



Comparative assessment of the vulnerability and resilience of 10 deltas

work document

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Internet

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

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Design and lay-out

Deltares

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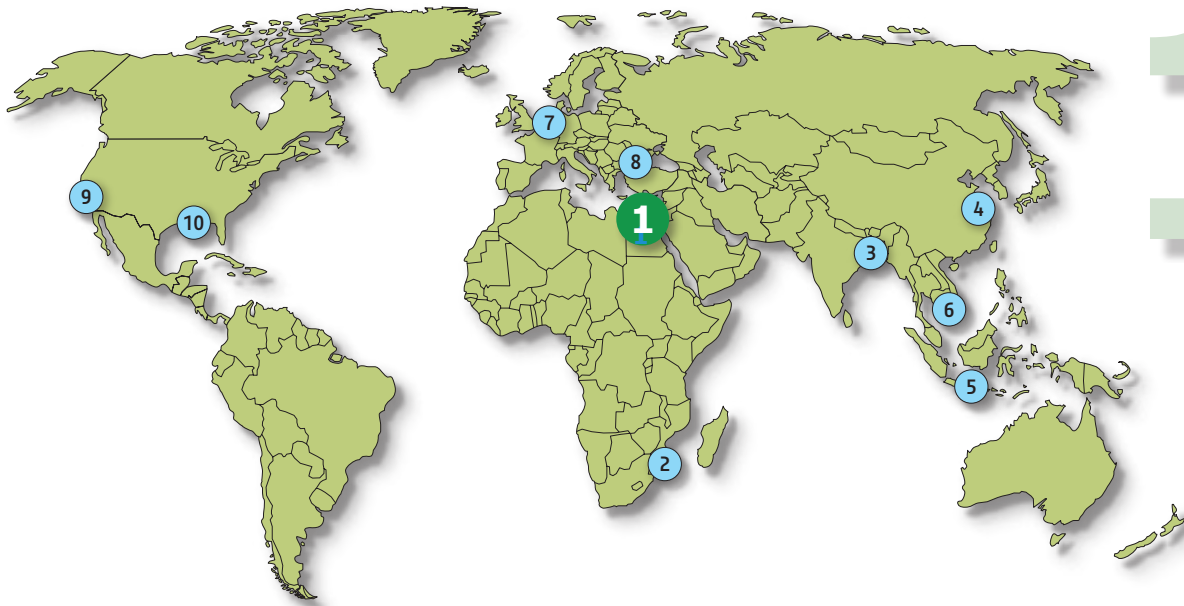
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Continent	Country	Delta	No
Africa	Egypt	Nile	1
	Mozambique	Incomati	2
Asia	Bangladesh	Ganges-Brahmaputra-Meghna	3
	China	Yangtze	4
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Nile delta

No

1



1 Current and future state of the Nile delta

1.1 Drivers of change

Summary of drivers of change

Demographic trends: About 35 million inhabitants are living in the Nile delta. The population density is about 1000 inhabitants/km² with a growth rate of 2% per year.

Economic developments: Economic conditions in Egypt have improved considerably over the years. In 1990-91, real GDP growth rate was 3.7%. By the end of fiscal year 1998, the growth rate reached 5%, fuelled primarily by private sector investment through continued rapid privatization and institution building (Egypt INC). Results of the economic and financial performance indicated a great improvement during FY 2006/2007 and first quarter of FY 2007/2008. Egypt's economy achieved a growth rate of 7.1% which is the highest growth rate in the preceding 10-year period.

The tourism, industry, agriculture, and service sectors are significant contributors to Egypt's economy. Tourism currently represents 11.3% of GDP, 40% of the total Egypt's non-commodity exports and 19.3% of Egypt's foreign currency revenues. The industrial sector's contribution to the GDP in 2006/07 was around 17.2%. The agriculture sector accounts for roughly 14.8 % of GDP. Also, agriculture contributes about 30% to Egypt's commodity exports, which makes it a major revenue-generator. And, of Egypt's overall labour force, 40% works in the agricultural sector, mostly in the Nile delta and Nile Valley.

The economic importance of the Nile delta comprises industrial centres, commercial and fishing harbours, large urban areas, tourism centres, agriculture activities, gas and oil production, and fisheries.

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

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

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

Research Gaps

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

1.1.1 Socio-economics (population growth- migration, economic development + most relevant sectoral developments, e.g. for agriculture, fisheries, industry)

Population

Population growth is certainly among the most pressing challenges that Egypt is facing in its developments. By 2003 the total population in Egypt is estimated at 72,5 million with an annual growth rate of 1,9%. By 2020 the population is estimated between 85 and 90 million. Some 50% of the Egyptian population lives in the Nile delta.

Economic development

Egypt's long-term macro-economic prospects look favourable, with progress set to accelerate on such structural issues as privatisation, trade liberalisation and deregulation. Egypt's main challenge is matching employment growth to the estimated 800,000 new job seekers coming into the labour market each year.

The agricultural sector, which represented 40% of GDP in 1960, now only produces 17% of GDP. It is almost completely in private hands. The industrial sector, of which 26% is still in public hands, produces 32% of GDP. The services sector, including governments is with 50% GDP the largest sector. In 2002 the annual GDP was some 4,000 US \$ per capita. Apart from the formal economy, Egypt has an extensive informal economy comprising street vendors, cleaners, gardeners etc. whose economic activities are not registered by the official statistics.

Agriculture

Agriculture is still a main economic activity in Egypt. The present agricultural strategy aims at food security (not self-sufficiency). Egypt is increasingly in a position to produce higher value food crops (e.g. fruits and vegetables) and non-food crops (e.g. cotton) and trade them to purchase staple food and have additional revenue and employment as well. The most important crops cultivated in the Nile delta are clover, maize, cotton wheat, rice, fruits and vegetables.

The agricultural sector has already implemented more reforms in terms of privatisation and liberalisation than any other sector in the economy. As a result crop yields in the Nile delta have increased dramatically to the extent that they are approaching the theoretical maximum. Farm incomes have however at the same time suffered from the increasing fragmentation of land property (inheritance). As a result the average farm income in the Nile delta is for more than 50% depending on salaries earned outside agriculture.

Parallel to the developments in the "Old Lands" (the Nile delta and Nile Valley), private sector agricultural investments in the Desert and fringes have been very successful in developing a modern (export) market oriented agriculture which is very innovative. Originally based on groundwater use, these entrepreneurs are now switching to using Nile water because groundwater is not sustainable.

If these trends continue unchecked, further marginalization of traditional agriculture in the Nile delta will be caused by increasing fragmentation of land properties and increasing water shortages due to strong economic developments (industry and modern agriculture) elsewhere. An innovation process is needed to transform the existing traditional agriculture in the Nile delta into an economic feasible alternative with new farming systems that can deal with lower water allocations and that integrate different agronomic activities to enable cradle to cradle principles. This cannot be done, however, without considerable migration of (hidden) unemployment to other sectors.

Animal husbandry

The animal husbandry sector is divided into a small scale, largely subsistence oriented sector catering for the farm family and its direct surroundings; and a modern sector catering to the urban consumer. Beef and milk production in Egypt is still underdeveloped. The country is not self-sufficient in these commodities. Considering the large water footprint of beef and especially milk, self sufficiency should be questioned.

Fisheries

The marine and inland waters of Egypt are reported to produce some 770,000 tons of fisheries products. Some 20% of this quantity is produced in the coastal lakes of the Nile delta. Virtually, all Egyptian semi-natural water bodies are fished to the maximum and some are overexploited already. Fish farming is a traditional economic activity in Egypt, with business units currently ranging from traditional village type ponds to modern governmental and private fish farms. Aquaculture as economic sector would get a boost if the ban on the use of fresh water would be lifted. The present ban for aquaculture to use freshwater, leaving only drainage water as an alternative, is a risky one because of pollution threats to the food chain.

Industry

Industry is a growing sector in the national economy of Egypt. Further industrial development is expected to play a major role in the socio-economic development of the country, providing employment for a large part of the growing population. The industrial policy is to create new cities and industrial zones outside of the Nile Valley and Delta.

1.1.2 Climate change (temperature/evaporation, sea level rise, precipitation/discharge)

Egypt is almost totally (95%) dependent on Nile water and has been so for thousands of years. The average annual evaporation of Upper Egypt and the Nile delta is 1,750 mm and 1,500 mm respectively. Lower Egypt is also favoured by some precipitation: the average annual precipitation in the delta ranges from 30 mm near Cairo to 200 mm on the Northern Coast compared less than 25 mm in Upper Egypt.

1.1.3 Subsidence

Land subsidence in the coastal zones of the Nile delta is caused by oil and gas production, soil compaction and (fault) tectonics, and is not compensated by sedimentation due to insufficient sediment supply by the Nile River. The coastal zones of the Nile delta are tilting with rates varying from 0.5 to 4.0 mm/year eastward.

1.1.4 Technological developments (e.g. regarding civil engineering, agriculture, ITC, energy)

In the field of hydraulic engineering, coastal engineering, hydrodynamics, and water management many research programs of NWRC, research institutions and universities have been carried out.

1.2 Pressures – impacts

1.2.1 Land and water use (occupation layer)

Summary of pressures in Occupation layer

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

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

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

Research gaps

- Land-use and land-cover change models – There is a need for models to predict land-use and land-cover changes, urban and rural land-use change, and agricultural land-use change. Models need to be appropriate for sea-level rise as well as climate change and ecosystem projects, including vegetation changes and loss of ground surface to permanent seawater flooding.
- Spatial planning – How can we optimally integrate the water management and sea flooding safety infrastructure into spatial planning concepts?
- Water use and treatment in industry, domestic and agriculture – Which innovations are needed in industry, domestic and agriculture for treatment and more efficient water use?
- Ecosystems, agriculture and salinisation - What are opportunities for using natural protectorates areas for water retention in salinating areas? Could wetlands function as blockades against salinisation of groundwater and salt water intrusion? There is a need to develop saline agriculture (including fish and algae) or cultivation of more salt-tolerant crops (e.g. sugar beet).
- Ecological flow requirements - Which ecological flow is required to maintain soil salinity in the Nile delta at acceptable levels for agriculture and in the coastal lakes for fisheries and biodiversity (and also control sea water intrusion)?

Population growth

Outside the Nile river valley and the delta, Egypt is desert. Consequently, most of the Egyptian rural population lives in the Nile Valley and delta. With a population growth rate of nearly 2% the pressure on the available space is the main issue of the Nile delta. Present government policy is to develop new infrastructure for economic activities (mainly industry) outside the Nile delta and Nile Valley. This creates a challenge of water supply, water purification and water recycling in these remote desert areas.

Hydrology

Since the construction of the High Aswan dam, the flow of the Nile is fully regulated. The discharge from Lake Nasser is (by international agreement) 55,500 million m³/year. Downstream of Aswan, the water levels and water distribution are controlled by a number of barrages. North of the delta considerable quantities of Nile water are diverted for irrigation, of which most of the drainage flows back to the Nile, leaving some 35,000 million m³ annually for the delta. In the future, a lower supply to the Nile delta can be anticipated due to upstream economic developments and diversions for agriculture in the deltaic fringes, especially during a number of consecutive drought years. The main water distribution network in the Nile delta may need to operate under discharges below the minimum design discharge. Modernization is warranted.

The Nile delta is underlain by an aquifer composed of a thick layer of sand and gravel with clay intercalations. The sediments are covered by a clay cap of varying thickness, up to 50 m in the northern part of the delta. In terms of abstraction the Nile aquifer is the most important aquifer in Egypt. However, since the aquifer is recharged by infiltration of excess irrigation water originating from Nile water released at Aswan, the Nile aquifer is not a separate resource. In the north groundwater abstractions cause seawater intrusion into the aquifer.

Intensification of agriculture

The water resources of Egypt are limited to the discharge of the river Nile, which is fully controlled by Lake Nasser. According to international agreements Egypt receives 55,000 million m³ per year. The main concern in water resources management in Egypt is to use the available water to the maximum extent for agriculture. The quantity of fresh water that is finally draining to the Mediterranean should be minimal. A major issue in Egypt is intensification of agriculture. In Egypt this is called horizontal expansion (more irrigated area with the same quantity of water).

1.2.2 Infrastructure (network layer)

Summary of pressures in Network layer

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

Research gaps

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

Infrastructure (general)

With some 50% of the Egyptian population living in the Nile delta, the delta comprises many cities and towns. Main cities are Alexandria and Port Said along the Mediterranean coast and Ismailia along the Suez Canal.

Main roads in the delta are the Mid Delta Road and the West Desert Highway, connecting Cairo with Alexandria and other main cities in the Middle and West delta. The Eastern Desert Highway connects Cairo with Ismailia, Port Said and other cities near the Suez Canal and Sinai.

The river Nile and its branches have been used for river transport since ancient times. In the Nile delta, the Damietta and Rosetta branches, the Nubaria Canal and Beihera Rayah are growing as proper means for navigation and transport, connecting the Mediterranean with the main river at Cairo and south to Aswan. The Ismailia Canal connects Cairo, on the river Nile, with Ismailia on the Suez Canal.

The water supply to the irrigated agricultural areas of the Nile delta is both by gravity and pumping. The delta barrages near El Qanater regulate the flows. The canal system is very extensive. Branch canals take off from the main or lateral canals and deliver the water to smaller distributary canals, which in turn deliver water to the field intakes (mesqas). Because the water level in the irrigation system is below field level in most of the area, the water has to be raised. The use of high-capacity diesel pumps has resulted in widespread inequity of water availability along tertiary canals. To improve irrigation efficiency, Egypt has converted most of its open drainage systems into subsurface pipe drainage systems. Subsurface drains keep groundwater levels well below the crop root zone but also allow a better discharge of excess irrigation water. The Integrated Irrigation Improvement and Management Project (IIIMP) provides training packages and on-farm infrastructure resulting in lower losses, and a continuous flow regime in the tertiary canals.

Egyptian farmers in the Nile delta are not (yet) used to (continuously) operate under water scarcity conditions. This will become their future, however. Working efficiently and effectively under scarcity conditions entails full control over the scarce resource. This can be achieved by local storage or possibly by complex ICT infrastructure to adjust farmers' needs (within his water rights) with supply through distribution networks. New farming systems need to be

developed to increase the water productivity for the farmer. His paradigm shift will be to shift from high economic returns per hectare towards high returns per m³.

1.2.3 Natural resources (base layer)

Summary of pressures in Base layer

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

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

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

Research gaps

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

Water quality

The combination of rapid population growth and intensification of agriculture requires permanent attention for the quality of surface water and groundwater. In the Nile delta most of the domestic (and sometimes even industrial) wastewater is discharged to the drains without any treatment. Re-use pumping stations are mixing drainage water with irrigation water, thus contaminating the water in the irrigation canals. The quality of groundwater in the Nile delta is threatened by over-exploitation of wells as well as leaching of agro-chemicals from the surface, leading to salinisation or contamination of the groundwater resource. Water quality

management has been declared a national priority in Egypt. At this moment, however, the legal regulations and institutional capacity, enforcement practices to guide this process are limited.

At present investments in wastewater treatment plants are being effectuated on a large scale. This, however, does not solve the diffuse pollution by wastewater of small villages. This diffuse pollution ends up in drains and irrigation canals. Water pollution is further compounded by uncontrolled solid waste dumping in both drainage and irrigation canals.

In the Nile delta fresh water is intensively used for agriculture. Irrigation and drainage systems have been developed long ago and are not always well maintained. The Egyptian government is implementing large programmes for improvement of irrigation and agriculture practices.

Shore protection / Coastal erosion management

Since the construction of the Aswan dam, most of the Nile sediments are trapped in Lake Nasser. Consequently, the sediment balance at the coast is disturbed, leading to coastal erosion at various locations. Shore protection and coastal erosion management are another important issue in the Nile delta.

Wetlands

The Nile delta comprises several coastal lagoons. As these lagoons are on the migration route of various birds these wetlands have an important ecological function. In the Delta Lake Burullus and Lake Bardawil are RAMSAR sites. Lake Bardawil (Sinai) is still pristine and still has its hyper-saline character and related biodiversity. Lake Burullus has been altered by human influence (drainage) into a brackish ecosystem. For both Lakes different ecological flow requirements may be needed, which is an important subject of study. As the coastal lagoons are at the end of the system the water quality is threatened by salinisation and contamination.

1.3 Governance (institutional/organizational aspects of delta management)

Summary of governance issues

Cooperation between (scale) levels and sectors of government:

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

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

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

Involvement of stakeholders and citizens: Although the Government of Egypt has realized the importance of stakeholders and citizens involvement in decision making process to increase public acceptability, it is still limited. The involvement of stakeholders and citizens is relatively higher at local level, whereas at the provincial and national levels are less.

A new master plan for the coastal zones is still far from community participation

Approaches for dealing with risks and uncertainties: To reduce loss of lives and land, Egyptian Government has implemented a comprehensive plan to manage the shoreline of the Nile delta.

There is a growing attention for awareness rising on climate changes impacts. Vulnerability of coastal zones to inundation due to sea level rise has been studied and many observation systems have been practiced.

Research gaps

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

The governmental structure of Egypt consists of three levels: the central government (26 Ministries); the Governorates and the districts. At the national level the Ministry of Water Resources and Irrigation (MWRI) is the prime responsible ministry for water resources management. At the de-central level 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.

1.4 Main indicators for drivers, pressures and governance

DRIVERS	Main indicators
Demographic trends	to be added..
Economic developments	
Technological developments	
Climate change	
Subsidence	
PRESSURES/IMPACTS	Main indicators
Land and water use (occupation layer)	to be added..
Network / infrastructure (network)	

layer)	
Natural resources (base layer)	
GOVERNANCE	Main indicators
Multi-level and multi-sectoral cooperation	to be added..
Public-private partnerships	
Involvement of stakeholders and citizens	
Approaches for dealing with risks and uncertainties	

1.5 Score card

The scores in the score card are just qualitative and indicative, based on the summary tables descriptions for each item (above). Each item is scored on a 5-points scale, related to resilience and sustainability.

The following two development scenarios are recognized:

- Scenario1, moderate perspective 2050: medium economic growth (1,2 %, WLO-scenario RC) and related medium technological developments, combined with medium climate change and sea level rise (KNMI-scenario G, relative sea level rise 0,30 cm)
- Scenario2, extreme perspective 2050: high economic growth (1,7%, WLO-scenario TM) and related high technological developments, combined with high climate change and sea level rise (KNMI-scenario W+, relative sea level rise 0,40 cm)

Delta	Land and water use (occupation layer)	Infrastruc-ture (network layer)	Natural Resources (base layer)	Governance	Overall Resilience & Sustainability indicator
Current Situation 2010	--	0	-	0	-
Scenario 1 moderate 2050	-	0	-	0	-
Scenario 2 extreme 2050	--	-	--	0	--

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

Clarification notes on the score card:

The current situation in the Nile delta can be described as close to moderate rather than low. The pressures on the occupation layer and the base layer will increase due to population growth and economic development in the country.

Furthermore, climate change and sea level rise will make the situation worse unless mitigation measures will be deployed and adaptation strategies planned.

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

2. Overview of currently applied adaptive measures in the Nile delta

Name of measure	Type of measure 1. Technical 2. Ecological 3. Economic 4. Institutional	Brief description	Strategy 1. Protect 2. Adapt 3. Relocate	Layer 1. Occup. 2. Network 3. Base
"National Strategy Study" on adaptation	4	Egypt's Ministry of Environmental Affairs is preparing a "National Strategy Study" on adaptation, including a vulnerability index to pinpoint the most endangered regions.	2	1,2,3
Water resources management plan	4	Updating water resources management plan (including decentralization of planning)	1,2	1,2,3
Coastal protection constructions	1	Protection constructions carried out by the Shore Protection Authority (SPA) (Damietta, Rosetta, and Al-Burullus).	1	2
Natural sand dune systems	2	Restoration/maintenance of natural sand dune systems	1	3
Construction of flood protection wall	1	Mohammed Ali Wall which protects low lands at Abu-Quir Bay in the western region of the Nile delta.	1	2
Research institutes	4	Resources and capacities of Coastal Research Institute (CoRI) built since 1971 and other related-research institutions in Egypt.	1,2	1,2,3
Raising banks of canals	1	Al-Salam Canal goes by Al-Manzalla Lake and its banks have levels more than 2 m above lake's water level.	2	2
Multifunctional flood protection	1	The international road	1	2

infrastructure		could act as the second defensive line to protect north zone of the country. UNDP in 1992 had a roundtable meeting about considering the road as a measure against the impact of sea level rise.		
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3. Overview of technical methods and tools to support delta management and development in the Nile delta

Overview of technical methods

- Capacity building programs
- Awareness programs
- Research programs
- Establishment of research entities in the field of water resources management and climate changes impacts and adaptation
- Establishment of the supreme climate change committee Construction of physical models and hydrodynamic labs
- Updating the research plans to cope with climate changes aspects as well as integrated management plans or water resources and coastal zones

4. Knowledge exchange and development

4.1 Lessons learned on delta management

Out of the research and implemented programs carried out, the following aspects are needed for the future:

- Capacity building in terms of staff, technologies, modelling,etc.
- A comprehensive national and regional response strategy
- Coordinative actions to minimize risks and maintain ecosystem
- Preparation of integrated plans for coastal zones and water resources management schemes
- Building co-operative mechanism to integrate all efforts
- Awareness program and media campaign
- Regional monitoring and observation system
- Regional data base and knowledge exchange system
- Regular Maintenance program for protection structures

4.2 Summary of research gaps and related needs for knowledge exchange

Drivers of change

See text above.

Pressures – potential problems / Challenges - opportunities

See text above.

Adaptive measures

Research gaps and related needs to be added..

Technical methods and tools

Research gaps and related needs to be added..

4.3 Some available illustrations (map of delta, typical sites, etc.)

To be added..

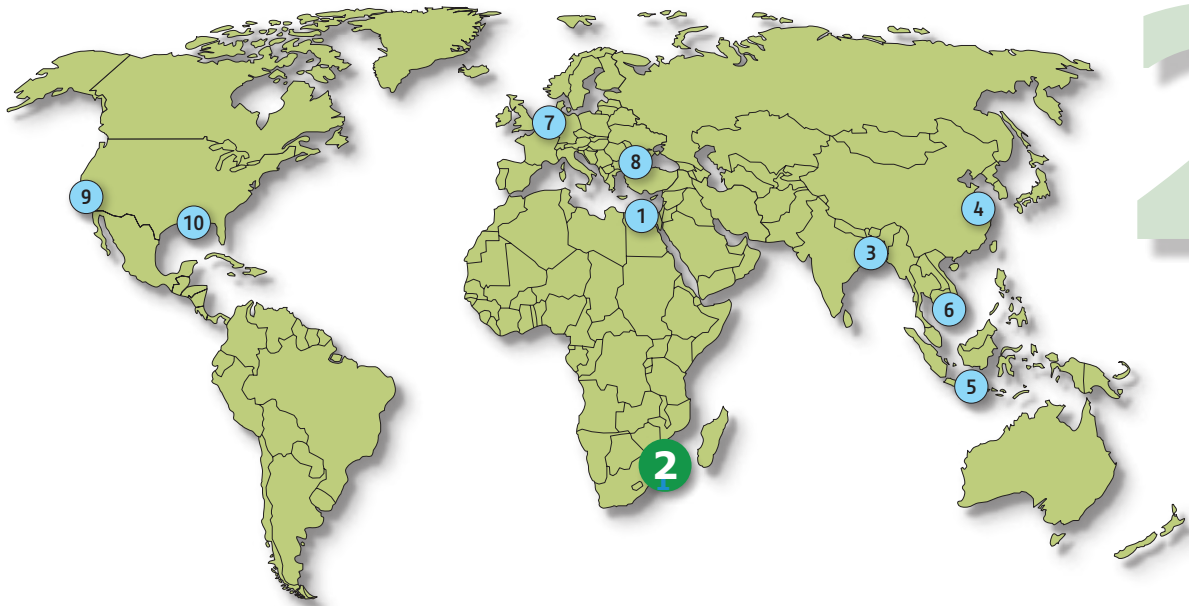
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Incomati delta

No

2



1. Current and future state of the Incomati delta

1.1 Drivers of change

Summary of drivers of change

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

Economic developments: The Incomati catchment is one of the fastest growing socio-economic regions in the SADC region, due to rapid developments along the Johannesburg-Maputo international axis of economic development, which is mainly situated in the catchment. Currently, 50% of the water, generated in the basin, is being withdrawn. Upstream, part of the water is being transferred to drier river basins in South Africa.

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

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

Subsidence: There are no evidences of subsidence in the delta, but it is believed that due to freshwater shortage and heavy extraction of ground water observed in the lower Incomati river basin, subsidence is likely to occur in the delta. On the other hand, there are evidences of accretion in the mouth. Aerial photography analysis over the period 1965 to 1991 showed that the Macaneta Spit, located at the mouth of the Incomati river, has been building up sediments. In addition, the spit was displaced, pushed and stretched south-east wards by an area of about 0.3147 km², during the period 1965 to 1982, and by about was 0.0899 km², during the period 1982 to 1991. The observed displacement seems to be the result of an accretion process.

Technological developments: The Science, Technology and Innovation Strategic Development Plan of Mozambique aims at the development of science and technology, including traditional knowledge, to increase the production of goods and services which will contribute to the poverty alleviation, economic development of the country and to the wellbeing of Mozambicans.

Solar energy is being promoted for pumping water to supply villagers for domestic use, and there are plan for applying on irrigation of the small scale farms. The technology used in agriculture is old-fashioned still, with exception of the sugar cane production which is mechanized. There are research on the production and improvement of draught resistant crops mainly for the villagers. There are no major building constructions in the delta; the government encourages the use of local material for the building of touristic lodges. There are plans to build large commercial aquaculture farms in the delta, which may bring technology development. The Ministry of Science and Technology promotes and encourages the use of ICT, so the internet and cellular phones are accessible throughout the delta. Further, the Ministry established a Millennium Village in the delta, which is an incubator of science and technology; this would improve the development and adoption of technologies.

Research gaps

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

1.1.1 Socio-economics (population growth- migration, economic development + most relevant sectoral developments, e.g. for agriculture, fisheries, industry)

Population

About 2,5 million inhabitants are living in the (urban) delta zone between Incomati Bay (Maputo) and the border of South Africa. The total population of Mozambique amounts 19,4 Million (World factbook, July 2005 est.). The estimates explicitly take into account the effects of excess mortality due to HIV/AIDS, which can result in lower life expectancy, higher infant mortality and death rates, lower population and growth rates, and changes in the distribution of population by age and sex than would otherwise be expected. The population is continuously growing (0.42 %/yr). Mozambique is still considered one of the poorest countries in the world. In 2003-2005 per capita income was \$290, the prevalence of AIDS was 16.2 percent, and infant mortality was 101 per 1,000. Mozambique has also been able to maintain steady economic growth rates averaging 6 to 7 % a year over the past decade. These are encouraging results, and within the Southern African region Mozambique is one of the fastest growing economies according to the SADC (2004), with an economic growth rate of 7.8 %. But Mozambique is still a least developing country (LDC) that faces considerable economic and human development challenges and the role and contributions of external development partners remain important.

There are considerable differences between Mozambique and Swaziland on the one hand and South Africa on the other hand, as far as socio-economic and technical developments are concerned.

Economic development

Economic development in the basin is rapidly increasing. The downstream part of the basin has significant ecological and socio-economic importance: the Incomati estuary is a nursery for commercial important fisheries including shrimp and a breeding ground for various aquatic birds. The hydrodynamics and productivity of the Maputo Bay depends largely on the freshwater input from the Incomati river.

There are large numbers of dams in the basin, 22 of which can be classified as large, and most of them located in South Africa. Mozambique has only one large dam, the Corumana Dam that was completed in 1988 and serves mainly as the storage component of an irrigation system.

The estuary has an extensive mangrove forest covering about 5000 ha near the mouth of the estuary. By serving as nursery grounds, the estuary and adjacent mangroves play a major role in the life cycles of economically important fish and shell fish species and therefore sustain a considerable proportion of local population and the fish industry. The estuary discharges into the Maputo Bay, which covers an area of about 1200 km², opened to the sea in the north. The bay can be considered as a dual ecosystem, which receives freshwater from the river through the eastern side, while the western side is influenced by open seawater with flourishing corals.

The Kruger Park is a large touristic asset to the area and partly depends on the Incomati Basin waters. Recently the Park is extending its boundaries into Mozambique (Peace Park).

Agriculture

The sectors providing the mainstay of the economy in the basin are agriculture (irrigated sugarcane) and forestry (rain-fed commercial tree plantations).

Fisheries

The estuary is the second important area for shrimp production in Mozambique. The annual catches of shrimp of the semi-industrial fleet are on average about 200 tons. Currently the fishery sector in Maputo Bay employs about 6,000 fishermen, from which about a half are engaged in shrimp fishery. The estuarine fishery contributes approximately 20% of the overall shrimp caught in the Maputo Bay. There are about 24 freshwater and estuarine fish species of significant social and commercial value in the Lower Incomati and in the Lake Chuáli, one of the large natural lakes in lower Incomati.

Industry

MOZAL, a large aluminium smelter, is one of the countries largest investments in the early 20-ies, and is situated near Maputo Bay.

Major industries outside urban areas in the basin are paper mills and sugar mills.

1.1.2 Climate change (temperature/evaporation, sea level rise, precipitation/discharge)

The climate in Mozambique is highly variable with frequent floods and droughts. Most of the sectors which contribute to the economy are either directly dependent on secure, sustainable water availability or are indirectly affected by water shocks. Sensitivity of the economy to water shocks indicates that between 1981 and 2004 GDP growth was reduced by an average of 1.1% point annually as a direct result of climatic variability. The total costs of these water shocks over this period are estimated at about US\$ 1.75 billion.

The general climate in the basin varies from a warm to hot humid climate in Mozambique to a cooler and dry climate in the upper basin parts. There is a summer rainfall (october-march) with a mean annual precipitation of about 740 mm/y. The lowlands are prone to tropical cyclonic storms. Climatic cyclicity between dry and wet periods (8-10 year cycle) has been identified for the lower regions and has been linked to the influence of El Nino on the region.

Climate change is expected to exacerbate the current problems through a combination of rising sea level and extreme river discharges (floods and droughts). Effects of climate change will influence the Incomati basin strongly. A recent study (2009), for example, indicates that in the near future (up to 50 years) an increasing frequency of cyclones together with sea level rise and associated salt intrusion, will have impact on the coastal floodplains. It will have serious effects on livelihood conditions (agriculture) and on environmental aspects. This also stresses the issue of safety and how to protect against floods, as well as the operation rules for the dams that are in the basin.

1.1.3 Subsidence (natural or human-induced)

I would only write a few lines here. As far as I can think of, there is not any significant subsidence in the Basin and not in the Bay as well. I don't know about eustatic rising or declining.

There are no evidences of subsidence in the delta, but it is believed that due to freshwater shortage and heavy extraction of ground water observed in the lower Incomati river basin, subsidence is likely to occur in the delta. On the other hand, there are evidences of accretion in the mouth. Aerial photography analysis over the period 1965 to 1991 showed that the Macaneta Spit, located at the mouth of the Incomati river, has been building up sediments. In addition, the spit was displaced, pushed and stretched South-Easterwards by an area of about 0.3147 km², during the period 1965 to 1982, and by about 0.0899 km², during the period 1982 to 1991. The observed displacement seems to be the result of an accretion process.

1.1.4 Technological developments (e.g. regarding civil engineering, agriculture, ICT, energy)

The Science, Technology and Innovation Strategic Development Plan of Mozambique aims at the development of science and technology, including traditional knowledge, to increase the production of goods and services which will contribute to the poverty alleviation, economic development of the country and to the wellbeing of Mozambicans.

Solar energy is being promoted for pumping water to supply villagers for domestic use, and there are plan for applying on irrigation of the small scale farms. The technology used in agriculture is old-fashioned still, with exception of the sugar cane production which is mechanized. There are research on the production and improvement of draught resistant crops mainly for the villagers. There are no major building constructions in the delta; the government encourages the use of local material for the building of touristic lodges. There are plans to build large commercial aquaculture farms in the delta, which may bring technology development. The Ministry of Science and Technology promotes and encourages the use of ICT's, so the internet and cellular phones are accessible throughout the delta. Further, the Ministry established a Millennium Village in the delta, which is an incubator of science and technology; this would improve the development and adoption of technology.

1.2 Pressures – impacts

1.2.1 Land and water use (occupation layer)

Summary of pressures

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

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

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

Research gaps

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

Pressure on available space

Apart from greater Maputo (near Maputo Bay) and Nylstroom, the basin has no major urban developments. Land use in the form of agriculture and forestry will increase.

Hydrology

The Incomati is rainfed. The average discharge of the Incomati watercourse at the estuary is about $100\text{--}200\text{ m}^3\text{ s}^{-1}$, corresponding to about 3,600 million m^3 per year, to which South Africa contributes 82%, Swaziland about 13% and Mozambique about 4%. The regime of the Incomati River is characterised as torrential with high flows during the wet season, from November to March and relatively low flows in the dry season, from April to October. On average, 60 to 80% of the mean annual flow occurs in a few months of the year. Figure 2 presents the runoff of the Incomati as observed at the Magude runoff station, the most downstream runoff gauge station. In most years runoff is below $100\text{ m}^3\text{ s}^{-1}$, and there are years with runoff near zero. This emphasise the upstream obstruction of water. The average annual evapo-transpiration estimated at about 1900 mm exceeds the precipitation estimated at about 740 mm.

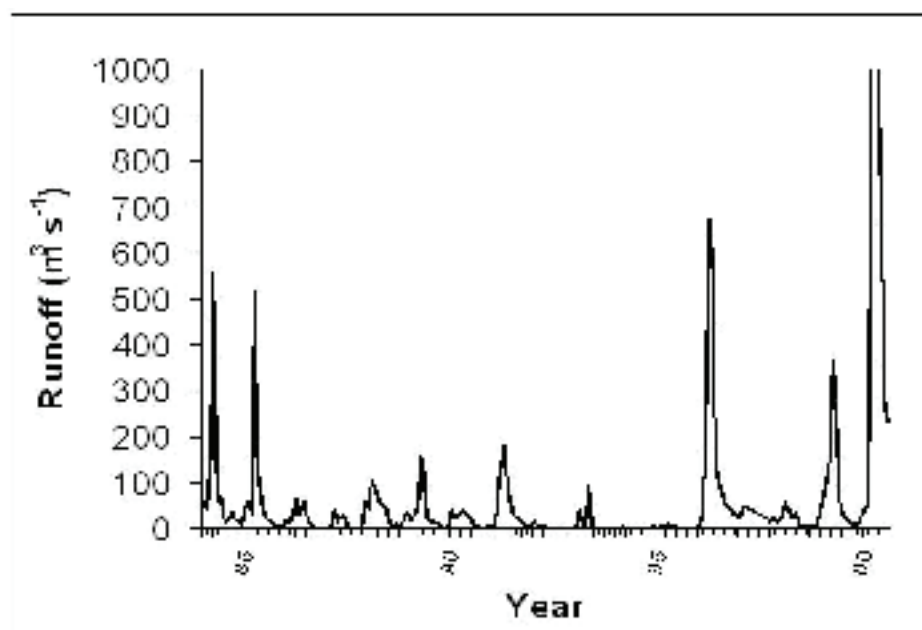


Figure 2. Time series of the Incomati River runoff at Magude (Hoguane *et al*, 2002).

The tide at the Indian Ocean is meso-tidal being in the range of 1-3m.

Vulnerability to flooding

Flooding occurs in the lower basin at irregular intervals, with impacts on agriculture, natural habitats, damage to infrastructure and loss of life. The most devastating flood occurred in the year 2000. In Manhiça, located at the lower Incomati, alone about 17,000 ha of cultivated land were flooded and 20,000 families were affected while 18 deaths were reported.

There are no flood protections along the river.

Freshwater shortage and deterioration of water quality

The two overriding issues in the Incomati River Basin are the modification of stream flow leading to draught and flood situations and water shortages. These are caused mainly by dams and reservoirs, water abstraction from these and inter-basin transfers to meet the increased demand for agriculture, urban and industrial developments. The mean annual irrigation water requirements for actual developed areas within the Incomati River Basin is estimated at 1125 million m³, and is distributed as follows: Mozambique (280), South Africa (670) and Swaziland (175). 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. Main coastal impacts of modification of stream flow and water shortages are:

- Deterioration of water quality resulting in pollution and consequent occurrence of water born diseases. Bacteria *Vibrio parahaemolyticus* and *Vibrio mimicus* were found in clams in the Incomati River mouth. Waterborne diseases, such as diarrhea, dysentery and cholera, occur almost every year, since 1994. About 50% of cases of waterborne diseases occur in Maputo. The diarrhea affects on average about 50000 people a year in Maputo. In 1997, an epidemic cholera occurred and affected about 4000 people in Maputo.
- Declining freshwater flow and increased salinity intrusion that threatens the agriculture potential in the lower Incomati basin. Salinity intrusion up to 80 km upstream has been observed. It is estimated that a runoff of 35 m³s⁻¹ is required to keep the salt intrusion below 20 km upstream. It is found that salt intrusion would affect about 850 ha of farming area.

1.2.2 Infrastructure (network layer)

Summary of pressures

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

Research gaps

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

Infrastructure (general)

The infrastructure in the Johannesburg-Maputo international socio-economic axis of development is rapidly improving.

The present drinking water production for the greater Maputo area is insufficient. Studies are being carried out how to meet the growing demands. The Incomati Basin may be used for this purpose.

Ageing infrastructure

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

1.2.3 Natural resources (base layer)

Summary of pressures

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

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

Research gaps

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

Coastal erosion

The margins of the delta are eroding mainly due to clearing of mangroves and vegetation over the dunes, storms and high river streams during floods.

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

Nature, loss of environmental quality and biodiversity

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

Pollution and reduced hydrodynamics directly or indirectly lead to modification of ecosystems and decline in biodiversity. Decreased freshwater flow has negative consequences for the ecosystem of the Incomati estuary and Maputo Bay because of its important function as spawning and nursery area for coastal fisheries.

Salinity intrusion up to 80 km upstream has been observed. It is estimated that a runoff of $35 \text{ m}^3 \text{ s}^{-1}$ is required to keep the salt intrusion below 20 km upstream. It is found that salt intrusion would affect about 850 ha of farming area.

1.3 Governance (institutional/organizational aspects of delta management)

Summary of governance issues

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

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

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

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

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

Research gaps

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

Given the fact that shortage of water is the main issue of the Incomati River basin, there have been major effort, in the individual countries and collectively, towards the management of this shared water course. Efforts to bring together countries sharing the Incomati river basin have a long history. In 1964, an agreement was signed between the Governments of South Africa and Portugal.

More recent measures include:

1. The establishment of a **Tripartite Permanent Technical Committee (TPTC)**, in 1983 by the Governments of South Africa, Swaziland and Mozambique to provide technical advice to the governments regarding management of the shared water courses.
2. In 1991 the **Piggs Peak Agreement** was signed by the Tripartite Ministerial Meeting of ministers responsible for Water Affairs. This agreement established, among others, the maintenance of a minimum cross-border release of $2 \text{ m}^3 \text{ s}^{-1}$ averaged over a cycle of three days for the lower riparian country. The agreement also initiated the Joint Incomati Basin Study (JIBS) aimed at expanding the knowledge base needed to develop and adopt

- policies and strategies for management of the Incomati water courses. The study was launched in 1992 and concluded in 2001.
3. The **Treaty on the Development and Utilisation of the Water Resources** of the Komati River Basin and the **Treaty on the Establishment and Functioning of the Joint Water Commission** were both signed in 1992 between South Africa and Swaziland. Both countries declared that they recognize the right of the Republic of Mozambique to a reasonable and equitable share in the use of the waters of the Incomati River Basin of which the Komati River Basin is an integral part.
 4. The establishment of a **Joint Water Commission** after formal agreement between Mozambique and South Africa in 1996. The Commission provides a forum through which issues related to the management of shared water courses are discussed. It promotes joint studies, data and information exchange and collaboration between the countries; ultimately, the Commission provides advice to the respective Governments.
 5. The **Protocol on Shared Watercourse Systems in the Southern African Development Community (SADC) region**, was adopted by the Heads of State in 1995, revised in 2000 and entered into force in 2003. This Protocol aims at fostering closer co-operation for judicious, sustainable and co-ordinated management, protection and utilization of shared watercourses and to advance the SADC agenda of regional integration and poverty alleviation.
 6. At the World Summit on Sustainable Development (WSSD), Johannesburg, 2002, the ministers responsible for water affairs in the three countries signed the **Tripartite Interim Agreement for Cooperation on the Protection and Sustainable Utilization of the Water Resources of the Incomati and Maputo Watercourses (IIMA)**. The agreement is intended to cover the period of time until comprehensive water agreements can be reached for both basins. It was decided that the joint body for cooperation between the countries shall be the TPTC, which was also tasked to implement the agreement. Concerning water requirements of the ecosystem, the agreement defines for the Incomati River at the border crossing with Mozambique an interim target for the minimum in-stream flow of 2.6 m³/s, which is higher than the 2.0 m³/s of the Piggs Peak agreement. An important document that is linked to the IIMA is the **Resolution of the TPTC on the Exchange of Information and Water Quality (REIWQ)**, also signed at the WSSD in 2002.
 7. Most recent developments are the drafting of the **Implementation and Action Plan for the IIMA** (2006) and the document on **Progressive Realization of the Incomati-Maputo Agreement (PRIMA)** (2006), which marks the start of a project organisation and priority projects that will set into motion the implementation of the IIMA.

In Mozambique, in particular, effort have been made towards strengthening institutions, developing policies and strategies and building technical and scientific capacity for negotiation and for an effective participation in the regional efforts towards management and sustainable use of the shared water courses. In 1991 a new **Water Act** establishing basic principles of water management was promulgated in Mozambique. The Act considers water as a scarce public resource and introduced payment for the abstraction of water by bulk water supplier companies, as well as for water used for irrigation and for hydropower production.

In 1995, The Government of Mozambique approved a new **National Water Policy** that emphasises integrated water resources management to maximise the benefits. The National Water Department (DNA), the government institution responsible for managing the water resources was strengthened. In addition, Regional Water Authorities (ARAs) were established in order to improve the capacity and efficiency of water management. A **National Water Commission (CNA)**, which functions at the ministerial level to support decision-making was also established.

The National Directorate of Water (DNA) in the Ministry of Public Works and Housing is responsible for strategic planning, regulation and supervision. Regional Water Authorities, ARA Sul, ARA Centro and ARA Zambesi, are responsible for operational management. ARA SUL is responsible for the southern part of the country up to the Save River. In areas not yet covered by an ARA, the Provincial Directorates of Public Works and Housing are the authority responsible for water resources management in the province (World Bank, 2007). Under ARA

Sul, there is the Unidade de Gestão de Bacia de Incomati (UGBI) responsible at the local level.

There is a development to decentralize operational water management.

A linked management approach that unites river basin and coast would contribute to the reduction or even prevention of most of the potential negative impacts mentioned above, including:

- (i) bridging the gap in terms of data and knowledge across the river basin;
- (ii) reducing the impacts of draughts and floods through sharing of information along the river basin from upper to down riparian countries,
- (iii) assuring equity in the water allocation between the sectors and across the countries, contributing to sustainable development and to reduction of potential conflicts in water use, through dialogue and mutual understanding between the stakeholders;
- (iv) reducing water pollution and degradation of downstream ecosystems and ecotones.
- (v) enhancing productivity of coastal ecosystems, in particular of fisheries in Maputo Bay, can be enhanced through maintenance of an ecological flow regime and
- (vi) assuring the development of industry and agriculture sectors in the lower as well as in the upper Incomati.

