*

Summary of governance issues

Cooperation between (scale) levels and sectors of government: The network of jurisdictional authorities, competences and boundaries is complex. It is divided into three subnational jurisdictions (Provinces) and 19 local governments (Municipalities or Departments). There is a complex network of institutions that have the competence to decide on the Parana Delta region. The diversity of functional authorities, complex institutional arrangements and conflicting visions on the area's role, converge in making the design and implementation of policies and measures, including water management and land use strategies, a difficult task. In addition, frequently decisions taken by agencies are conflicting with the functions allocated by the regulatory framework and their legal assignment of competences, and in between government agencies, so the conflict on environmental issues is reflected within the institutions, at the different levels of government and even in the decision making process itself

Cooperation between government and private sector: The private sector is very diverse and includes from small scale cooperatives up to large institutions. Beyond some initiatives developed by the INTA (Instituto Nacional de Tecnología Agropecuaria) and the INTI (Instituto Nacional de Tecnología Industrial) or programs like PROSAP (Programa de Servicios Agricolas Provinciales), the level of cooperation between the public and private sector is low. One remarkable Public-Private enterprise is the Management Plan for the Delta of Tigre (Plan de Manejo de las Islas del Tigre), developed by Fundación Metropolitana and the government of the Department of Tigre in 2013.

Involvement of stakeholders and citizens: The civil society is strongly involved in the Parana Delta, either through research institutions and local groups who fight for the fulfillment of environmental rights and the protection of the region. Today there are more than 35 civil society organizations that focus their work on the Parana Delta and the surrounding area. The level of participation has increased as the threats manifest more visible. Also, an increase in the participation of NGOs in the design of public policies and monitoring processes of territorial planning is observed.

Approaches for dealing with risks and uncertainties: The National Water Institute (Instituto Nacional del Agua, INA) has an important role through hydrological alerts and warnings of flood events, which has a great importance Apart from that, there are no approaches to dealing with risks and uncertainties in terms of processes and policy.

Research gaps

- *Need for enforcement of existing legislation and plans.*
- *Increase of the tools for citizen participation in decision making process.*
- *Development of integrated management plans taking into account the heterogeneity of the delta and the different kinds of actors involved*