Thus, a linked management approach would benefit the economy sectors, the population and the ecosystems along the river basin to the coast.

1.4 Main indicators for drivers, pressures and governance

DRIVERS	Main indicators
Demographic trends - population in delta - migration	- number of people and growth rate - migration trend in delta (annual percentage in/out)
Economic developments - status of (total) economy - sectoral developments	- diversity of income generating activities - per capita GDP, growth rate, % contribution by delta - main sectors, growth rate - unemployment rate
Technological developments - Agricultural and aquaculture - civil engineering - ITC - energy generation	- percentage of GDP spent on innovation and research in each sector - number of initiatives of application of renewable energies
Climate change - air and sea water temperature - sea level rise - precipitation / discharge	- change of air and sea water temperature - change of sea level (mm/year) - change of precipitation (mm/year) or river discharge (M ³ /year)
Subsidence - natural and human induced subsidence	- rate of subsidence (mm/year)
PRESSURES/IMPACTS	Main indicators
Land and water use - pressure on space - shift in land use / urbanisation - degradation of mangroves - water demand	- number of inhabitants, population density, change in land value - % urban area, urbanization rate - water deficit / number of days with interrupted water

- flood vulnerability	supply - mangrove deforestation rates (m ² /year) - % area vulnerable for flooding / number of vulnerable people / value of vulnerable assets
Network / infrastructure - flood protection system - irrigation and drainage - water supply & sanitation - roads, railways and ports	- flood risk (safety level), % of delta protected (high-medium-low) - area of the delta under irrigation - number water supply infrastructures - number people with access to water supply - amount of water treated - extent of road infrastructures - number of ports (+ volume of goods)
Natural resources - sediment supply - mobility of delta distributaries - coastal erosion / wetland loss - mangrove degradation - fisheries resources depletion - biodiversity loss	- sediment flux rates - erosion and accretion rates (cm/year) - erosion and accretion rates (cm/year) - mangrove deforestation rates (m ² /year) - fish catch rates (kg/hr or kg/fishing gear) - biodiversity index
GOVERNANCE	Main indicators
- multi-level and multi-sectoral coordination	- existence of integrated plans (delta plan, national adaptation plan etc.) - existence of interministerial committees, multi scale level and multidisciplinary committees etc.
- public-private partnerships	- number of PPP's - scale of PPP's (geographic, budget, time span)
- involvement of stakeholders and citizens	- existence of legal instruments for participation (e.g. spatial planning instr.) - number of NGO's involved in planning and decision making
- approaches for dealing with risks and uncertainties	- existence of adaptive management, adaptation strategies etc. (long term) - existence of risk management, emergency systems etc. (short term)

1.5 Score card

The scores in the score card are just qualitative and indicative, based on the summary tables descriptions for each item (above). Each item is scored on a 5-points scale, related to resilience and sustainability.

The following two development scenarios are recognized:

- Scenario1, moderate perspective 2050: medium economic growth (1,2 %, WLO-scenario RC) and related medium technological developments, combined with medium climate change and sea level rise (KNMI-scenario G, relative sea level rise 0,30 cm)
- Scenario2, extreme perspective 2050: high economic growth (1,7%, WLO-scenario TM) and related high technological developments, combined with high climate change and sea level rise (KNMI-scenario W+, relative sea level rise 0,40 cm)

(Note: do we need the Mozambican scenarios here? from INGC in Maputo, Prof Rui Brito from UEM)

Delta	Land and water use (occupation layer)	Infrastructure (network layer)	Natural Resources (base layer)	Governance	Overall Resilience & Sustainability indicator
Current situation 2010	0	-	-	-	-
Scenario 1 moderate 2050	-	-	0	-	-
Scenario 2 extreme 2050	-	-	0	-	--

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

Clarification notes on the score card:

The pressure on the occupation layer and the base layer will increase in time by socio-economic development, climate change and sea level rise. Most critical issues will be extremes in floods and droughts, but also the higher frequency of tropical storms. In land use planning and development of infrastructure and technology there is increased awareness on environmental issues. This would reduce the negative impacts on the natural resources and ecosystems, but by far not enough to guarantee sustainable use of the natural resources. It is expected that the population pressure will lead to overexploitation and degradation of the resources, even if innovative technologies and integrated planning will be applied. Governance is increasing in power by improvement of integrated and participatory approaches. Although the country's economy is one of the fastest growing in Africa, economic development, technical infrastructure and governance are still largely dependent on donors. This affects the overall resilience and sustainability. The situation will worsen in case of more extreme scenarios.

2. Overview of currently applied adaptive measures in the Incomati delta

Overview of possible adaptive measures (in the three layers) based on current practices and innovative technological developments. The measures are classified in types of measures (technical, ecological, economic and institutional/organizational), related strategy (protect, adapt, relocate) and involved layer (occupation layer, network layer, base layer).

The main underlying actions aimed at alleviating the negative impacts of the Modification of Stream Flow in the estuarine and coastal ecosystem, which in turn require knowledge of on the river flow requirement for the health of the downstream ecosystems. The main action may be clustered in five categories as follows: (i) a better understanding of the ecosystems structure and functioning; (ii) establish ecological flow regime; (iii) strengthening capacity and co-operation of institutions involved in IRBM and ICZM; (iv); and (v) harmonisation of legislation related to resources exploitation and to the socio-economic aspects.

Name of measure	Type of measure	Brief description	Strategy	Layer
	1. Technical 2. Ecological 3. Economic 4. Institutional		1. Protect 2. Adapt 3. Relocate	1. Occup. 2. Network 3. Base
<i>Establish and strengthen regional water management units</i>	4	<i>Improving the governance of the river basin</i>	1, 2, 3	1, 2, 3

<i>Integrated the ICZM into IRBM</i>	2, 3	<i>Adopting an integrated management approach to assure sustainable development</i>	2	1, 2, 3
<i>Establish linkages between river basin and estuarine and coastal processes</i>	2	<i>Improving our understanding of the river runoff influence on the health of the ecosystems for improved resource use and management</i>	1, 2, 3	1, 3
<i>Establish environmental flow regimen</i>	2, 3	<i>Aiming at sustaining the ecosystem health and natural resources availability</i>	1, 2, 3	2, 3
<i>Establish a network/forum for IRBM and ICZM</i>	1, 4	<i>Aiming at improving the river basin monitoring and governance</i>	1, 2, 3	3
<i>Improve cooperation and information sharing among riparian states and within relevant national institutions</i>	1, 4	<i>Aiming at improving the river basin monitoring and governance</i>	1, 2, 3	3
<i>Assessment of the extent of water pollution and its impact.</i>	1	<i>Determining the impact of the pollution of agricultural runoff and of the suspended sediments in the delta and coastal ecosystems</i>	1, 2, 3	3
<i>Propose techniques for water treatment</i>	1, 3	<i>Treatment of waste water for re-use, and so addressing the issue of water shortage and pollution</i>	2, 3	3
<i>Improve monitoring of relevant processes in the river basin</i>	1	<i>Monitoring of the river basin processes to support management measures</i>	1, 2, 3	3
<i>Increase efficiency of water use</i>	3	<i>Aiming at addressing the issue of water shortage through Improvement of water usage and preventing water wastage</i>	2, 3	3
<i>Studies on impacts of the modification of stream flow on ecosystem structure and function</i>	2	<i>Determination of the impact of the regulation of the river on ecosystem health, resources availability</i>	2, 3	3
<i>Assessment of environmental and socio-economic impacts</i>	2, 3	<i>Determination of the impact of the regulation of the river on the socio-economic development</i>	1, 2, 3	1, 3
<i>Development of</i>	4	<i>Improving governance</i>	1, 2, 3	1, 2, 3

<i>regulation for sustainable use of waters</i>		<i>on river basin management for sustainable development</i>		
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3. Overview of technical methods and tools to support delta management and development in the Incomati delta

Overview of methods and tools for assessments, planning and decision making on delta management and development issues (very incomplete):

Name of tool	Brief description	Institute	Available at
Catchment2 Coast	Hydrological river basin model with mangrove/shrimp module	CSIR Stellenbosch and Delft Hydraulics	idem
STREAM-INCOMATI	Simple model to indicate effects of Climate Change	CZM_Centre at RIKZ	Deltares, DNA Mozambique

Name of tool	Brief description	Institute	Available at
SWAT	The Soil and Water Assessment Tool	DNA and ARA-SUL	
FIMISYS Lender Sea	2- D Coastal hydrodynamics	National Institute of Hydrography and Navegation - Mozambique	
Mike -21	3-D Hydrodynamic model	National Hydrographic and Navigation Institute - Mozambique	
ArcGIS With river basin and stream flow environmental analysis	GIS tool with river basin and stream flow environment analysis	GIS laboratory, Eduardo Mondlane University	
ArcView	GIS tool	GIS laboratory	
MapInfo	GIS tool	GIS laboratory	
ERDAS	Digital and analogue image processing	GIS laboratory	

4. Knowledge exchange and development

4.1 Lessons learned on delta management

Along the river basin, from the source down to the estuaries and coastal zones, intervene different stakeholders with different interests implying different resource use, water uses and water usage, which in some cases are conflicting. As a consequence the river basin and coastal zones are prone to conflict in resource use. The presence of different stakeholders and interest makes the task of sustainable resource use and management a challenging one.

On the other hand, an integrated resource management in this context requires the involvement of the different stakeholders in appropriate forum and context, which again is a challenge since it is difficult to build a common understanding in a multivariable stakeholder scheme with different interests, culture, backgrounds and expertise. It should underlined that the consensus building using participatory processes is a very important tool in building agreement on how to resolve conflicts. The other lesson that should be mentioned is the fact that often people are reluctant to change, yet the changes are occurring and will accelerate in the future. There is a dilemma regarding the population growth and resources availability. The population is growing at higher rates and the resources are shrinking leading to overexploitation of the resources and degradation of habitats, which appeals to innovative technologies of producing more food and at higher frequencies. Since the developing countries cannot afford to improved technology they are the most vulnerable to the impact of global climate changes.

4.2 Summary of research gaps and related needs for knowledge exchange

Drivers of change

Demographic trends: development of integrated water management and spatial planning concepts and tools for a growing population and economic development in the basin

Economic developments: how to become less dependent from donor money

Climate change: how to cope with extremes (floods, droughts); how to organise linked dam operation rules to adapt and cope with these events.;

Overall: how to balance availability and demand of water resources in a closed Basin, in which the majority of the resources is already used.

General challenges and constraints.

The complexity of managing transboundary institutions in an environment where the demand for water exceeds the existing supply poses many challenges. Any additional allocation to one of the countries or sectors would mean a reduction elsewhere, and it is likely to be highly contested by the other countries. Looking at the long track of measures taken as is given in the above section 3, the countries have succeeded in moving ahead a long way on the route of political negotiations and shared vision development. Now the main challenge is to further implement the agreements. Main challenges to linked river basin and coastal area management include:

- **An improved understanding of the linked river basin and coastal systems** where water allocation is often based solely on the water demand for domestic use, agriculture and power production, and a better insight in the ecological river flow requirements. Application of existing methods for determination of ecological river flow requirement should support the political negotiating process.
- **Improve transboundary co-operation** regarding information sharing: Strong competition on the water use and development between the countries may encourage countries to withhold information and data for their own benefit. Organisations such as the TPTC/Tripartite Permanent Technical Committee and their supporting government capacities have contributed already considerably but need to be further enforced and grow in order to implement Agreements such as the IncoMaputo Interim Agreement (2002)
- **Improve national and regional capacity**, particularly in Mozambique and Swaziland, for long-term research and monitoring programmes, required for the formulation of management strategies. Insufficient capacity hinders the effective management and negotiation of new management arrangements. The challenge is to use the scarce human and financial resources as efficient as possible.
- **Water quality** Water quality and quality improvement needs special attention

Adaptive measures

How to cope with growing demands for water in a changing environment? How to use water more efficient (new irrigation methods, ground water storage?, public opinion on water usage and spillage, water and poverty water and gender) How to find the right balance between the great water takers and the small and less powerful rural users?

Technical methods and tools

Exchange of knowledge and tools is greatly needed. Models on water resources availability and demand; integrated spatial planning; systematic transboundary monitoring of data and experience to handle these data (storage and retrieval and writing of synthesis and evaluation reports); downscaling of global/regional climate models; use of remote sensing in IWRM; early warning systems; experience with the application and use of flood vulnerability and climate vulnerability indices.

4.3 Some available illustrations (map of delta, typical sites, etc.)
(several illustrations are available from Frank vd Meulen at Deltares)



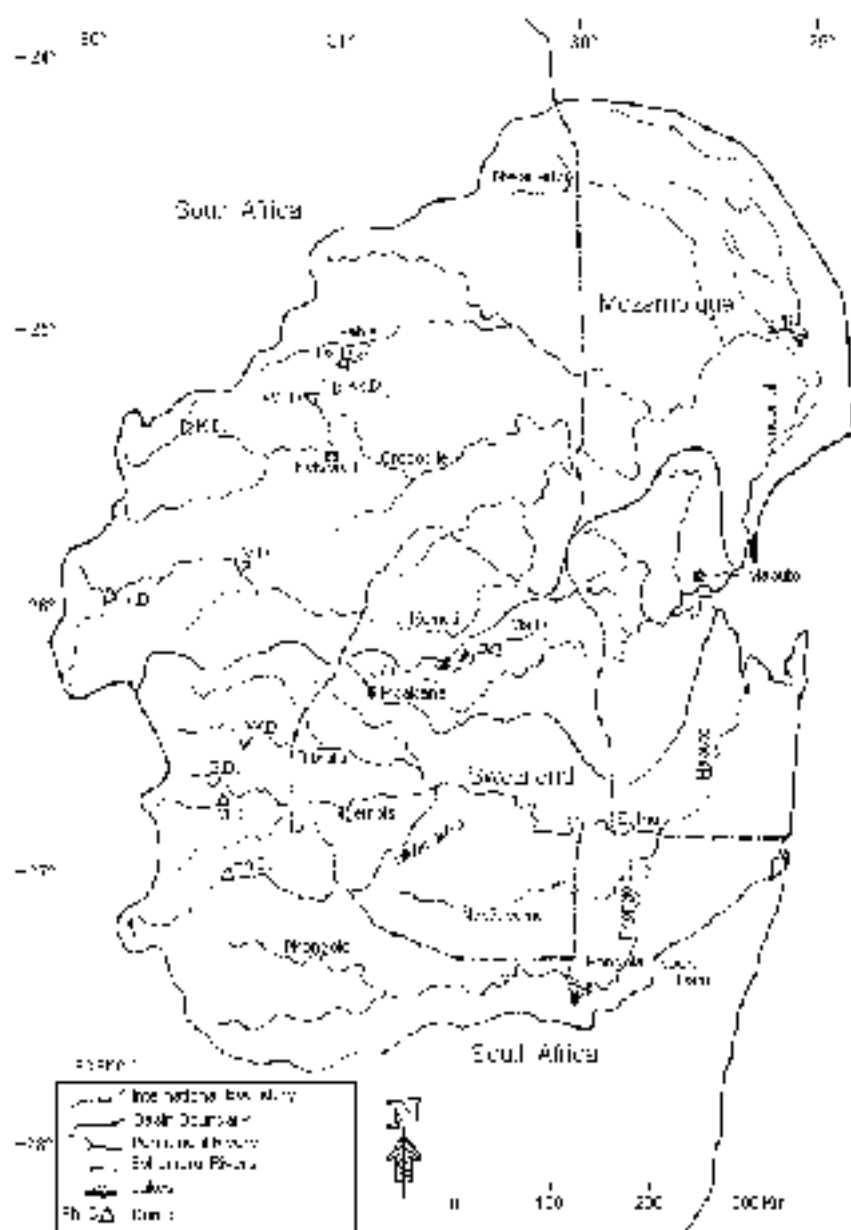
Incomati floodplain at Marracuene, near Maputo Bay. Indian Ocean Dunes in far background.



The Incomati floodplain with Indian Ocean in distance. Maputo townships are seen at bottom.



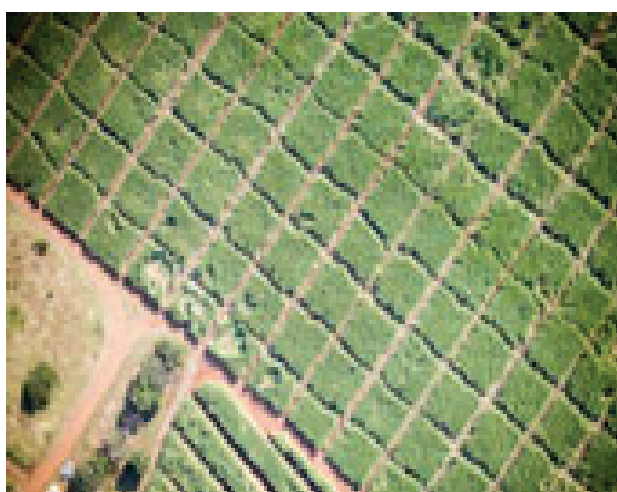
The water courses of the Incomati, Maputo and Umbeluzi Rivers in southeastern Africa, forming delta's in Mozambique. The Incomati catchment is comparable to that of the Meuse River in size.



Incomati, Umbeluzi, and Maputo river basins (bottom) showing the dam network.



The Incomati River Basin is shared by Mozambique (31%), South Africa (63%) and Swaziland (6%) and covers an area of approximately 47,000 km². (Source: JIBS 2001).



An irrigated sugar cane plantation in the Incomati Basin.

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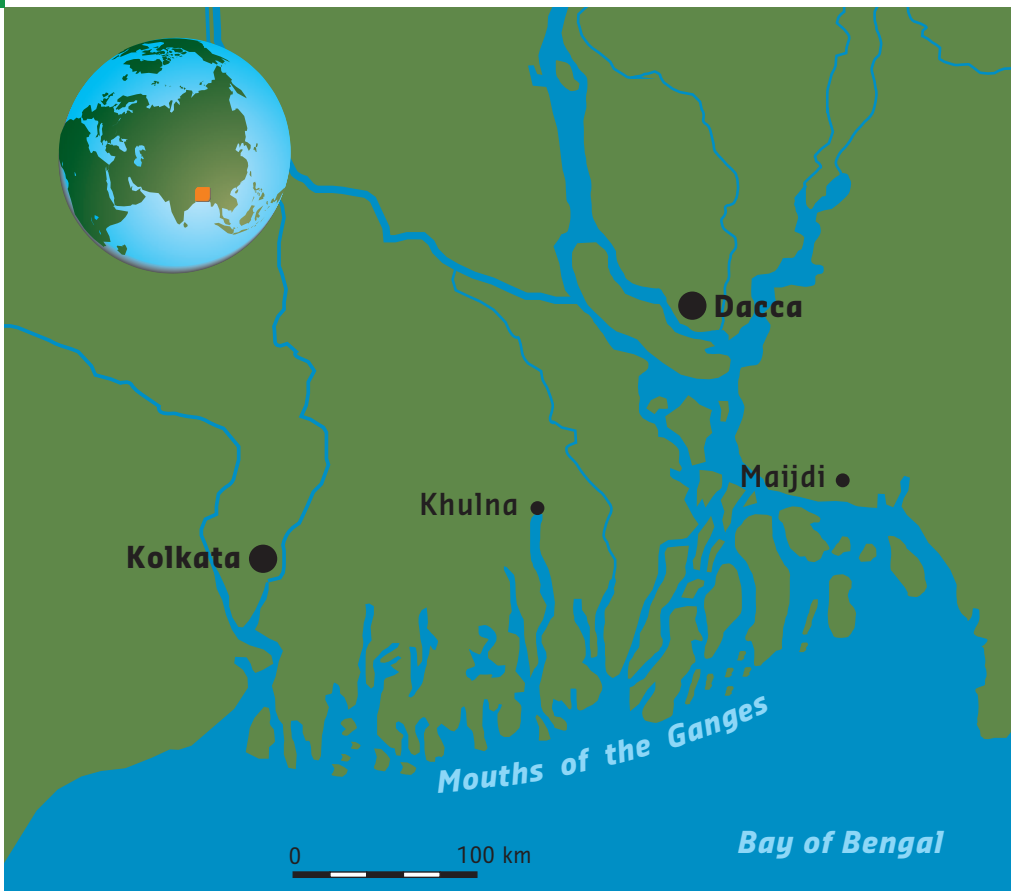
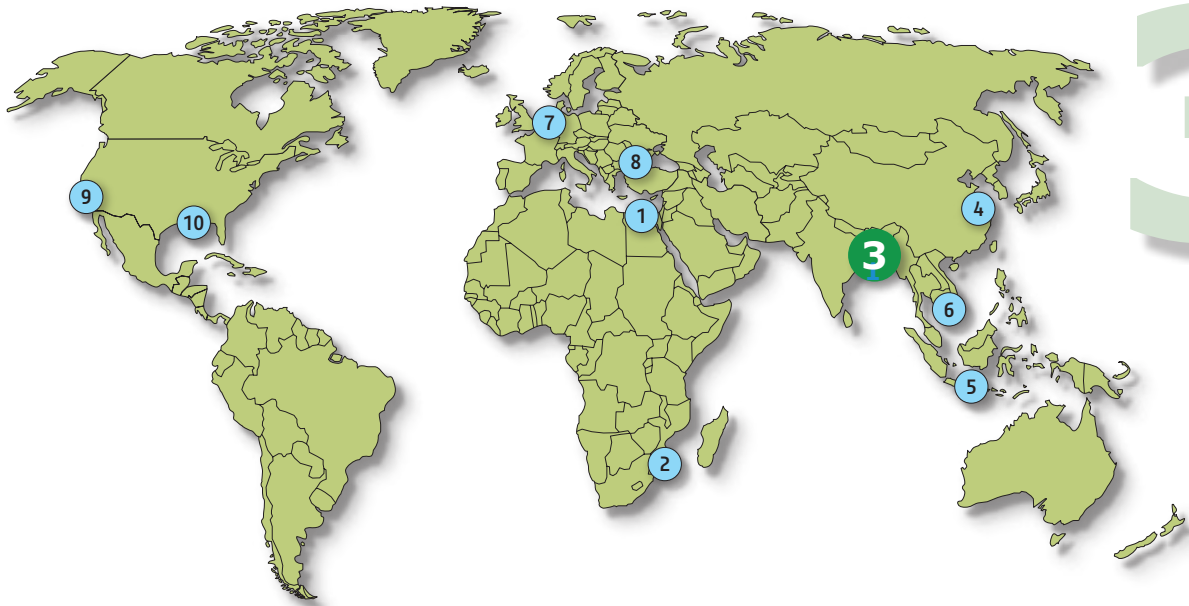
Other important reading

- Several UNESCO-IHE MSc theses on the Incomati estuary and river basin.
- Studies on hydrodynamics and on salt intrusion in Maputo Bay and the Incomati river mouth (Huub Savenije, Marieke de Groen, Marloes Mul)
- Stream Incomati (CDrom)
- Catchment 2 Coast. Deltares Publication of a EU project in the Incomati River Basin and coastal zone

Ganges-Brahmaputra-Meghna delta

No

3



1. Current and future state of the Ganges-Brahmaputra-Meghna delta

N.B. This speaks only of Bangladesh but the delta covers West Bengal in India as well.

1.1 Drivers of change

Summary of drivers of change

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

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

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

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

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

Research gaps

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

1.1.1 Socio-economics (population growth- migration, economic development + most relevant sectoral developments, e.g. for agriculture, fisheries, industry)

Population

Some 156 million people live on the delta, despite risks from floods caused by monsoons, heavy runoff, and tropical cyclones. Most of the Ganges-Brahmaputra-Meghna Delta has a population density of some 1226 inhabitants per km² making it one of the most densely populated regions on earth. The annual growth rate is 1.292%¹.

Economic development

The major part of the nation of Bangladesh lies in the Ganges-Brahmaputra-Meghna Delta, and many of the country's people depend on the delta for survival. Bangladesh's predominantly agricultural economy depends heavily on the discharge of the Ganges, Brahmaputra and Meghna, with their periodic flooding and drought. Although one of the world's poorest and most densely populated countries, Bangladesh has made major strides to meet the food needs of its increasing population, through increased domestic production augmented by imports. Nonetheless, an estimated 10% to 15% of the population faces serious nutritional risk. Although improving, infrastructure to support transportation, communications, and power supply is rather poorly developed. Bangladesh is limited in its reserves of coal and oil, and its industrial base is weak. The country's main endowments include its vast human resource base, rich agricultural land, relatively abundant water, and substantial reserves of natural gas. Natural gas serves as the main source for the chemical industry. It covers about 74% of the commercial energy used by the country.

Bangladesh historically has run a large trade deficit, financed largely through aid receipts and remittances from workers overseas. Since independence in 1971, Bangladesh has received more than US\$30 billion in grant aid and loan commitments from foreign donors. Efforts to achieve Bangladesh's macroeconomic goals have been problematic. The privatization of public sector industries has proceeded at a slow pace. The IMF and World Bank predict GDP growth over the next 5 years will be about 6.0%. The per capita GDP is about US\$ 400.

Agriculture

Most inhabitants of the delta earn their living from agriculture. Although rice and jute are the primary crops, the importance of maize and vegetables is augmenting. Due to the expansion of irrigation networks, some wheat producers have switched to cultivation of maize which is used mostly as poultry feed. Thanks to fertile soil and normally ample water supply, rice can be grown and harvested three times a year in many areas. Due to a number of factors, the labor-intensive agriculture has achieved steady increases in food grain production despite the often unfavorable weather conditions. These include better flood control and irrigation, a generally more efficient use of fertilizers, and the establishment of better distribution and rural credit networks. Population pressure continues to place a severe burden on productive capacity, creating a food deficit, especially of wheat. Foreign assistance and commercial imports fill the gap. Underemployment remains a serious problem, and a growing concern for the agricultural sector will be its ability to absorb additional manpower. Finding alternative sources of employment will continue to be a challenge for governments, particularly with the increasing numbers of landless peasants who already account for about half the rural labour force.

Fisheries

At all stages in the hydrologic cycle but particularly during the post-monsoon, riverine fish is captured by the rural community. Reduction in discharge during the dry season has declined natural fish populations. Coupled with the impacts of flood control schemes and a lack of systematic management, capture fisheries have considerably reduced. In recent years, fish farming is developing in existing ponds in the delta. Shrimp and carps are the main species. Most of these fish are exported. The shrimp industry has grown into a nationally important resource. The industry relies on the tidal waters of the Sundarbans and surrounding areas for the supply of shrimp larvae which are netted and then transferred to inland brackish water lagoons and ponds.

¹ http://en.wikipedia.org/wiki/Demographics_of_Bangladesh

Industry

The development of industry in Bangladesh is relatively slow. Nevertheless, Bangladeshi entrepreneurs are successfully competing in the global garments market. This private industry has created some 2 million jobs, mostly for women. The labor-intensive process of ship-breaking for scrap has developed to the point where it now meets most of Bangladesh's domestic steel needs. Other industries include sugar, tea, leather goods, newsprint, pharmaceutical, and fertilizer production.

1.1.2 Climate change (temperature/evaporation, sea level rise, precipitation/discharge)

The Ganges-Brahmaputra-Meghna Delta lies mostly in the tropical wet climate zone. In general, maximum summer temperatures range between 38 °C and 41 °C (100.4 and 105.8 °F) and April is the hottest month in most parts of the country⁷. January is the coolest month, when the average temperature for most of the country is 16–20 °C (61–68 °F) during the day and around 10 °C (50 °F) at night². Heavy rainfall is characteristic for Bangladesh. With the exception of the relatively dry western region of Rajshahi, most parts of the country receive at least 2,300 mm of rainfall per year⁷. Because of its location just south of the foothills of the Himalayas, where monsoon winds turn west and northwest, the region of Sylhet in north-eastern Bangladesh receives the greatest average precipitation. From 1977 to 1986, annual rainfall in that region ranged between 3,280 and 4,780 mm per year⁷.

Kolkata, a major coastal city in the delta, is also vulnerable to impacts of climate change, such as increased flooding, storm surges, etc. (World Bank, 2010). Even without taking account of the effects of climate change, the delta is highly vulnerable to present weather extremes. Approximately 25% of the land surface is flooded on a yearly basis. The expected effects of climate change vary considerably for the different parts of the country. The coastal zone will be affected by an increase in intensity and frequency of cyclonic storm surge, sea level rise, salinity intrusion and water logging. Yearly maximum temperature will increase by 0.2°C in 2050 and 0.21°C in 2070 whereas minimum temperature will increase by 1.24°C in 2050 and 1.43°C by 2070 under A2 scenario (BRTC, 2008). Again yearly rainfall will increase by 4.0% in 2030, 2.3% in 2050 and 6.7% in 2070 under A2 scenario (BRTC, 2008). Again in dry season during December, January and February rainfall will decrease by 8.7% in 2030, 4.7% in 2050 and – 1.8% in 2070 under A2 scenario (BRTC, 2008). This excess rainfall will aggravate the severity of existing flood condition also. If rainfall will increase by 13% and sea level will rise by 17 cm (according to IPCC, 2007) 12% to 16% more will be inundated in the Ganges and Brahmaputra basin (IWM, 2008). There is also clear evidence in West Bengal that sea levels along the coast has been rising (Dwivedi and Sharma, 2005). As the rainfall will decrease in dry period drought will become more severe in near future. Almost two-third of the 40 million strong labour force is engaged in agriculture and related activities, which are largely nature and water-dependent. These are the sectors likely to be hit hardest by climate change, particularly in the southern coastal and northern drought-prone areas of Bangladesh. The population in the coastal area appears to be most vulnerable to the effects of climate change. If rainfall will increase by 10% and sea level will rise by 62 cm, the permanent inundated area will increase by 16% in the coastal area (IWM, 2007). If sea level will rise by 62 cm tide will propagate more 20 km in the southwest region of Bangladesh (IWM, 2007). The impact of sea level rise will make the salt water front move further upstream and together with lower stream flows the freshwater vegetation will be depleted rapidly (World Bank, 1999 and Sandilyan et al 2010).. If sea level will rise by 88 cm 4 ppt isohalines moves further inland by 12 km (IWM, 2005). In the western part of Sundarbans the increased salinity with a rise of 88 cm SLR is in the range of 22 to 25 ppt, whereas at present the salinity is within 20 ppt. The low salinity zone is the eastern part of the Sundarbans, where salinity varies from 12 to 15ppt will be increased to 16 to 20 ppt for 88 cm sea level rise. This change in salinity will affect not only the productivity of the mangrove ecosystem but the entire bio-diversity of the Sundarbans (IWM, 2005 and Sandilyan et al 2010).

² http://en.wikipedia.org/wiki/Geography_of_Bangladesh#Climate

According to IWM (2007), if sea level will rise by 62 cm in 2080 8.8 million more people will expose to high salinity (>5 ppt), 25.1% farming opportunity will decrease, agriculture contribution to GDP will decrease by 3%, 15 % fishing opportunity will decrease, wage labour opportunity will decrease by 25% and 19.9 million women will be vulnerable due to reduction of suitable area of livestock and about 4.0 million women will be vulnerable in the same year due to reduction of suitable area of cottage industries.

A study covering the period 1970-2000 showed that relative sea level rise at the south western extremity of the delta was 3.14mm/yr. A similar study by the same group of researchers for the period 2000-2009 has reported relative sea level rise at 17.8 mm/yr (WWF). Relative sea level rise takes into account tectonic subsidence, compaction, and thermal expansion of water (WWF).

1.1.3 Subsidence (natural or human-induced)

Dhaka University Earth Observatory (DUEO) in collaboration with Lamont-Doherty Earth Observatory of Columbia University, New York has installed 18 continuous geodetic GPS in Bangladesh during the period 2003 to 2007. These GPS were installed to monitor the three dimensional motion of the earth's crust in order to study crystal dynamics and earthquake hazards in Bangladesh.

The GPS data were processed with Gamit_Globk software developed by MIT, USA. The result shows that the north-eastern part of Indian plate covering Bangladesh is moving 4 to 5 cm per year with respect to International Terrestrial Reference Frame (ITRF). The vertical component of the GPS time series plots demonstrate that the Bengal Basin as a whole is subsiding, including Dhaka, Sylhet, Patuakhali and Khulna areas.

The GPS in Khulna is one of the network stations of DUEO installed in URP Discipline building of Khulna University on 15 May, 2003. This site has data gap due to poor maintenance. However, the result from collected data shows Khulna is going down by 9.55 mm/year.

The lower deltaic area of Bangladesh is located on two active troughs, Faridpur Trough and Hatiya Trough. In this area, three types of subsidence are recognized (Hoque and Alam 1997):

- Tectonic subsidence
- Compaction of peat layers; and
- Human induced subsidence.

Tectonic subsidence

Tectonic subsidence has relevance in understanding the impact of climate change and variability. The subsidence of the Bengal Basin is largely the result of tectonic forces, and can be attributed to two major factors. One is related to the isostatic adjustment of the crust (sediment load and the rise of the Himalayas), while the other is related to dewatering and compaction of the sediments of the Bengal Fan. Tectonic subsidence usually occurs over a large extent of area, and unlike the subsidence due to groundwater withdrawal, is relatively uniform and proceeds at a slow rate. Areas subjected to tectonic subsidence are generally bounded by active faults or hinge zones-as is the case in the Bengal Basin.

Bangladesh is situated where the India-Sunda subduction zone rises from oceanic depths to subaerial exposure as a result of the incipient continent collision where the trench meets the huge sediment accumulation of the Ganges-Brahmaputra-Meghna delta. The Arakan segment between the Andaman Islands and Bangladesh ruptured in 1762. The event in 1548 could have ruptured the Bangladesh segment. This segment is clearly active, but whether it breaks in great earthquakes is unknown and is a question with huge societal implications.

The thicker continental crust of India has collided with the Burma Arc in the Naga segment, northeast of the Shillong Plateau. South of the plateau, the boundary exhibits typical oceanic subduction features, including accretionary prism, forearc wedge, forearc basins, and volcanic

arc, but remains onshore for 300km. The belt of accretion is extremely wide and shallowly dipping. After encountering the Indian continental shelf, the accretionary prism broadens northwards into a wide fold-and-thrust belt with an extremely low surface slope. The thrust front extends halfway across the Ganges-Brahmaputra-Meghna delta and is partially buried. Because of the huge thickness of sediments entering the subduction zone, this is one of the rare 'oceanic' subduction zones where even the deformation front, which is usually along a deep trench, is exposed on land. Further details can be found in Uddin and Lundberg (2003).

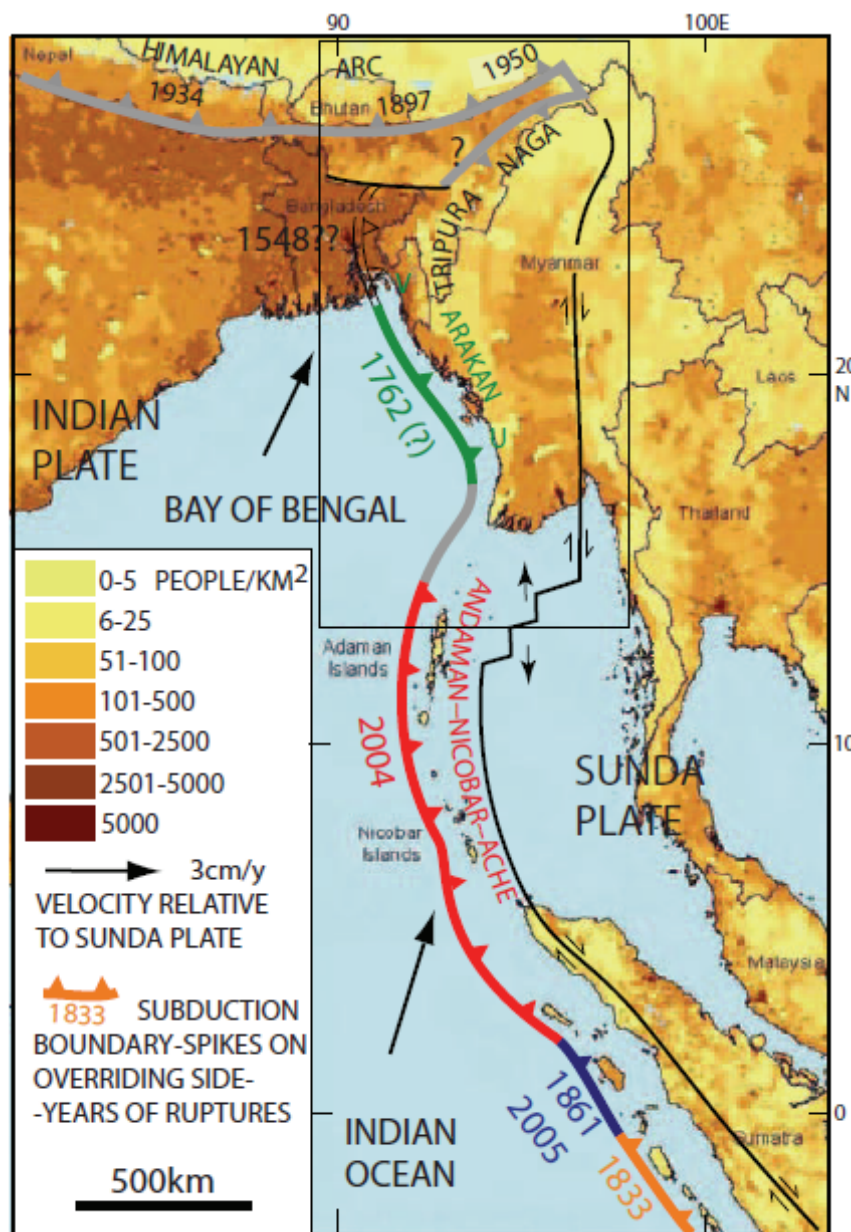


Figure 1: Map showing Plate Movement due to Tectonic Activity

Compaction of peat layers

Parts of lower deltaic plain are underlain by several layers of peat; in some places, even within 35m of depth. The compaction of these peat layers and swamp mud often results in local subsidence in the coastal area. A large tract of agricultural land and land under vegetation in coastal areas is subjected to this type of subsidence (Hoque & Alam 1997). Moreover, Subsidence may also occur due to abstraction of groundwater in mining situation in

local area because the water extraction decreases the groundwater pressure while coastal basins consist of large volumes of unconsolidated sediment overlying by peat layers.

Human induced subsidence

Another type of subsidence in local dimension is human-induced. Human-induced sedimentation impacts when human activities affect the river systems, catchment areas and deltas, the sediment supply processes are disturbed. Embankments along river channels keep sediment out of the adjacent land. The construction of dams and reservoir in upstream areas for flood protection, power supply, and irrigation can stop or strongly decrease the downstream supply of sediment. The Bangladesh coast is threatened by rising sea level due to various factors. The results based on the analysis of past 22 years of tidal data of the Bangladesh coast reveal that the annual mean tidal level in the eastern Bangladesh coast is rising at an alarmingly high rate of 7.8 mm/year, which is almost twice the observed rate in the western region (O. P. Singh, Marine Geodesy- 2002). This type of sea level trend seems to be the result of hanging local conditions like increased precipitation and land subsidence during the recent decades. There is no specific regional scenario for net sea level rise, in part because the Ganges-Brahmaputra-Meghna delta is still active and morphology highly dynamic. Literature suggest that the coastal lands are receiving additional sediments due to tidal influence, while there are parts where land is subsiding due to tectonic activities (Huq et al. 1996). Since the landform is constituted sediment decomposition, compaction of sediment may also play a role in defining net change in sea level along the coastal zone. A review of the literature and expert opinion suggest that sediment loading may cancel out the effect of compaction and subsidence, so that net sea level rise may be assumed.

1.1.4 Technological developments (e.g. regarding civil engineering, agriculture, ICT, energy)

The need for faster technological development is increasingly felt in Bangladesh. Development plans of Bangladesh have emphasized science and technological research to develop technologies through adoption of imported technology as well as development of indigenous technologies. As the country is heavily dependent on imported technologies, proper planning is required for its effective transfer through acquisition, assimilation and adoption. Technological development can categorised as follows:

Civil Engineering:

As Bangladesh is a developing country, civil engineering works have not been saturated yet. According to statistics of *Emporis* 190 tall buildings (more than 12 floors) have already been constructed in Bangladesh, 74 buildings are under construction and 13 more buildings are planned.³ Bangladesh is a riverine country: about 700 rivers⁴ including tributaries flow through the country. That is why the government has to build bridges to make effective road communication. The Government of Bangladesh has already built a 4.8 km Bangabandhu bridge on Jamuna River and planned to build another 5.4 km bridge on Padma River. These two are the longest bridges in Bangladesh. Except these two we have many bridges all over the country. In the coastal area there are about 2500 cyclone shelters⁵ but according to our present population we need at least 5000 cyclone shelters.

Bangladesh Water Development Board (BWDB) has constructed 125 polders in the coastal region. These polders contain 5107 km of embankment, 134 regulators, 1164 flushing inlets and 5932 km of drainage channels. Due to the presence of these polders 12,80,479 hectares of valuable land has become flood free and 831 883 ha area has been brought under cultivation. For the past 37years, these polders have been playing vital role in increasing agricultural production, improving livelihoods of the people and environment in the coastal region.

³ <http://www.emporis.com/en/wm/ci/bu/sk/?id=100200>

⁴ http://www.banglapedia.org/httpdocs/HT/R_0208.HTM

⁵ http://en.wikipedia.org/wiki/Tropical_cyclones_in_Bangladesh

Agriculture:

Bangladesh has a primarily agrarian economy. Agriculture is the single largest producing sector of the economy since it comprises about 30% of the country's GDP and employs around 60% of the total labour force. The performance of this sector has an overwhelming impact on major macroeconomic objectives like employment generation, poverty alleviation, human resources development and food security.

But this sector has undergone through many challenges such as rapid shrinkage of agricultural land (1% p.a.), population growth (1.292% p.a.), floods, salinity intrusion, droughts, climate change and variation, rapid urbanization, lack in agricultural research and education, developing stress tolerant varieties, etc. Degradation of land and water resources is also putting a constraint on agricultural developments (Rasul and Thapa 2004). To make the country self-sufficient in food production, it needs to develop agriculture sector technologically. A new salt-resistant paddy - BRRI Dhan 47 - is offering hope to coastal farmers in southern Bangladesh whose crops are affected by saline water and climate change⁶. It needs to develop stress (flood, submergence, drought, heat etc.) tolerant crop through technological development like this. Farmers are using 10% hybrid technology for agriculture in our country. To produce more production it needs more research in the hybrid technology. Also, farmer adoption rates and effectiveness of extension programs need further improvement.

ICT:

ICT sector is rapidly developing even in rural communities (Khan 2004). An updated National ICT policy was introduced in 2008. Also, the current Government has made "Digital Bangladesh" an integral part of its Vision21 for the country (see www.digitalbangladesh.gov.bd). Digital Bangladesh is an Idea that includes the IT use for management, administration and governance to ensure transparency, accountability and answerability at all levels of society and state. Building of a country wide IT backbone is essential for a Digital Bangladesh. Currently, government owned Telephone Company, Private Mobile Operators, Railway Communication System, Active Internet Service Providers total Bangladesh is already under a digital network.

Bangladesh signed in with submarine cable on March 27, 2004 and reached to its end user from June 2005. An organization named South East Asia-Middle East-West Europe-4 (SEA ME WE 4) connected Bangladesh and 12 others countries with high speed data communication facilities. The submarine cable boosts Bangladesh internet connection speed 68 times faster than it was before. Bangladesh Telegraph and Telephone Board (BTTB) and more over 100 internet service providers (ISPs) have capacity to serve 150-megabyte per second data rate⁷. Introduction of submarine cable network in Bangladesh is obviously a great achievement. It is a reliable communication system for Bangladesh, so far has made a great development of our IT sectors, taken our country in the home of information and boosting our economy through its fastest data transfer rate, increasing the number of ISP operators.

A suite of tools (process models) for predication of the impacts of climate change on floods, salinity intrusion in groundwater water and rivers, morpho-dynamics, storm surges have been developed and are being routinely used for natural resources management, assessment of different adaptation options, re-engineering of existing infrastructure, development project formulation etc.

⁶ <http://www.irinnews.org/report.aspx?ReportId=88426>

⁷ <http://www.amarneed.com/2010/05/02/submarine-cable-connecting-bangladesh-to-the-world-of-high-tech-information-technology/>

Energy:

Existing capacity of power generation is 3331 MW from public sector and 2045 MW from private sector.

1.2 Pressures – impacts**1.2.1 Land and water use (occupation layer)****Summary of pressures**

Pressure on space: With some 1226 inhabitants/km² the delta is one of the most densely populated regions on earth.

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

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

Research gaps

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

Pressure on available space

The Ganges-Brahmaputra-Meghna Delta belongs to the most densely populated areas of the world. With a population density of more than 1,226 inhabitants/km² and a growth rate of 1.292% the pressure on the available space is high. It is observed that population may increase by 150% in 2080 and by 43% in the year 2050 under A2 scenario. In Bangladesh the delta is still active with very unstable river branches. Riverbank and island erosion is one of the major issues, and is probably the most important natural cause of landlessness and forced resettlement. Again climate change will impose another threat to the available space. If rainfall will increase by 10% and sea level will rise by 62 cm, the permanent inundated area will increase by 16% in the coastal area (IWM, 2008).

Agriculture and flood protection

The majority of the population of the Ganges Delta depends on agriculture and agro-related industry. Over 60,000 people each year are made landless by bank erosion along the main rivers. The annual rate of erosion is estimated 10,000 ha whereas the natural accretion is only 2,500 ha. Bangladesh cannot afford to lose any land to erosion and erosion control is a top priority.

A second factor constraining agricultural production and safety of the agricultural population is flooding. Almost every year floods occur in Bangladesh, with varying intensity and magnitude. In a normal year 20% of the country is inundated by river spills and drainage congestions. Floods with a return period of 100 year may inundate 60% of the country. Flood protection and irrigation improvement is another main concern in Bangladesh. Up to now some 1,600 km² of agricultural land is well protected. Floods may also occur due to cyclonic storm surges also. Although the frequency of these floods is low (major storm surge related floods are

reported in 1970, 1991 and 2007) the floods may be extremely devastating. For example, the cyclone of April 1991 induced a storm surge of 6 – 7.5 m height and caused nearly 150,000 deaths. The 1970 Bhola cyclone was less powerful, but is nonetheless the deadliest tropical cyclone on record. The exact death toll will never be known, but it is estimated that between 300,000 and 500,000 people lost their lives. To reduce loss of lives and property, Bangladesh focuses on the development of flood forecasting and warning systems.

But climate change may enhance all of these problems due to increase in precipitation and sea level rise. If rainfall will increase by 13% and sea level will rise by 17 cm (according to 4th IPCC) 12% to 16% more area will be inundated in the Ganges and Brahmaputra basin (IWM, 2008). Again intensity and frequency of cyclonic storm will increase due to climate change (AR4, 2007) which will aggravate the cyclonic flood also.

Hydrology

The average annual discharge of the three rivers into the Bay of Bengal is approximately 30,000 m³/s. During flood, the maximum discharge may exceed 80,000 m³/s whereas the minimum discharge may drop to some 6,000 m³/s. The major floods occur during the months from June through September. From the analysis of historical data of Bahadurabad in Jamuna River from 1956 to 2007, it has been found that severe flood may come more frequently in near future (IWM, 2007). Another threat may come from climate change on the flow of these three rivers. It has been found from the study that if rainfall will increase by 13% on the GBM basin and sea level will rise by 17 cm maximum flood level will increase by 37 cm in the Bahadurabad in Jamuna River which may create additional 13000 m³/s flow in monsoon (IWM, 2007).

1.2.2 Infrastructure (network layer)

Summary of pressures

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

Research gaps

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

Infrastructure (general)

The Ganges Delta is intersected by a dense network of river branches and other watercourses. On one hand this network sustains a cheap means of transport and provides the water and sediment required for intensive agriculture. On the other hand, during high river discharge or storm surges from the sea, the watercourses enlarge the risk of flooding. The abundant presence of open water also hampers the development of road transport.

Infrastructure development in the Ganges Delta primarily aims at flood protection and agricultural water supply in dry periods. Floods are a permanent threat to the population of the delta. About every ten years more than 50% of the area is flooded when river discharges reach extreme values. In addition, heavy local precipitation may exceed the drainage capacity; and typhoons may produce storm surges up to 10 – 15 m. Nevertheless, water resource managers have attempted to develop the land and water resources of the Ganges-Brahmaputra-Meghna delta through irrigation, drainage, flood control and flood proofing. Early plans calling for large scale irrigation only led to the construction of the Farakka Barrage, which controls the Ganges flows just upstream the border between India and Bangladesh.

Since the 1960s Bangladesh has implemented over 600 large, medium and small-scale projects providing flood protection and irrigation facilities to 1,600 km² of agricultural land. Structural measures such as large and small-scale pumped irrigation, flood control with river embankments, polders, sluices, and cyclone shelters, and drainage improvements with new drains have been applied all over the delta. Non-structural measures have also been introduced, with policies to encourage small-scale irrigation using treadle pumps and small diesel or electric pumps, flood warning and cyclone warning systems.

River navigation is an important means of transport in the delta. Due to decreasing dry season flows and siltation of some branches, the potential of river navigation is declining and a shift to road and rail transport is required. The existing road and rail network supports north-south movement in corridors parallel to the major river branches. Ferries are used to cross the many open watercourses. Construction of new roads to areas currently served by navigation requires considerable investment and will cause some loss of agricultural land.

1.2.3 Natural resources (base layer)

Summary of pressures

Coastal erosion: Riverbank and island erosion is one of the major issues. Erosion is a bigger problem than flooding. The average annual pace of net accretion in the Meghna Estuary is about 18.8 km² over the last 30 years.

Loss of biodiversity: Especially the mangrove forests (Sundarbans) are highly valuable but also under high pressure from encroachment⁸ and exploitation. It is also vulnerable to accelerated climate change and sea level rise.

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

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

Research gaps

A well calibrated and validated morphological model of river, estuary and sea need to be developed to calculate the bank erosion and land reclamation more accurately in present and future condition.

An ecological model needs to be developed to observe the change in bio-diversity due to human intervention. Quantification of ecosystem services and estimation of benefits to livelihoods and the economy are required.

A well calibrated and validated salinity model of river, estuary and sea should be developed to understand the existing situation and to analyze the impact of climate change and sea level rise on salinity and its consequences on agriculture, fisheries, drinking water and biodiversity.

⁸ No significant encroachment of mangrove forests on the Indian side since 1943.

Water quality

The main issue related to water quality is the provision of reliable drinking water. Currently the surface water gets polluted by the discharge of untreated domestic and industrial sewage. While Bangladesh has made significant progress in supplying safe water to its people, large differences in coverage exist across the country. Latrine usage is very poor, averaging only 16% in the rural areas. Diarrheal diseases constitute a major health problem in Bangladesh, killing over 100,000 children each year. All of these problems will aggravate in near future due to climate change.

In the late 1970s, many groundwater wells were drilled to replace the traditional contaminated surface water sources. However, in 1993, high arsenic concentrations were discovered in shallow aquifers. Current understanding (2001) is that 25% of the population in the delta are exposed to contamination exceeding national standards, with another 25% that do not meet WHO standards. This problem exists in the West Bengal part of the delta also (Routh et al 2003).

In the coastal area especially in the southwest region scarcity of salt free water is very severe. Due to lack of upstream flow salinity intrudes more and more in this region which creates problem to drinking water, fisheries, agriculture and bio-diversity especially the Sundarban bio-diversity. In the eastern hilly region, drinking water of Chittagong district is collected from Halda River. Again Halda River is the only natural spawning ground of Indian carps (rohu, katla and mrigala). Normally salinity level in the Halda River is below 1 ppt which is suitable for spawning and drinking. But the salinity level of this river completely depends on the supply of water from Kaptai dam at the upstream of Karnaphuli River. Minimum 500 m³/s flow from Kaptai dam is required to maintain the salinity level below 0.5 ppt at Mohra at the downstream of Halda River. If sea level will rise there is a possibility to intrude more salinity in the Halda River which may destroy the natural spawning ground of Indian carps. In that case more flow is required from Kaptai dam.

Nature

The country supports a wealth of biodiversity, including numerous species of mammals, birds, reptiles, amphibians, freshwater and marine fish, molluscs and vascular plants. Many of these species are of international significance, such as the Asian Elephant, Royal Bengal Tiger, Gharial and Gangetic Dolphin.

The dense population and consequent demands for goods and services has subjected the country's natural resources to overexploitation. In particular the Sundarban Mangrove forest, being a Ramsar site needs special attention. There is a real danger for degradation due to human interference. Another danger for Sundarban is cyclonic storm surge because the last sever cyclone AILA destroyed a large part of Sundarban. The coastal area of Bangladesh experiences cyclonic storm almost in every year and its intensity and frequency increases day by day due to climate change.

IWM & CEGIS (2007) stated that ecosystems and biodiversity probably at greatest risk of all sectors sensitive to climate change. In context of terrestrial ecosystem, the mangrove ecosystem (the Sundarbans) and forest dependent wild lives are most important and will be threatened by the SLR. Only three important plant species-Sundri, Gewa and Keora are considered as indicator of changing terrestrial biodiversity. Based on the sea level rise impact on salinity extent and level it has been found that the suitable area for two mangrove species the Gewa and the Keora will be increased from 6,959 km² (base year 2005) to 7,837 km² and 8,245 km² in the year 2050 and 2080 respectively under scenario A2 with SLR 27 cm and 62 cm respectively as shown in Figure 5.8. However it is evident that *Sundri* dominant area will be transformed to Gewa and Keora plants due to sea level rise in the southwest part (the Sundarbans) of coastal area (CEGIS, 2005).

Wetlands

The ecologically sensitive wetland areas of Bangladesh are under great pressure from encroachment and their utilization as sources of subsistence and production. The Sundarban Mangrove forest, being a Ramsar site requires special attention as significant parts of the

forest have been lost due to human interference, increased salinity levels and high pace of siltation.

1.3 Governance (institutional/organizational aspects of delta management)

Summary of governance issues

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

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

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

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

Research gaps

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

Bangladesh has a highly centralized government with a strong administrative culture. Decisions are taken at the centre, even for local matters. For administrative purposes the country is divided into six divisions, sixty four districts and four hundred sixty four sub-districts. Public goods such as embankments, roads, bridges, schools, hospitals and other public facilities are provided and operated by the government. This system of providing services free of cost requires strong and accountable local agencies. Currently, efforts are underway to improve core governance systems in areas such as public procurement, financial management and fiscal reporting. Several reforms to improve sectoral governance are also underway.

The government of Bangladesh, with the assistance of international donor organizations, has introduced a National Water Policy, which guides all the activities in the water sector from the perspective of Integrated Water Resources Management. Moreover, the government has prepared a National Water Management Plan (NWMP) considering long term need, management and utilization of water resources cross cutting all sectors. In 2005, government declared a Coastal Zone Policy, providing a general guidance to all concerned for the management and development of the coastal zone in a manner that the coastal people are able to pursue their life and livelihoods within secure and conducive environment.

1.4 Main indicators for drivers, pressures and governance

DRIVERS	Main Indicators
Demographic Trends - Population in delta - Migration	- Number of people and growth rate - Migration trend in delta (annual percentage in/out) - Literacy rate
Economic development - Status of (total) economy - Sectoral (Industry, Fisheries, Agriculture) development	- Per capita GDP, growth rate, - Main sectors, growth rate - Unemployment rate
Technological development - Food/agriculture - Civil/Hydraulic engineering - ITC - Energy generation (Alternate Energy source)	- Per cent of GP spent on: Agriculture research, ICT, energy generation and Civil/Hydraulic Engineering projects - Using of HYV (area) - Mobile phone subscription - Internet connections
Climate change - Temperature / evaporation - Sea level rise - Precipitation / discharge	(Down scaling of global IPCC scenarios) - change of temperature & evaporation (max., avge. and min) at representative met stations - change of sea level (mm/year) - change of precipitation (mm/year) at representative met stations - change in frequency / intensity of cyclonic storm - river discharge (MCM/yr) at representative gauge stations
Subsidence - Natural and human induced subsidence	- cause of subsidence (e.g. geologic, ground water extraction or oil exploration) - rate of subsidence (mm/year) - Groundwater extraction rate
PRESSURES / PROBLEMS	Main indicators
Land and water use - Pressure on space - Shift in land use / urbanization - Water demand - Flood vulnerability/Water logging - Salinity intrusion	- number of inhabitants, population density, change in land value - % urban area, urbanization rate - water deficit / number of days with interrupted water supply - % area in different flood risk categories - % of people in flood risk areas - Area under saline water
Network / Infrastructure - Flood protection system (Coastal Polder) - Irrigation and drainage - Water supply and sanitation - Roads railways and ports - Cross dam - Cyclone shelter	- Flood risk (safety level), % of delta protected (high-medium-low) - % of delta under irrigation - % of infrastructure which needs to be upgraded - No. of floods or flooding days per year - % of people with access to water supply, % untreated waste water - Water sanitation risk index

	- Density of infrastructure, number of ports (+ volume of goods) - % of area under irrigation - Length of national and regional road network in good condition (km) - Length of (river) flood protection embankment in good condition (km)
Natural resources - Freshwater shortage / salinity intrusion - Pollution - Flood hazard - Coastal erosion / wetland loss - Biodiversity loss - Sediment supply - Mobility of delta distributaries - Land reclamation - River network - Mangrove forest - Fisheries - Natural gas	- Number of polluted areas (water, soil, air) - % of polluted areas (water, soil, air) - Frequency of storms (storm surge) / frequency of extreme river discharge, flood hazard level (high-medium-low) - Annual loss of land (km²/year) / average erosion rate (m/year) - Total area of wetland / % of wetlands protected by treaties - Biodiversity index (e.g. LPI) - Soil erosion in catchment (Mton/year) - Fluvial sediment transport (Mton/year) - River discharge (peak/low and variability) - % of sediment trapped in reservoirs - (planned) dams in main tributaries in the catchment - Existences of dykes/embankments along delta distributaries
GOVERNANCE	Main indicators
- Multi-level and multi-sectoral cooperation	- Existence of integrated plans (delta plan, national adaptation plan etc.) - Existence of inter-ministerial committees, multi scale level committee etc.
- Public-private partnership	- Number of PPP's - Scale of PPP's (geographic, budget, time span)
- Involvement of stake holders and citizen	- Existence of legal instruments for participation (e.g. spatial planning instr.) - Number of NGO's involved in planning and decision making - Number of major public consultations
- Approaches for dealing with risks and uncertainties	- No. of Climate Change adaptation strategies and projects - No. of risk management or emergency strategies

1.5 Score card

The scores in the score card are just qualitative and indicative, based on the summary tables descriptions for each item (above). Each item is scored on a 5-points scale, related to resilience and sustainability.

The following two development scenarios are recognized:

- Scenario1, moderate perspective 2050: medium economic growth (5%/yr, Regional Communities-scenario) and related medium technological developments, combined with medium climate change and sea level rise (to be determined by expert)
- Scenario2, extreme perspective 2050: high economic growth (7-8%/yr, good trade links to Europe and North America) and related high technological developments, combined with high climate change and sea level rise (to be determined by expert)

Table 2. Scorecard for delta assessment

<i>Delta</i>	Land and water use (occupation layer)	Infrastruc-ture (network layer)	Natural Resources (base layer)	Governance	Overall Resilience & Sustainability indicator
Current situation 2010	--	--	--	0	--
Scenario 1 moderate 2050	--	-	-	-	-
Scenario 2 extreme 2050	--	--	--	-	--

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

Clarification notes on the score card:

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

2. Overview of adaptive measures in the Ganges-Brahmaputra-Meghna delta

Overview of possible adaptive measures (in the three layers) based on current practices and innovative technological developments. The measures are classified in types of measures (technical, ecological, economic and institutional/organizational), related strategy (protect, adapt, relocate) and involved layer (occupation layer, network layer, base layer).

Name of measure: Cyclone shelter

Brief description: Recent history proven the effectiveness of killas (raised earthen mount) and cyclone shelters as safe heaven during the cyclone induced storm surges. It is expected that the high risk and risk zone will expand and this will create more population and property exposed to the cyclone induced hazards. In year 2050 the estimated additional exposed population will be 20 million. To address this, more cyclone shelters and killas will be required.

Name of measure: Coastal Embankment

Brief description: Bangladesh already employs coastal embankment towards management of coastal the embankment crest levels were designed using historic water level analysis without considering any probable sea level rise in future. It has been found that with 27cm sea level rise 4 numbers of polders will be submerged, and this number will increase to 13 polders with 62 cm sea level rise (IWM and CEGIS, 2007). The embankment inundation can be avoided by raising the crest according to the influence of SLRs. The drainage will be slower

because of higher rainfall and higher downstream water levels. This could be partially addressed by increasing the sluice openings (number of vents). The estimation of drainage openings and raising of crest requires detailed study and analysis.

Name of measure: Early Warning

Brief description: Bangladesh Meteorological Department (BMD) is entrusted with all sorts of weather forecasting. Weather warning system including cyclone came into being historically through evolution in order to mitigate suffering of people. It is observed from recent past cyclone (1997) the accurate and timely forecasting system and timely publicity, mobilization and action were very effective to reduce the loss of life and damage to properties. The severity of cyclone 1997 (maximum wind speed 220km/hr) was similar to the severity of 1991 where maximum wind speed was 225km/hr, but number of death was only 134 compared to number 138,882 in 1991. The local community voluntarily participated in dissemination of cyclone early warning under Cyclone Preparedness Program (CPP) project. It is feared that the cyclone frequency and intensity will be increased due to climate change and thus more people will be exposed to this disaster. As proven under CPP, the early warning with more innovative approach could be one of the most effective coastal defences. The dissemination technology should adapt the advance communication media like mobile system and community radio alongside CPP approach. The current warning signalling system should also be modernized and people oriented.

Name of measure: Afforestation

Brief description: Mangrove forests functions as natural physical barrier against tidal and ocean influences by means of their large above-ground aerial root systems and standing crop. Mangroves act to trap and stabilize sediment and reduce the risk of shoreline erosion. Mangroves also reduce the wave height due to their ability to dissipate wave energy. Under CERP, the modelling study showed that the mangrove forest with width of 600m decreases the surge height of approximately 0.45m around the south end of Hatia. The World Conservation Union (IUCN) compared the death toll from two villages in Sri Lanka that were hit by the recent devastating Tsunami. Two people died in the settlement with dense mangroves, while up to 6,000 people died in village without similar vegetation. Forest Department (FD) in Bangladesh has implemented a project named Coastal Green Belt Project (1995-2002) under which over 1300 km of embankment plantations, 7500 km of strip plantations, 665 ha of foreshore plantations was carried out. Under Coastal Embankment Rehabilitation project (CERP) huge plantation was done both on embankment slopes and foreshore. The intention of the foreshore plantation was to protect the embankment from direct wave action which is very detrimental to the sustainability of the polder. The SLR will increase the wave action on the embankment system where the implementation of concept of CGP and CERP could be an adaptive or preventive measure.

Strategy: Adaptation

Layer:

Name of measure: Dredging

Brief description: The government in Bangladesh has reportedly prepared a concept paper with strategies to implement short-term, medium- term and long-term projects for dredging important rivers in the country. Because most of the rivers in our country are silted up as the major rivers carry huge amount of sediment (almost 1 billion ton) from upstream. Dredging will help to restore the river network and improve water communication.

Name of measure: Adaptation Studies

Brief description: Recently, there have been a couple of climate change adaptation studies for important cities in the delta: *Assessment of Climate Change Vulnerability and Adaptation Options for Kolkata* (funded by the World Bank) and *Strengthening the Resilience of the Water Sector in Khulna to Climate Change* (funded by the ADB). Also, other studies include Coastal Vulnerability Assessment (by TERI) and Climate Change Adaptation in Rural Areas of India (funded by GTZ).

Name of measure	Type of measure	Brief description	Strategy	Layer
	1. Technical 2. Ecological 3. Economic 4. Institutional		1. Protect 2. Adapt 3. Relocate	1. Occup. 2. Network 3. Base
Coastal Embankment/ Polder	1	See above	1, 2	2
Cyclone shelter	1	See above	1, 2	2
Early warning	1, 4	See above	1, 2	1, 2
Coastal Afforestation	1, 2	See above	1, 2	2, 3
Land Reclamation	1, 3	Major rivers of our country carry 1 billion ton of sediment each year, this can be trapped and can develop new land (including in coastal areas)	2, 3	1, 2, 3
Tidal River Management	1, 4	Tidal river management (TRM) is a method that reduces the water logging in the land and also reduces siltation in the river bed.	2	2
Salinity tolerant HYV rice (BRRI – 40, 41) cultivation, HYV vegetable	1		2	2
Fresh water reservoir	1, 3	Fresh water reservoir can be constructed to supply water for drinking and agriculture during dry season	2	2
Dredging	1	See above	2, 3	2
Improve public education	4	Next generation needs to be informed and prepared about future challenges	1, 2	1
Strengthening of River Embankments	1	Erosion and river flooding are major challenges in this active delta	1	2
Construction of Ganges Barrage	1	Assist in managing dry season flow in the southwest region	2	2
Protection of forests and wetlands	2	Establish and manage protected areas	1	1, 3
Adapted forms of building and construction	1, 3	Floating houses and facilities	2	1
Improving fisheries production	1, 2, 3	Reduce impacts of FCDI schemes, prepare for salinity intrusion in SW region, increase wetlands productivity and reduce pollution of water bodies	2	1, 2, 3

Improve crop productivity	1, 3, 4	Improve agriculture extension, introduce saline and drought tolerant varieties	2	1
Review of road and rail designs and subsequent re-engineering if required	1, 4	Current designs do not take into account of climate change	2	2
Coping with increased salinity	1, 2, 3, 4	Develop plans and strategies to cope with increased salinity with respect to water supply, irrigation, ecosystem services, etc.	1, 2, 3	1, 2, 3

3. Overview of technical methods and tools to support delta management and development in the Ganges-Brahmaputra-Meghna delta

Overview of methods and tools for assessments, planning and decision making on delta management and development issues:.

Name of tool	Brief description	Institute	Available at
2D HD Model	Hydrodynamic and morphology model of key rivers in the delta	Institute of Water Modelling	www.iwmbd.org
ADSS	Arsenic Decision Support System	Centre for Environmental and Geographic Information Services	http://www.cegisbd.com/
BoB Model	Bay of Bengal Model, including storm surge prediction tool	Institute of Water Modelling	www.iwmbd.org
DRAS	Drought Assessment Framework (DRAS)	Centre for Environmental and Geographic Information Services	http://www.cegisbd.com/
EMIN	Environmental Monitoring Information Network	Centre for Environmental and Geographic Information Services	http://www.cegisbd.com/
Flood Forecasting Tool	Used by Flood Forecasting Warning Centre	Bangladesh Water Development Board supported by IWM	http://www.ffwc.gov.bd/
Flood Warning System	Used in West Bengal	Irrigation and Waterways Department (West	http://www.wbiwd.gov.in/application/index.php

		Bengal)	
GBM Model	Mike Basin based planning model for the Ganges-Brahmaputra-Meghna Basins	Institute of Water Modelling	www.iwmbd.org
NDDS	National Water Resources Database Data Dissemination Software	Water Resources Planning Organisation	http://www.warpo.gov.bd
NWP Tool	Numerical weather prediction tool	Bangladesh Meteorological Department	http://www.bmd.gov.bd/nwp.php
PRECIS	Regional Climate Change Modelling	Institute of Water & Flood Management	www.teacher.buet.ac.bd/diriwfm/
Regional 1D HD Model	Hydrodynamic model of key rivers throughout the delta	Institute of Water Modelling	www.iwmbd.org
SAL Model	Salinity model for river system in south of the country	Institute of Water Modelling	www.iwmbd.org
WATSURF	Community based Flood Information System Software	Centre for Environmental and Geographic Information Services	http://www.cegisbd.com/

4. Knowledge exchange and development

4.1 Lessons learned on delta management

- Bengal delta is one of the most vulnerable to climate change impacts
- It is envisaged that climate change will cause increase in intensities and frequencies of floods, droughts and storm surge
- Millions of people will be vulnerable the changing situation
- Adverse impacts of climate change are already being experienced in different parts of Bengal delta
- The capacity of the government and the private sector is limited to cope/manage the challenges
- There is a growing awareness in the government, community, private sector, and scientific community of the impending climate change impacts
- Over the last 35 years, the Government of Bangladesh, with the support of development partners, has invested over \$10 billion to make the country less vulnerable to natural disasters. These investments include flood management schemes, coastal polders, cyclone and flood shelters, and the raising of roads and highways above flood level.
- The government has formulated the Bangladesh Climate Change Strategy and Action Plan; limited resources have been mobilized to implement the action plan partly. More progress in this area is required. Support from the international community is necessary for the purpose.
- Already research in new varieties of climate resilient crops is undergoing
- Research in climate proofing of infrastructure is necessary
- Bangladesh has a suite of advanced suite of process models which are capable of predicting climate change impacts on water resources, salinity, storm surge, river and coastal morphology; these tools can better perform if climate predictions could be down scaled with more accuracy

- Existing hydrological and meteorological monitoring system, though quite extensive, needs to be upgraded and extended;
- For proper delta management followings areas to be attended
 - Monitoring of morphological process and tidal dynamics
 - Changes in temporal and spatial variation of salinity
 - Land building both inside and outside of the polder area
 - Land reclamation in the Bay of Bengal
- Systematic data collection on the hydrological and morphological process including datum of the area relevant to national datum and mean sea level (MSL)
- Adaptive measures to be evolved to live with impacts due to upstream intervention
- Development of road infrastructures in the Delta area without consideration of adequate drainage facility
- Building up of homesteads, growth centre and township without consideration of integrated linkage
- Lack of proper sanitation and impact of climate change
- Arsenic contamination and it's adverse impact due to climate change in the Delta area
- Mathematical hydraulic models (Regional models, Bay of Bengal model, ground water model and urban drainage model) are found to be effective in planning in the area facing dynamic changes in the estuaries and also affected by tropical cyclone and sea level rise.
- Data collection in the dynamic estuary poses a great challenge in both resource requirement and also in terms of difficulties
- Use of remote sensing in generating the data in the dynamic estuary to trace the change of various parameter would be great help
- Bangladesh has significant experience and knowledge in extreme events, however, limited resources and technology, institutional capacity and fragmented development policies and plans are the major constraints for effective management of these events
- The people of the area have developed some indigenous coping measures against extreme events, these could very appropriately adopted and enhanced to develop adaptation strategies at the grass roots

4.2 Summary of research gaps and related needs for knowledge exchange

Drivers of change and Pressures – potential problems / Challenges - opportunities

- Development of relationship between water salinity and soil salinity in the coastal area including islands
- Capacity building in digital data management
- Use of ICT in the coastal community
- Use of tidal fluctuation, solar radiation and wind in generating energy in rural areas
- Making faster and cheaper methods for potable drinking water
- Real-time cyclone induced storm surge inundation forecasting in the coastal region
- Enhancement of land reclamation process
- Cost effective bank protection methods
- Integrated coastal zone management
- Development of data collection network for sea level rise (SLR)
- Artificial recharge of freshwater during monsoon to prevent rise in salinity in ground water
- Development of economic methods to raise the embankment height against climate induced cyclonic storm surge
- Invention of HYV salinity tolerant crop
- Regional co-operation in the upstream to develop:
 - Long lead Flood Forecasting
 - Storage reservoir in the upstream to release fresh water flow during lean period to facilitate power generation, navigation, irrigation and availability of fresh water for drinking and household use.

- Basin wide pollution model to monitor changes and develop necessary adaptation
- Capacity building in using basin level models
- Regional co-operation in the downstream to develop:
 - To update and operationalise storm surge inundation forecasting induced from tropical cyclone in the areas from India to Myanmar coast
 - Joint research in the management of Sundarban mangrove forest
 - Restoration and preservation of the ecosystem of St. Martin Island
 - Development of economically feasible design for the maintenance of marine drive
 - Intelligent dredging in the port area and in other navigational routes
 - Integrated management of water resource of the Karnaphuli River for power generation, reduction of salinity, maintenance of navigational depth and flushing of sediment at the port area towards sea.
- Nature and extent of subsidence needs further research.
- Uncertainties in climate change predictions need to be reduced.
- Reliable methods for downscaling from GCMs and RCMs required.
- New research is required in the development of tools for assessment of impacts on various sectors based on the predictions from process models.
- Comprehensive database on climatic, natural resources and socio-economic parameters is necessary to support various research and development initiatives
- Integrated natural resource management
- Conservation of bio-diversity

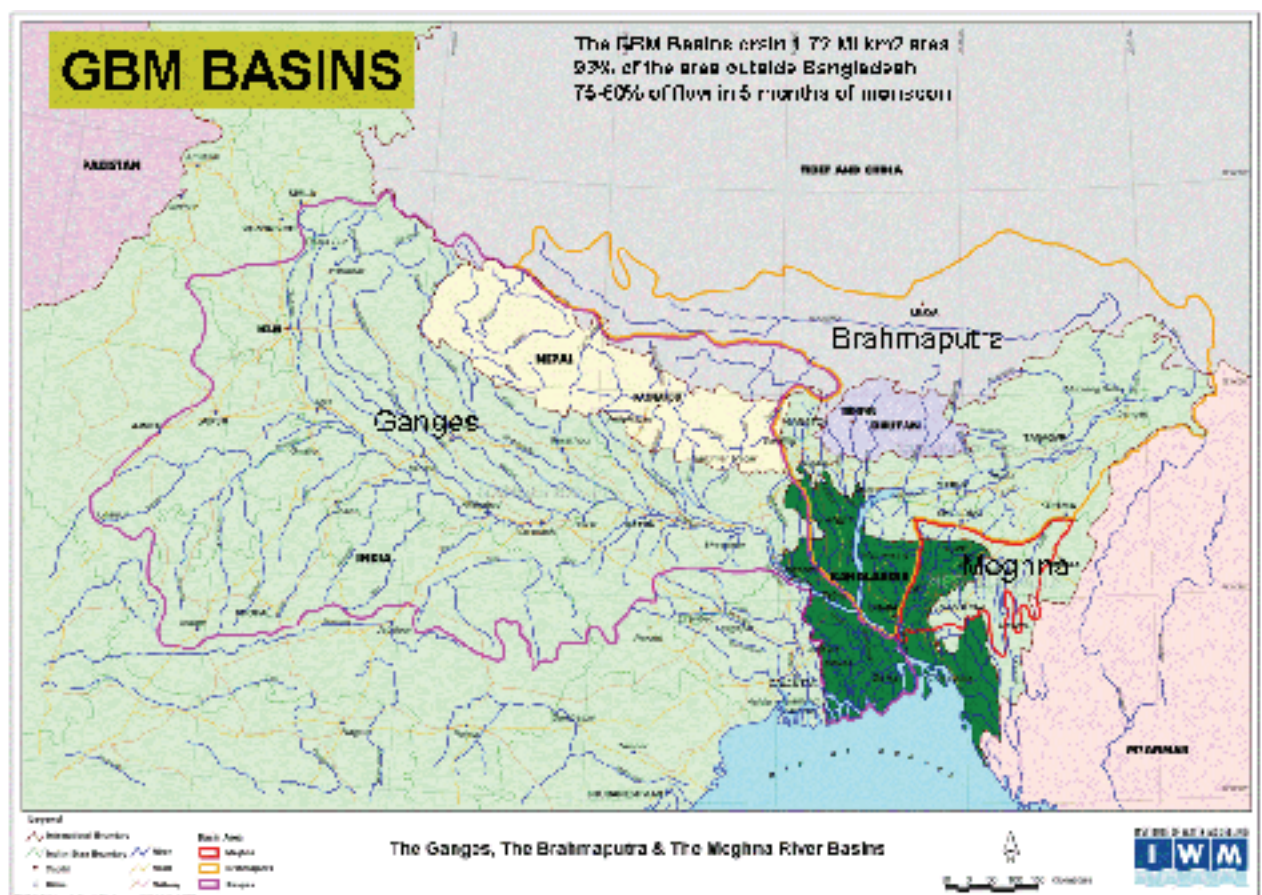
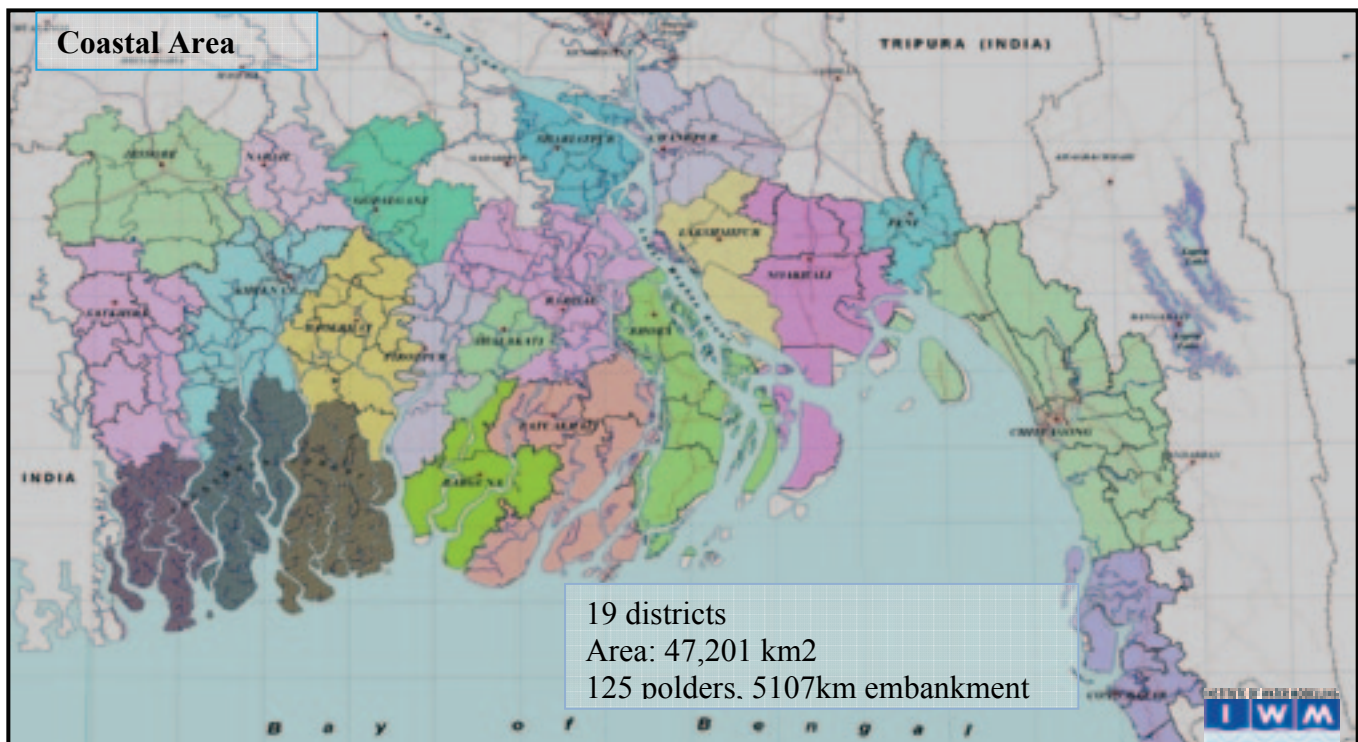
Adaptive measures

- Research on various adaptation measures like, salinity and flood resilient crop varieties, guidelines on climate proofing of infrastructure, reduction of GHG emission
- Re-engineering of existing infrastructure to make them climate proof
- Capacity building of institutions and community to cope with the changing climate
- Identification and harnessing safe and affordable water supply sources
- Re-engineering of existing infrastructure like flood and coastal embankment, drainage, communication, power, irrigation etc.
- Improved river management including river bank erosion management
- Flood and salinity resilient crop varieties
- Improved flood, drought and storm surge preparedness, response and mitigation system
- Quantification of ecosystem services and estimation of benefits to livelihoods and the economy are required.
- Adaptive management techniques need to be improved through better education.
- Data collection, monitoring and evaluation system requires improvement.
- Work on integrating policies and updating existing National plans required.

Technical methods and tools

- Development of salinity intrusion model for Delta area to assess the present temporal and spatial distribution of salinity and possible impact on its intrusion due to decrease of upstream flow and sea level rise.
- Tool for forecasting of erosion and deposition pattern in the rivers and estuaries
- Improvement in 7-10 day flood forecasting is required.
- Hydromet system needs to be expanded into the Bay of Bengal.
- Further research on cyclone forecasting and tracking required. Sediment

4.3 Some available illustrations (map of delta, typical sites, etc.)



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Yangtze delta

No

4



1. Current and future state of the Yangtze delta

1.1 Drivers of change

Summary of drivers of change

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

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

Climate change: The average temperature is increasing. The precipitation and water flow to the estuary had been changed in timing and spatial distribution. Climate change is affecting Yangtze delta from both upstream and the sea.

Subsidence: Yangtze delta subsided 7 mm in 2007 and 5 mm in 2009, the sinking rate is decreasing as the government is implementing several methods to prevent subsidence.

Technological developments:

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

Research gaps

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

1.1.1 Socio-economics (population growth- migration, economic development + most relevant sectoral developments, e.g. for agriculture, fisheries, industry)

Population

Shanghai is one of the largest cities of the world and located in the Yangtze Estuary. Since the early 1950s, the city has experienced an urban sprawl with a rapid increase of the population from about 5 million inhabitants in 1960 to around 20 million today and the expansion of space, from 159 km² in 1975 to 1,179 km² in 2005.

The population could be 75 million if talking about the entire Yangtze Delta region including the other two provinces).

Population growth rate for permanent residents was 0.27% 2009.

Economic development

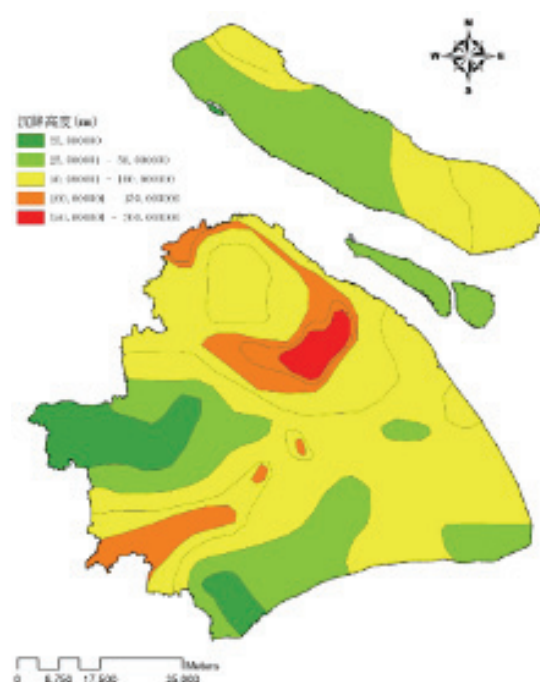
Yangtze delta (Shanghai) is the financial and logistics center of China, there are tens of industrial or high-tech zones as well as a modern finance district named Lujiazui attracting most of the world famous companies to settle. Shanghai has recorded a double-digit growth for 15 consecutive years since 1992. In 2008, Shanghai's nominal GDP posted a 9.7% growth to 1.37 trillion yuan, being 4.55% of China's total. Shanghai's total GDP is 219 billion USD in 2009, the annual growth rate is 8.2%.

1.1.2 Climate change (temperature/evaporation, sea level rise, precipitation/discharge)

Since 1951, the annual average temperature of Shanghai has been increasing with a rate of 0.21°C per 10 years. The annual precipitation does not change much but the timing and spatial distribution had changed. To tackle with sea level rise impacts, Shanghai had raised its flood prevention indicator, in which risks are hidden.

1.1.3 Subsidence (natural or human-induced)

From figure below it is clear that a large part of the land behind the dikes subsides. The subsidence in 15 years varies from 2.5cm in the dark green areas to over 15cm in the red areas. Syvitski (2009) believes the rate of the rise in the Yangtze River estuary water level relative to the sea level is 3-150 mm/yr, at the most dangerous Grade Five.



Distribution chart of the rate of land subsidence in Shanghai

1.1.4 Technological developments (e.g. regarding civil engineering, agriculture, ITC, energy)

The Yangtze delta is such a place where Shanghai and many other mega cities agglomerate, bringing extreme tense between the rich biodiversity and human activities. The technological development in this delta must take serious consideration to fulfill the needs from both sides.

Civil engineering: To safeguard the drinking water safety of more than 20 million inhabitants, Shanghai has spent much energy on water source maintainance. The most important project recently is the Qingcaosha Reservoir, which is located right in the center of Yangtze estuary and has an area of 70 km² (volume 435million m³). Qingcaosha Reservoir is designed to supply water for 70% Shanghai population and for extreme situation of salt water intrusion, it can secure 30-60 days water supply without external in-flow. It's a brave attempt to build such an hydraulic engineering in the center of the estuary, which requires advanced technology.

Agriculture: In the Yangtze delta agriculture depends largely on reclaimed land, which is saline. Technological measures are taken to remove salinization and make the land more fit for agriculture.

Navigation channel: The estuary navigation channel is of great significance to waterway transportation not only within the Yangtze delta, but also along the whole Yangtze basin. It also makes great contribution to the regional and national economic development. Due to the huge sediments transportation, the original depth of the mouth bar area is 6 meters, which had obviously restricted the navigation development in the estuary. The navigation channel project started from 1998 and is now able to achieve the channel depth of 12.5m through treatment of the riverbed as well as dredging.

Ecological measures, e.g. releasing activity, are used to restore the biodiversity: jetties of the channel are developed into artificial oyster reef as well as important feeding and living habitat for other aquatic species, while ecological dredging technology is used to form new wetland habitat.

Energy facilities: Shanghai is on its way to sustainability, off shore wind farm has been built near the coastal region and electronic public transportation vehicles are introduced.

1.2 Pressures – impacts

1.2.1 Land and water use (occupation layer)

Summary of pressures

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

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

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

Research gaps

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

Pressure on available space

Yangtze delta is having great requirement of land during the fast urbanization process. In the past 50 years Shanghai has converted more than 1600km² farm land into construction land, which is 26.3% of the total land of Shanghai.

Reclamation is an important method for Shanghai to increase its land, more than 1000 km² wetland had been reclaimed since 1949. Some main industry areas of Shanghai are built on reclaimed land such as: Shanghai Chemical industry zone, Shanghai petrochemical industry zone, Pudong international airport, Lingang port city, etc.

The Yangtze estuary kept growing for thousands of years thanks to the heavy sediment load of Yangtze River. However, in recent years the sediment load has, as opposed to the change of water discharge, shown a drastic drop due to the plenty of upstream hydraulic projects since 1960's, especially during the years after 1990, when many large-sized reservoirs were built. It is to be expected to keep decreasing in the future. If such trend continues, the estuary wetland would very likely stop growing, or even appear degradation.

Nowadays Shanghai is facing the serious fact that land consuming rate is faster than the natural wetland growth rate, which causes the degradation of wetland status in coastal Shanghai.

Vulnerability to flood

Shanghai, the estuary city has an average elevation of just 4 m above sea level. To the east of Shanghai is the East China Sea. The city is bisected by the Huangpu River, a tributary of the Yangtze. Shanghai is situated on the soft mud of the delta and natural subsidence is estimated at 2 to 2.6 m. Flood risk is increasing in the Yangtze delta because of the subsidence and coastal wetlands degradation.

Freshwater shortage

Shanghai is a typical water quality-induced water shortage city, which has been listed by the United Nations as one of the six cities gravely deficient in drinking water of the 21st century. At present, the water supply of Shanghai comes mainly from the upstream Huangpu River (66% of total), the Chenhong Reservoir (16%) and several inland rivers and groundwater (18%). Faced with the increasing demand for water supply, Shanghai City will adopt the strategy of “Two Rivers and Several Reservoirs”, the former referring to the Yangtze River and the Huangpu River and the latter Chenhong Reservoir, Qingcaosha Reservoir, Upper Huangpu River Reserve Area and the Dongfeng Xisha Reservoir, three of which located at the Yangtze Estuary. The strategy plans to get 70% of the water supply for Shanghai City in the year 2012.

The safety of water supply for the city is under the combined influence of the competition for the development and utilization of the water resources in the whole river basin, including the upstream storage, the midstream impoundment and the downstream diversion. The conflict that must follow a dry season would definitely lead to a water shortage at the estuary, which is also under the dual influence of land subsidence and sea level rise. Due to the decrease of upstream discharge, seawater backflow, and lasting salt water intrusion, the Yangtze River experienced an exceptionally low water discharge in 2006, during which time the water discharge at Datong was distinctly lower than the historical average, in September and October dropping over a half. The saltwater intrusion took place in September in the same year, three months earlier than the normal time and occurred 14 times into the spring of next year, posing serious threats to the safety of water supply for Shanghai.

1.2.2 Infrastructure (network layer)

Summary of pressures

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

Research gaps

- How to minimum the negative impacts on the nature and environment during the infrastructure construction and management.
- How to compensate the above impacts of infrastructures.
- How to develop a more environmental friendly way for construction and management. of infrastructure.
- How to adopt natural solutions.

Infrastructure (general)

Shanghai is among the most advanced cities in China, there are two international airports: Pudong and Hongqiao. The Shanghai Metro is the 9th busiest system worldwide and the largest in the world by length (420 km). Elevated road(or city high way) is common in Shanghai, the fast growing private vehicle number is causing more traffic jams, the government controls the growing rate by limiting the car license number per month. Cycling is losing position in citizens.

Shanghai is serving as the financial and logistics center of China. It has the world's largest cargo port with a total of 560 million tons of cargo transported in 2007.

Approved by the central government, the Yangtze estuary deepwater navigation channel regulation project went into operation in Jan. 1998. The objectives of channel water depth for

its three phases are 8.5m, 10m and 12.5m respectively (theoretical datum plane). Till Mar. 2010, the 3rd phase project succeeded to achieve the water depth of 12.5 meters. Now the project has transferred into water depth maintaining procedure.

Expo 2010 has lead to large investment of infrastructure, (the estimated total amount is 40~60 billion USD).

1.2.3 Natural resources (base layer)

Summary of pressures

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

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

Research gaps

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

Coastal erosion

An estuarine wetland grows from the sediments from the upper reaches. The Yangtze River has been the most important freshwater source and sediment channel of central China. The land at the Yangtze estuary extended for several hundred kilometers over the past two million years. Historical records show a sedimentation rate of 20-50 m from 1950 to 1995, during which time the wetland also expanded quickly.

The Yangtze estuary kept growing for thousands of years. However, in recent years the sediment load of the Yangtze River has, as opposed to the change of water discharge, shown a drastic drop due to the plenty of upstream hydraulic projects since 1960's, especially during the years after 1990, when many large-sized reservoirs and dams were built. It is to be expected to keep decreasing in the future. If such trend continues, the estuary wetland would very likely stop growing, or even appear degradation.

The forecast for the future 100 years' sea level rise is 60 cm, while the decrease of the Yangtze sediment load has become an undisputable fact. Continual retention at upstream, excessive erosion of the midstream riverbed and extensive embankment of the downstream mudflats all contribute to the continuous decrease of estuarine sedimentation.

Loss of environmental quality and biodiversity:

The discharge of municipal organic waste water as well as industrial chemical polluted water causes water quality problems. Over the last 50 years the pollution level in the water of the Yangtze has shot up 73% originating from hundreds of cities and villages along the river. The estuary in particular is affected, receiving all pollutants from the upper catchment. Every year 25 billion tons of sewage and industrial waste is discharged into the Yangtze resembling 42 % of China's total sewage and 45 % of the industrial discharge. Because of severe pollution the Yangtze river has lost its natural resilience to buffer pollution with her self-purifying capacity, to which wetlands form the main contribution, and a severe threat to all life in the river and public health has emerged.

Meantime, two of the lakes in the catchment area of Huangpu River – Tai Lake and Dianshan Lake – suffer from pollution, and blue algae blooming outbreaks in later years – such as in June 2007 – have put a spotlight on the vulnerable water supply situation of Shanghai.

The Yangtze Estuary enjoys the richest aquatic biodiversity in China and the highest potential in fishery industry. It is the feeding site, spawning ground, and habitat for various fishes, and particularly, it is an important habitat for fishes that migrates between salty and fresh waters. Recently, however, with the intensive human activities, the estuary ecosystem is vulnerable to threats from pollution, wetland reclamation, large-scale irrigation constructions, and overfishing, leading to a sharp decrease in species richness and diversity. Chinese sturgeon, Japanese eel and Chinese mitten crab are representatives of the endangered and commercial species in the Yangtze Estuary.

1.3 Governance (institutional/organizational aspects of delta management)

Summary of governance issues

Cooperation between (scale) levels and sectors of government: Cooperation between different government sectors is not easy or efficient enough, but it's improving. Shanghai is relatively more open than most other parts of the country, NGO, private companies and public are having more influences.

Existing relevant governmental organizations are:

- Tai lake basin management bureau
- Yangtze delta mayor forum
- Yangtze delta information sharing platform

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

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

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

Research gaps

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

Cooperation between levels and sectors of government:

Chinese government has typical centralized authority. This leads to power of execution as well as ruling risk.

There is a Protected Area network along Yangtze, 3 nature reserves in the Yangtze Delta are included.

In 2008, Shanghai, Jiangsu and Zhejiang signed MOU on the environmental protection of Yangtze Delta, including six main cooperation sections from pollutant control to information sharing.

Cooperation between government and private sector:

Shanghai is one of the most open city in China and had developed a wide international cooperation network. Shanghai has 59 sister cities. Among these cities, many locates in estuary and delta area, such as Hamburg of the Germany, Liverpool of the UK, Rotterdam of the Netherlands, San Francisco of the USA, Barcelona of the Spain, etc. With each of these city, there are mutual cooperation programme under implementation.

Involvement of stakeholders and citizens:

WWF is active in the Yangtze delta, on-going projects include:

- Water resource restoration in Dalian lake, which contains both wetland restoration and sustainable mechanism in local community lifestyle.
- Wetland and bio-diversity conservation, from aqua life to birds and mammals.
- Low carbon development road map.
- An overall recommendations called Estuary Vision.
- And World Estuary Alliance

Information sharing and cooperation

There are some platforms for information sharing and cooperation promotion, which is helpful to improve the integrated management and development of the Yangtze Delta:

Name of tool	Brief description	Institute	Available at
United research center of the Yangtze Delta	This center is co-organized by the Shanghai Academy of Social Science(ASC), Jiangsu ASC and Zhejiang ASC. It is a platform to promote research cooperation of the Yangtze Delta.	Shanghai Academy of Social Science(ASC), Jiangsu ASC and Zhejiang ASC.	http://www.yangtze.org.cn/
Urban economic coordination alliance of the Yangtze Delta.	This alliance was established in 1992 and have 16 member cities. The main purpose is to promote regional economic coordinative development.	Coordination Committee for Finance and Economy of each member cities.	http://www.people.com.cn/GB/paper40/13292/1192535.html

1.4 Main indicators for drivers, pressures and governance

DRIVERS	Main indicators
Demographic trends	- Population: 20 million - Density: 2800/m² - Migration trend: +0.27%/yr
Economic developments	- GDP: 219 billion USD in 2009 - Annual growth rate: 8.2% - GDP/cap
Technological developments	- Rate of investment of R&D to GDP
Climate change	- Annual temperature change - Annual precipitation change - Rate of coastal wetland to the total municipality area
Subsidence	- Ground water extraction - Rate of subsidence: 10mm/yr - Relative land subsidence rate

PRESSURES/IMPACTS	Main indicators
Land and water use (occupation layer)	- Rate of construction area - Rate of green area - Rate of wetland - Water quality distribution of rate of water quality better than grade V - Urban area: 2050 km² - Urban ratio: 30%
Network / infrastructure (network layer)	- Flood risk - % of delta protected - % of infrastructure which needs to be upgraded - Number of floods or flooding days per year - % people with access to water supply - % untreated waste water - Water sanitation risk index - Density of infrastructure, number of ports
Natural resources (base layer)	- To be added..
GOVERNANCE	Main indicators
Multi-level and multi-sectoral cooperation	- Big events that can bring different sectors together - Masterplan development and results - Relevant laws, regulations and policy documents released
Public-private partnerships	- Clipping of website or media release - Relevant campaign - Numbers of people that had participated in relevant activities
Involvement of stakeholders and citizens	- Information exposure - Public participation regulations
Approaches for dealing with risks and uncertainties	- An overall risks prevention action plan

1.5 Score card

The scores in the score card are just qualitative and indicative, based on the summary tables descriptions for each item (above). Each item is scored on a 5-points scale, related to resilience and sustainability.

The following two development scenarios are recognized:

- Scenario1, moderate perspective 2050: medium economic growth (1,2 %, Regional Communities-scenario) and related medium technological developments, combined with medium climate change and sea level rise (to be determined by expert)
- Scenario2, extreme perspective 2050: high economic growth (1,7%, Transatlantic Market-scenario) and related high technological developments, combined with high climate change and sea level rise (to be determined by expert)

Table 2. Scorecard for delta assessment

Delta	Land and water use (occupation layer)	Infrastructure (network layer)	Natural Resources (base layer)	Governance	Overall Resilience & Sustainability indicator
Current situation 2010	-	+	-	0	0
Scenario 1 moderate 2050	-	+	-	+	0
Scenario 2 extreme 2050	--	0	--	+	--

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

Clarification notes on the score card:

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

2. Overview of adaptive measures in the Yangtze delta

Overview of possible adaptive measures (in the three layers) based on current practices and innovative technological developments. The measures are classified in types of measures (technical, ecological, economic and institutional/organizational), related strategy (protect, adapt, relocate) and involved layer (occupation layer, network layer, base layer).

Name of measure	Type of measure 1. Technical 2. Ecological 3. Economic 4. Institutional	Brief description	Strategy 1. Protect 2. Adapt 3. Relocate	Layer 1. Occup. 2. Network 3. Base
IRBM	1, 2, 4	Facilitate e-flow researches and promote IRBM in the Yangtze River	3	2
Rain storage	1	Making full use of rain water through the purifying effects of natural wet lands	2	2,3
better extraction points	3, 4	selecting better extraction points of fresh water within the Yangtze estuary.	2	2
Enhance sedimentation	1	strengthening current wetlands to tackle the upstream sediment decrease	1	3
Dynamic wetland area	2	Maintain certain ratio of wetland, balance	1	1

		between wetland and reclaimed land		
Green dredging	2	Use dredging sediments to create new wetland	2	2,3
Invasive species	2	Control invasive species	1	3
Nature reserve	3, 4	Establish more nature reserves	1	1
Re-introduction	1,2,3,4	Re-introduce large mammals to help increase biodiversity eventually	1	1,3
Urban planning	1,3,4	Urban planning measures to achieve low-carbon.	2	2
New tech	1,3	Technological measures to achieve low-carbon.	2	1,2
Lifestyle	3	New lifestyle of citizens to achieve low-carbon	2	1

3. Overview of technical methods and tools to support delta management and development in the Yangtze delta

Overview of methods and tools for assessments, planning and decision making on delta management and development issues:.

Note: So far, there are no specific assessment and planning tools for the Yangtze Delta.

There are some platforms for information sharing and cooperation promotion, which is helpful to improve the integrated management and development of the Yangtze Delta.

4. Knowledge exchange and development

4.1 Lessons learned on delta management

- There are many stakeholders and complicated relationship, effective communication platform is essential;
- There is no conflict between human and nature, with certain solutions they can benefit each other rather than fight;
- Demos are crucial for delta management to show the solution and leverage larger scale projects;

4.2 Summary of research gaps and related needs for knowledge exchange

Drivers of change

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

Pressures – potential problems / Challenges - opportunities

- **Occupation layer**
 - A sustainable mode of land reclamation based on sufficient coastal wetland conservation.
 - Risk assessment of sea level rise based on urban spatial pattern assessment.
 - Urban hydro-environmental improvement.
- **Network layer**
 - How to minimum the negative impacts on the nature and environment during the infrastructure construction and management .
 - How to compensate the above impacts of infrastructures.
 - How to develop a more environmental friendly way for infrastructure construction and management.
- **Base layer**
 - The distribution of nature resources and their interactive relationship with human activities.
 - Recommendation on future natural resources conservation and utilization.
- **Governance**
 - How to achieve integrated management by bringing different sectors to one platform.
 - How to strengthen the legal system to better safeguard the estuary/delta safety.,
 - How to develop a long-term and short-term integrated management mode.

Adaptive measures

- How much wetlands(ratio) do we need to maintain for the safety of the coastal city? Is that measurable?
- What are the effective methods to control invasive species such as *Spartina Alterniflora*?
- How to link adaptation and mitigation together? Such as the CO2 credit of coastal wetlands.

Technical methods and tools

New technical measures to increase energy efficiency

4.3 Some available illustrations (map of delta, typical sites, etc.)





References

- Yangtze Estuary Vision report, WWF, 2010
- Top 10 rivers at risk report, WWF
- Crisis for Chinese Estuaries and Deltas, Yun Caixing, ECNU
- Sinking deltas due to human activities, James P.M. Syvitski, Nature Geoscience
- Mega-stress for mega-cities. WWF, 2009

Ciliwung delta

No

5



1. Current and future state of the Ciliwung delta

1.1 Drivers of change

Summary of drivers of change

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

Economic developments: The Indonesian economy and politics are rapidly developing. In 2007 the annual income per capita was some US \$ 2000,- and GDP growth amounted to 6.3%. Jakarta alone contributes to about 25% of the National GDP.

Climate change: The effects of climate change may be strong. Changes in length and intensity of the rainy season are likely to continue, which could result in longer dry seasons and shorter but more intense wet seasons. Changing rainfall patterns will have a large impact on food production, thus affecting food security.

The mean sea level in the Jakarta Bay will increase as high as 0.57 centimetres (cm) per year. This coupled with subsidence as high as 0.8 cm per year, as observed in the Jakarta Bay, can have a large impact on flood risk, urban productivity and infrastructure.

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

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

Research gaps

Downscaled multi-ensembles climate change scenario analysis: Even though climate scenarios for Jakarta were reported based on one or several climate models, an analysis focusing on the statistical probability of extreme weather events (extreme precipitation intensity, abnormal long wet season duration, frequency of droughts, etc) is lacking. This statistical information is necessary to assess the capacity of existing infrastructures to cope with the extremes and to decide if infrastructure upgrading is required.

Socio-economic development projections: The growth of Jakarta metropolitan and other surrounding urban centers (Bogor, Depok, Tangerang, Bekasi) along with their economic growth is inevitable. A set of socio-economic development projections based on current trends and existing city development plans (e.g. mass transport system, land allocations for trade and service centres, etc.) will be helpful for exploring and anticipating future pressures and ecological and socio-economical risks.

1.1.1 Socio-economics (population growth- migration, economic development + most relevant sectoral developments, e.g. for agriculture, fisheries, industry)

Population

Java has a population of 130 million inhabitants and a population density of more than 1000 inhabitants per km². It is the most densely populated island in the world. The population of Jakarta has risen sharply from 1.2 million in 1960 to 8.8 million in 2004, counting only its legal residents. The population of greater Jakarta is estimated at 23 million, making it the fourth largest urban area in the world.

In 2005 the population growth rate for Indonesia had decreased to some 1.3% whereas Jakarta's population growth rate remained at 3,6% per year.

Economic development

The Indonesian economy and politics are rapidly developing. In recent years the development was hindered by a series of natural disasters, such as the Tsunami in Aceh and Western Java and the earthquakes in central Java. Nevertheless, in 2007 the annual income per capita was some US \$ 2000,- and GDP growth amounted to 6.3%. Jakarta alone contributes to about 25% of the National GDP. This has made the country economically very dependent on Jakarta. Therefore, the country is highly sensitive and vulnerable on any hazards or major disruptions that could occur in Jakarta. Even though the wealth presents in Jakarta, high population growth rate together with high level poverty and inequitable distribution of wealth results in major problems for Jakarta. The city has difficulties to provide basic needs such as water and shelter to the poor residents, which are most vulnerable when floods and other disasters occur.

1.1.2 Climate change (temperature/evaporation, sea level rise, precipitation/discharge)

The Jabodetabek area (the urban area of Jakarta, Bogor, Depok, Tangerang and Bekasi; some 5,500 km²) has a wet season that runs approximately from December till May. Maximum rainfall amounts are generally observed in January and February, due to heavy monsoon rainfall. Differences in rainfall volumes between the wet season and the dry season occur in the northern part of the Jabodetabek area. In the southern part of the area orographic effects cause relatively high rainfall amounts, even in the “dry season”. The rainfall in the area is characterized by high intensity short duration storms. Even in the wet season, long dry spells can occur between storm events. Rainfall is generally concentrated in the afternoons and evenings.

Mean annual precipitation ranges from about 1500 mm at the Java Sea coast to over 4000 mm in the mountainous upstream part of the catchment.

Making observations of climate change is hampered by the strong influence of the El Niño Southern Oscillation (ENSO) on the Indonesian climate. There is considerable public debate about the effect of global heating on the El Niño - La Niña cycle; however there is no proven evidence yet that intense and more frequent El Niño and La Niña events are caused by or are causing climate change. As some changes still emerge from the statistical analysis of time series, the effects of climate change may be strong.

Annual mean temperature in Indonesia has been observed as increasing by around 0.3 degrees Celsius since 1990. Evident changes in the length and intensity of the rainy season have occurred. In the southern part (South Sumatra, Java and Eastern Indonesia) at most stations wet season rainfall has increased while dry season rainfall has decreased. For several years now, farmers in the villages of Java have been talking about the abnormal seasons. The ancient rice farmers' wisdom on the structure of the seasons has been devalued by climate change. In most of Sumatra, comparing the periods 1961-1990 and 1991-2003, the onset of the wet season is now 10 to 20 days later and the onset of the dry season is now 10 to 60 days earlier. Similar shifts have been seen in most of Java. Changes in length and intensity of the rainy season are likely to continue. In the future, parts of Indonesia, particularly in regions located south of the equator, could have longer dry seasons and shorter but more intense wet seasons. Changing rainfall patterns will have a large impact on food production, thus affecting food security.

Sea level rise will probably affect fish and prawn production, lead to saltwater intrusion into groundwater, destroy coastal wetlands and submerge small islands. Based on past observation from 1993 to 1999, the mean sea level in the Jakarta Bay shows an increasing trend of 0.23 cm per year (Sofian and Kozai 2004). Global warming could increase the rate as high as 0.57 cm per year (Anonymous 2010). This coupled with the land surface decline can have a large impact on urban productivity and infrastructure.

1.1.3 Subsidence (natural or human-induced)

Several areas in Jakarta are subsiding rapidly. The rate of land subsidence varies spatially and temporarily with estimates about 1 – 15 cm/year. Northern Jakarta can undergo faster subsidence rate up to 20 – 25 cm/year (Abidin et al. 2009).

There are four different types of land subsidence that could be expected in the Jakarta and its surrounding areas: subsidence due to groundwater extraction, subsidence induced by the load of constructions, subsidence caused by natural consolidation of alluvial soil and tectonic subsidence.

The variation in rates of subsidence is mainly due to combined variations of these causes. The geology of northern Jakarta predominantly consists of thick, soft and young alluvial soil, which is more compressible while than the shallower and older alluvial deposit in the southern Jakarta. The demand of clean water is higher in the central part of Jakarta and in the north where heavy construction buildings are mainly located. These have caused the land subsidence is north Jakarta is greater than in the south.

1.1.4 Technological developments (e.g. regarding civil engineering, agriculture, ITC, energy)

Jakarta currently is developing a mass rapid transportation system to enhance public transport services. Heavy construction of highways (toll roads) had taken place for the last 20 years by the development of circular inner city and outer ring road toll roads, and to connect with the nearby cities. Information technology and communication have grown rapidly. Numerous communication providers have emerged. However, manufacturing and industries have shifted to the outskirts of Jakarta, mainly to Bekasi Tangerang and Depok. Meanwhile, agriculture development is very low due to reduction of farmland. It indicates that Jakarta has shifted from industrial and manufacturing base to service city.

For the whole country, government budget for research and innovation technology development is less than 1% of the national GDP, mostly spent in Java. However, in 2005, Jakarta contributes to about 26.4% of the national GDP in the construction sector, 20.1% in transportation and communication, and 19.3% in services. These may reflect the domination Jakarta in technological development relative to the rest of the country.

1.2 Pressures – impacts

1.2.1 Land and water use (occupation layer)

Summary of pressures

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

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

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

Research gaps

Spatial Plan in Jakarta: At present the special autonomy of Jakarta is developing the Jakarta Spatial Plan for 2010-2020. However the spatial plan process lacks community participation and it is unclear how the plan will address the hydrology functions in Jakarta. The spatial plan as government policy should be based on sustainable delta and watershed ecosystem management.

Scenario based risk assessment of natural and social hazards: In accommodating high economic growth and in providing better services to the community, the Metropolitan of Jakarta will require all efforts to be more resilient to disasters. An integrated scenario based risk assessment of natural and social hazards could help in shaping city development and urban planning. The assessment should include ecosystem valuation, especially addressing linkages of ecosystem services with disaster risk reductions, existing and planned infrastructure and water supply development.

Water Footprint Study: Over-use of ground water in Jakarta by hotels, industries and households have been reduced significantly the amount of ground water. This is increasing the vulnerability of Jakarta by salt water intrusion, sea level rise and land subsidence. Land-use changes in upstream and coastal areas of Jakarta resulted in significant reduction of forests, lakes, rivers and mangroves areas surrounding Jakarta. This situation has decreased the hydrology functions in the Jakarta's delta.

Hydrology

The rivers draining to Jakarta have regularly caused floods. The flood of February 2007 was one of the worst floods ever experienced in Jakarta (return period 50 years). The flood covered 70% of the metropolitan area, whereas 30% was inundated over 100 cm water. The rivers that flow through Jakarta respond very fast to rainfall. The rain falls with high intensities, which means relatively large amounts of rainfall become available for runoff without infiltration. Also a large percentage of the area is urbanised, which causes low infiltration percentages and high (overland) flow velocities. Furthermore the area upstream of Bogor is very steep, leading to high flow velocities.

Analysis of previous flood events (the 1996, 2002 and 2007 floods) shows that extreme flood events mainly occurred in January or February, as a result of heavy monsoon rain. The floods are often caused by successive rain storms, with the majority of rain falling in one or two hours. Sea water levels did not contribute much to the flood extent of the 1996, 2002 and 2007 flood events.

However, the impact of sea water levels on the flood extent is expected to increase. Under normal conditions coastal gates are closed to avoid sea water intrusion and to maintain preset water levels in the major drainage system. Under severe flood conditions the coastal gates are opened, based on the tide, to drain excess water to the sea. The Flood Hazard Mapping Study (Deltares, 2007) has shown that in future this will no longer be possible. But even today a severe flood threat is present when rain induced floods coincide with high sea water levels.

Already today sea water levels can be more than 2 meters higher than parts of North Jakarta. Severe subsidence over the past 30 years has caused Jakarta to sink to very critical levels. It is expected that North Jakarta will subside at least another meter over the next 20 years. When severe rain induced floods coincide with high sea water levels, flood water cannot be drained to the sea and it is likely that very rapid water level rise will occur in the Northern part of the city. Even a fully rehabilitated drainage system will not be able to cope with these conditions and flood preparedness and flood warning are required to avoid severe damage and casualties. Large-scale additional sea defense measures will be required to prevent permanent inundation (from the sea) of northern Jakarta.

Pressure on available space

The core problem for the Ciliwung delta is the out-of-control urbanization of Jakarta. The rapid urbanisation of Jakarta results in severe shortcomings in the provision of infrastructure. Occupation of floodplains as well as inadequate infrastructure for piped water supply and solid waste disposal exacerbate the flooding problem in Jakarta.

Vulnerability to flood

Almost half of the area is below sea level and is still subsiding. The city is prone to inundation due to excessive rainfall and flash floods. Changes of land use in the upper Ciliwung catchment and increasing urbanization all over the basin will only aggravate the existing problems. Groundwater withdrawal for water supply will increase the subsidence and the vulnerability of the area. There is a clear lack of storage or diversion options; the construction of the new Eastern Banjir Canal will only partly solve the problems.

Freshwater shortage

Land conversion from forest to agriculture and urban area results in water shortages during the dry season. Broad Integrated Water Resources Development studies for West-Java in general and Ciliwung basin in particular were initiated in the eighties already and have continued till today. Masterplanning projects were done and resulted in various strategies to mitigate the water shortage problems. However, only part of the projects and measures were implemented and the pressure on the system has only been increasing since then. 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.

1.2.2 Infrastructure (network layer)**Summary of pressures**

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

Research gaps

Ecosystem based planning: The whole spatial development plan should be integrated with river basin and coastal management (water front city vision) and water supply-demand management, and should consider ecosystem service benefits for climate change adaptation and mitigation, DRR, pollution control, etc. Moreover this should be combined with the on-going development of a mass-and-rapid transport system.

Impact studies: Some policies, especially for economic development might lead to unintended negative impacts. For example, dumping waste into a river can create negative impacts for downstream people. This situation has already happened in Jakarta's delta.

Infrastructure development as part of Spatial Plan in Jakarta (see also above in 'Summary of pressures in Occupation layer')

Infrastructure (general)

The Indonesian economy is rapidly developing and due attention is given to the development of infrastructure in its capital Jakarta. Nevertheless, the rapid urbanisation of Jakarta results in severe shortcomings in the provision of infrastructures. The development of road infrastructure is lagging behind the growth of traffic, resulting in severe traffic jams during almost the entire day. With some 50% of Jakarta situated below mean sea level and only 25%

of this area protected by embankments, some 6 million inhabitants are vulnerable to flooding. The vulnerability for flooding is further increased by people living in the flood plains. Whereas the Ciliwung river's flood-plain was green in 1972; over 10% of the floodplain area is occupied by housing in 2005, mostly as slum dwellings in Jakarta.

Inadequate infrastructure for piped water supply influences the flooding problem in Jakarta. Only 47% of Jakarta's households have access to piped water supply within 200 metres of their dwelling. Such inadequate water infrastructure results in both households and commercial establishments (retailers, offices, industries and others) extracting ground water for their basic water needs. Over half of metropolitan Jakarta's households draw their water supply from shallow wells (i.e. less than 15 meters deep) whereas businesses rely on deep wells (up to 250 meter deep). Many scientists believe that deep groundwater extractions are primarily responsible for land subsidence, particularly those observed in the coastal, western and northeastern parts of Jakarta. Solid waste disposal in drains reduce the discharge capacity of these drains and as a consequence aggravate the flooding problems.

Ageing infrastructure

Although some of the infrastructure is relatively recent, rehabilitation is needed, especially with respect to drainage systems. This is particularly true for the flood control infrastructure around the city of Jakarta, which largely dates back to the beginning of the 20th century. The same applies to irrigation and drainage works that once were part of the rural agricultural system around Jakarta, but now are part of the city. In the upper catchment some of the hydraulic infrastructure was built more recently, but certainly their capacity is not adapted to the current flows and volumes of water anymore.

1.2.3 Natural resources (base layer)

Summary of pressures

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

Loss of biodiversity: Water quality is a major issue as many upstream domestic and industrial waste water is discharged untreated. Moreover the quality of the ground water is threatened by salinisation. Consequently the whole physical, biological and ecological system in the Ciliwung basin as well as in the coastal wetlands is at stake. Unless remedial action is taken the system is in clear jeopardy.

Research gaps

Data sharing and interoperability system: Detailed and regularly updated data are necessary to assess existing conditions and trends in the delta, and to enable integrated water resource management and coastal management. Currently data are fragmented, scattered and in various formats at many research and governmental institutions with planners and practitioners. A data sharing and interoperability system will help for trend analysis, scenario development, modelling, and integrated planning.

Land use changes in upstream areas and coastal areas of Jakarta: Forest, lakes, rivers and mangroves areas surrounding Jakarta have been significantly reduced. This situation has decreased the hydrology functions in the Jakarta's delta.

Coastal erosion

Locally there is coastal erosion due to natural and man-made factors. Islands in the Bay are disappearing as a result of coral reef destruction. Other human interventions along the coast are just aggravating the situation. Integrated Coastal Zone management is very much needed. This will require a further development of the institutional situation with regard to the mandate of national and local authorities to control and manage coastal developments.

Loss of environmental quality and biodiversity:

The quality of the surface water in the river and canal system in and around Jakarta forming Ciliwung Delta is quite bad, due to the disposal of untreated wastewater in Jakarta's urban area as well as discharges from industry and agriculture all over the basin. The quality of the ground water is threatened by salinization (as a consequence of over- abstraction) and contamination by infiltration of polluted surface water. Industrial discharges are not or badly controlled. Consequently the whole physical, biological and ecological system in Ciliwung basin as well as in the coastal wetlands is at stake. Unless remedial action is taken the system is in clear jeopardy.

To consider ecosystem services in planning will require rich and regularly updated data and information for base-lining existing conditions, trend analysis, scenario development, modeling and planning. Data are fragmented and scattered in various research institutions, government institutions, planners and practitioners. They exist in various formats. A data system accommodating spatial and non-spatial will be necessary to allow data sharing and to ensure their interoperability which will be useful in conducting trend analysis, scenario development, modeling and integrated planning such the ecosystem based coastal management or integrated water resource management.

1.3 Governance (institutional/organizational aspects of delta management)**Summary of governance issues**

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

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

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

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

Research gaps

Communication platforms and tools: Problems of conflicting vertical and horizontal authorities and agencies, accountability and inter-regional transparency in sectors, partial management, weak laws/regulations and weak institutional capacity are still main gaps in governance. Development of a framework for integrated delta management would be required with the objective to setup a good institutional structure and capacity, and a common perception (vision) for all delta stakeholders at national and sub-national levels.

Sustainable Financing: Until now there are no benefit/economic sharing schemes based on mutual partnerships between water providers and users. The quality, quantity and flows of water in delta Jakarta has reduced because of mis-management and inappropriate budget to restore, manage and protect sound hydrology functions in Jakarta's delta..

Credible Watershed Management Body: Because of lack of coordination between governmental organisations, watershed and delta areas in Indonesia, including Jakarta, are not well managed. Based on WWF ID review on water regulations, there are more than 15 regulations in Indonesia about water, with different interests and lack of synergy.

The Indonesian Government is currently in a decentralization process. The main challenge in the decentralization process is to prevent decentralized processes from becoming ineffective. Capacity building, for instance for water boards and catchment area commissions in the water sector, and promotion of cooperation (among institutes and between institutes and the central government) are important themes. Indonesia recognizes the increasing importance of sustainable development of water resources in dealing with floods and droughts. Prevention of excessive groundwater use and careful priority setting for increasing water demands are the main issues in this field.

Indonesia's Ministry of Public Works, the agency in charge of urban planning, recognized that expansion along the lowlands in Jakarta's northern coast or into the higher elevations in the south were the most ecologically threatening directions of expansion. In 1984 the Ministry therefore devised a "Jakarta Out" strategy that envisages the city expanding to the east and west. However, this sensible plan soon lost out to commercial interests: large scale conversion of green spaces and wetlands into urban-industrial areas. The low-lying coastal plains in north Jakarta, with poor soil bearing capacity for buildings, has become a dense industrial and housing zone.

Whatever preventive and mitigating measures will be taken, it is unlikely that Jakarta will ever be free of flooding. In line with the current national strategy on flood management, it therefore becomes increasingly important to think in terms of managing flood risks rather than only flood prevention. Flood risk management covers a wide range of non-structural measures next to structural measures. Non-structural measures are often cheaper than structural measures, but more complex to implement, as many stakeholders are involved, often with conflicting interests.

1.4 Main indicators for drivers, pressures and governance

DRIVERS	Main indicators
Demographic trends	- Number of population in Jakarta or Jakarta-Bogor-Depok-Tangerang-Bekasi (Jabodetabek) - Population growth rate in Jakarta or Jabodetabek - Migration flow trend in Jakarta or Jabodetabek
Economic developments	- Per capita GDP and GDP growth rate - % contribution of Jakarta to national GDP - Main sector GDP growth rate
Technological developments	- % GDP spent for research and technology development - Number of patents and other relevant innovation property rights released - % contribution of Jakarta to GDP in construction sector, transportation and communication (ITC), and services.

Climate change	- Change in temperature (°C) - Rate of sea level change (mm/year) - Change of precipitation (mm/year) - Change of river discharge (M³/sec) - Change in drought index - Change in number of days with extreme rain intensity or more than 100 mm/day (days/year)
Subsidence	- Known causes of subsidence (natural or/and human induced) - Average rate of land subsidence and maximum rate of subsidence in Jakarta (mm/year)
PRESSURES/IMPACTS	Main indicators
Land and water use (occupation layer)	- Population density - Change in land value or price - Rate of settlement development area or urbanization - % coverage of public/domestic water supply network - Number of days with interrupted water supply - % area flooded by annual flood
Network / infrastructure (network layer)	- % of delta protected from annual flood or/and five year flood (high-medium-low) - % of Jakarta or Jabodetabek under irrigation - % of infrastructure (road, railways and ports) which needs to be upgraded, based on load-capacity ratio - % households or people with access to public water supply, or % households use untreated water - Water sanitation risk index or other indices that describe the capacity to access clean water, such as water poverty index*
Natural resources (base layer)	- Drought index - % area of delta (Jakarta) with salinity problem - Frequency of tide surge (day/year) - Frequency of extreme rain above 100mm/day (day/year) - Average coastal erosion rate (m/year) - Soil erosion in catchment (Mton/year) - % of sediment trapped in reservoirs - River discharge (average, peak/low and variability) (m³/sec) - % of polluted areas (water or river, soil, air) - Biodiversity index or bio-/ecological indicator measurement - Dams in main tributaries in the catchment - Existence of dykes/embankments along delta distributaries - Water pollution (WWF)
GOVERNANCE	Main indicators
Multi-level and multi-sectoral cooperation	- Existence of integrated plans - Existence of inter-ministerial committee - Existence of multi scale level committee - Umbrella policy based on delta and watershed boundaries and management (WWF)
Public-private partnerships	- Number of public-private partnerships - Scale of PPPs (geographic, budget, timespan)

Involvement of stakeholders and citizens	- Existence of legal instruments for participation (e.g. laws, planning instrument) - Existence of legal public forum for involvement in planning and decision making - Number of NGOs involved in planning and decision making - % of planning and decision making process with NGO's involvement
Approaches for dealing with risks and uncertainties	- Existence of adaptive management (sectors and inter-sectors) - Existence of planned adaptation strategies - Existence of risk management

1.5 Score card

The scores in the score card are just qualitative and indicative, based on the summary tables descriptions for each item (above). Each item is scored on a 5-points scale, related to resilience and sustainability.

The following two development scenarios are recognized:

- Scenario1, moderate perspective 2050: medium economic growth (1,2 %, Regional Communities-scenario) and related medium technological developments, combined with medium climate change and sea level rise (to be determined by expert)
- Scenario2, extreme perspective 2050: high economic growth (1,7%, Transatlantic Market-scenario) and related high technological developments, combined with high climate change and sea level rise (to be determined by expert)

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Scenario 1 moderate 2050	--	--	--	0	--
Scenario 2 extreme 2050	--	-	--	0	-

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

Clarification notes on the score card:

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

2. Overview of adaptive measures in the Ciliwung delta

Overview of possible adaptive measures (in the three layers) based on current practices and innovative technological developments. The measures are classified in types of measures (technical, ecological, economic and institutional/organizational), related strategy (protect, adapt, relocate) and involved layer (occupation layer, network layer, base layer).

Name of measure	Type of measure 1. Technical 2. Ecological 3. Economic 4. Institutional	Brief description	Strategy 1. Protect 2. Adapt 3. Relocate	Layer 1. Occup. 2. Network 3. Base
More green open spaces in the spatial plan	2	Allocated more green open space to improve local ecosystem services to absorb water, regulate local climate, etc.	2	3
Waste management	2,4	Improving the management of waste including behavioral change of the residents	1	1,2,3
Maintaining and improving water infrastructure, including flood control	1	Maintaining and improving existing infrastructure for drainage and irrigation, to distribute water and to reduce flood	1,2	2
Maintaining and improving sewer infrastructure	1,2	Sewer improvement and maintenance	1	2,3
Improve disaster preparedness	1,4	Increase awareness and preparedness to extreme climatic events, such as through improvement of an early warning system	1,2	2
Management of health care and education	3	Improve health care and education for the poor, future investment for more resilient society	2	2
Integrated Coastal Zone Management (ICZM)	4	Management improvement for better coordination among institutions	1,2	1
Mangrove conservation and replanting	2	Conserving mangrove to protect from the impact of storm surges and other oceanic hazards, and to better protect against impacts of global warming induced climate extremes	1,2	3
Building with nature	2,3	Lowering ecosystem impact of real estate development by	2	2,3

		harnessing nature through, for example: water use recycling and waste management		
High rise apartment block	1,2	Reducing use of land space by developing high rise building blocks to minimize the use of land space	1,2	2

3. Overview of technical methods and tools to support delta management and development in the Ciliwung delta

There is no delta based management system in the Ciliwung Delta, instead the management is quite sectoral based on water resources, forestry, land use and coastal reef system. These are managed in different and uncoordinated sectors. Methods and tools for assessments, planning and decision making on delta management and development issues of Ciliwung are therefore scattered in many research institutions and consulting partners.

- The groundwater is under the Ministry of Mines and Energy. Several monitoring wells are located in Jakarta greater region. Data and information is available in this Ministry.
- The surface water is under the Ministry of Public Works. They are managed under the Ciliwung-Cisadane Rivers Basin Management Unit. Mostly are done through networked river gages and rainfall monitoring system.
- The atmospheric water is under the National Agency for Meteorology, Climatology and Geophysics (BMKG). These are monitoring weather system network in Jabodetabek area.
- The forest/mangrove and the coral reef are under the Ministry of Forestry. Some of the coral islands in the Jakarta Bay are under the special National Marine Parks Management.
- The land tenure system is under the Agency of Land Management. The agency, together with the Provincial Government (DKI) land services unit regulate the permit and land tenure system.
- Several environmental (chemical, biological) monitoring and spasmodic temporal mapping of the Jakarta Bay oceanographic, chemistry and biological conditions were developed by the Research Center of Oceanography LIPI.
- Flood and hydrological modeling studies of the upstream Ciliwung has been carried out by the Research Center for Limnology LIPI.

Overview of methods and tools for assessments, planning and decision making on delta management and development issues:.

Name of tool	Brief description	Institute	Available at
NewTrees	This method for monitoring the planting trees through geospatial. We can see the position and map of the trees by Nokia mobile phone.	WWF Indonesia, GECC Division	
InVEST	Invest (integrated valuation of ecosystem services and trade-off) is a spatial plan tool that	WWF, TNC, Stanford University	http://www.naturalcapitalproject.org/InVEST.html

	develop by WWF, TNC, Stanford University, with focus to indentify and valuate the ecosystem services in landscape levels		
RHA	Rapid Hydrological Appraisal. This tool can be used to assess the hydrology functions of watershed area and forcasting the hydrology functions with some scenarios.	ICRAF SEA	http://www.worldagroforestrycentre.org/sea

4. Knowledge exchange and development

4.1 Lessons learned on delta management

Unlike coastal areas in general, delta is a place where a river system meets the ocean system. The morphology of the delta depends on the energy between these two systems. Any disruption on one of the system will affect the energy balance between the two systems that could alter the morphology of the delta. Many disruptions come from the land where most human activities take place to make changes. For example, land opening for farming will change the local runoff and downstream sedimentation. Development of a dam will affect the upstream-downstream connection, sedimentation, etc. Development o a dyke is an example of disruption from the ocean side that could alter the energy behavior of the sea current and eventually alter sand deposition behavior and the shape of the delta. Therefore, the management of deltas should be an integration of river basin management and ocean management.

Governance is an important aspect in the management of sustainable delta. The management of delta requires good vertical and horizontal coordination among relevant development sectors and management units to link up management vision, environment, technical aspect and legal aspect in one clear vision. Coordination with management units of the neighbouring upstream and coastal regions is also important. Good institutional structure and capacity are general requirements for good governance.

Ciliwung Delta is a place for Jakarta Metropolitan that continuously grows. This delta has many problems to support the fast growing economic development of Jakarta, such as land subsidence, erosion, floods, lack of water supply, overcrowding population, poverty, poor waste management, etc. Climate change increases the severity of all these problems with rising sea-levels, extreme weather causing more severe floods, storm surges and water depletion, greater uncertainties in predicting natural environment. Poor residents are most vulnerable to these multi-hazards and will suffer most when the hazards occur. The economic development in the delta region therefore should be integrated with disaster risk reduction, climate change adaptation and poverty alleviation.

The development of delta, planning and design, therefore, should be based on current vulnerability and risk, and projected risk that are supported by data. Governance system is required to facilitate the whole process in implementing, operating and mainstreaming climate change adaptation. Data that are interoperable are essentials for baseline setting and trend analysis in the construction of socio-economic and physical scenarios. The data and constructed scenarios are used to assess current vulnerability and risk, and future impacts and risks, which eventually will be the basis for development planning and designing.

In the past, a lot of lakes found in surrounding Jakarta, but only few lakes are still there because many lakes have been converted to other purposes, such as housing complex, road and other big infrastructures. Those lakes are important for hydrology functions especially for catching and dumping the water from up-stream and rain fall before flowing to the delta. This system has been un-effective after the lakes areas smaller (WWF).

4.1 Summary of research gaps and related needs for knowledge exchange

Drivers of change

The growth of Jakarta metropolitan and other surrounding urban centers (Bogor, Depok, Tangerang, Bekasi) along with their economic growth are inevitable. Many factors drive changes in Ciliwung delta to current state, among them are population density and high population growth rate, high economic development, technology enhancement, and natural threats such as land subsidence and annual floods.

Research gaps and needs:

- **Socio-economic development projection tool:** Development of a set of socio-economic development projections based on current trends will be helpful for understanding the causes of changes. Incorporating existing city development plans (e.g. mass transport system, land allocations for trade and service centers, etc.) in the tool helps in exploring and anticipating future pressures, and ecological and socio-economical risks. It may serve as a management supporting tool to reduce the adverse impacts of development by controlling the key drivers through policy and regulations.
- **Downscaled multi-ensembles climate change scenario analysis:** Even though climate scenarios for Jakarta were reported based on one or several climate models, an analysis focusing on the statistics of projected extreme weathers (extreme precipitation intensity, anomaly long wet season duration, frequency of droughts, etc) is lacking. This statistical information is necessary to assess the capacity of existing infrastructures to cope with the extremes and when infrastructure upgrading is required.

Pressures – potential problems / Challenges – opportunities

- **Occupation layer and related research gaps**

Spatial Plan in Jakarta: now the special autonomy of Jakarta is developing the Jakarta Spatial Plan for 2010-2020. However the spatial plan process lack of community participation and how the plan address hydrology functions in Jakarta. The spatial plan as government policy should be based on sustainable delta and watershed ecosystem management (WWF).

Scenario based risk assessment of natural and social hazards: In accommodating high economic growth and in providing better services to the community, the Metropolitan of Jakarta will require all efforts to be more resilient to disasters. An integrated scenario based risk assessment of both natural and social hazards could help in shaping city development and urban planning. The assessment should include: ecosystem valuation to consider linkages of ecosystem services, with disaster risk and vulnerability reductions; existing and planned infrastructures including water supply development; and coping capacity of existing and planned protecting infrastructures such as the undergoing East Flood Canal project. Poverty and disaster rapid response capacity as important parameters of vulnerability should be considered in the assessment.

Water Footprint Study: Over-used of ground water in Jakarta by hotels, industries and households have been reducing significantly the water under ground and increasing the vulnerability of Jakarta from sea water intrusion, sea level rises and land subsidence (WWF).

Land-used changed in Up-stream and Coastal areas of Jakarta: Forest, lakes, rivers and mangroves areas surrounding Jakarta have been significantly changing, all becomes smaller. These situation has reduced the hydrology functions in the Jakarta's delta. (WWF)

- **Network layer and related research gaps**

Ecosystem based planning: The effort of improving Jakarta development plan, or re-designing with “water front city vision”, taking the benefit of undergoing development of a mass-and-rapid transport system, will require understanding and integration of ecosystem and ecosystem services in the planning framework. The whole spatial development plan should be integrated with river basin and coastal management (water front city vision) and water supply-demand management, and should consider ecosystem service benefits for climate change adaptation and mitigation, DRR, pollution control, etc.

Impact studies: Some policies, especially for economic development might lead to unintended negative impacts. For example, dumping waste into a river can create negative impacts for downstream people (WWF). This situation has already happened in Jakarta's delta.

Infrastructure development: as part of Spatial Plan in Jakarta, mentioned above (WWF).

- **Base layer and related research gaps**

Data sharing and interoperability system: Rich and regularly updated data are necessary to portray existing and changing trends of delta condition, to enable integrated planning based on holistic and rich information such as in water resource management and coastal management. Data are fragmented and scattered in various research institutions, government institutions, planners and practitioners. They exist in various formats. A data sharing and interoperability system will help for monitoring purposes and trend analysis, scenario development, modeling, and integrated planning.

Relevant data for these drivers of changes are available. Some are regularly updated, whereas others are not. Integrating all these data both in spatial and tabular forms and systematic clusters based on themes and time scale variation is necessary for portraying current state, identifying trends of changes, and for developing projected future states.

Land-used changed in upstream and coastal areas of Jakarta: Forest, lakes, rivers and mangroves areas surrounding Jakarta have been significantly reduced. This situation has decreased the hydrology functions in the Jakarta's delta (WWF).

- **Governance and related research gaps**

Communication platforms and tools: Problems of conflicting vertical and horizontal authorities and substances, accountability and inter-regional transparency in sectors, partial management, weak laws/regulations and weak institutional capacity are still main gaps in governance. Development of a model for integrated delta management (IDM) is necessary with objectives an establishment of good institutional structure and capacity, and an establishment of common perception (vision) for all delta stakeholders at national and sub-national levels. The development of this IDM will exercise the followings: establishment of a communication forum, development of a frame for IDM, training for trainers in IDM, development of educational modules, training and socialization of IDM, implementation of IDM, and comparative study on IDM with other deltas that have similar characteristics for benchmarking.

Sustainable Financing: Until now no benefit/economic sharing schemes based on mutual partnerships between water provider and users. For most of key stakeholders, water as a commodity and rewards from God. But in fact, the quality, quantity and flows of water in Delta Jakarta has reduced (WWF).

Credibel Watershed Management Body: Because of lack coordination and ego sectoral among government body, watershed and delta areas in Indonesia, including in Jakarta, has mis-management. Based on WWF ID review on water regulations, there is more 15 regulations in Indonesia discussed about same subject: water, with different interest and lack of synergize (WWF).

Adaptive measures

Adaptation should consider no regret measures. No regret measures are actions that could benefit for now and future. Jakarta has a number of good adaptation examples of no regret measures. For examples, maintaining and improvement infrastructure to support citizen resilience and to protect from hazards including water supply, river dredging and flood control, creation of new green open spaces through better city spatial planning, improvement in waste management through clean water program, mangrove plantation, etc. However, these measures may need to be enhanced to prepare for future variability that could be more extreme. Infrastructure development to protect from current and potential hazards under climate change and sea level rise, such as construction of dykes for coastal protection and canal development for flood control are in progress.

Adaptation should also address poverty alleviation in addition to other measures such as the infrastructure development. The poor living in Jakarta are usually lack of basic needs such as shelters, clean water and access to health service. They are most vulnerable to disasters. Furthermore, many of them occupy and use land resources illegally that could cause uncontrollable impacts on the ecosystem services that are important for larger communities in general. For example, the poor people occupy river bank and flood plain, which are buffer zone and space for water excess during wet season. Linking adaptation with poverty alleviation can be done through job creation and the development of livelihood that are less sensitive to climate change impacts.

Above all, there is a need to promote integrated delta management that integrates the main land (catchment) and coastal low land and the dynamic link between them in the management. The management considers also dynamic links between the three different layers: base, infrastructure and occupation layers. With changing in ecosystem as driven by climate change, sea level rise and population increase for example, the potential impacts under current infrastructure should be understood so that infrastructure adjustment and improvement can be addressed when necessary and to be designed in synergy with city service infrastructures and spatial plan.

WWF recognized the following research gaps regarding adaptive measures:

- Spatial Planning based on Delta Ecosystem
- Sustainable Lakes Management

Technical methods and tools

There is no institution with a specific function to manage the Ciliwung Delta. The management is very sectoral in approach and uncoordinated. Technical methods and tools to support delta management are scattered in many institutions and consulting partners.

A robust decision support system (DSS) based on many scenarios is required for better and more justified decision making process, planning and coordination among various sectors. The DSS will have to be supported by several methods and tools such as:

- a high resolution regional climate model to generate multi-ensemble high spatial and temporal resolution,
- socio-economic model to project future economic development and demographic change,
- land use change model to identify areas of potential growth.

In addition, a well developed database system to accommodate spatial and tabular data, as well as time series data to support trend analysis, projection, simulation, as well as for monitoring.

WWF recognized the following research gaps regarding technical methods and tools:

- Water Foot Print Study
- Raining Haversting Method
- Payment for Environmental Study (PES)

4.2 Some available illustrations (map of delta, typical sites, etc.) to be added..

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Mekong delta

No

6



1. Current and future state of the Mekong delta

1.1 Drivers of change

Demographic trends: The number of inhabitants of the delta is some 17 million, the population density is 425 inhabitants/km², with a growth rate of 0.6% per year⁹

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

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

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

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

Research gaps

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

1.1.1 Socio-economics (population growth- migration, economic development + most relevant sectoral developments, e.g. for agriculture, fisheries, industry)

Population

The population density in the Vietnamese part of the Mekong River Delta is high compared to other regions of the country. The number of inhabitants of the delta is some 17 million. The population growth rate is 0.6%.

Economic development

In the last 25 years, Vietnam's economy changed from a plan-economy into a modern free market economy. Under the name "Doi Moi" (literally: change and renewal) Vietnam carried through significant economic and political reforms. From 1996, Vietnam's economy was among the fastest growing economies of Asia. According to figures from the General Statistics Office in Hanoi, Vietnam's economy grew 8.5 percent in 2007, the fastest pace since 1996. Industry and construction accounted for 42 percent of Vietnam's economy in the first quarter of 2008. Agriculture, forestry and fisheries, which accounted for 14 percent of Vietnam's economy in the first quarter, grew at a 2.9 percent pace, up from 2.6 percent in the same period in 2007. Per capita GDP increased from US\$ 200 in 1996 to over US\$ 700 in 2006.

In the framework of the Doi Moi, the Vietnamese government identified the Mekong Delta as a priority area for economic development. The target is to increase the production of food, commodities and consumer goods by 8% per year.

⁹ General Statistics Office, Statistical Yearbook of Vietnam 2009

Agriculture

The delta is one of the world's most productive agricultural and fishery regions. In Vietnam alone, it is responsible for producing half of the country's rice, 60 percent of its fish-shrimp harvest, and 80 percent of its fruit crop. Over 90 percent of Vietnam's total national rice export comes from the Mekong delta, which is why it is known as the rice bowl of Vietnam.

The Vietnamese portion of the Mekong Delta occupies 40,058 km²¹⁰, of which 24,000 km² are now used for agriculture and aquaculture and 4,000 km² for forestry. Rice cultivation in the delta is a relatively recent practice with floating rice being used prior to paddy rice during wet season flooding. Primary products from the delta contribute over 30% to the Gross Domestic Product and the delta is Vietnam's rice bowl, producing 50% of the nation's rice and contributing to Vietnam's place as the second largest rice exporter in the world.

One of the reforms of the "Doi Moi" policy, is that private enterprise is allowed in agriculture which enabled farmers to lease land for up to 50 years. In 2007 the Vietnamese government stopped charging irrigation service fees, to further promote agricultural enterprises.

A constraining factor for agriculture is the salinity of surface water in large parts of the delta and the problem of acidification of sulphate rich clays.

Fisheries

The lower Mekong River and its delta support one of the largest inland fisheries in the world. Cambodian people in rural areas rely heavily on fisheries for their subsistence. Fish provide from 40% - 60% of animal protein intake for people in rural areas – even those living far from water. Over the past decade, aquaculture, primarily shrimp and pangasius or Vietnamese catfish, has grown in production from a few thousand tons to over 1 million tons in 2009 generating a value of over US\$1 billion while shrimp farming grew steadily to reach a total production of over 380,000 tons. These species, mainly farmed in the Mekong delta, are associated with great benefits to the Vietnamese economy (WWF Vietnam).

The Vietnamese portion of the delta yields an annual harvest of about 400,000 metric tonnes of fish. Approximately 156,000 tonnes of this are derived from the brackish water and estuarine zone. However, fish production has been declining in recent years as a result of over-exploitation, forest destruction, drainage of wetlands for agriculture and the effects of toxic chemicals such as Agent Orange.

National estimates suggest that 244,000 tons of freshwater fish were captured in 2001; this declined to 209,000 tons by 2003. About three quarters of this capture came from the Mekong delta¹¹. Estimates may considerably understate total catch as much of the freshwater capture fishery is informal – from river to plate. Participation in the freshwater fishery is extraordinarily high in some areas of the Mekong Delta where up to 80% of local populations depend upon the freshwater fishery for subsistence (WWF Vietnam).

In a substantial part of the delta, the brackish water conditions make the water unsuitable for rice irrigation during the dry season. Farmers in these areas have adapted to the changing freshwater-salt water environment by evolving a rotating rice-shrimp system to maximize income through both rice and high value, intensive or semi-intensive shrimp production.

The marine capture fisheries in the coast of the Mekong Delta are estimated at at least 60% of the total marine capture fisheries in Vietnam, equivalent to about one million tons of fish per annum (total marine capture fisheries in Vietnam = 1.5-1.7 million tons/year)(WWF).

Industry

Industry is fast growing all over Vietnam. In the Mekong delta a substantial part of the industry is related to agriculture and aquaculture. Concerning water resources, the industrial development may be conflicting with agriculture. On one hand agriculture and industry will compete for the scarce groundwater resources, on the other hand, untreated industrial wastewater is polluting the surface water.

¹⁰ According to Decision No. 2097b/QĐ-BTNMT dated 29 October 2009 of Minister of the Ministry of Natural Resources and Environment.

¹¹ GSO (Government Statistics Office) in Ministry of Fisheries and the World Bank. 2005. Vietnam Fisheries and Aquaculture sector study
http://siteresources.worldbank.org/INTVIETNAM/Resources/vn_fisheries-report-final.pdf

1.1.2 Climate change (temperature/evaporation, sea level rise, precipitation/discharge)

The climate in the delta is tropical monsoon and is influenced by both the southwest and northeast monsoons. In general the dry season runs from December to April while the wet season is from May to November. The average annual temperature in the delta is close to 28°C. The mean monthly evaporation is around 150 mm. Monthly precipitation ranges between 0 mm in the dry season and around 250 mm in the wet season. There is a considerable spatial variation in annual rainfall across the delta. The average annual rainfall ranges from less than 1,500 mm in the central region and northwest to over 2,350 mm in the south.

The Mekong Delta is among the 3 most vulnerable deltas in the world to climate change. Almost the entirety of the Mekong Delta is below 5 m above sea level, making it one of the most vulnerable deltas to sea level rise (climate change) in the world. About 38% of the delta will be submerged under water if the sea water rise 1 m. Extreme climate and water regime events; like longer draught spells, earlier and more severe floods, higher temperature, are affecting the crops and aquaculture production. Heavily populated, the delta is under threats spreading of tropical diseases caused by higher temperature. Climate change is a major threat to the Mekong River delta. Syvitsky et al (2009) classified the delta as being 'in peril', based on reduced aggradation rates, increased compaction and rising sea levels, which mean that the delta is sinking relative to sea level. The reduction of mangroves means that the coastline becomes more vulnerable to erosion and storm surges.

1.1.3 Subsidence (natural or human-induced)

Changing water regime might affect to the delicate balance of mangrove growth and expansion. The consequence can be a further loss of mangrove belt along the coast line. Erosion, followed by loosing arable land, is inevitable. Less sediment load in water, caused by lower river discharge and by dam construction up-stream adds to the problem of soil subsidence. The significance of the impacts on sedimentation has not been fully explored, but some main areas can be recognized: (i) destabilisation of the Mekong Delta due to reduced sediment; (ii) change in habitats of species; (iii) loss of nutrients to support agriculture; (iv) loss of nutrients and sediment to support aquaculture and marine capture fisheries in the coastal area of the Mekong Delta (WWF).

Over exploitation of mangrove for construction and fire wood, introducing shrimp cultivation in mangrove forest area are other damaging factors to the mangrove belt. All of these causes, together, might damage the mangrove to a status that cannot be reversed, where conservation efforts will produce no results.

Sediment load is also very important to support the marine fisheries in the coast in the Mekong Delta (WWF).

1.1.4 Technological developments (e.g. regarding civil engineering, agriculture, ITC, energy)

Agriculture development

Rice production of the Mekong delta, accounted for more than 50% of the whole Vietnam, was almost doubled from 1995 to 2009 (from 12 M tons to 20.5 M tons). Rapid growth of rice production is due to large scale water control projects, reclaiming of acid sulphate soils, expanding rice field areas into the wetlands, etc.

Aquaculture

Shrimp pond areas expanded rapidly in the past 10 years. Currently, more than 500,000 ha of shrimp cultivation area has been developed in the Mekong delta, mostly in the brackish water, or saline water intrusion areas. Part of the mangrove forest was removed for shrimp cultivation.

In the last 5 years, fresh water fish cultivation, especially cat fish, is a booming business.

Irrigation and drainage projects

Recently, several water control projects have been implemented in the Mekong Delta aiming to boost rice production. The most noticeable projects are:

- The Plain of Reeds project with the goal is to reclaim the acid sulphate soils and provide irrigation for an area of 600.000 ha to cultivate rice.
- The Long Xuyen Quadrangle project: focused on draining flood water to the Gulf of Thailand and reclaim the soils.
- Ca Mau Peninsula project to bring fresh water to the salt-intruded areas for rice cultivation.
- *South Mang Thit* project: saline water control project.

1.2 Pressures – impacts**1.2.1 Land and water use (occupation layer)****Summary of pressures**

pressure on space: The population density is 425 inhabitants/km² and with a growth rate of 0.6% per year, pressure on space will increase in future

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

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

Research gaps

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

Hydrology and flooding

The Mekong Delta divides into two distributaries from its apex at Phnomh Penh in Cambodia: the Mekong (Tien) and the Bassac (Hau Giang). Further downstream these channels subdivide into nine channels, the Nine-Headed Dragon or Cuu Long River.

Floods are part of the way of life in the Mekong delta, bringing down sediments and nutrients to renew the floodplain. Traditionally the negative connotation of the word “flood” did not exist in the Delta. The year was divided into a 6 month rising water season (Mùa nước nổi) and a 6 month low water or dry season (Mùa khô). Life was determined by the river’s movements. At the onset of the rising water season people planted rice, during the season they fished and collected wetland resources, then harvested rice during the low water season.

Flash floods of tributaries and extreme mainstream flood events can be destructive and cause enormous damages. On the other hand, the annual moderate floods are a natural phenomenon that is essential to food security (agriculture and fish production) and biodiversity (sustenance of the fresh water ecosystems). The notion that floods bring benefits begins to be widely acknowledged, especially in the delta in Vietnam. Studies of the last 45 years of Mekong flow data show no systematic changes in the hydrological regime of the Mekong. The flow of the lower Mekong is regulated by Cambodia’s Great Lake, Ton Le Sap, in the upper delta. The lake acts as a flood storage in the wet season until early October and a supply reservoir in the dry season. The mean annual flow volume of the Mekong river amounts to some 475,000 million m³. In 2005 a flood volume of 500,000 million m³ caused inundation of nearly 50% of the delta. With a storage capacity of some 60,000 million m³, Ton Le Sap is a crucial source of water supply to the delta in the dry season.

In the dry season, flow in the Mekong is insufficient to prevent saline intrusion and extensive salinization of waterways occurs in the lower delta. During a normal dry season, the maximum extent of salt water intrusion covers somewhere between 15,000 km² and 20,000 km². Streams and canals in the 1 Mekong Delta are influenced by the tides of both the East and

West Seas. In the East Sea the tide is semidiurnal with a large tidal amplitude of 3 to 3.5m. The tidal effects from the East Sea propagate over much of the delta. Farmers use these tidal fluctuations to drain and flood their lands. Drainage of floodwaters can be impeded if wet season floods coincide with the spring tide. Tides in the West sea are diurnal with a tidal range of about 0.4 to 1.2 m.

Upstream of the delta, dams have been built on the mainstem in China and in the tributaries in lower basin, bringing changes to the sediment dynamics and altering flow regimes.

Pressure on available space

The Vietnamese part of the Mekong Delta covers some 12% of the area of Vietnam. With some 20% of the Vietnamese population living in the Mekong Delta, the population density in the delta is relatively high (425 inhabitants/ km² in the delta against 250 inhabitants/km² in Vietnam). With a population growth rate of 0,6% the pressure on the available space is increasing. An important issue related to the available space is flood protection. Recently the Government of Vietnam adopted a 'Living with Floods' Strategy for the Mekong River Delta, meaning more attention to flood benefits and preservation of vulnerable ecosystems. Many changes have occurred in the Mekong Delta to support agricultural and aquacultural expansion and intensification. Canals, dikes and roads have altered the natural dynamics of the flood regime. Mangroves have been cut down and replaced with shrimp ponds, and canals and dams have opened up brackish areas to rice farming. Continuing agricultural and aquacultural expansion threatens more loss of mangroves in the delta. Increasing use of groundwater is also of concern, increasing risks of saltwater intrusion, as well as contributing to compaction of the sediment layers (WWF Vietnam).

Agriculture

The Mekong Delta is primarily a rural landscape. Can Tho, with a population of just over a million people, is the main city and Ho Chi Minh City just north of the delta boundaries is its main hub as well as the largest city in Vietnam.

85% of the population in the Mekong Delta is rural. Agriculture and agro-related industry is the main source of living. In the Mekong Delta, land resources are the main constraining factor in the development of agriculture. On one hand a substantial area (potentially 40% of the delta) has become unsuited for agriculture due to acidification of sulfate containing soils; on the other hand saline surface water affects the quality of the land. A major issue in the Mekong Delta is reclamation of saline and acid affected soils.

1.2.2 Infrastructure (network layer)

Summary of pressures

ageing infrastructure The delta has an extensive canal and embankment system, some of which over 100 years old.

Proposed hydropower dams on the lower Mekong mainstream

Research gaps

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

Infrastructure (general)

The rivers in the Mekong Delta are bordered by natural levees that are formed through silt depositing. The levees are intensively used for housing and roads amongst others as they are the last to flood. The levees separate the rivers from depressions that flood during the flood season. The infrastructure in the Cambodian part of the delta consists of a few roads only, colmatage irrigation systems and a few small scale irrigation schemes.

The Vietnamese part of the delta is characterized by a dense network of canals, levees and roads and well developed irrigation and flood management systems. The French colonization of Indochina 120 years ago initiated major canal construction over much of the Vietnamese Delta, particularly for transport. Canal construction for irrigation and drainage has accelerated in 1910 - 1930 and since the end of the Indochina War in 1975. The delta has now over 10,000 km of major canals that have profoundly changed the hydrological and hydraulic regime in the delta.

Many of the problems are due to agricultural expansion policies, that are continuing today. To accommodate further expansion there are plans for further hard infrastructure, including levees and sea wall construction, as well as adaptive measures such as the introduction of rice varieties with a higher tolerance for salinity.

In the watershed the trend is for further harnessing of the Mekong river for hydropower. Another 11 dams are planned for the Mekong mainstem in Thailand, Laos and Cambodia. If these dams are built, fish migrations will be blocked and the life-giving sediment and nutrients that nourish the delta will diminish (WWF Vietnam).

To prevent seawater intrusion along the Ca Mau Peninsula and South China Coast a series of 12 massive sluices or tidal floodgates have been installed on the major rivers and canals connected to the East and West China Sea. The gates open automatically on the ebb and close on the spring tide.

Groundwater has been extracted in the Vietnamese part of the Mekong Delta for almost 100 years, however its systematic assessment has only taken place since 1975. Because increasing development, the long dry season in the southwest, and pollution of surface water from salinity, acidity, domestic wastes and suspended sediment, groundwater use is growing.

1.2.3 Natural resources (base layer)

Summary of pressures

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

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

Research gaps

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

Water quality

The quality of the surface water in the Mekong Delta is threatened by three sources: drainage of acid water from sulphate containing soils (as 40% of the delta area), intrusion of saline water through open river mouths and the pollution of human activities and industry. Industrial activities, such as pulp and paper mills, textile mills and chemical factories, are increasing within the delta. Together with increased waste from shipping, the industries are creating a serious pollution problem. One of the targets of the national socio-economic development plan 2006 – 2010 is that 70% of the industrial zones will be equipped with treatment plants. The polluter pays principle will be leading.

Groundwater is available all over the delta. Due to the deteriorating quality of surface water, groundwater is more and more used for the provision of drinking water. Groundwater is also

an attractive resource for industrial water supply as well as for agriculture in periods with saline surface water. Overexploitation of groundwater, leading to salinisation of sources, is a major concern.

Shore protection / Coastal erosion management

The sediment balance of the Mekong river is, compared to other major deltas, relatively stable. Although there are significant developments in the Mekong basin, still considerable quantities of sediments are transported to the sea. As a consequence, the Ca Mau Peninsula is still extending, while some coastal erosion occurs at other locations.

Nature

The Mekong waters host over 1,100 species of fish¹², one of the highest species counts of any river system in the world. The continuing variation in hydrology and the variety of habitats allow the persistence of many species, which all require different conditions. Small islands and riverine sand-bars are common on stretches of the Mekong and its tributaries. The smaller sand bars and islands provide safe breeding sites for many species of waterbirds, some of which are globally rare and endangered. Permanent and seasonal wetlands include reed and sedge beds, swamps, lotus ponds, inundated grasslands and inundated forest. One of the most important wetland habitats is the seasonally inundated riparian forest found on the gently-sloping plains adjacent to lakes, rivers and tributaries. Over 200 species of plants have been found in these inundated forests and 363 species of fish use this habitat as a feeding, breeding, and nursery ground and it is vitally important for breeding colonies of large waterbirds¹³.

The mangrove and Melaleuca forests constitute an important forestry resource, potentially capable of meeting the local demand for construction materials, firewood, fodder for domestic animals and other forest products. In addition, the Melaleuca forests provide a valuable harvest of honey from wild bees' nests, amounting to five or six litres of honey per hectare per year.

The mangrove forests also play a very important role in coastal protection and land reclamation. Mangrove species not only retard erosion due to tidal action (of vital significance in a region prone to typhoons), but also tend to accumulate sediments around their root systems, thereby accelerating accretion of new land.

Wetlands

The Mekong Delta wetlands belong to the most bio-diverse areas in the world. Along the coast extensive mangrove forests are found which constitute a natural shore protection. In inland wetlands, grasses and Melaleuca forests are found. Melaleuca forests are promoted in the Mekong Delta as the trees grow on acid soils and reduce the acidity of the surrounding water. The wood of Melaleuca trees is used for timber and firewood. Application of Melaleuca wood in the wood industry (ply-wood, card-board) is growing.

Bird species are concentrated in the few remaining natural wetlands and number approximately 350 species. A total of 256 bird species have been recorded at Tram Chim wetlands in the Plain of Reeds alone, including the world's largest flying bird the sarus crane (*Grus antigone sharpii*).

Sand and gravel extraction

Impacts have already been felt from sand and gravel extraction upstream and in the Mekong Delta, resulting in coastal erosion. The impacts would be even more severe if dams are built on the lower Mekong mainstream and block sediment from flowing downstream.

¹² MRC, Fishes of the Mekong – how many species are there? Catch and Culture, Volume 15, No.2, August 2009

¹³ Chavalit Vidhayanon, 2008. "Fishes of the Mekong Delta,"

1.3 Governance (institutional/organizational aspects of delta management)

Summary of governance issues

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

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

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

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

Research gaps

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

At the international level, The Mekong River Commission (MRC) coordinates joint management of the shared water resources of the Mekong Basin and development of the economic potential of the river.

In Cambodia, the main responsibility for water resources planning and development is with the Ministry of Water Resources and Meteorology (MOWRAM). Other Ministries involved are a.o.: Ministry of Rural Development (water supply, sanitation, land drainage in rural areas and small scale irrigation); Ministry of Public Works and Transport (study, survey and construction of river works for navigation and water transport); Ministry of Environment (Protection of natural resources and environmental quality). The National Committee on Disaster Management has a mandate a.o. to coordinate flood management.

At the national level in Vietnam, several ministries are involved in the management of the Mekong Delta: the Ministry of Agriculture and Rural Development in charge of land tenure, land use and rural infrastructure development; Ministry of Natural Resources and Environment, regulations in development (Convention on Biological Diversity, Ramsar conventions); Ministry of Planning and Investment in charge of preparation of National 5-years socio-economic development plans as well as the overall national planning and coordination.

In the governmental structure of Vietnam, provinces have a considerable autonomy. The delta has 13 provinces. The provinces are further subdivided into districts and communities. At each level (province, district, and commune) Peoples Committees represent the central government and control the activities within the area.

At the local level capacity building is needed for water management as well as for local governance, service organisations and public enterprises. Also the system of laws and regulations as well as its maintenance, requires attention.

1.4 Main indicators for drivers, pressures and governance

DRIVERS	Main indicators
Demographic trends	• Population growth • Poor family ratio • Immigration
Economic developments	• GDP growth • Agriculture ratio in GDP • Annual rice production • Aquaculture and fishery growth, trends of natural fish stock • Annual aquaculture and fishery production
Technological developments	• Number and coverage area of new water control projects • Number of coverage area of industry zones
Climate change	• Temperature • Extreme events of flood and draughts • Sea water levels
Subsidence	• Sedimentation vs. subsidence rates at the river mounths
PRESSURES/IMPACTS	Main indicators
Land and water use (occupation layer)	• Rice cultivation areas • Fish and shrimp pond areas • Industry and urban areas
Network / infrastructure (network layer)	• % area under irrigation, flood control • Flood depth, arrival date and duration • Number of households can access to safe water
Natural resources (base layer)	• Waste discharge • Agro-chemical concentration in rivers • Water demands fro agriculture, industry, and urbanization
GOVERNANCE	Main indicators
Multi-level and multi-sectoral cooperation	• Number of new policies, laws, ordinances, etc. related with climate change issued • Number of Mekong Delta regional plans on the issues • Number of governmental officials trained on the subjects • Number of communes introduced adaptation measures
Public-private partnerships	• Number of climate change reallted projects funded by private companies • Number of public-private workshops/conferences on

	the issues Number of policies related with public-private partnership on the issues
Involvement of stakeholders and citizens	- Policies related with grass root participation - Number of NGO acting in the region
Approaches for dealing with risks and uncertainties	- Adaptation strategies - Adaptation national and regional plans - Communes with adaptation plans

1.5 Score card

The scores in the score card are just qualitative and indicative, based on the summary tables descriptions for each item (above). Each item is scored on a 5-points scale, related to resilience and sustainability.

The following two development scenarios are recognized:

- Scenario1, moderate perspective 2050: medium economic growth (1,2 %, Regional Communities-scenario) and related medium technological developments, combined with medium climate change and sea level rise (to be determined by expert)
- Scenario2, extreme perspective 2050: high economic growth (1,7%, Transatlantic Market-scenario) and related high technological developments, combined with high climate change and sea level rise (to be determined by expert)

Table 2. Scorecard for delta assessment

<i>Delta</i>	Land and water use (occupation layer)	Infrastructure (network layer)	Natural Resources (base layer)	Governance	Overall Resilience & Sustainability indicator
Current situation 2010	0	0	-	0	0
Scenario 1 moderate 2050	-	+	+	+	+
Scenario 2 extreme 2050	-	+	-	+	0

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

Clarification notes on the score card:

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

2. Overview of adaptive measures in the Mekong delta

Overview of possible adaptive measures (in the three layers) based on current practices and innovative technological developments. The measures are classified in types of measures (technical, ecological, economic and institutional/organizational), related strategy (protect, adapt, relocate) and involved layer (occupation layer, network layer, base layer).

Name of measure	Type of measure 1. Technical 2. Ecological 3. Economic 4. Institutional	Brief description	Strategy 1. Protect 2. Adapt 3. Relocate	Layer 1. Occup. 2. Network 3. Base
Collaboration among the Mekong riparian countries	4	Impacts of man-made structures upstream can overweight all efforts downstream.	1	2
Embankment and strengthening of the low-medium flood areas	1	In the Mekong Delta, embankment by low-dyke system helps to prolong the cropping agenda, which will secure harvesting of a second crop	1	2
Strengthening and improving Living-together-with-floods program in the deep-flooding areas	4	New cropping systems, new crops, aquaculture,... have been introduced in the flood prone areas with success. The results need to be more sustainable.	2	1
Water storage to cope with the drought spell	1	Ponds for water storage for supplementary irrigation in dry season and for aquaculture	2	1
Wetland protection	2	Reserve and protect wetland to store water in dry season and also to reduce flood in the wet season	1	3
Mangrove protection	2	Protect and restore mangrove belts along the coastline to prevent erosion, protect arable lands, reserve bio-diversity, habitats	1	3
Micro-finance program	4	The program proved to be very effective in poverty reduction, which affect to open resources protection	1	1
Adapted forms of building: house on stilt	1	Very common in the flood areas in the Mekong delta	2	1
Awareness raising	4	Regional programs on	2	1

		climate change impacts, adaptation, risk management		
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3. Overview of technical methods and tools to support delta management and development in the Mekong delta

Overview of methods and tools for assessments, planning and decision making on delta management and development issues:.

Not yet developed, tools in Rhine River delta can be used and help the Mekong delta to develop its own.

Examples of collaboration among the riparian countries along the Rhine River can share to the Mekong River region.

RIBASIM can be an powerful tool, if it can be adapted to the Mekong delta, ARK can also be very useful (n.b. some additional explanation is needed here...)

Name of tool	Brief description	Institute	Available at
To be added..			

4. Knowledge exchange and development

4.1 Lessons learned on delta management

To be added..

4.2 Summary of research gaps and related needs for knowledge exchange

Drivers of change

- Multi-disciplinary research to study, in **one research**, multi-layer, multi-aspect, multi-dimension of climate change impacts and resilience.
- Impacts of climate change to the most vulnerable communities
- Tendencies of extreme climate and water flow events

Pressures – potential problems / Challenges – opportunities

Occupation layer

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

Network layer

- Conflicts of water-, land- uses in the areas of newly developed projects

Base layer

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

Governance

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

Adaptive measures

To be added..

Technical methods and tools

To be added..

4.3 Some available illustrations (map of delta, typical sites, etc.)

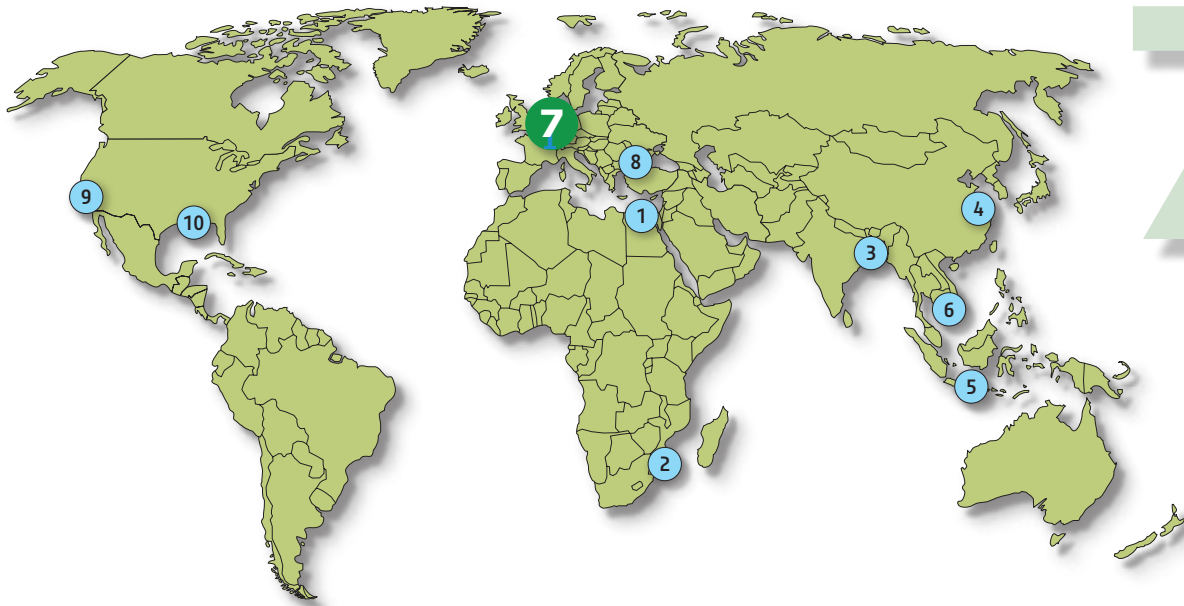
To be added..

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Rhine-Meuse delta

No



1. Current and future state of the Rhine-Meuse delta

1.1 Drivers of change

Summary of drivers of change

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

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

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

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

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

Research gaps

Demographic trends: Developing spatial planning concepts for a stable or decreasing population.

Economic developments and climate change: How to come to a sustainable (low carbon emission) energy future for the Netherlands?

Subsidence: Which land use and management change is needed to reduce surface-lowering due to peat compaction and oxidation?

1.1.1 Socio-economics (population growth- migration, economic development + most relevant sectoral developments, e.g. for agriculture, fisheries, industry)

Population

The Netherlands have about 16 million inhabitants. The population is almost stable with a minor growth. With nearly 500 inhabitants per km² the Netherlands are densely populated. About 40% of the population is concentrated in the urban zone between Rotterdam and Amsterdam, where the population density is above 1000 inhabitants per km².

Economic development

The combination of a well developed sea port and a navigable river that connects the delta with a huge hinterland, provided favorable conditions for the development of the Dutch economy. In the past centuries a chain of cities and industrialised areas have evolved. The economic importance of these harbors extend far beyond the delta. The Netherlands are a wealthy country. The per capita GDP is close to US\$ 30,000. Most people are employed in services and industry.

Agriculture

Only 3,5% of the population is employed in agriculture, though 55% of the area is used for agriculture. Of this area two third is used for dairy farming. Agriculture and the connected agribusiness contributes significant to the Dutch economy. The sector accounts for 23% of

the Dutch export. With an export surplus of 7.5 billion euro agriculture is still an important factor in the Dutch economy.

Fisheries

In the Netherlands fish is caught at sea, along the coast and in inland waters. Fish breeding is, although promising for the future, not yet well developed. Sea fishers bring their fish to the Netherlands from remote fishing grounds. The main part of the caught is exported. Along the coast fisheries are focused on mussels and clams. Professional fishery on inland waters is decreasing.

Industry

Traditional industries in the Netherlands are oil refinery, steel and chemical industry. The importance of agro-related industry and knowledge intensive industry is increasing.

1.1.2 Climate change (temperature/evaporation, sea level rise, precipitation/discharge)

The Netherlands have a moderate climate, influenced by the North Sea. The mean winter temperature is just above 0°C ; the mean summer temperature 16°C . The average annual precipitation is near 800 mm, varying between less than 400 mm in dry years and over 1,100 mm in wet years. The average annual evaporation amounts to 475 mm. In summer the evaporation may exceed 5 mm/day where in winter it becomes almost zero.

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

1.1.3 Subsidence (natural or human-induced)

The situation in the delta now, from a morphological point of view, can be summarised as follows (Changing estuaries, changing views, H. Saeijs et al., Nijmegen, 2004): The transition zone between rivers and the sea has disappeared in most places. Sculpting of the landscape by the tide has been reduced or is absent altogether. Sedimentation processes, which guaranteed that sea-level rise was accompanied by increases in the height of the land, have stopped because of dams and embankments. In the areas with reduced tide, resulting in new volumes and forces, the dimensions of the banks and creeks are changing. After closing the branches, the sea started to rearrange the sand masses along the coast. New sandbanks developed. This “voordelta” (fore-delta) is considered to be very natural and almost no activities are allowed. No-one knows, or is able to calculate, the outcome of this process.

1.1.4 Technological developments (e.g. regarding civil engineering, agriculture, ICT, energy)

Public and Private partners have joined forces in the Network Delta Technology. The ultimate goal of this group of experts is to ensure the safety of the Dutch citizens for the next centuries to come. Generating awareness for the importance of a sustainable and safe delta system in the Netherlands is a first prerequisite for achieving this goal. Investing in and stimulating innovation is a second. For this reason the network continuously develops an innovation agenda. The activities in this agenda are concretely executed by different renowned knowledge institutes in the Netherlands. The network enhances cooperation, accelerates the innovation process and contributes to the practical implementation of these innovations.

1.2 Pressures – impacts

1.2.1 Land and water use (occupation layer)

Summary of pressures

pressure on space: With a population density of around 500 inhabitants/km² the delta is densely populated which implies a high pressure on space.

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

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

Research gaps

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

Pressure on available space

With a population density of around 500 inhabitants/km² the delta is densely populated; in particular in the western part there is a high pressure on available space. Last major land reclamation was in the 1960's. Later on, various new plans have been developed including extension of the coast south of The Hague and artificial islands in the North Sea. As yet, none of these plans have been implemented.

Hydrology

Being fed partly by rain and partly by snowmelt from the Swiss Alps, the Rhine has a mixed discharge character with two significant flow peaks: one in the winter and a much lower one in summer, originating from snowmelt. The mean discharge is 2,200 m³/s, the maximum discharge may reach 16,000 m³/s. The Rhine has its minimum discharge, some 1600 m³/s, in October.

The tide at the North Sea is semi-diurnal, with an amplitude of about 0.5 m in the North to more than 1 m in the Southern part of the coast. Under storm conditions, the sea level may rise 3 to 4 metres above average.

Vulnerability to flooding

Flood protection standards are among the highest in the world. Although the probability of flooding is quite small, potential consequences of a flood are high. Sea level rise and new investments will further increase flood risk. Current standards date back to the 1960s. Because of increases in the number of people and assets to be protected, the new Delta Committee recently proposed to increase the safety level with a factor 10. Maintaining and improving the flood protection systems.

Freshwater shortage

Although The Netherlands generally has abundance of water from rainfall and external supply through the rivers Rhine and Meuse, occasionally dry years occur and then serious water shortages are experienced, which affect agriculture, energy (cooling water) and shipping (lower navigation depths). In dry years around 90% of freshwater supply of the Rhine is

directed towards one opening to the sea (Nieuwe Waterweg) to avoid salination of this opening, which is the main reason why the Dutch freshwater system is vulnerable for dry periods. Sea levels will increase the problem of salt water seepage and increase the need for flushing. Due to climate change an increase is expected in the frequency and extent of water shortages. To secure future water supplies the new Delta Committee has proposed to raise the target level of Lake IJssel with some 1.5 m. Water of this lake is used for water supply of the western and northern part of the country

1.2.2 Infrastructure (network layer)

Summary of pressures

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

Research gaps

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

Infrastructure (general)

The Netherlands is a man-made country. Without dikes, 65% of the area would risk flooding. A substantial part of the land has been reclaimed from the sea. The largest reclamation scheme of the 19th century was that of the Haarlemmermeer in 1852, with a size of well over 18,000 hectares. In the 20th century the reclamation of a substantial part of Lake IJssel added over 150,000 ha to the Dutch land resources.

Initially infrastructure development in the Netherlands was focused on flood protection. The coast and the many kilometers of riverbanks are protected by solid dikes. Traditionally, the main water management issue was the discharge of excess water. In the low part of the Netherlands polder areas are drained by dense systems of ditches and canals. Pumping stations discharge the water to collector drains and finally to the main water system.

Several extreme dry summers in the seventies, introduced the issue of water supply. The water management since then aimed at water supply in dry periods as well. A complex system of river branches, canals and control structures makes it possible to distribute the water over the country according to the water demands.

In connection with this controlled water distribution the focus shifted in the eighties further to water quality and ecological management. Legislation was made to control the emission of pollutants and all over the country sewage treatment plants for domestic and industrial water were built.

Climate change may cause sea-level rise and larger discharges of the rivers. In the nineties again a new element was introduced in Dutch water management: building with nature. For the coastal zone the concept of resilience was developed and for the rivers a comprehensive set of projects is being carried out to give more room to the rivers.

Ageing infrastructure

Some of the infrastructure is already centuries old, other infrastructure is from a more recent date. Sea level rise may shorten the useful lifetime of the storm surge barriers in the

southwestern delta. Adaptation of infrastructure to new conditions induced by climate change will require major investments in the coming decades, albeit still a very small portion of the GNP. The new Delta Committee has proposed to set-up a so-called Delta Fund to secure the necessary funds.

1.2.3 Natural resources (base layer)

Summary of pressures

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

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

Research gaps

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

Coastal erosion

Coastal erosion is well controlled with extensive sand nourishments. Sea level rise will increase the maintenance nourishments needs. Most recently the new Delta Committee proposed to extend the coast line with some 1,000 m through additional coastal nourishment. Such extension, to be effectuated in a couple of decades, should offer coastal cities and villages with new development opportunities.

Nature

Perhaps the most salient natural features of the delta lie in the estuarine branches of the rivers. The area outside the dikes covers almost 125,000 hectares, of which 85,000 hectares are water, 23,000 hectares are intertidal areas, and about 17,000 hectares are more or less permanently dry. Waterfowl visit the delta in large numbers. Almost one million birds are counted each year. Together, 38 species exceed the 1% standard of the Ramsar Convention on Wetlands of International Importance. The specific estuarine values, however, have been severely diminished and – without interference – will decline further. The Dutch organization for statistics (CBS) calculated that the natural value of the marine delta was around 38% of an undisturbed situation (Natuur Compendium, 18 december 2008).

Also the natural heritage along the river branches and the coast deserves attention. The meandering nature of the river has been transformed, through damming and straightening, so that it now flows through a fixed bed, largely separated from its flood plain. Recently, river- and coastal zone management aim at the restoration of the natural dynamics of rivers and coast.

Loss of environmental quality and biodiversity

Due to the Delta Works most of the delta estuaries were turned into stagnant salt or freshwater lakes. In the closed estuaries, shoreline erosion forms a threat for the remaining terrestrial and transitional zones between the dike and water. In the remaining open estuaries, the Eastern and Western Scheldt, the vulnerability of salt marshes to erosion also increased. Besides these morphologically induced problems most waters also suffer from an impoverished water quality. The worst situation exists in the freshwater Lake Krammer-Volkerak, where eutrophication processes caused by agricultural runoff lead to a very bad water quality with extensive scums of blue green algae. Some years ago, the provincial managing authorities have drafted a vision for the future, in which the restoration of estuarine

dynamics has a prominent place. Central to this vision is to partially restore the tidal dynamics and/or to restore the link with the rivers, while maintaining the same level of safety. Plans are being developed and partly underway to improve the situation.

1.3 Governance (institutional/organizational aspects of delta management)

Summary of governance issues

Cooperation between (scale) levels and sectors of government: The major water bodies in the delta are managed by the national government. Apart from the sectoral management line of responsibility (water management) there is also the administrative line of responsibility.

Recently a high level 'Delta Commission', instituted by the Dutch government, drafted a vision for the long term development of the Dutch Delta. Central to this vision is to partially restore the tidal dynamics and/or to restore the link with the rivers, while maintaining the same level of safety. Currently a delta programme is responsible to prepare the plans and lead them through to implementation from now till 2050.

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

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

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

Research gaps

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

Currently, the major water bodies in the delta are managed by the national government. As part of the Ministry of Transport and Water Management, Rijkswaterstaat has the task to develop and implement a long term integrated policy towards the future of the delta waters. Key elements of the policy are the improvement of the natural purification capacity of the delta estuaries and restoration of salt-freshwater gradients and land-water gradients.

Apart from the sectoral management line of responsibility (water management) there is also the administrative line of responsibility: state government – provincial administration – municipal administration. The estuarine delta falls under the jurisdiction of three provinces: the province of Zeeland, Zuid- Holland en Noord-Brabant. Practically the entire province of Zeeland falls within the delta.

The role of the provinces is changing from a predominantly reactive one (for issuing permits and overseeing developments) to a more active one. An important tool for this role is integrated area management.

Recently, a high level Delta Commission, instituted by the Dutch government, drafted a vision for the long term future, in which the restoration of estuarine dynamics has a prominent place.

Central to this vision is to partially restore the tidal dynamics and/or to restore the link with the rivers, while maintaining the same level of safety. Plans are being developed and partly underway to improve the situation. The costs of implementation of such plans will be significant, most likely billions of Euros. Currently a delta programme is responsible to prepare the plans and lead them through to implementation from now till 2050.

The traditional flood risk management strategy in the Netherlands is (legally) based on preventing floods by constructing dikes and other structures. Changed societal views in the Netherlands calls for more resilient flood management strategies; the social and economical values should indicate which level of risk is accepted and how much can be spent to prevent floods, taking into account also other values (nature, culture). How to increase the speed of recovery in case of a flood event will be addressed as well.

1.4 Main indicators for drivers, pressures and governance

DRIVERS	Main indicators
Demographic trends - population in delta - migration	- number of people and growth rate - migration trend in delta (annual percentage in/out)
Economic developments - status of (total) economy - sectoral developments	- per capita GDP, growth rate, % contribution by delta - main sectors, growth rate - unemployment rate
Technological developments - food / agricultural - civil engineering - ITC - energy generation	- percentage of GDP spent on innovation and research in each sector
Climate change - temperature / evaporation - sea level rise - precipitation / discharge	<i>(Downscaling of global IPCC scenarios)</i> - change of temperature / evaporation - change of sea level (mm/year) - change of precipitation (mm/year) or river discharge (M3/sec)
Subsidence - natural and human induced subsidence	- cause of subsidence (e.g. geologic, grond water extraction or oil exploration) - rate of subsidence (mm/year)
PRESSURES/IMPACTS	Main indicators
Land and water use - pressure on space - shift in land use / urbanisation - water demand - flood vulnerability	- number of inhabitants, population density, change in land value - % urban area, urbanization rate - water deficit / number of days with interrupted water supply - % area vulnerable for flooding / number of vulnerable people / value of vulnerable assets
Network / infrastructure - flood protection system - irrigation and drainage - water supply & sanitation - roads, railways and ports	- flood risk (safety level), % of delta protected (high-medium-low) - % of delta under irrigation - % of infrastructure which needs to be upgraded - number of floods or flooding days per year - % people with access to water supply, % untreated waste water - water sanitation risk index* - density of infrastructure, number of ports (+ volume of goods)
Natural resources - freshwater shortage / salinity intrusion - pollution - flood hazard - coastal erosion / wetland loss - biodiversity loss - sediment supply - mobility of delta distributaries	- number of droughts or drought days per year / % of delta with salinity problems - % of polluted areas (water, soil, air) - frequency of storms (storm surge) / frequency of extreme river discharge, flood hazard level (high-medium-low) - annual loss of land (km ² /year) / average erosion rate (m/year) - total area of wetlands / % of wetlands protected by treaties

	- biodiversity index (e.g. LPI)** - soil erosion in catchment (Mton/year) - fluvial sediment transport (Mton/year) - river discharge (peak/low and variability) - % of sediment trapped in reservoirs - (planned) dams in main tributaries in the catchment - existence of dykes/embankments along delta distributaries
GOVERNANCE	Main indicators
- multi-level and multi-sectoral cooperation	- existence of integrated plans (delta plan, national adaptation plan etc.) - existence of interministerial committees, multi scale level committee etc.
- public-private partnerships	- number of PPP's - scale of PPP's (geographic, budget, time span)
- involvement of stakeholders and citizens	- existence of legal instruments for participation (e.g. spatial planning instr.) - number of NGO's involved in planning and decision making
- approaches for dealing with risks and uncertainties	- existence of adaptive management , adaptation strategies etc. (long term) - existence of risk management, emergency systems etc. (short term)

1.5 Score card

The scores in the score card are just qualitative and indicative, based on the summary tables descriptions for each item (above). Each item is scored on a 5-points scale, related to resilience and sustainability.

The following two development scenarios are recognized:

- Scenario1, moderate perspective 2050: medium economic growth (1.2 %, WLO-scenario RC) and related medium technological developments, combined with medium climate change and sea level rise (KNMI-scenario G, relative sea level rise 0.30 cm)
- Scenario2, extreme perspective 2050: high economic growth (1.7%, WLO-scenario TM) and related high technological developments, combined with high climate change and sea level rise (KNMI-scenario W+, relative sea level rise 0.40 cm)

<i>Delta</i>	Land and water use (occupation layer)	Infrastruc-ture (network layer)	Natural Resources (base layer)	Governance	Overall Resilience & Sustainability indicator
Current situation 2010	+	++	0	+	+
Scenario 1 moderate 2050	0	++	0	+	0
Scenario 2 extreme 2050	-	++	-	+	-

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

Clarification notes on the score card:

The pressure on the occupation layer and the base layer will increase in time by economic development, climate change and relative sea level rise. Most critical issues will be related to drought and salinisation. Although economic development may also lead to more innovative technical solutions to critical issues, this might not be enough to safeguard sustainable development. Currently the estuarine natural value is low because hard infrastructure limits

natural dynamics such as tides and natural brackish zones. In the fluvial part of the delta, however, water quality has much improved over the past decades and many river restoration projects are ongoing in the embanked floodplains. The infrastructure will be maintained under all scenarios because of legal arrangements. Also the Governance aspects and mechanisms are expected to be the same in time. In both scenarios the overall resilience and sustainability indicator will decrease, a bit more in the extreme scenario.

2. Overview of currently applied adaptive measures in the Rhine-Meuse delta

Overview of possible adaptive measures (in the three layers) based on current practices and innovative technological developments. The measures are classified in types of measures (technical, ecological, economic and institutional/organizational), related strategy (protect, adapt, relocate) and involved layer (occupation layer, network layer, base layer).

Name of measure	Type of measure 1. Technical 2. Ecological 3. Economic 4. Institutional	Brief description	Strategy 1. Protect 2. Adapt 3. Relocate	Layer 1. Occup. 2. Network 3. Base
<i>Re-enforcement of dikes and dams</i>	1	Design and construct dikes and dams, according to agreed safety levels	1	2
<i>Compartmentation</i>	1	Reduce adverse affects of flooding by existing (infra)structure or new constructions	1, 2	2
<i>'Buiding with nature'</i>	1, 2	Widening soft coastal defence structures, using natural processes	1	2
<i>'More space for water'</i>	1, 2	Designation of selected areas of land for retention and storage	2	1
<i>Adaptation of polder groundwater levels</i>	1	Raise groundwater levels in peaty areas to reduce surface lowering due to peat oxidation	1, 2	1, 3
<i>Land reclamation</i>	1	Extensive sand suppleions or construction of polders	1	1, 2
<i>Nature reserves</i>	2	Establishment and management of protected areas	2	1, 3
<i>Adapted forms of building and construction</i>	1, 3	Floating houses and facilities	2	1
<i>Financial instruments</i>	3	Financing mechanisms to support economic development	2	1
<i>Risk based allocation policy</i>	1, 3	Land-use will depend on agreed safety levels and related zoning	2, 3	1

<i>New institutional alliances</i>	4	Enhance multi-sectoral cooperation and implementation of effective measures	1, 2, 3	1, 2, 3
<i>Education and awareness raising</i>	4	Educational programs on hazards, vulnerability and risk management	2	1
<i>Insurance</i>	4	Insurance products for damage due to storms and floods	2	1
<i>Retreat</i>	1	Permanently evacuate low-lying vulnerable areas	3	1, 2

3. Overview of technical methods and tools to support delta management and development in the Rhine-Meuse delta

Overview of methods and tools for assessments, planning and decision making on delta management and development issues:.

Name of tool	Brief description	Institute	Available at
RIBASIM	River Basin Planning and Management tool	Deltares, The Netherlands	http://delftsoftware.wldelft.nl/index.php?option=com_content&task=view&id=15&Itemid=65
STREAM	Spatial Tool for River basins and Environment and Analysis of Management options	Institute for Environmental Management IVM, The Netherlands	http://unfccc.int/adaptation/nairobi_work_programme/knowledge_resources_and_publications/items/5485.php
Delft3D	Coastal management tool regarding hydrodynamics, sediment transport and morphology and water quality	Deltares, The Netherlands	http://delftsoftware.wldelft.nl/index.php?option=com_content&task=view&id=15&Itemid=65
ARK Routeplanner	Assessment and cost benefit analysis of climate adaptation options	WUR, The Netherlands	http://promise.klimaatvoorruijnt.nl/pro1/publications/show_publication.asp?documentid=1503&GUID=daf2fdee-fc8f-4966-ba80-a69e42145082

4. Knowledge exchange and development

4.2 Lessons learned on delta management

In 2004 the University of Nijmegen and the Erasmus University published a report on a paradigm shift in thinking on dealing with delta challenges. The disadvantages of the hard engineering approach followed by the Dutch since 1953 have become clearer, having changed ecosystems and morphological processes. The authors argue that ultimately this will

lead to higher risks for safety and continuously increasing costs. Based on the Dutch experience of delta interventions they conclude the following lessons:

1 'Look before you leap'

safety declines! There is no way back after land reclamation and dyke construction. The '53 flood was a disaster waiting to happen, and it might happen again. The dependence on dykes and other infrastructure will always intensify over time so opting for short-term safety is inevitably connected to increasing long-term vulnerability. Moreover, once a dyke is built, people will always use the new land to the maximum: new investments are made, so the material impact of a disaster increases rapidly. In the end, ecological values will always decline, bringing sometimes unexpected side-effects.

2. Look for reversible measures

When modification of the natural system seems to be inevitable, always try to use reversible measures: as knowledge develops, other solutions might be found which could still be applied. We cannot predict all the changes that will occur when an estuary is modified; the hydromorphological and ecological changes are still poorly understood. Experts should work on developing knowledge about estuarine systems while not forgetting that we cannot know everything: unexpected and very unpleasant side-effects will probably occur. This calls for reversible and flexible solutions. Better to be safe than sorry!

When irreversible changes have been made it might be possible to reduce their impacts, but the measures are usually very costly and the result will always be less than the original situation. The best action to undertake in a changed estuary is to minimise the increase of dependence on infrastructure. This can be done by restoring the natural processes wherever possible. Risk assessment should focus not only on minimizing the risk of a disaster occurring but also on minimising the impact by not allowing large investments at vulnerable locations.

3. Try to make a complete environmental cost-benefit analysis

The value of (unaffected) ecosystems should be included in cost-benefit analyses as far as possible. The value of the safety that nature provides if we do not interfere is an example. At the same time, the intrinsic values of nature cannot be expressed in money, so the value will always be higher than can be calculated.

4. Create public awareness related to ecosystem functioning and safety

Public participation may result in better understanding of ecosystems: how they function, the advantages they offer, the essentials of a dynamic system and the ecological coherence of an estuary. When the short- and long-term consequences of, for example, obstructing connectivity is explained, people will better understand the importance of an intact ecosystem. The result may be greater good will for sustainable developments, even if, for the short term unpopular measures have to be taken such as giving land back to the sea. Creating awareness is a very important task for the government and for educational institutions.

Although their conclusions have not been undisputed, there is a growing common understanding in the Netherlands that natural processes need more recognition when designing infrastructural measures in the delta. For example, the latest Deltacommittee advice is based on the principle that her proposals 'are to harmonise as far as possible with natural processes: building with nature and other ecological processes'.

4.3 Summary of research gaps and related needs for knowledge exchange

Drivers of change

- *Demographic trends* – Developing spatial planning concepts for a stable or decreasing population.
- *Economic developments and climate change* – How to come to a sustainable (low carbon emission) energy future for the Netherlands?

- *Subsidence* – Which land use and management change is needed to reduce surface-lowering due to peat compaction and oxidation?

Pressures – potential problems / Challenges - opportunities

Knowledge gaps

Occupation layer

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

Network layer

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

Base layer

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

Governance

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

Adaptive measures

- *Dike and dam design* – How should future dikes and dams be designed to withstand higher floods, while at the same time also providing space for other functions than flood protection?

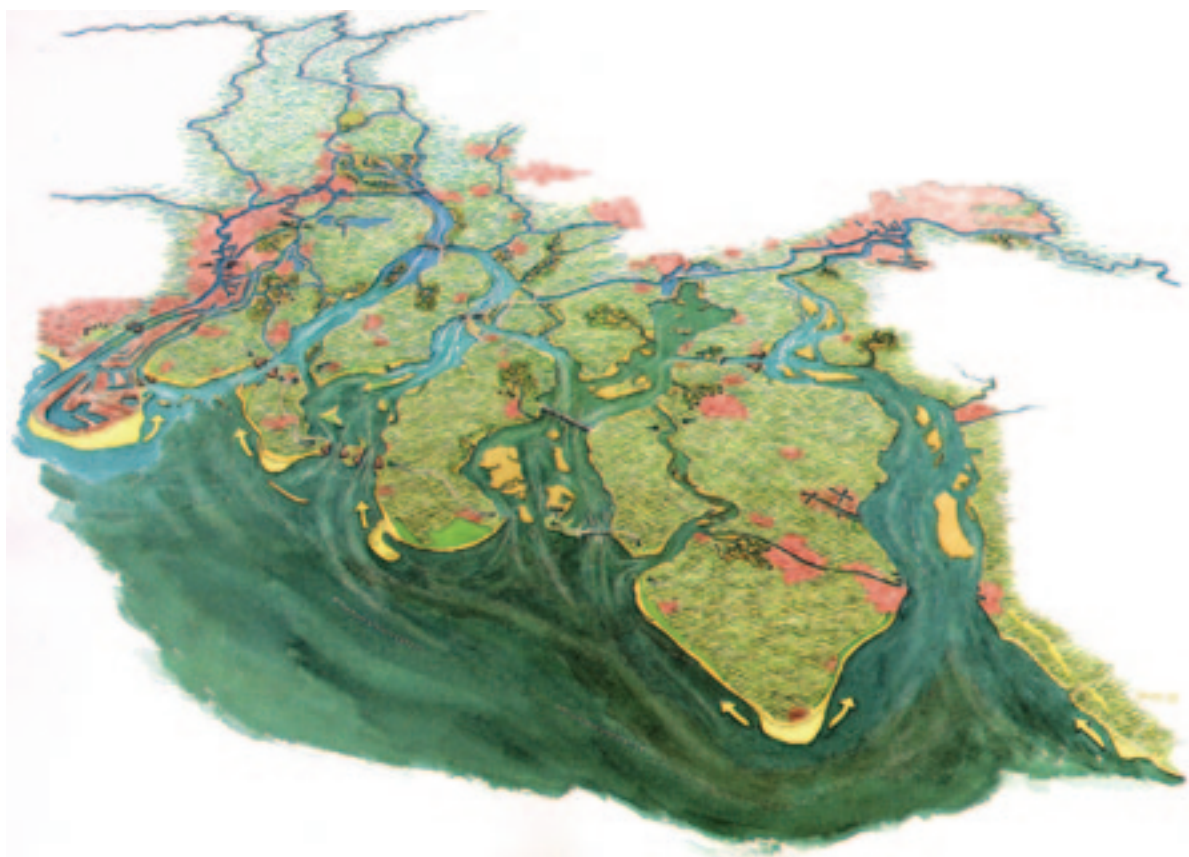
- *Water storage* – Development of concepts for combination of water storage with various types of land-use.
- *Freshwater management* – Which adaptation measures are needed to guarantee availability of sufficient freshwater with continued sea-level rise and subsidence, and increased occurrence of long periods of drought?
- *Compartmentation and infrastructure* – Which adaptations of the infrastructure are needed for implementation of a compartmentation strategy to reduce flood damage?
- *Ecosystem-based coastal protection, flood management, and freshwater management* – How can natural processes be used to build dynamic, strong coastal dune system? How can natural areas behind the dikes be used to store floodwaters and freshwater for dry periods?
- *Re-opening river mouths* – How can estuaries that have been closed in the past, be re-opened as to minimize ecological impact of closure, while maintaining necessary flood protection?

Technical methods and tools

- *Improvement of morphodynamic models* – Morphodynamic models need to be improved to predict the impact of new or adapted flood protection infrastructure on delta morphology.
- *Methods for assessment of the impact and effectiveness of measures* – Methods need to be developed for assessing the effectiveness of technical measures and policy instruments to reduce flood risk, for assessing the implications of their implementation for urban and countryside environments, and for assessing the robustness of comprehensive flood risk management strategies in view of uncertainty about climate change.
- *Guidelines for the design of measures* – Guidelines need to be provided for the design of long-term flood risk management alternatives and individual measures based on effectiveness, robustness, and contribution to the development of entire regions.
- *Decision-support systems* – How should decision-support systems and other integral analysis tools for policymakers be adapted to enable better comparison of the values associated with safety, economy, and environment?

4.4 Some available illustrations (map of delta, typical sites, etc.)

Future vision of WWF Netherlands for the Dutch South West Delta:



WWF's long term vision for the South West Delta (Hoogtij voor laag Nederland, 2008): sand nourishment along the coast, reopening arms, creating new floodplains to allow sedimentation to raise with the sea and strengthening safety with shorelines.

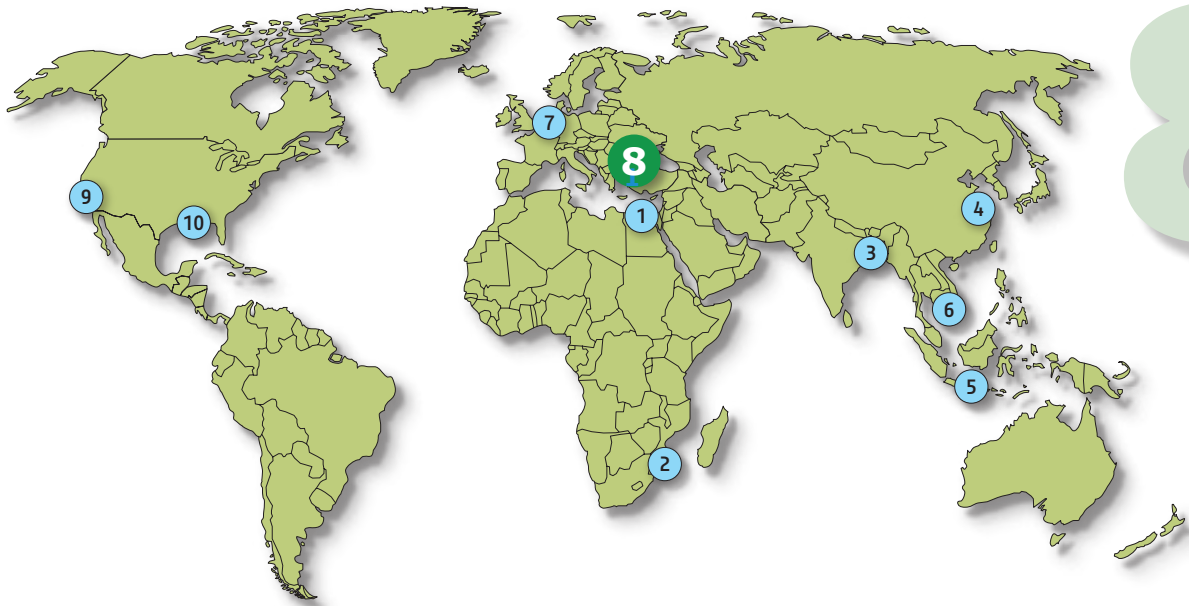
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Danube delta

No

8



1. Current and future state of the Danube delta

1.1 Drivers of change

Summary of drivers of change

Demographic trends: The total population in the Romanian part of the Danube delta, was estimated at 14,295 inhabitants in 2002 and 12,643 in 2007, showing a decreasing trend (1652 inhabitants lost in 5 years). The average population density is about 5 inhabitants/km². There are 23 rural settlements (only 3 have more than 1,000 inhabitants) and only one town - Sulina (4,593 inhabitants in 2007, 4,358 in 2010).

Economic developments: Last 2 decades witnessed the industrial and intensive agriculture failure in the Danube delta Biosphere Reserve territory.

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

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

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

Technological developments:

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

Research gaps

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

1.1.1 Socio-economics (population growth- migration, economic development + most relevant sectoral developments, e.g. for agriculture, fisheries, industry)

The Romanian Danube Delta Biosphere Reserve (DDBR) covers an area of about 5,800 km², encompassing beside the delta proper (3,510 km²), also the Razim-Sinoie lagoonal Complex (1,145 km²), the coastal marine waters up to the 20 m isobath, adjacent to the deltaic and lagoon front (1,030 km²), the Danube floodplain upstream the delta to Isaccea town (102 km²), and the Danube channel-bed between Isaccea and Cotul Pisicii, up to Ukrainian border (13 km²). The Ukrainian part of the Danube Delta represents the secondary delta of Kilia branch and covers 464 km². (Gâștescu and Știucă, 2008).

Population

The total population in the Romanian part of the Danube Delta, was estimated at 14,295 inhabitants in 2002 and 12,643 in 2007, showing a decreasing trend (1652 inhabitants lost in 5 years). The average population density is less than 5 inhabitants/km². There are 23 rural settlements (only 3 have more than 1,000 inhabitants) and only one town - Sulina (4,593 inhabitants in 2007, 4,358 in 2010). More than 14 nationalities are living within the Danube Delta Biosphere Reserve. The ethnic structure of population in DDBR in 2002 was as follows: *Romanians*: 12,666 people (87%), *Lipovan Russians*: 1,438 people (10%), *Ukrainians*: 299

people (2%), *other nationalities*: 1% (<http://www.ddbra.ro>). The Lipovans and the Ukrainians settled within the Danube Delta during the 18th century. It is worth to be mentioned that in the towns and villages around the borders of DDBR are living over 145,000 inhabitants and about the same number can be considered to live along the Ukrainian section of the Danube river and delta. This situation implies, of course, a potential high pressure on the Danube Delta area.

Economic development

Until the 2nd World War, the economic activities developed in Danube Delta area focused on two directions: navigation along the main branches of the Danube Delta and traditional activities of the inhabitants, developed usually close to their settlements (fishing, sheep and cattle raising, agriculture, hunting). During the next fifty years, and specially after 1960, the economic development and natural resource use increased considerably within and around the Danube Delta, with very bad consequences over the environment quality. After 1990 the situation improved, both by reducing industrial activity and by protection and ecological restorations programs implemented by the new created Danube Delta Biosphere Reserve Authority (DDBRA).

Fishing

Catching fish was the basic occupation of the Danube Delta inhabitants since very old times. At present, fishing continues to be a major activity, even if the fish capture rate diminished and the quality of fish got worse. There are four categories of fish resources : fresh water fisheries (160,000 ha of inland water bodies), marine resources (about 103,000 ha, along the Danube Delta coastal zone), (temporary/seasonal) migratory fish supply (inside the Danube Delta, along the main branches and at their mouths in the coastal zone) and aquaculture (in several fresh water fish ponds, covering 52,000 ha, at this time abandoned or declining). The total fish catches diminished in the last years: fresh water captures has declined from 10-20,000 t/y before 1970, to 5-6,000 t/y in the last years; the migratory fish catches decreased from 300 t/y in 1960 to 6 t/y in 1994 and 19 t/y in 2003 for sturgeons and recorded variable amounts (200-2,400 t/y) for Danube herring; the marine fish catches diminished from 7-8,000 t/y before 1988 at less 1,000 t/y at present, and valuable species are reduced; finally, the fresh water fish farms reduced drastically their supply (4-6,000 t/y before 1977), 70-75% of their surface being lost (abandoned or ecologically restored) (in Gâstescu and Știucă, 2008).

Industry

Industrial activities have been developed particularly after the 2nd World War, mainly close-by the DDBR area, particularly in Tulcea. The industrial dynamics showed an intensive increasing trend in the second half of the last century, followed by a drastic failing after 1990, due to both the economic decline of the country and to the implementation of new politics for environmental protection. The active industrial units consist now of shipyards and metallurgical and alumina factories in Tulcea, baritine mine in Somova, limestone open mine in Mahmudia and some small agro-related or fish-related industrial units (Tulcea, Jurilovca).

Agriculture

Traditional agriculture has always been practiced in the Danube Delta even if on a small scale, on the riverine levees and on the old littoral accumulative formations, without major impact over the natural environment. After 1960, the equilibrium was considerably changed by important embankment and canalization works, construction of large agricultural polders (Pardina – 27,000 ha, Sireasa – 7,500 ha), fish ponds and forest plantations. In 1990, the agricultural polders covered 53,000 ha (only 39,000 ha in use); at present, the used area diminished because of the worsening of soil qualities, or by natural flooding (Sireasa) or ecological rehabilitation. The Babina (2,100 ha) and Cernovca (1,580 ha) islands/polders have been restored in 1994 and 1996.

Sheep and cattle-breeding

This activity was a temporary one in the old times, when the shepherds came from East Carpathians and Moldavia to the Danube Delta with the purpose of feeding and protecting their flocks in wintertime. In the second part of the 19th century the sheep and cattle raising became a permanent occupation, on a sustainable base, but only of local importance. There are 22,490 ha of natural pastures and grasslands within the DDBR area.

Navigation

The Danube Delta branches have been used for navigation since the oldest times, but a modern system of navigation was introduced only after 1856, when the seat of the Danube Commission was established at Sulina. The navigation along the Sulina branch was highly improved between 1858-1902 by cutting several meanders and embanking and deepening the canal in order to allow oceanic ships to navigate upstream of the Danube river as far as Braila harbour (170 km).

Tourism

Touristic activities in Danube Delta are increasing, and are more and more focused on environmental tourism. At present, there is a great number of modern hotels and pensions, camping sites and water transport facilities, improving these activities, contributing to a better knowledge of a very special area and, also, offering work opportunities to local people.

Technological developments:

Lots of human interventions were made during the period 1960`s – 1980`s. These interventions can be divided into:

- a) The so called “reed period” (1960-1970): changes in the natural circulation pattern by digging canals,
- b) The “fish-period”: 1970 – 1980: changes in land uses : creation of large fish ponds;
- c) The “agriculture period” (1980 – 1990): transforming wetlands into agricultural polders (more than 35,000 ha).

These changes improved food production, navigation and industrial output, but negatively affected the functioning of the valuable, delta ecosystem through loss of tidal land, pollution and increased coastal erosion. The cutting of meanders along the southernmost arm of Sf. Gheorghe has also occurred in the mid – late 1980`s.

Furthermore, the construction of sluices which closed the Razelm – Sinoe former coastal lagoon system changed its character. It transformed the lagoon system into a series of large coastal lakes and surrounding wetlands which salinity changed from brackish to freshwater. The aim of this change was to initiate more productive freshwater fishery and to create a reserve for irrigation water for the neighboring areas from Northern Dobrudja.

All these activities were stopped when the Danube Delta Biosphere Reserve was established 2 decades ago. Almost no significant intervention has been done since – except for maintenance works along the Sulina Canal. “Soft” engineering measures, such as restoration and re-naturation of former agricultural polders and ponds for fish farming were also taken.

1.1.2 Climate change (temperature/evaporation, sea level rise, precipitation/discharge)

The Danube Delta has a continental-temperate climate, with pontic influences due to the vicinity of the Black Sea, characterised by hot dry summers and very cold winters. The mean annual temperature in Tulcea is 11°C, with absolute minimum air temperature of - 27.2 °C (18.01.1963), and absolute maximum air temperature of + 39.7 C (02.08.1945). It is the sunniest region of Romania (about 2,500 hours of sunshine/year). The evaporation is about 1,000mm/year, favorised by the strong and frequent winds, resulting in long periods of drought in the summer. The northwest winds cause frequent storms in spring and autumn. Precipitation is influenced by the north Dobrogean tableland and by the Black Sea. The average rainfall is higher in Tulcea (438.4 mm) and lower in Sulina (330.5 mm), close to the Black Sea. Average air humidity is about 80% at Tulcea , and increases towards the east: 84% at Sulina. In wintertime air humidity may reach up to 88-96%. Winds blow 80% of the year and with almost the same frequency from all directions. However, the prevailing direction is from the northwest, followed by the north wind.

Mean multiannual discharge of the Danube river is 6,515 m³/s, from which 58% is taken by Kilia branch, 20% by Sulina and 22% by Sf. Gheorghe branch. The maximum water discharge was recorded in April 2006 (16,500 m³/s), and the minimum in October 1921 (1,350 m³/s).

The DDBR is heavily exposed to erosion which may be aggravated by climate change. During the last century the maregraphic observations have shown the tendency of rising by 1.5-4

mm/year of the relative sea level. Despite of a not very critical value of the sea level rise, the impact on the shore zone will be quite strong due to combined effect of the level rising, wind set-up, shortage of beach sediment feeding and anthropogenic pressure on the coastal area. The sealevel rise of more than 20-30 cm (as it is forecasted for 2020-2030) will significantly affect the Danube water and sediment discharge within the delta front. At the same time a rise by 20-30 cm will flood the lowest areas within the coastal zone and will enhance the flood risks on the entire delta territory (Panin, 1999).

1.1.3 Subsidence (natural or human-induced)

The Danube Delta is situated in an area of high mobility of the Earth crust, repeatedly affected by strong subsidence and important sediment accumulation. The present-day variations of the Black Sea level depend on seasonal, multiannual or eustatic changes of sea water balance as well as on the deformation of free water surface under the influence of different external forces. At present, the subsidence of the coastal zone nearby the Danube Delta is appreciated to 1.5-1.8 mm/yr. (Panin, 1999).

1.1.4 Technological developments (e.g. regarding civil engineering, agriculture, ICT, energy)

First important civil engineering works were realised between 1858-1902, when Sulina branch was shortened (by cutting meanders), dredged and embanked in order to make possible the navigation of oceanic ships. During the next century, numerous canals have been digged to facilitate the water circulation within the delta and navigation. One of the last hydrotechnical work was the cutting of 6 meanders of Sf. Gheorghe branch in the years eighties. The modification of the water circulation inside the delta caused by the construction of several important magistral canals (Crisan - Caraorman and Mile 36) determined strong filling up processes in many lakes and secondary channels, directly influenced by the Danubian sediment loads.

The idea of transforming the extensive reed areas into agricultural polders was introduced by the old European Commission for the Danube, but before 1979 polder construction was never a success. The main polders – Pardina (27,000 ha) and Sireasa (7,500 ha) – have been realised in the next decade, initially with good results, but during the last 20 years the active area was reduced and the quality of the harvest diminished.

The intensive human intervention in the Danube Delta area determined the loss of ecological integrity. When the DDBRA was born, in early 1990, at the moment of the political change these works were stopped, and attention was directed to restoration activities, protection and sustainable development.

1.2 Pressures – impacts

1.2.1 Land and water use (occupation layer)

Summary of pressures

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

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

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

Research gaps

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

pressure on space

Due to the establishment of the Danube Delta Biosphere Reserve and the connected existence of the spatial planning policy, there are no significant conflicting pressures on space. Existing pressures though are generated mainly by:

- town development and tourism (Sulina)
- poorly controlled tourism development (Portita, southern part of the Reserve – Chituc area, Danube delta banks in the vicinity of villages – uncontrolled camping – even though regulated)

vulnerability to flood

Being a Biosphere Reserve wetland, even though the area is flood-prone, its vulnerability to floods is minimal, except for the inhabited areas. Almost all settlements in the Danube Delta Biosphere Reserve have areas where floods occur occasionally.

In what regards the floods related to storm surges, these also occur along the coast, mainly in the central part of the Sulina - Sf. Gheorghe coastal strip, as well as between Portita and South Periboina in the south (in front of the Razelm Sinoe Lagoon System). The littoral bar is frequently overwashed by waves during winter / severe storm surges, influencing thus the water salinity in the mainly freshwater lakes behind the littoral bars.

freshwater shortage

Freshwater shortages in the Danube Delta Biosphere Reserve are not related to the water quantity issues, but to the obsolete infrastructure of water abstraction – treatment – distribution – collection – waste treatment – discharge in the existing settlements from the Delta. Nevertheless, the latter years have witnessed the development of wide and comprehensive projects for the rehabilitation / construction of civil water consumption and treatment in all Danube Delta settlements (mainly EU funds).

1.2.2 Infrastructure (network layer)**Summary of pressures**

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

Research gaps

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

As Biosphere Reserve, the territory of the Danube Delta is mainly lacking infrastructure – on purpose in order to protect it from effects of uncontrolled tourists. Existing infrastructures are though related to navigation and fisheries (Sulina Canal and other human-cut canals and channels), embankments for agricultural purposes, Sulina – Sf.

Gheorghe road (built in the past 2 decades). Most of the human-cut channels and canals were left to natural evolution, fishing pond infrastructure – has been subject to re-naturation programmes, while most of the embankments have been subject to the same policy. Some embankments protecting settlements have been subject to restoration. The road between Sulina and Sf. Gheorghe has been destroyed in some parts by the catastrophic floods from 2010. The Sulina Navigation Waterway has been subject to an extensive restoration programme.

1.2.3 Natural resources (base layer)

Summary of pressures

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

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

Research gaps

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

Coastal erosion

Human interventions (building of Sulina Jetties, cutting of Sulina Canal, as well as of Sf. Gheorghe meanders, reduction in sediment supply due to Danube damming) abruptly changed the natural coastal evolution trends. This resulted in an average rate of shoreline retreat of 3.7 m/year, a loss of 47 ha/year from the delta. The maximum rate erosion of almost 25 m/year is recorded on Sahalin Island (Panin, 1999, Vespremeanu-Stroe et al., 2007, Stanica & Panin, 2009).

The Danube Delta coast can be divided into two major sediment circulation cells, each with its specific characteristics:

The Sulina – Sf. Gheorghe sediment circulation cell has a total length of the coast of just under 60 kilometres. The general water circulation here, as in the entire NW part of the Black Sea, is North – South oriented. The Sulina navigation jetties induce an abrupt change reversing the near coast circulation, south of these obstacles, to a clockwise south to north direction. Erosion rates are greater than the natural trends

Sahalin Island, the southern boundary of the Sulina – Sf. Gheorghe coastal cell, is a lateral curved bar, situated near front of the river mouth. The island is continuously shifting to the south east direction. The entire bar system is at the same time however migrating shorewards by overwashing and is thus retreating also due to reduced sediment supply.

The southern sediment circulation cell is about 100 kilometres long. The complex shoreline dynamics include sections with intense erosion, whilst others are stable or even advancing. Change in coastline orientation influences the circulation patterns. At Cape Midia the Midia Harbour northern jetty, projecting 5 km offshore, effectively blocks all sediment transported by littoral drift.

Studies comparing annual erosion rates in both sedimentary cells show that shoreline retreat from the 1960s – 1980s was greater than in the two decades. This change in erosion rate may be connected to the North Atlantic Oscillation (Vespremeanu-Stroe et al. (2007), although it was also during the 1970's and 1980's that the big dam constructions had strong,

initial impacts on the Danube River & Delta system. These dam constructions contribute to significant reductions in sediment supply to the Delta and its coast (Panin & Jipa, 1998, Ungureanu & Stanica, 2000).

Although erosion rates have adjusted and slowed during the last decades, erosion due to human activity is still greater than natural trends.

Loss of biodiversity

Due to the significant pressures during the communist regime, which had aimed to transform the entire delta into agricultural polders and fisheries, the biodiversity loss in that period was significant. Nevertheless, since the establishment of the Danube Delta Biosphere Reserve, two decades go, a dramatic improvement has been observed. Spatial planning measures, as well as restoration of agricultural polders and fish ponds have also contributed to this. A reduction in fish stocks has been anyway observed.

1.3 Governance (institutional/organizational aspects of delta management)

Summary of governance issues

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

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

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

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

Research gaps

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

Cooperation between (scale) levels and sectors of government:

The activities and environmental protection programme in the Danube Delta Biosphere Reserve are under the coordination of the Danube Delta Biosphere Reserve Administration, (Romanian Ministry for Environmental Protection and Forests). The other institutional actors with role in regulating activities in the Danube Delta are: local administrations of the settlements within the Biosphere Reserve (for the areas covered by their jurisdiction), Lower Danube River Administration - Ministry of Transports – navigation, Ministry of Internal Affairs – border police and coast guard, Ministry of Agriculture – dept. of fisheries, Romanian Waters National Authority – coastal zone management.

The cooperation between these institutions is well regulated by laws, nevertheless sometimes gaps in communication occur. Also – in case of conflicting interests disputes may appear.

Cooperation between government and private sector:

Private initiative is not well developed and where it exists it is resumed mainly to agri-tourism and other small fishery, tourism, subsistence business. Traditional fishermen have individual fishing permits and quotas. Small business in villages and only town (Sulina) is made by a small number of business people. Tourism is also led by private investors with traditional tourist facilities, as well as by locals, which host tourists in their homes (family business, agri-tourism). The activity of private investors and businesses is regulated by the government according to the spatial planning management framework of the Danube Delta Biosphere Reserve Administration.

Involvement of stakeholders and citizens:

Local communities are represented by NGO's and professional associations. Thus, a number of environmental NGO's are very active in the Danube Delta Biosphere Reserve area. Their activities range from monitoring, volunteering in environmental campaigns, such as increase of awareness, litter gathering etc. Professional associations also exist – mainly of traditional fishermen. If no public consultations were ever made, due to the EU integration process important projects are presented in public and citizens are invited to participate and take their stand. Nevertheless, even though a dramatic improvement has been observed in this field, a lot still has to be done to improve both communication and integration of local views (one of the reasons may also be conflicts between local interests such as fishing and environmental protection of endangered species).

Approaches for dealing with risks and uncertainties:

The Danube Delta Biosphere Reserve has had as primary aim the achievement of sustainable development in the area. The first steps comprised the restoration and maintenance of the natural equilibrium of the delta. Using mainly internationally funded projects, the Reserve Administration successfully restored several former agricultural polders to wetlands.

Restoring and sustainably managing the nature conservation values of the nature reserve raised several delicate issues, which can be grouped in two main categories:

- Retaining local communities and maintaining their traditional habits.
- Dealing with changes to the delta habitats and leaving nature to take its course, by mitigating adverse human impacts.

The DDBRA developed management plans using spatial planning as a tool (see Fig. 1 - land-use map of the DDBRA). The entire area has been divided into three zones: strictly protected areas (50,600 ha) and areas of traditional, economic use (306,100 ha), which are separated by buffer zones (223,300 ha). While access in the first category is strictly controlled, the areas of economic use have been regulated in plans, which establish a series of traditional activities (such as fishing and reed harvesting) with well established maximum quotas.

Existing situation is analysed and management plans are discussed and adapted to new situations every few years.

1.4 Main indicators for drivers, pressures and governance

DRIVERS	Main indicators
Demographic trends	- number of people and growth rate - age of local population - migration trend in delta (annual percentage in/out)
Economic developments	- per capita GDP, growth rate, % contribution by delta traditional activities - unemployment rate
Technological developments	- ..

Climate change	- change of temperature / evaporation - change of sea level (mm/year) - change of precipitation (mm/year) or river discharge (m3/sec)
Subsidence	- rate of subsidence (mm/year)
PRESSURES/IMPACTS	Main indicators
Land and water use (occupation layer)	- number of inhabitants, population density - % settlements area - % number of vulnerable people / areas in settlements
Network / infrastructure (network layer)	- flood risk (safety level), % of delta protected (high-medium-low) - % of infrastructure which needs to be upgraded according to the specific plans of the Biosphere Reserve Administration) - number of floods or flooding days per year - % people with access to water supply, % untreated waste water - people with water sanitation - navigation intensity / no. of transiting ships
Natural resources (base layer)	- % of polluted areas (water, soil, air) - frequency of storms (storm surge) - frequency of extreme river discharge, flood hazard level (high-medium-low) - annual loss of land (km2/year) / average erosion rate (m/year) - total area of wetlands / % of wetlands protected by treaties - biodiversity index (e.g. LPI)** - fluvial sediment transport (Mton/year) - river discharge (peak/low and variability) SHOULD BE USED ALSO: - % of sediment trapped in reservoirs - (planned) dams in main tributaries in the catchment - existence of dykes/embankments along delta distributaries
GOVERNANCE	Main indicators
Multi-level and multi-sectoral cooperation	- existence of integrated plans (delta plan, national adaptation plan etc.) - existence of interministerial committees, multi scale level committee etc.
Public-private partnerships	-
Involvement of stakeholders and citizens	- existence of legal instruments for participation (e.g. spatial planning instr.) - number of NGO's involved in planning and decision making
Approaches for dealing with risks and uncertainties	- existence of adaptive management , adaptation strategies etc. (long term) - existence of risk management, emergency systems etc. (short term)

1.5 Score card

The scores in the score card are just qualitative and indicative, based on the summary tables descriptions for each item (above). Each item is scored on a 5-points scale, related to resilience and sustainability.

The following two development scenarios are recognized:

- Scenario1, moderate perspective 2050: medium economic growth (1,2 %, WLO-scenario RC) and related medium technological developments, combined with medium climate change and sea level rise (KNMI-scenario G, relative sea level rise 0,30 cm)
- Scenario2, extreme perspective 2050: high economic growth (1,7%, WLO-scenario TM) and related high technological developments, combined with high climate change and sea level rise (KNMI-scenario W+, relative sea level rise 0,40 cm)

Delta	Land and water use (occupation layer)	Infrastruc-ture (network layer)	Natural Resources (base layer)	Governance	Overall Resilience & Sustainability indicator
Current situation 2010	+	+	+	0	+
Scenario 1 moderate 2050	0	0	0	+	0
Scenario 2 extreme 2050	-	0	-	+	0

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

Clarification notes on the score card:

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

2. Overview of currently applied adaptive measures in the Danube delta

Overview of possible adaptive measures (in the three layers) based on current practices and innovative technological developments. The measures are classified in types of measures (technical, ecological, economic and institutional/organizational), related strategy (protect, adapt, relocate) and involved layer (occupation layer, network layer, base layer).

Name of measure	Type of measure	Brief description	Strategy	Layer
	1. Technical 2. Ecological 3. Economic 4. Institutional		1. Protect 2. Adapt 3. Relocate	1. Occup. 2. Network 3. Base
Restoration of former agricultural polders and fish ponds	1, 2, 3, 4	Restoration of former agricultural polders – i.e. opening the artificial banks / dykes on areas	Restore (different from the above 3.)	1, 2, 3

		artificially created and dried – letting the Danube waters in the former agricultural areas – are successful restoration techniques used by the DDBR Administration – after studying effects and impacts of such measure. Nature then restores itself in these areas in just a matter of few years.		
“No intervention” policy within the delta	2, 4	DDBR Administration ceased dredging most of the human cut canals connecting the inter-distributary lakes – leaving the nature restore by itself.	Restore	1, 2, 3
Financial instruments	3	Financing mechanisms to support economic development	2	1
Education and awareness raising	4	Educational programs on the unique character of the Danube Delta, as well as hazards and vulnerability	2	1

3. Overview of technical methods and tools to support delta management and development in the Danube delta

Overview of methods and tools for assessments, planning and decision making on delta management and development issues:.

Name of tool	Brief description	Institute	Available at
Spatial planning of the Danube Delta Biosphere Reserve territory.	Division of the DDBR territory into strictly protected areas, buffer zones and regulated area open to traditional economic activities	Danube Delta Biosphere Reserve Administration	Danube Delta Biosphere Reserve Administration
Delft3D	Coastal management tool regarding hydrodynamics, sediment transport and morphology and water quality	Created by Deltares, The Netherlands, applied by GeoEcoMar, Romania	http://delftsoftware.wldelft.nl/index.php?option=com_content&task=view&id=15&Itemid=65 former with GeoEcoMar. not yet valid (not renewed license) , Deltares
SHYFEM	Coastal management tool regarding hydrodynamics	Institute of Marine Sciences (ISMAR) – CNR, Italy,	ISMAR, GEOECOMAR

		applied by GeoEcoMar, Romania	
Various GIS software	Geographic Decision Support System	Danube Delta Research and Development Institute, GeoEcoMar, Antipa Marine Researches Institute, DDBR Administration	Danube Delta Research and Development Institute, GeoEcoMar, Antipa Marine Researches Institute, DDBR Administration (various layers)

4. Knowledge exchange and development

4.1 Lessons learned on delta management

Until the end of the Romanian communist regime in 1989, the Danube Delta was subject to damaging human activities. Two years later, the Delta became a Biosphere Reserve and restoration of the natural environment turned into a long term goal.

All activities (from research to proposed management plans) associated with this have been undertaken in cooperation with international institutes and organisation concerned with wetlands and coastal research, management and administration.

The Danube Delta area has received international funding and expert assistance (Dutch, EU, World Bank and US) for projects dealing with critical issues. The spatial planning management strategy has worked very well in the context of this wide Biosphere Reserve area with very low population density, even though many efforts are still needed to fully enforce the decision and regulations.

The integrated delta management plans are nevertheless in need for a concentrated effort also from managers upstream the river as well as in the neighboring coastal / marine areas – proving thus the need to integrate all efforts in a river – delta – sea macrosystem coherent management plan.

4.2 Summary of research gaps and related needs for knowledge exchange

Drivers of change

See text above.

Pressures – potential problems / Challenges - opportunities

See text above.

Adaptive measures

Research gaps and related needs to be added..

Technical methods and tools

Research gaps and related needs to be added..

4.3 Some available illustrations (map of delta, typical sites, etc.)

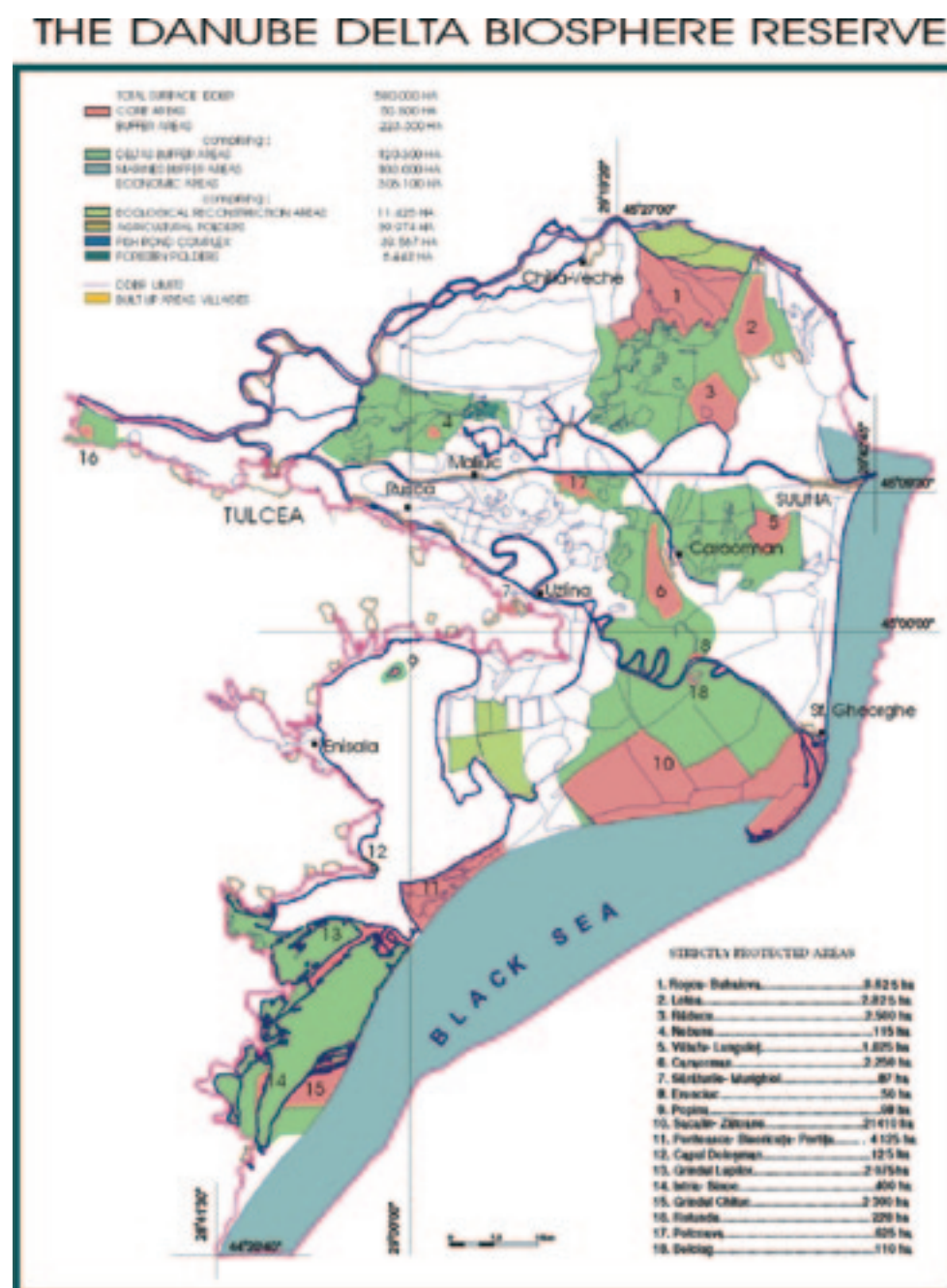


Fig. 1. Spatial planning in the Danube Delta Biosphere Reserve

Land use map and spatial planning of the Danube Delta Biosphere Reserve (580,000 ha), delimited by the red line.

Pink/red – strictly protected areas (nature sanctuaries). Green – buffer zones. White – traditional economic use areas (for fisheries, reed harvesting, ecological tourism, etc.). Light green – areas in need of ecological reconstruction. The marine part of the Danube Delta coast is also a buffer zone. (Source: see website DDBR Administration)

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California Bay-Delta

No



1. Current and future state of the California Bay-Delta

1.1 Drivers of change

Summary of drivers of change

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

Economic developments: The state of California ranks among the most developed areas in the world with per capita income of about US\$ 40,000. As a state alone California is the eighth largest economy in the world. The Delta is the hub for California's water supply, moving water from north to south. About 25 million Californians rely on water from the Delta for their drinking water supply and 1.5 million hectares of agricultural land are farmed with irrigation water from the Delta.

The San Francisco Bay area is for a large part dependent on its water supply from the Hetch Hetchy project coming from the Sierra Nevada Mountains. The economy here is primarily driven by the financial, IT, agriculture and tourism industries.

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

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

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

Research gaps

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

1.1.1 Socio-economics (population growth- migration, economic development + most relevant sectoral developments, e.g. for agriculture, fisheries, industry)

Population

The total population of the State of California is about 38 million people. Over one in ten Americans live in California and the state's population continues to grow. With a population of somewhat more than 500,000 people, the delta's community is largely rural. In July 2000, the delta counties plus the nine San Francisco Bay Area counties have a combined population of nearly 9 million inhabitants. The combined population of the drainage basin and the area outside the basin that receives delta water exports is over 25 million. In the future, the number of people dependent on water supply from the delta will grow considerably, though there are studies underway to decrease California's reliance on the Delta for water supply.

Economic development

The state of California ranks among the most developed areas in the world. It has the estimated eighth-largest economy in the world with per capita income of about US\$ 40,000 per year, above the average for the US. California is home to several large cities, like Los Angeles, San Jose, San Francisco and Sacramento. In addition, many California cities depend heavily on the water resources for drinking water use. For example, the Los Angeles Aqueduct (400 km long), the California Aqueduct (700 km long) and the Colorado River Aqueduct supply drinking water to the city of Los Angeles and the Hetch Hetchy Aqueduct (300 km long) supplies water from Yosemite Valley to 2.5 million people in the Bay Area. The availability of fresh water and the ability to move it across the state from north to south has been the big driver for economic development in California.

Agriculture

California is the world's fifth-largest supplier of food and agricultural commodities. Of the 3.5 million hectares of irrigated farmland in California, about 1.5 million hectares are irrigated from delta-associated water supplies, resulting in at least US\$ 27 billion in agricultural income, which equals 45 percent of California's agricultural production. In total 25 percent of all fruits and vegetables consumed in the US are produced in California.

Fisheries and wildlife

The delta provides valuable habitat for a variety of fish and wildlife. Fisheries in the delta is mainly for recreation. However the delta fish population has seen a huge decline in number of species and diversity, also non native species have been introduced or migrated to the delta. The decline of fish is largely dedicated to the water conveyance activities that take place and reduced water quality due to drainage outflow.

In San Francisco Bay the ecosystem has also been heavily altered as fish, shellfish and other aquatic life was introduced.

More than 212 non-native species of plants and animals inhabit the Bay-Delta. There are about 100 exotic invertebrate species and the estuary shellfish species is now dominated by introduced species. The estuary is considered the most invaded aquatic ecosystem in North America.

Industry

The primary industry in the delta and the Central Valley is related to agriculture. In other parts of the state such as the Bay Area and the Los Angeles Metropolitan Area, a mixture of high growth industries is found, including: advanced manufacturing, aerospace, automotive, biotechnology, construction, information technology, retail, and transportation.

1.1.2 Climate change (temperature/evaporation, sea level rise, precipitation/discharge)

California's Bay-Delta is unique among inland deltas because of its wet winter and dry summer precipitation regime. The Mediterranean climate in California is important because it drives a crucial mismatch between the timing of California's water demands and water supplies. The delta's climate is also unusual in its extreme variability, which routinely yields extended periods of drought or periods of widespread flooding. It must also be understood

that California lies within multiple climate zones, and thus each region will experience unique impact from climate change. The state is therefore developing regionally appropriate adaptation strategies. The main climate change impacts on California in general are:

- California will experience a change in precipitation in the Sierra Nevada Mountains from snow to more rain. This means that less water will be stored in a natural snow pack and that precipitation in the mountains will reach reservoirs sooner. This poses flood and storage challenges that California will have to deal with. Simulations show an up to 80 percent decrease in the Sierra snowpack by the year 2100.
- The 'high' sea level rise scenario that is used is 40 centimeters until 2050 and 140 centimeters in the year 2100. This will significantly increase the flood risk in the Bay Area and the Sacramento San Joaquin Delta. Over the last century a 19 centimeter sea level rise has been recorded at the Golden Gate Bridge already.
- Precipitation patterns will also change. The general picture is that the different climate zones will experience extended periods of drought followed by more intense rain events.

1.1.3 Subsidence (natural or human-induced)

Subsidence is a major issue in the Sacramento and San Joaquin Valleys as well as in the Delta. Peat soils have subsided over 9 meters in some areas, creating so called delta islands (polders). The subsidence is caused by peat soil oxidation and also wind erosion due to farming practices. Extensive farming started in the Delta in 1860's.

In the Bay Area there are reclaimed wetlands that suffer from subsidence, primarily due to groundwater pumping. The parts of the bay that were filled to support housing and commercial development simply sink as they were built on soft soils and bay mud. The high subsidence rates in both the Delta and the Bay Area increase flood risks.

1.1.4 Technological developments (e.g. regarding civil engineering, agriculture, ITC, energy)

In order to reduce the vulnerability of the water system in the Delta and the Bay Area the state of California is aggressively developing plans to increase resilience of the water and ecosystems.

On the water supply side there is a large efforts underway to reduce water use by urban water conservation programs and agricultural water use efficiency programs. Urban water users are more restricted in their water use and landscaping that uses less water is supported and in some cases enforced. In agriculture farmers switch to other more efficient irrigation methods, such as micro drip irrigation, and apply different irrigation regimes that reduce water use and can increase yield.

The ecosystem in the Delta has suffered tremendously from the water export south of the Delta. In order to restore the ecosystem and secure a reliable water supply to southern California the state started a planning process called the Bay-Delta Conservation Plan. This plan involves the construction of a new isolated conveyance facility that will take water north of the Delta from the Sacramento River down to the South Delta Pumping stations. This facility will be either a canal or tunnel, or a combination of both with a maximum capacity of 500m³/s. To mitigate for the negative effects of this facility over 80,000 hectares of wetland will be restored.

The progressiveness California displays as a state to reduce greenhouse gas emissions also carries over to the adaptation side. This is especially visible in addressing sea level rise and water supply needs. Although limited adaptation measures have been applied to date a lot of research is being conducted to understand the impacts as well as what is needed for adaptation planning.

1.2 Pressures – impacts

1.2.1 Land and water use (occupation layer)

Summary of pressures

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

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

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

Research gaps

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

Pressure on available space

In the Sacramento-San Joaquin Delta, pressure on the available space is not a major issue. The delta constitutes only a relatively small area within the Central Valley, and it has no significant advantages for settlement compared to other areas in the Central Valley. The large population centers are the Bay Area, Sacramento and the Los Angeles, San Diego area. There is a large demand on the available space in the Bay Area, the moderate climate and high tech industries attract a lot of people. The Bay Area is therefore expanding eastward towards the delta.

Housing development

Several large scale housing developments have been realized in flood prone areas in and around the delta in recent years as. A good example of this is the Natomas area in Sacramento. An issue in the Delta is that the levee systems around the delta islands have been developed to protect agricultural lands, not urban areas. The existing relatively low levels of flood protection of 1 in 100 years are a concern.

In the Bay Area parts of San Francisco Bay have been filled between the late 1800's and the 1960's to create more land for development. With this practice 600 square kilometers of Bay waters have been filled. However just high enough to be above bay water levels, not taking into account that sea level will rise.

Agriculture

Since the start of the Gold Rush in 1848, California's streams have been tapped to meet the ever-increasing demand for water. At first water was captured to support hydraulic mining. In the twentieth century, federal and state water projects increased storage and conveyance capacities, for flood control, water supply, power and recreation resulting in spectacular prosperity for the state. The agricultural water demand has been dominant for a long time and

still uses about 80% of all developed water. However with increasing urban demands more and more compete with agricultural use.

Hydrology

The variability of the delta climate reflects in the variable discharges and salinities in the bay and delta's ecosystems and other resources. Freshwater discharge through the delta, which captures 42% of California's runoff feeds San Francisco Bay and partially flushes ocean salt from the estuary's waters.

The average annual inflow to the delta in the period 1980 – 1991 amounts to 1,080 m³/s, with the Sacramento and San Joaquin Rivers contributing over 75 percent. Historically, the runoff volume of the San Joaquin River was about one-third of the volume of the Sacramento River, so most of the fresh water inflow to the delta originates from the north.

In addition to precipitation-derived runoff, the bay-delta is influenced by the Pacific Ocean in the form of twice-daily tides that deliver a large amount of coastal ocean water and tidal energy to the delta's hydraulic network. The magnitudes of the tidal flows diminish at locations further into the delta, but nonetheless, for most of the bay-delta, twice-daily tides and varying inputs from rivers and streams result in highly dynamic conditions within a single day.

Water management

California has grown to a population of 36 million, with an economy that is the seventh-largest in the world, largely on the strength of its large-scale integrated approach to water management. However, opportunities for increasing supply to satisfy growing demand are becoming limited, and environmental problems are creating a growing need to reallocate water to the ecosystem. As California's population grows, increasing urban water needs will have to be met mainly by improving water management instead of by developing new supplies within the Sacramento-San Joaquin system.

Severe droughts in the last thirty years emphasized the fact that water is precious, while also showing the possibilities for water conservation. The old way of thinking about water as flowing 'wasted' to the sea is replaced with the recognition that every drop of water flowing in a river to the sea contributes to valuable ecosystem functionality. Today, individual water consumption is less than it was thirty years ago, and water planners are often more concerned with water reliability and quality than with increasing supply.

The water quality in the delta and San Francisco Bay is affected by a broad range of toxic chemicals contributed by agriculture, industry, sewage treatment plants, shipping, highway traffic and urban stormwater runoff. The ocean also contributes salts and bromide that affect water quality. Sources and fates of contaminants entering the delta are not yet well understood. Concerns for drinking water quality are primarily salinity, turbidity, organic carbon and bromide. The most important concern for agricultural water use is salinity. Concerns for environmental water quality include nutrients, dissolved oxygen, pesticides, mercury and selenium.

1.2.2 Infrastructure (network layer)

Summary of pressures

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

Research gaps

Research needs to be done on hydraulic conveyance and storage infrastructure: In which one looks at alternatives to potentially modify infrastructure to meet water demands and to provide flood control subject to climate change impacts on wet/dry precipitation timing and magnitude.

Because of climate change California will experience more extreme heat and changes in electricity demands. Research is needed to study atmosphere ocean general circulation models used to evaluate climate change and extreme heat impact on state electricity demands. The linkage to water is the impact on operations of reservoirs in the Sierra Nevada and Coastal Range.

Hydraulic Conveyance and Storage Infrastructure: Key ideas: need to potentially modify infrastructure to meet water demands and to provide flood control subject to climate change impacts on wet/dry precipitation timing and magnitude.

Infrastructure (general)

The water resources of the delta not only serve the State and federal projects but also many agricultural and municipal water diverters surrounding and within the delta itself. The bay-delta system provides drinking water for two-thirds of the State's population, irrigation supplies for some 45% of California's agricultural production, and is a primary water source for California's trillion dollar economy. About 190 m³/s of freshwater is pumped from the south side of the delta by the federal Central Valley Project and 300m³/s by the State Water Plan to supply municipal and agricultural water demands in southern and central California.

The development of delta infrastructure started in the period from 1850 to 1920, with the emphasis on flood protection. Farmers enclosed and drained wetlands to establish farms. Until the turn of the century, most local landowners, officials and engineers had little experience with levee construction and failures occurred frequently. In the period after 1920 the emphasis shifted to water development first and to restoring the environment later. During this period, state and federal agencies built the great dams on the Sacramento, the San Joaquin and their tributaries to capture and store spring flood waters for release during the dry season. It was also during this period that the Central Valley became the core of California's extensive water redistribution system. As part of the infrastructure for the Central Valley Project, the Delta Cross Channel was constructed in 1951 to move Sacramento River water efficiently into the southern delta from which it is exported further south. The 1992 Central Valley Project Improvement Act was aimed at protecting the natural resources of the Central Valley. The act allocated for instance a water reserve of 32 m³/s specifically to sustain fish and wildlife.

Apart from the water distribution infrastructure, also a transport infrastructure developed. Three highways, three railroad lines, five high-voltage power Lines and hundreds of gas lines crisscross the delta region. Ships transport millions of tons of cargo via the deepwater channels to Sacramento and Stockton. Thousands of recreational boats use its other waterways.

1.2.3 Natural resources (base layer)**Summary of pressures**

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

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

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

Research gaps

Research is needed on climate change impacts on California's coastlines. As information is needed by coastal managers to adapt to climate change, including: inland, coastal and near shore water quality, species and habitat protection, inland flooding, coastal erosion, saltwater intrusion, cliff failure, wetland loss and beach loss.

Due to climate variability more research should be done on precipitation modelling. Key ideas for this topic include need for statistical models to accurately model precipitation volatility and extreme precipitation events at individual locations and in micro climates. Need to estimate spatial distributions of precipitation for various applications (e.g., rainfall and runoff models, watershed modelling, surface water modelling, flood control).

Research is also needed on the impacts of earthquakes and other natural disasters on surface and subsurface structures. Liquefaction, groundwater level rise impacts, subsidence due to pumping, instability of foundations with water level rises, levee failure, channel erosion, sedimentation of channels (e.g., need for periodic dredging and channel maintenance).

Nature

The California Bay Delta is home to a diverse array of ecosystems and more than 700 plant and animal species. 91 species of fish and 225 species of birds can be found in the delta. It is a critical resting and feeding area on the Pacific.

Flyway for migratory birds as well as an important breeding ground for many waterfowl species. 31 species occurring in the delta are listed as threatened or endangered under state and federal endangered species statutes. Some of the smaller unimproved islands in the delta provide suitable habitat for birds and other wildlife. In recent years, large tracts of land in the delta have been set aside for wildlife management and protection.

Wetlands, Shore protection / Coastal erosion management

The damage caused by hurricane Katrina in the Mississippi Delta raised the concern that a similar event could be devastating to California Bay. Protection of the area against floods caused by extreme storm events, but no hurricanes, has become a major concern in around the San Francisco Bay and Sacramento-San Joaquin Delta.

1.3 Governance (institutional/organizational aspects of delta management)

Summary of governance issues

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

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

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

support and consensus. This is very intensive approach however.

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

Research gaps

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

There is a dense governance framework for the delta, its drainage basin and San Francisco Bay. It includes intricate and dynamic interplay between local governments, who have primary authority in land-use decision making, and state and federal agencies that have both direct and indirect influence on decision on land use and natural resources. Decisions on local land use issues are often subject to environmental review by a variety of natural resource management agencies within the state and federal government.

Water is managed and allocated according to its chemical, physical and biological properties and the beneficial uses that it provides. Surface water in California is highly regulated, whereas groundwater is not. California lacks a strong linkage between its planning for water resources and its planning for land uses.

In 1994, state and federal resource agencies signed an agreement that led to the formation of CALFED: a cooperative organization, working with other governmental and water and environmental agencies, to find long-term solutions to the delta dilemma. To accomplish this, CALFED and its staff have focused on reliable quality water supply, ecosystem restoration, levee rehabilitation, increased water storage, and improved water conveyance. In 2000, the CALFED Bay-Delta Program was established to address the problems of water reliability, ecosystem restoration, levee integrity, and water quality in the delta and its tributaries.

In October 2008 the State of California launched a Delta Vision Strategic Plan, to achieve a healthy delta and a more reliable water system for Californians. The plan identifies seven goals as well as 22 strategies and 73 actions needed to achieve these goals. The vision states that the current governance structure for water and the delta has failed. A key strategy in achieving the goals is creation of a new governance structure with needed legal authority and competencies.

The following table gives an overview of recent plans most relevant for delta management:

Name of tool	Brief description	Institute	Available at
Delta Plan	Following the Delta Vision process the state of California will now develop a comprehensive Delta Plan for the Sacramento-San Joaquin Delta	Delta Stewardship Council	Under development. Completed on January 1, 2012 www.deltacouncil.ca.gov
Bay Delta Conservation Plan	The Bay Delta Conservation Plan (BDCP) is being prepared through a collaboration of state, federal, and local water agencies, state and federal fish agencies, environmental organizations, and other interested parties. The goal	California Natural Resources Agency	Under development. Plan completed in 2012. 50 year construction period www.bdcweb.com

	is to identify water flow and habitat restoration actions to recover endangered and sensitive species and their habitats in California's Sacramento-San Joaquin River Delta. A range of alternatives for providing species/habitat protection and improving water supply reliability will be evaluated.		
Bay Plan	Management Plan for San Francisco Bay	San Francisco Bay Conservation and Development Commission	www.bcdc.ca.gov
Water Plan	The California Water Plan provides a framework for water managers, legislators, and the public to consider options and make decisions regarding California's water future. The Plan is updated every five years.	California Department of Water Resources	http://www.waterplan.water.ca.gov/
Floodsafe	Flood management plan aiming to reduce risk of floods	California Department of Water Resources	http://www.water.ca.gov/floodsafe/
2009 Delta Reform Act	New act that put the co-equal goals of a restored delta ecosystem and a more reliable water supply into law. It also includes the establishment of the Delta Stewardship Council, a water master and several other provisions	State of California	
Assembly Bill 32: Global Warming Solutions Act	Act which put greenhouse gas emissions reduction goals for 2020 into law.	California Air Resources Board	http://www.arb.ca.gov/cc/ab32/ab32.htm

1.4 Main indicators for drivers, pressures and governance

DRIVERS	Main indicators
Demographic trends	- Increasing population
Economic developments	- Agriculture from commodity crops to high value fruits and vegetables - Front runner position in green and clean technologies
Technological developments	- New water infrastructure (levees, storage, aqueducts (under development)) - Water conservation -
Climate change	- Sea level rise - Changes in precipitation (reduced snow pack) - Salinity intrusion - Extended periods of drought

Subsidence	- Peat soil oxidation - Wind erosion of peat soils
PRESSURES/IMPACTS	Main indicators
Land and water use (occupation layer)	- Overexploitation of water resources
Network / infrastructure (network layer)	- Aging infrastructure – both water supply and flood control
Natural resources (base layer)	- Poor water quality - Salinity intrusion - Non native species
GOVERNANCE	Main indicators
Multi-level and multi-sectoral cooperation	- to be added..
Public-private partnerships	- Market based solutions – beneficiary pays
Involvement of stakeholders and citizens	- Large public involvement - Stakeholder driven and bottom up approach
Approaches for dealing with risks and uncertainties	- to be added..

1.5 Score card

The scores in the score card are just qualitative and indicative, based on the summary tables descriptions for each item (above). Each item is scored on a 5-points scale, related to resilience and sustainability.

The following two development scenarios are recognized:

- Scenario1, moderate perspective 2050: medium economic growth (1,2 %, Regional Communities-scenario) and related medium technological developments, combined with medium climate change and sea level rise (to be determined by expert)
- Scenario2, extreme perspective 2050: high economic growth (1,7%, Transatlantic Market-scenario) and related high technological developments, combined with high climate change and sea level rise (to be determined by expert)

Table 2. Scorecard for delta assessment

<i>Delta</i>	Land and water use (occupation layer)	Infrastructure (network layer)	Natural Resources (base layer)	Governance	Overall Resilience & Sustainability indicator
Current situation 2010	0	-	-	0	-
Scenario 1 moderate 2050	+	0	0	0	0
Scenario 2 extreme 2050	-	-	-	0	-

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

Clarification notes on the score card:

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

2. Overview of adaptive measures in the California Bay-Delta

Overview of possible adaptive measures (in the three layers) based on current practices and innovative technological developments. The measures are classified in types of measures (technical, ecological, economic and institutional/organizational), related strategy (protect, adapt, relocate) and involved layer (occupation layer, network layer, base layer).

Name of measure	Type of measure	Brief description	Strategy	Layer
	1. Technical 2. Ecological 3. Economic 4. Institutional		1. Protect 2. Adapt 3. Relocate	1. Occup. 2. Network 3. Base
Wetland restoration	Ecological	There are numerous wetland restoration efforts underway in the San Francisco Bay and the Delta to restore the ecosystem and provide flood protection	Adapt	Network/Base
Bay-Delta Conservation Plan	Technical and ecological	Plan to restore 80,000 hectares of wetland area and construct a new water supply conveyance facility around the Delta	Adapt	Network

Flood standard increase	Institutional	Raise the safety standard to a higher level from the 1 in 100 existing standard	protect	Network
Reduce reliance on the Delta for water supply	Institutional/technical	Reduce reliance on the delta by exploring water conservation measures and other potential resources	Adapt	Base
Reverse subsidence	Ecological/technical	Growing peat back on delta islands with specific plant species and	adapt	Base

3. Overview of technical methods and tools to support delta management and development in the California Bay-Delta

Overview of methods and tools for assessments, planning and decision making on delta management and development issues:.

Name of tool	Brief description	Institute	Available at
Water balance modeling		Various organizations	http://www.cwemf.org/ModelingClearinghouse/modch.htm
Ground water modeling		Various organizations	http://www.cwemf.org/ModelingClearinghouse/modch.htm
Reservoir operations modeling		Various organizations	http://www.cwemf.org/ModelingClearinghouse/modch.htm
Hydrodynamic modeling		Various organizations	http://www.cwemf.org/ModelingClearinghouse/modch.htm
Sediment Transport Modeling		Various organizations	http://www.cwemf.org/ModelingClearinghouse/modch.htm
Aquatic species modeling		Various organizations	http://www.cwemf.org/ModelingClearinghouse/modch.htm
Vegetation models		Various organizations	http://www.cwemf.org/ModelingClearinghouse/modch.htm

4. Knowledge exchange and development

4.1 Lessons learned on delta management

Water is the most contested resource in California and the Sacramento-San Joaquin Delta is in the heart of the battle. California's growth over the past 160 years has been driven by the availability of fresh water and the ability to move it to places where it was needed. Today, the resource is over depleted and used in an unsustainable way. With this in mind California is revising its strategy on water use from the Delta and developing a plan that will meet the co-equal goals of a restored and enhanced delta ecosystem as well as a more reliable water supply.

For San Francisco Bay, California recognized its importance in the 1960's by putting a halt to further filling of the Bay. Now with new challenges in the form a sea level rise, California is taking a very progressive stand in addressing this and making San Francisco Bay a test bed for adapting to sea level rise.

4.2 Summary of research gaps and related needs for knowledge exchange

Drivers of change

California is known for its strong research institutes. Amongst others these are UC Berkeley, Stanford, UC Davis, UCLA and Scripps Oceanographic Institute. The high level research that is being conducted provides a lot of input for current delta management as well as future changes. The large uncertainty is climate change and related issues such as subsidence, water supply, flood protection and ecosystem health.

Economic Considerations: Key ideas: to develop instruments for cost-benefit analyses and risk management, incorporating future climate change

Pressures – potential problems / Challenges - opportunities

- **Occupation layer**

Land Use and Land Cover change models. Key ideas: need for models to predict land use and land cover changes, urban and rural land use change, agricultural land use change, urbanization, land use models. Model needs to be appropriate for climate change and ecosystem projects, including vegetation changes and loss of ground surface to permanent flooding

- **Network layer**

Climate Change, Extreme Heat and Electricity Demands. Key ideas: Atmosphere ocean general circulation models used to evaluate climate change and extreme heat impact on state electricity demands. The linkage to water is the impact on operations of reservoirs in the Sierra Nevada and Coastal Range.

Hydraulic Conveyance and Storage Infrastructure: Key ideas: need to potentially modify infrastructure to meet water demands and to provide flood control subject to climate change impacts on wet/dry precipitation timing and magnitude.

- **Base layer**

Climate change impacts on California's coastlines. Key ideas: information is needed by coastal managers to adapt to climate change, including: inland, coastal and near shore water quality, species and habitat protection, inland flooding, coastal erosion, saltwater intrusion, cliff failure, wetland loss and beach loss.

Precipitation Modeling. Key ideas: need for statistical models to accurately model precipitation volatility and extreme precipitation events at individual locations and in micro climates. Need to estimate spatial distributions of precipitation for various applications (e.g., rainfall and runoff models, watershed modeling, surface water modeling, flood control).

Geotechnical Considerations. Key ideas: impacts of earthquakes and other natural disasters on surface and subsurface structures. Liquefaction, groundwater level rise impacts, subsidence due to pumping, instability of foundations with water level rises, levee failure, channel erosion, sedimentation of channels (e.g., need for periodic dredging and channel maintenance).

- **Governance**

Governance Considerations. Key ideas: institutional changes to enable implementation of measures for adaptation to climate change.

Adaptive measures

Sea Level Rise Key ideas: In the Sacramento San-Joaquin Delta there is potentially a need to strengthen or raise heights of existing levees for flood control and a secure water conveyance system.

Economic Considerations: Key ideas: to develop instruments for cost-benefit analyses and risk management, incorporating future climate change.

Technical methods and tools

Water Supply Management Models. Key ideas: management models should integrate groundwater storage and use, reservoir storage, surface water conveyance, water markets, urban & agricultural water demands, water rights, environmental demands, changes in precipitation patterns and runoff for enhanced water supply management

Hydrologic and Environmental Monitoring Key ideas: improve and continue monitoring and data collection activities related to future climate change. Examples of monitoring variables include temperature, precipitation, stream flows, snow pack, ocean and Delta water levels, water quality, land use changes.

Flood Control Measures and Management. Key ideas: flood control infrastructure (e.g., levees, dams, channels), innovative measures, rainfall and runoff modeling, updated floodplain maps.

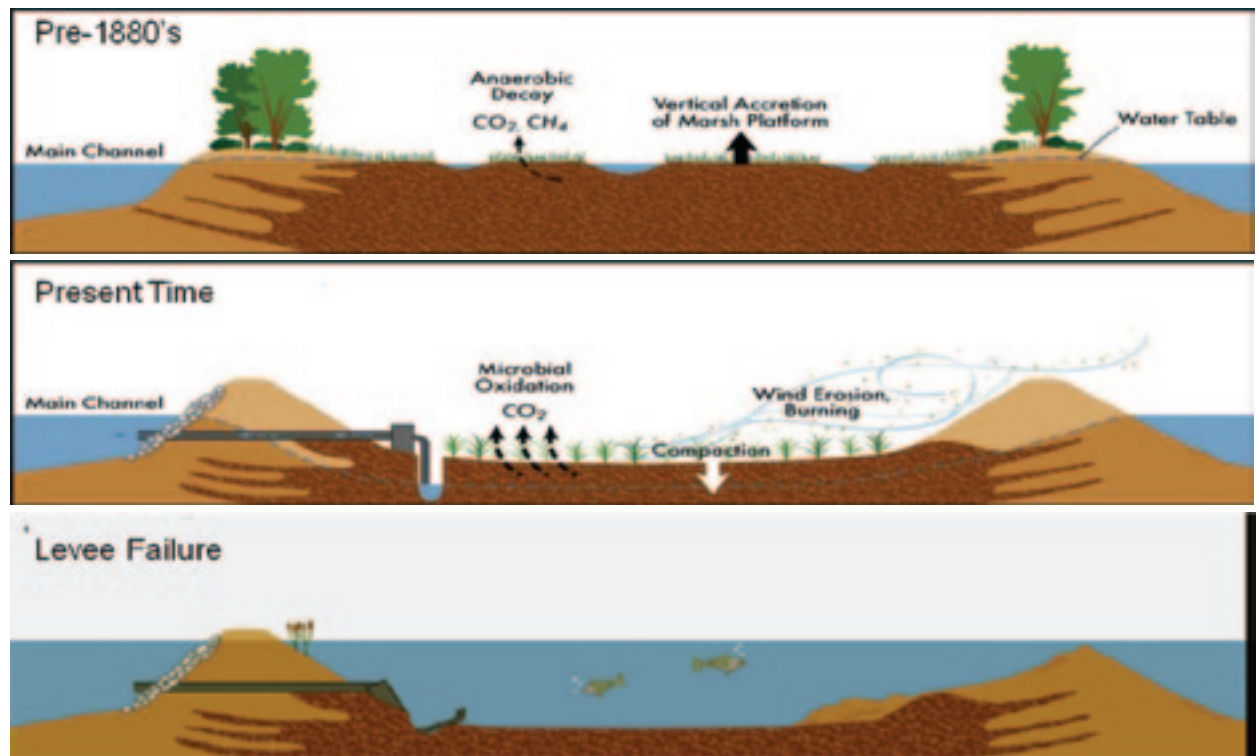
4.3 Some available illustrations (map of delta, typical sites, etc.)



Golden Gate Bridge



California



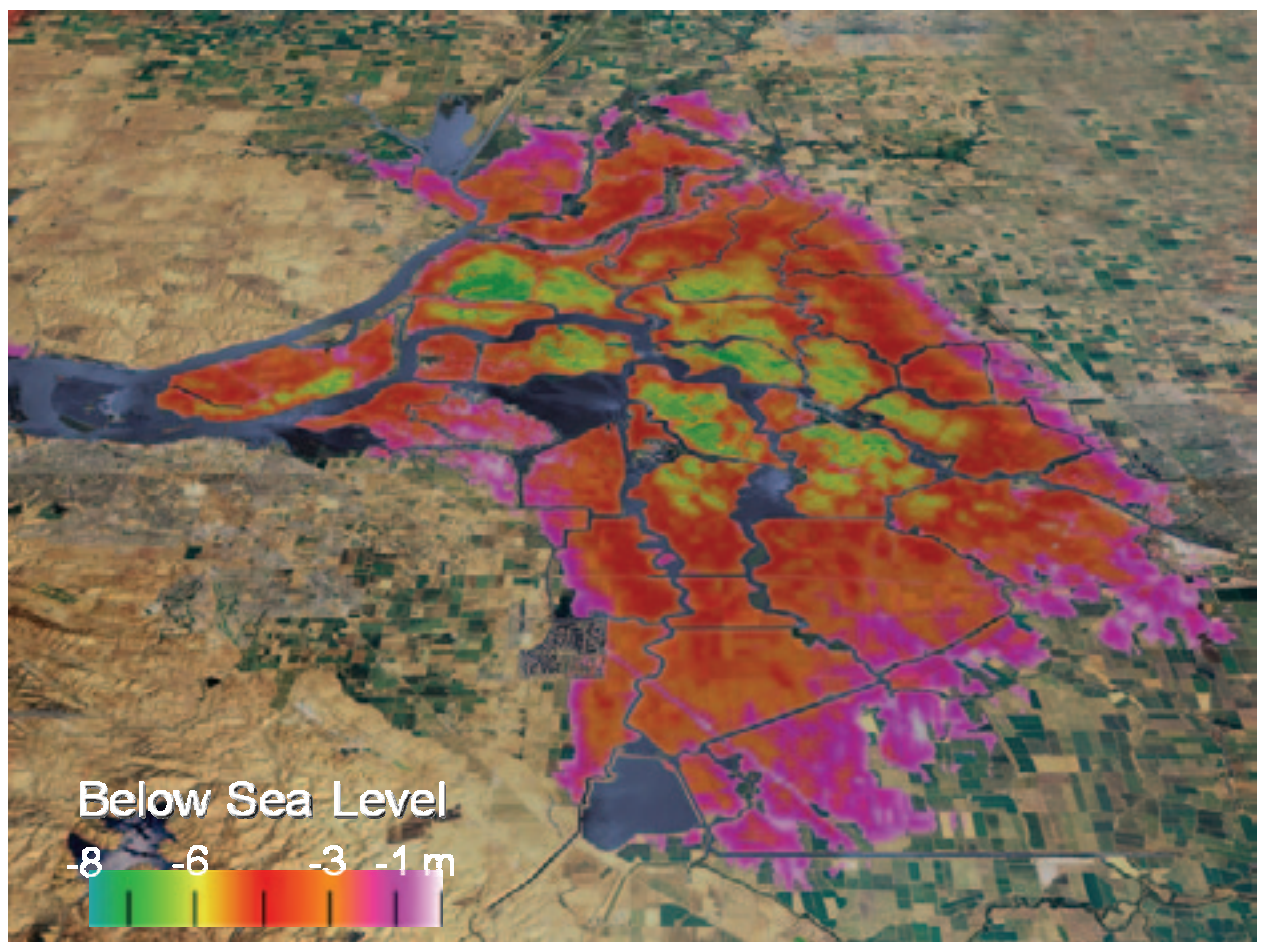
Delta Islands



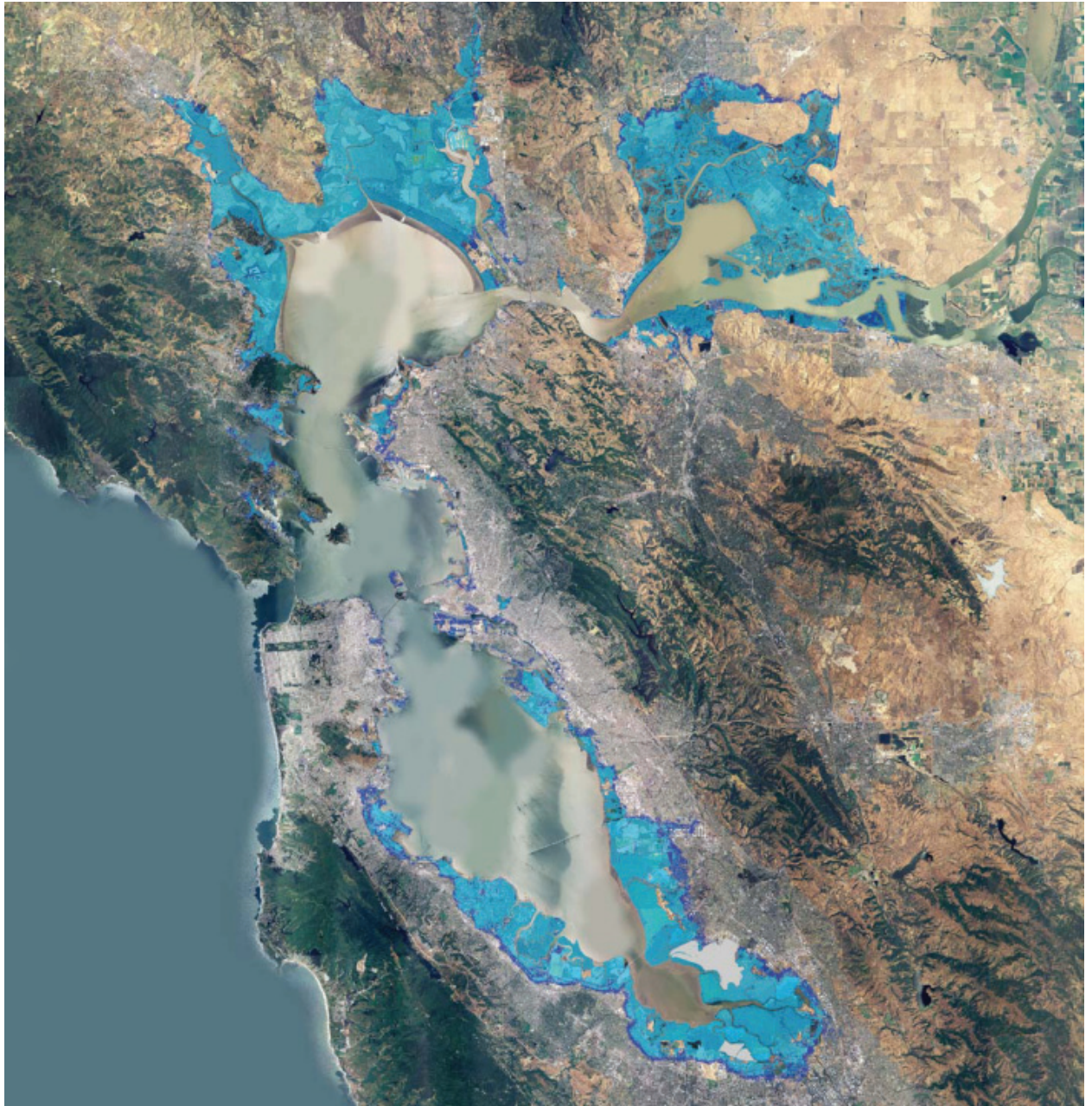
Levee Failure



Major fault lines in the San Francisco Bay Area



Subsidence in the Sacramento-San Joaquin Delta



Sea level rise in California Bay-Delta

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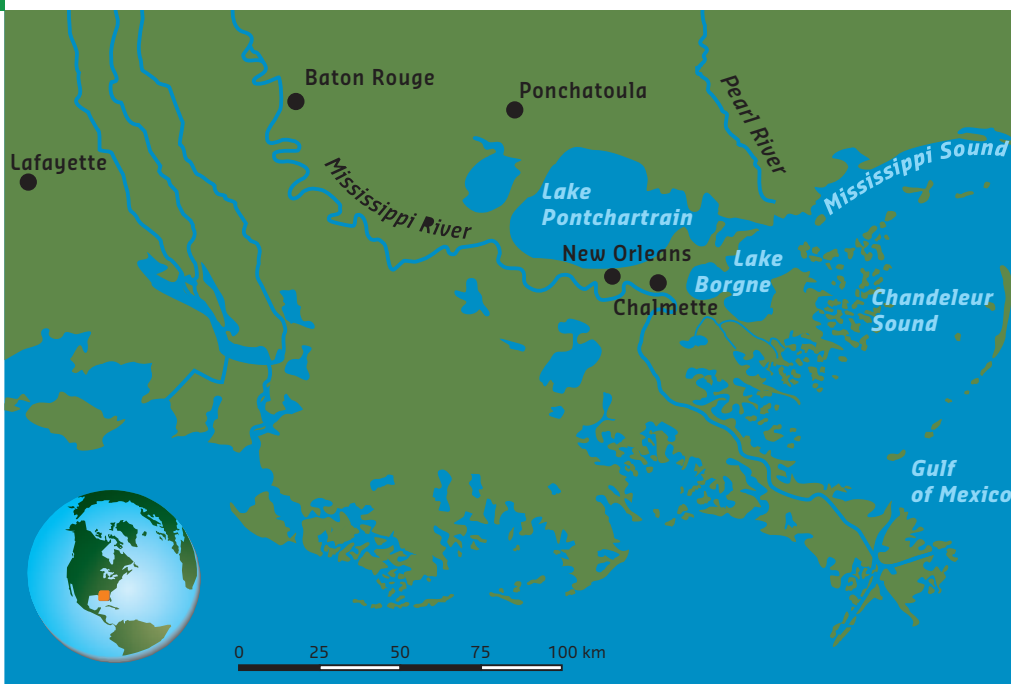
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Mississippi River delta

No



10



1. Current and future state of the Mississippi River delta¹⁴

1.1 Drivers of change

Summary of drivers of change

Description and demographic trends: The Mississippi River delta region, located in south-eastern Louisiana, USA, consists of alluvium deposited by the Mississippi River over the course of seven thousand years.

A product of fluidity and dynamism, the Mississippi River delta resists clear cartographic delineation as a geographical feature. Some argue that the delta starts at the Old River Control Structure (where bifurcation first occurs, near Simmesport, Louisiana); others use the term “delta” to refer to the entire lower Mississippi River floodplain, which is of course actually a valley. There is also subjectivity in separating the “deltaic plain” from the “Chenier Plain”—that is, the coastal lands of south-western Louisiana formed as river deposits were swept westward by longshore currents—as well as in separating the river’s “delta” from its “estuary,” the fresh-and-salt-water mixing zone and the outlying barrier islands.

This study views the Mississippi River delta as lying southward of a line between Lafayette and Baton Rouge, which aligns with the historic coastline and marks where the terraces and bluffs forming the southern-most walls of the alluvial valley peter out. Stretching southeastwardly from this line to the present-day mouth of the Mississippi lies the heart of the Mississippi deltaic plain.

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

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

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

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

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

¹⁴ not be confused with the **Mississippi Delta**, a region located in the state of Mississippi

twentieth century.

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

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

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

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

(<https://www.cct.lsu.edu/site40.php>)

Research gaps

More research needs to be done on investigating new concepts of flexible infrastructure that is capable of responding to the dynamic conditions of the delta. Research efforts to create various forms of "soft infrastructure" in the delta need to be encouraged. For instance, the idea that wetlands are a type of "living infrastructure" that is more effective than traditional forms of "hard infrastructure" in protecting against storm surge is relatively new. Initiatives to promote living infrastructure projects so far have been piecemeal.

More research needs to be done on the effects of Hurricane Katrina on the delta's population. The catastrophe created a diaspora of the region's population, forcing delta citizens to relocate to other locations in the country. In the five years following the disaster, many citizens have moved back to the delta, but thousands are still in exile.

More research needs to be done on sediment-related infrastructure. While it is widely agreed that sediment is fundamental to wetlands restoration and long-term delta sustainability, there is little consensus on a cost-effective way to move the right sediments in the needed quantities to their target destinations. Transportation options range from siphoning to barging.

Comprehensive database on infrastructure, climate, natural resources and socio-economic conditions is necessary to support various research and development initiatives.

1.1.1 Socio-economics (population growth- migration, economic development + most relevant sectoral developments, e.g. for agriculture, fisheries, industry)

Population

The Mississippi Delta Region as defined above is home to roughly 1.5 million people, of whom two-thirds live in metro New Orleans and about one-quarter live in New Orleans proper. Other significant population clusters on the delta (small cities) include Houma, Thibodaux, Raceland, and Morgan City, followed by numerous small towns and unincorporated communities. The vast majority of the delta's population lives on the topographic ridges (natural levees) formed over 5000-7000 years wherever the Mississippi River and/or its distributaries flowed and thus deposited the largest quantities of the coarsest sediments.

The delta's population is famously diverse, and has been since colonial times (1700s). People of Native American, French, African, Caribbean, Spanish (namely Isleno, or Canary Islanders), German, Slavic, Irish, Italian, Acadian ("Cajuns"), Vietnamese, Chinese,

Honduran, Cuban, and Mexican ancestry call the delta home today. Many residents can trace local lineages here to over two centuries.

Economic development

Apart from traditional fishing and farming enterprises, economic activities in the delta include navigation, activities related to the oil and gas industry, and petrochemical processing. Recreation and tourism are quite significant for the local economy. Following Katrina, the leisure tourism economy slumped and the business tourism (convention) trade particularly suffered; both have since stabilized but remain below pre-Katrina, pre-Recession levels. Government programs and private philanthropic organization have, in many ways, contributed to the Delta economy. Similar to Hurricane Katrina, in the wake of the BP Deepwater Horizon Oil Disaster, more programs and philanthropic organization have emerged and play a (temporary) role in subsidizing local economies. It should be noted that Louisiana is a net importer of federal dollars; it receives far more tax dollars from Washington than it sends.

Agriculture

For over two centuries, agriculture has been a mainstay of the delta economy. Sugar cane and rice were introduced to the region by European settlers from the Caribbean in the 18th century. Early agriculture also included limited tobacco production and indigo. Agriculture expanded into labor-intensive plantation systems when thousands of captured Africans were transported as slaves from West Africa. Many entered the Mississippi Delta through the slave market at New Orleans. Thus, in the early 19th century, sugar became the Delta's premier crop. Cotton, grown primarily in the alluvial valley north of Baton Rouge, was shipped through the delta for transshipping at New Orleans, but was generally not grown on deltaic soils. Mechanization starting in the 1930s altered agricultural economics. During the late 20th century, lower delta agriculture was predominantly run by families and non-resident corporate entities that held large landholdings. Their operations are heavily mechanized with low labor costs. Such farm entities are capital-intensive, where hundreds and thousands of acres are used to produce market-driven crops such as sugar, rice, and soybeans.

Fisheries

The Mississippi River supports one of the most diverse fisheries in the world. At least 183 species of freshwater fish live in the delta. Marine and estuarine fisheries in the delta, including a substantial share of shellfish (oysters, mussels, clams, etc.) are in excess of one million tonnes per year. However; native fish stocks have been declining in number. Approximately 6% of the native fish species in the delta are found on the endangered, threatened, or special concern lists of the U.S. Fish and Wildlife Service. Aquaculture (fish farming) is growing in importance with the main species of farmed fish being catfish. Crawfish and shrimp are also important to the Delta economy. In the wake of the BP Deepwater Horizon Oil Disaster it is difficult to assess the extent of devastation it has caused to the fisheries of the coast and its long-term impact.

Industry

The hardwood timber industry used to be an important segment of the lower delta economy until the mid-20th century.

The petroleum industry developed in the South as early as 1902. In 1946 the first offshore drilling rig was brought to the delta. Offshore oil drilling proved so successful that it began supplanting the more traditional economic pursuits of fishing and farming. Onshore oil and gas exploration today has come to a virtually complete stop in the delta.

The petrochemical industry came to the delta region during the 1930s, as refineries sprang up along the Mississippi River. The petrochemical industry has significantly changed the Lower Mississippi Delta region. In addition to bringing many external corporations to the region, the petrochemical industry spurred the growth of local infrastructure to support its production, research, and development activities.

In recent years, due to the growth of the automobile industry in the South, many parts suppliers have opened facilities in the delta. Moreover, the 1990s legalization of casino

gambling in Mississippi has boosted the delta's economy, particularly in the areas of Tunica and Vicksburg.

1.1.2 Climate change (temperature/evaporation, sea level rise, precipitation/discharge)

The climate in the delta is subtropical; freezing conditions occur occasionally, but rarely near the coast. The major climatic events are hurricanes that strike the region frequently, and floods derived from upstream runoff. During winter, the mean monthly temperature in the delta is 13C ; the mean monthly temperature in summer is 28C. The annual precipitation in the delta amounts to some 1,500 mm.

1.1.3 Subsidence (natural or human-induced)

Subsidence rates, which vary greatly both temporally and spatially, range around 0.5 to 1 mm or more per year in some areas, but can approach 10 mm in some areas when measured relative to the rising sea.

The rate of loss of land elevation (sinking rate) in New Orleans has varied generally within the range of 0.16 to 0.6 inches per year" (Shinkle, 2004). Extensive areas of artificially-drained New Orleans have sunk by two to three meters in well under a century, which equates to about three centimeters per year. Rates are much lower, but still alarmingly high, in non-urbanized areas.

According to USGS reports, a major cause of subsidence is the extraction of gas and oil. A recent report stated "The Gulf Coast Basin is a region where subsidence and fault activation are common around large, mature oil and gas fields even though moderately deep hydrocarbon production has generally been disregarded as the primary cause." (USGS, Subsidence and Fault Activation Project, 2010).

Other reports indicate that "Subsidence and wetland loss in coastal Louisiana continue to create concerns for government officials because their inferred causes influence plans for coastal restoration and hazard mitigation. Recent studies by the USGS show that in the Mississippi delta plain, subsidence and wetland loss correlate both temporally and spatially with long-term, large-volume production of oil, gas, and associated formation water." (Robert A. Morton et al, 2010)

1.1.4 Technological developments (e.g. regarding civil engineering, agriculture, ICT, energy)

As part of an effort to foster renewable energies and promote local economies, the shift from industrial agriculture to "urban agriculture" offers new opportunities. Local companies specializing in renewable energy related to solar photovoltaics, solar thermal, biomass, geothermal and other forms or alternative energy are slowly beginning to emerge in the Gulf Coast region. Like Florida, Louisiana and Mississippi could be leaders in the effort to produce energy from crops and timber because of their vast amount of farm acreage and its mild climate, which permits crops to be grown virtually year round. For example, the Farm to Fuel® initiative, which began in 2006, was created to "enhance the market for and promote the production and distribution of renewable energy from Florida-grown crops, agricultural wastes and residues, and other biomass and to enhance the value of agriculture products or expand agribusiness in the State."

1.2 Pressures – impacts

1.2.1 Land and water use (occupation layer)

Summary of pressures

pressure on space: The population is not very dense, less than 100 inhabitants/km².

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

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

Research gaps

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

Pressure on available space

The accessible area of the Mississippi Delta is some 15.000 km². With about a million inhabitants, the population is not very dense, less than 100 inhabitants/km². About 50% of the population lives in New Orleans.

The Mississippi Delta is situated in a hurricane sensitive area. In 2005, hurricane Katrina caused flooding and devastation of an extensive area, including New Orleans. In 2008, hundreds of thousands of people have still not returned. Restoration of damaged infrastructure and housing is still an important issue in the Mississippi Delta. The main issue connected to resettlement of the city is the improvement of the reliability of flood protection.

Hydrology

The name Mississippi literally means big water (misi, “big”; sipi, “water”). Although the Mississippi can be ranked as the fourth longest river in the world, in terms of discharge, the Mississippi’s rate of 17,000 m³/s is the eighth largest in the world.

In its headwaters, the Mississippi is a clear, fresh stream. Downstream of the confluence with the Missouri River near St. Louis the river becomes a turbulent, cloudy-to-muddy river. Beyond the confluence with the Ohio the lower Mississippi attains its full magnitude. The Ohio being the larger branch, below the Ohio confluence the Mississippi swells to more than twice the size it is above. Often a mile and a half from bank to bank, the lower Mississippi quietly descends towards the Gulf of Mexico.

That all of coastal Louisiana, including New Orleans, protrudes so broadly beyond the ancient continental coastline attests to the magnitude of the Mississippi River. Most rivers do not form deltas at all (either for lack of water volume or sediment load), but rather admixtures of fresh and salt water—estuaries—as they discharge into the sea. Two-thirds of the world’s thirty-two most populous cities abut estuaries, including New York City on the Hudson. Larger sediment-bearing rivers that do form deltas are still usually at the mercy of wave or tidal action in influencing the shape and size of their alluvial deposits. These formations protrude modestly from the coastline, usually in the triangular form of the Greek letter Δ (hence the term). Others blend in smoothly with adjacent coasts. A number of great cities adjoin or occupy these types of deltas, which are termed “wave-” and “tide-dominated deltas.” *River-dominated deltas*, on the other hand, occur in those rare circumstances when rivers bear enough water and sediment to overpower the dynamics of the receiving lake or sea, enabling the channel to meander, jump, send off distributaries, and build land faster than waves or

tides can sweep it away. The resultant formations jut out dramatically into the receiving water body, often with multiple lobes spanning a broad area. River-dominated (or fluvial) deltas are more common in lakes than in seas, because few of the world's rivers are large enough to overpower coastal currents. The Mississippi Delta ranks as one of the best examples of exactly that: a river-dominated multi-lobe delta protruding into a sea. New Orleans represents one of the very few metropolises to occupy such a dynamic young feature (Campanella, 2010, excerpted with permission).

Hurricanes are a way of life in the Mississippi delta. The hurricane season of 2005 was the most devastating in recent times, when Hurricane Katrina struck New Orleans and Hurricane Rita made landfall in western Louisiana / Texas. Some 260 km² of marshes were converted into open water, as a consequence of erosion during these storm surges. In addition, large parts of New Orleans were flooded. These events triggered intensive improvements to the flood protection system of the delta.

Agriculture

Agriculture in the Mississippi Delta is concentrated in large scale, heavily mechanized enterprises. The farms are capital-intensive, producing market-driven crops such as cotton, sugar, rice, and soybeans. Most of the agricultural area is well protected against floods and pumps are used to drain the excess water. Agriculture relates to two issues in the Mississippi Delta: water quality deterioration due to the drainage of nutrients and the conversion of wetlands into dry land.

The Delta region, because of its rich alluvial soil and its sub-tropical climate, is operating below its full potential as a major continental hub for agricultural activity. Specifically, urban agriculture is an area where the Delta has a lot of future potential.

1.2.2 Infrastructure (network layer)

Summary of pressures

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

The focus on the river's function for navigation has contributed to the accelerating degradation of the delta's environments.

While some flood protection and navigation infrastructure should be reinforced, in some areas infrastructure needs to be removed or modified in order to allow the restoration of natural hydrologies.

Research gaps

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

Infrastructure (general)

Road infrastructure in the Mississippi Delta is concentrated near the city of New Orleans. Downriver from New Orleans, the Road Network is not very well developed as it mainly serves local transport.

The US has long utilized the Mississippi river system as a major transportation corridor for shipping goods to international markets, as well as supplying goods to the interior of the country. Early infrastructure development thus primarily aimed at navigation and flood control. From 1870, when the US Army corps of Engineers in support of navigation and improved flood control began leveeing and jettying the river to increase flow velocity and prevent flooding, the geomorphology of the delta is influenced by human interference. The large river Mississippi River flood of 1927 triggered the construction of the Mississippi River levee system. Flood protection, mostly aimed at dealing with river floods but also aimed at providing protection against hurricane surges, nowadays determines the hydrodynamics of the delta. Almost a third of the delta has now been protected through the construction of various types of impoundments. These are areas which are completely or partly surrounded by levees, with water levels controlled to some extent. In these protected areas flooding and the flood related deposition of sediments has reduced. In a substantial part of the city of New Orleans, pumps completely remove water and the area is converted to dry land.

In 1965, the 120 km long man-made Mississippi River Gulf Outlet (MRGO) navigation canal was completed, connecting the Gulf of Mexico to the Port of New Orleans' Inner Harbor Navigation Canal (IHNC) in eastern New Orleans. The MRGO provides deep-draft, ocean-going vessels with access to the Port of New Orleans' IHNC wharves, but the use of this canal is not intensive and maintenance efforts are substantial. Because of its limited use, considerable maintenance effort, but also the increased transport of salt water to the New Orleans area, MRGO will most likely be abandoned in the near future.

1.2.3 Natural resources (base layer)**Summary of pressures**

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

loss of biodiversity: The main issue in the Mississippi River delta is the conservation of some 5,000 km² wetlands, which comprise 65% of the Gulf of Mexico's coastal wetlands. However, wetlands are disappearing at an alarming rate since decades, caused by a number of factors (see coastal erosion). The main issue related to water quality in the Mississippi River delta is eutrophication.

Research gaps

More interdisciplinary research needs to be done into the loss of biodiversity and the relationship between lack of sediment and land subsidence.

Efforts to establish forms of "ecotourism" in the delta are slowly increasing. Currently there is an untapped potential in ecotourism to become an economic driver in the delta region and to help restore the biodiversity of the region.

Water quality

The main issue related to water quality in the Mississippi Delta is eutrophication. The sources of nutrients, causing eutrophication of the water bodies and waterways in the delta, are: inadequately treated sewage and agricultural and urban runoff. Reduction of the wetland area has aggravated the problem.

Another water quality problem which has received widespread attention is the seasonally severe and persistent oxygen depletion of the bottom waters of the Northern Gulf of Mexico south of Louisiana. The oxygen depletion (hypoxia) is linked to the nutrient flux discharged by the Mississippi.

The eutrophication and lack of oxygen has created a "Dead Zone" the size of the state of New Jersey in the Gulf of Mexico.

Nature

With some 5,000 km² of wetlands, the Mississippi Delta constitutes an important natural resource. The potential rates of marsh production in the Mississippi Delta are the highest in North America. Freshwater input maintains a salinity gradient from fresh to saline that creates estuarine conditions and supports a high diversity of wetland and aquatic habitats which are optimal for estuarine species.

In the 1990s hunting developed as a new economic activity in the lower Mississippi Delta. Hunting in the delta is primarily for game such as whitetail deer, wild turkey, and waterfowl, along with many small game species. For many years the hunting and fishing have also attracted visitors in the regional tourism economy.

Along these lines, ecotourism is beginning to play a role in local economies, but its full potential is far from reached.

Wetlands, Shore protection / Coastal erosion management

The main issue in the Mississippi Delta is the conservation of wetlands, which comprise 65% of the Gulf of Mexico's coastal wetlands. 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 km² of coastal wetland has been converted to open water. A number of factors have been linked to 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.

Consequently, all of these factors have denied a process crucial for the formation and maintenance of barrier islands. Barrier islands are an end result of a complex process: the disappearance of the barrier islands is a result of the interventions that have severed the river from its landscape.

Reversing coastal erosion in the delta entails opening up the Mississippi River levees through diversions and crevasses to the greatest extent possible, while minimizing the disruptive effect the flowing water would have on inhabited areas, transportation infrastructure, fisheries (particularly oyster harvesting), and legal rights on land owners. Even if all these obstacles were overcome, new evidence indicates that there is simply not enough sediment in the Mississippi River to overcome expected rises in sea level. A 2009 *Nature Geoscience* article reported that, even if now-diminished sediment loads are restored, Mississippi River would lack sufficient sediment supply to counter predicted one-meter rise in sea level during the twenty-first century. "We conclude that significant drowning [of the Mississippi Delta] is inevitable...because sea level is now rising at least three times faster than during delta-plain construction.... Every decade of delay [of massive coastal restoration] will increase the mass balance deficiency by more than a billion tons of sediment.... [We must] restore the delta region to a desired level of sustainability, or plan an inevitable retreat" (Blum and Roberts, 2009).

1.3 Governance (institutional/organizational aspects of delta management)

Summary of governance issues

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

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

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

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

Research gaps

The 1990 Act was a big step, but more cooperation between Federal, State, and local agencies needs to occur soon if the delta wants to keep alive, or go further and revive, its wetlands.

More research needs to be done into the productive potential of private/public initiatives. A historical example of a successful private/public partnership is Eads's jetties in the late 19th century.

In the efforts to restore historical hydrological patterns in the delta, there is a growing debate about whether the government should exercise "imminent domain" to acquire private lands that could be used either as sites of infrastructure or as stewardship areas.

The governance of activities in the Mississippi Delta is carried out by a combination of Federal, State and local agencies. The US Army corps of Engineers is the federal agency charged with the primary responsibility for managing the Mississippi River for the national interest associated with navigation and flood control. The Corps also has permit authority over all activities which have an impact on coastal waters and wetlands, which it exercises in conjunction with the state of Louisiana.

A relatively new addition to the federal governance arrangement is the coastal Wetlands Planning, Protection and Restoration Act of 1990 which created a task force of 5 federal agencies and the state of Louisiana to develop a “comprehensive approach to restore and prevent the loss of coastal wetlands in Louisiana”.

A complicating problem of wetland management in the Mississippi Delta is land ownership. A mosaic of private and public properties that rarely coincide with natural drainage basins characterises land ownership patterns. Thus management plans are most often formulated for management units instead of natural landscape units such as drainage basins.

Present federal policy focuses on the River's function for navigation. This focus on navigation has contributed to the accelerating degradation of the delta's environments.

1.4 Main indicators for drivers, pressures and governance

DRIVERS	Main indicators
Demographic trends	- Declining population of New Orleans - Post-Katrina diaspora
Economic developments	- Oil and gas industry - Unemployment rate - Coastal economy devastation following Katrina and BP Oil spill
Technological developments	- Levees along Mississippi River to maintain river navigation,
Climate change	- Greenhouse gases - Global warming - Change in sea level
Subsidence	- Subsidence rate is greatest in areas cut off from river water and sediment
PRESSURES/IMPACTS	Main indicators
Land and water use (occupation layer)	- River is constrained thereby denying areas fresh water, sediment and greater biodiversity
Network / infrastructure (network layer)	- River navigation and "flood protection" demands levees along Miss. River, which denies water and sediment to coastal areas
Natural resources (base layer)	- % area affected by salinity - Annual loss of land (km²/yr) - Biodiversity index - Fluvial sediment transport (Mton/yr)
GOVERNANCE	Main indicators
Multi-level and multi-sectoral cooperation	- Integrated Wetland Management Plan
Public-private partnerships	- Number of PPPs - Total budget of PPPs
Involvement of stakeholders and citizens	- No. of statewide agencies involved in Wetland restoration - No. of local and national agencies involved in planning and decision making - No. of major public consultations
Approaches for dealing with risks and uncertainties	- Climate Change adaptation strategies and projects - risk management and emergency strategies - hurricane evacuation plans

1.5 Score card

The scores in the score card are just qualitative and indicative, based on the summary tables descriptions for each item (above). Each item is scored on a 5-points scale, related to resilience and sustainability.

The following two development scenarios are recognized:

- Scenario1, moderate perspective 2050: medium economic growth (1,2 %, Regional Communities-scenario) and related medium technological developments, combined with medium climate change and sea level rise (to be determined by expert)
- Scenario2, extreme perspective 2050: high economic growth (1,7%, Transatlantic Market-scenario) and related high technological developments, combined with high climate change and sea level rise (to be determined by expert)

Table 2. Scorecard for delta assessment

Delta	Land and water use (occupation layer)	Infrastruc- ture (network layer)	Natural Resources (base layer)	Governance	Overall Resilience & Sustainability indicator
Current situation 2010	0	0	-	0	-
Scenario 1 moderate 2050	-	0	-	+	0
Scenario 2 extreme 2050	-	+	--	+	-

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

Clarification notes on the score card:

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

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

2. Overview of adaptive measures in the Mississippi River delta

Overview of possible adaptive measures (in the three layers) based on current practices and innovative technological developments. The measures are classified in types of measures (technical, ecological, economic and institutional/organizational), related strategy (protect, adapt, relocate) and involved layer (occupation layer, network layer, base layer).

Name of measure	Type of measure	Brief description	Strategy	Layer
	1. Technical 2. Ecological 3. Economic 4. Institutional		1. Protect 2. Adapt 3. Relocate	1. Occup. 2. Network 3. Base
Promote awareness of main causes of wetland devastation and solutions	2, 4	Citizens and policy makers need to clearly understand the issues of land loss	1, 2	2,3
Dealing with increased salinity	1, 2	Develop plans for addressing changes in salinity in the region	1, 2,3	1, 2, 3
Improve agriculture and promote aquaculture in the region	1, 2, 3	Develop initiatives to increase the diversity of agriculture in the region	1, 2	1, 2, 3

3. Overview of technical methods and tools to support delta management and development in the Mississippi Delta

Overview of methods and tools for assessments, planning and decision making on delta management and development issues:.

Name of tool	Brief description	Institute	Available at
HEC-RAS model	The Hydrologic Engineering Center (HEC) has developed various computer software for hydrologic engineering and planning analysis procedures.	US Army Corps of Engineers	http://www.hec.usace.army.mil/software/
Modeling sedimentation	Sedimentation Models	various	http://serc.carleton.edu/NAGTWorkshops/sedimentary/visualizations/sedmod.html
Modeling river delta formation	Delta Evolution Models	National Center for Earth Surface Dynamics (NCED)	

The current paradigm has the Army Corps of Engineers at the center of all decision making in the Delta. However, with the development of a new coastal master plan for Louisiana, it may be more effective, in the future, if local agencies partner with state- and federal-level agencies to negotiate, develop and manage various projects for the region.

4. Knowledge exchange and development

4.1 Lessons learned on delta management

- **Deltas need fresh water and sediment**

Deltas are flood plains; they are existentially tied to occasional inundations. Riverine injections of fresh water and sediment counteract the soil compaction and wave action that naturally reduce alluvial deposits. Building deltaic cities in a manner that accommodates seasonal flooding—by primarily urbanizing higher natural levees, by leaving low-lying swamps and marshes undeveloped to store water, and by strategically “perforating” riverfront levees—balances urban requirements with deltaic processes. “Perforating” riverfront levees means diverting the river’s fresh water and sediment (suspended load as well as bedload) out of the channel and onto adjacent wetlands, via controlled diversions, sediment siphons, and uncontrolled crevasses. Sediment dredged from navigation-impeding shoals (which develop wherever the river is diverted) should be siphoned into wetlands, not merely mobilized in the water column and dumped uselessly into the sea. Sediment may also be excavated from the bottom of nearby bays and pumped onto wetlands (“dedicated dredging”), to speed the land-creation process (Campanella, 2010; excerpted with permission).

- **Strengthen existing levees, but avoid building new ones**

Deltas are products of fluidity and dynamism. Humans resist such geological volatility, and seek to tame it by imposing rigidity, constraint, and order upon it. Levees are the premier tool of anthropogenic control of unruly alluvial environments, and, when built sturdily, succeed in reducing the nuisance of springtime floods. But they inevitably trigger sinkage of the soils behind them, particularly when accompanied by municipal drainage. They also eliminate fresh water and sediment inputs to the backswamp and marshes, compromising their ecological and geological health. *Existing* levees that protect populated areas, of course, must be maintained, strengthened, heightened, and regularly inspected, but *new* levees across open marsh are usually ill-advised, as they will further strangle coastal processes and continue to lure people into harm’s way (Campanella, 2010; excerpted with permission).

- **Soft edges can protect better than hard edges**

New Orleans’ nineteenth-century floods inundated only about one-tenth the population, damaged a small percentage of homes, destroyed even fewer, and hardly killed anyone. In fact, some floods even saved lives, by flushing out stagnant mosquito-breeding dumps. What made New Orleans resilient to those historical floods was the fact that the city’s rear flank petered out softly into the backswamp; most floodwaters accumulated harmlessly in vacant lowlands while higher urbanized areas generally remained dry. It was not until humans built levees, drained, and populated those lowlands that flooding became problematic there. Deltaic urbanism is safer when the “soft” protections of natural topography and marshy buffers are exploited to the maximum, and the “hard” protection of levees, floodwalls, gates, and barriers are deployed only when necessary (Campanella, 2010; excerpted with permission).

- **Levee Construction Lessons**

Breaches during Hurricane Katrina revealed certain truisms about levee construction. The best levees are built of pure, cohesive clays with a minimum of organic matter and a minimum of coarse soil particles such as sand. Levee elevations must be periodically raised to account for local subsidence and sea level rise. If floodwalls are built atop or in lieu of earthen levees, their steel sheet piling should penetrate the earth in the form of a stable “T-wall,” rather than the unstable “I-walls” (lacking lateral support) that Katrina’s surges pushed over. Sheet piling should penetrate deeply, beyond the porous layers of peat and sand that allow seepage to pass. Floodwalls should also have concrete aprons on their dry sides, to prevent undermining if and when overtopping occurs. Short-sheeting, excessive organic matter, inconsistent soil texture, insufficient height, inadequate lateral support, and unprotected shoulders were the immediate causes of most Katrina levee failures. Centuries of environmental manipulation and deltaic deterioration were the ultimate cause (Campanella, 2010; excerpted with permission).

- **Healthy deltas need healthy valleys**

Water quality, volume, sediment load, biota, and other inputs arrive at a delta from across hundreds of thousands of square miles, regardless of jurisdictional lines. Integrated management among the various basins, agencies, states, and nations comprising a watershed is necessary to maintain the health of deltas. The New Orleans region bears a disproportionate share of the burden of basin-wide environmental impacts, including dam and lock construction on sediment-bearing tributaries (diminishing sediment supply in the river), fertilizer and urban runoff (causing the hypoxic “dead zone” in the Gulf of Mexico), pollutants in the river (affecting drinking water supplies), and invasive species such as zebra mussel and Asian carp (Campanella, 2010; excerpted with permission).

- **Municipal drainage comes at a cost**

Draining the swamps around New Orleans helped solve the age-old problem of vector-borne disease. It also created a new problem. Water being a major component of deltaic soils, drainage caused the soil body to shrink and collapse, sending half the metropolis below sea level. Finding an aesthetic way to integrate runoff into the cityscape (through canals, as the Dutch do), or to store it in specially designed areas that double as parks when dry, restores the hydric component to the soil body and reduces subsidence rates. Storing water on the cityscape also reduces pump capacity requirements, and minimizes the need to activate the pumps after every rainfall (Campanella, 2010; excerpted with permission).

- **Pumping stations should be optimally sited**

Pumping stations—which remove runoff in urbanized deltas via outfall canals into adjacent water bodies—should be located at the mouths of said canals, not at their headwaters. In this manner, runoff is “pulled” from throughout the city via low, below-grade outfall canals and raised at the very last moment. Such pumps can also double as canal gates, preventing outside water from intruding inland. This design eliminates the need for levees and floodwalls intruding through neighborhoods. New Orleans in the 1890s located its pumps in the middle of the area being drained, at the headwaters of the outfall canals, where they “pushed” runoff into Lake Pontchartrain. Decades of subsidence forced the pumps to push that runoff uphill by increasingly steeper inclines. This meant that the outfall canals had to flow above houses, requiring levees and floodwalls to contain them. It also meant that incoming storm surges penetrated the (ungated) outfall canals and dangerously raised water levels—until, finally, the point of floodwall collapse during Katrina. Most planners now agree that pumping stations should be relocated to the lakefront (as they are in Jefferson Parish and New Orleans East, which learned from New Orleans’ mistake). Such a relocation would allow canals to be redesigned to flow below grade, and beautified into urban amenities as they are in Amsterdam. Financial constraints, however, currently prevent this costly correction from being enacted. There is also a concern that below-grade canals would increase subsidence rates (Campanella, 2010; excerpted with permission).

- **Canals usually bear more costs than benefits**

Deltaic cities often begin as transshipping nodes and develop into ports of national or international importance. Competition forces ports to make docking at their wharves as fast, cheap, and efficient as possible, a pressure that often justifies the excavation of navigation canals. Throughout coastal Louisiana, oil and gas companies joined the shipping industry in scoring and scouring the deltaic plain with innumerable manmade waterways. Most seemed to make sense at the time, but their long-term costs may ultimately kill this place. Canals that have proven to be more detrimental than beneficial should be barricaded with rock barriers, pilings, gates, or other devices to prevent further salt-water intrusion, and if feasible, filled in with sediment (Campanella, 2010; excerpted with permission).

- **Deltaic sustainability entails grappling with dilemmas**

Whereas a problem typically ends with a solution, a dilemma usually ends with a choice—a difficult value judgment, which yields unpleasant consequences and unhappy stakeholders. Saving deteriorating deltas will mean that some human communities, despite their historical, cultural, and economic significance, will have to relocate to minimize future loss and allow aggressive coastal restoration to commence. Resistance will be passionate, and oftentimes imbued with social tensions and historical distrusts. But the geophysical realities of sea level

rise demand that we make mature decisions about where and how humans inhabit deltas—else they will be made for us (Campanella, 2010; excerpted with permission).

4.2 Summary of research gaps and related needs for knowledge exchange

Drivers of change

More research needs to be done on investigating new concepts of flexible infrastructure that is capable of responding to the dynamic conditions of the delta. Research efforts to create various forms of "soft infrastructure" in the Delta need to be encouraged. For instance, the idea that wetlands are a type of "living infrastructure" that is more effective than traditional forms of "hard infrastructure" in protecting against storm surge is relatively new. Initiatives to promote living infrastructure projects so far have been piecemeal.

More research needs to be done on the effects of Hurricane Katrina on the Delta's population. The catastrophe created a diaspora of the region's population, forcing Delta citizens to relocate to other locations in the country. In the five years following the disaster, many citizens have moved back to the Delta, but thousands are still in exile.

More research needs to be done on sediment-related infrastructure. While it is widely-agreed that sediment is an important ingredient in the vitality of the region, there is little consensus on what is the best way to move sediment to its target destination. Transportation options range from pumping it through pipes to moving it on barges.

Comprehensive database on infrastructure, climate, natural resources and socio-economic conditions is necessary to support various research and development initiatives.

Pressures – potential problems / Challenges - opportunities

- **Occupation layer**

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

- **Network layer**

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

- **Base layer**

More interdisciplinary research needs to be done into the loss of biodiversity and the relationship between lack of sediment and land subsidence.

Efforts to establish forms of “ecotourism” in the Delta are slowly increasing. Currently there is an untapped potential in ecotourism to become an economic driver in the Delta region and to help restore the biodiversity of the region.

- **Governance**

The 1990 Act was a big step, but more cooperation between Federal, State, and local agencies needs to occur soon if the Delta wants to keep alive, or go further and revive, its wetlands.

More research needs to be done into the productive potential of private/public initiatives. A historical example of a successful private/public partnership is Eads's jetties in the late 19th century.

In the efforts to restore historical hydrological patterns in the Delta, there is a growing debate about whether the government should exercise “imminent domain” to acquire private lands that could be used either as sites of infrastructure or as stewardship areas.

Adaptive measures

- **Adapting by Building Above the Grade**

A key adaptive measure in an urbanized delta is for structures, particularly residences, to be raised on pilings or piers. This tradition prevailed in New Orleans for over two hundred years, only to be abandoned after World War II in favor of cheap concrete slabs poured at grade level. Living at grade level places too much faith in flood-control and drainage infrastructure. Building above the grade empowers the individual to play a role in minimizing personal flood damage, should other systems fail (Campanella, 2010; excepted with permission).

- **Adapting by Diverting the River and Siphoning Sediment**

Diverting the Mississippi River out of its manmade straightjacket and allowing it to deposit its sediment-laden waters into adjacent coastal wetlands is widely viewed as fundamental to saving the Mississippi Delta. Crevasses—that is, uncontrolled diversions—are even better. But locks and dams on the western distributaries of the Mississippi River system have so radically reduced the quantity and quality of sediment reaching the delta that diversions and crevasses are no longer sufficient to restore coasts. Sediment must be actively mined from the bottom of the river, and possibly the continental shelf, and siphoned into the wetlands. Gravity alone will not solve this problem.

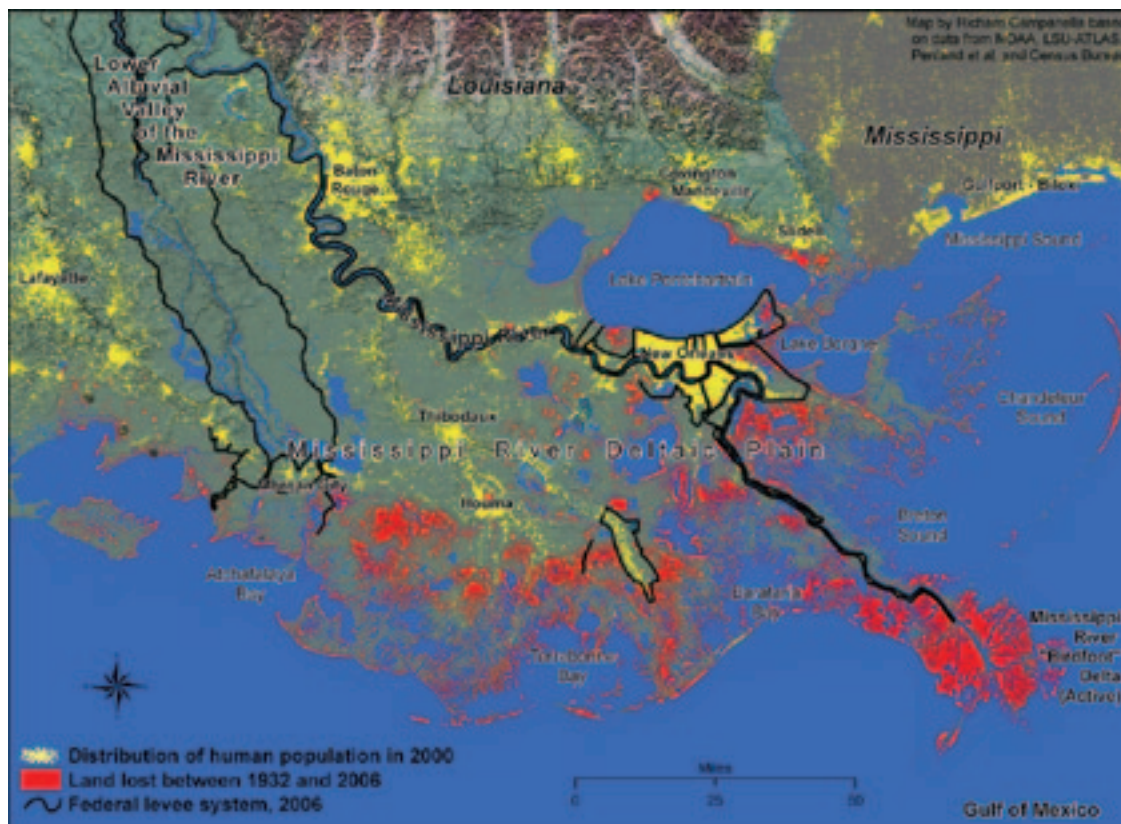
Unfortunately, legal issues complicate restoration efforts. Well over three-quarters of the Louisiana coastal region is in private hands. Leases of adjacent water bodies for fisheries and other resources further complicate the cadastral landscape. A single coastal restoration proposal thus affects numerous parties, livelihoods, and ways of life. Coping with this complexity requires legal mechanisms, compensation funds, mitigation plans, and other creative solutions (Campanella, 2010; excepted with permission).

Technical methods and tools

One valuable technical tool for delta management, particularly regarding soil subsidence and coastal erosion, is LIDAR (Light Detection and Ranging) technology. LIDAR sensors are flown from both satellite and aerial platforms, with the latter producing very high-resolution digital elevation models that measure topographic elevations to within centimeters. In 2000-2003, the Federal Emergency Management Agency and the State of Louisiana funded the capture of LIDAR data for the most flood-prone parishes of Louisiana, including the delta, to produce topographic maps with unprecedented accuracy. The sensor, mounted in an aircraft flying at 2600 meters altitude, emits 15,000-30,000 laser pulses per second aimed at the target site. The exact time and direction of each pulse are recorded as it leaves the sensor and as it returns after reflecting off surface features. Because the speed of light is constant, the system is able to compute the distance to and from the target, and because a Global Positioning System (GPS) is integrated with the sensor, exact geodetic coordinates are associated with

each pulse. From these raw data, analysts are later able to compute the precise longitude, latitude, and elevation of millions of points scattered irregularly upon the target area. Not just the earth's surface but buildings, cars, most vegetation, and other features are also captured, and must be removed through a post-processing algorithm to map the underlying topographic elevation. A continuous surface is then interpolated from the points, from which are extracted contours at intervals as detailed as 15 centimeters, or digital elevation models with five-meter-resolution pixels. The FEMA LIDAR maps represent the most detailed and comprehensive elevation mapping ever conducted in the delta region, and for the city of New Orleans (Campanella, 2006, excepted with permission).

4.3 Some available illustrations (map of delta, typical sites, etc.)



Map by Richard Campanella; used with permission.

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