Deltares

Enabling Delta Life

Towards sustainable development of deltas, estuaries and coastal zones

Trends and responses: executive summary

Note:

This Executive Summary basically describes the main findings as described in more detail in the main report of the research. However, for a few topics the scope of the Executive Summary is a bit wider than the main report, as the contents has been enriched with comments from members of the International Advisory Committee of Aquaterra.

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Trends and responses:

executive summary

January 21, 2009

Framework of delta research

This research is part of the preparation of the Aquaterra 2009 conference, the World Forum on Delta and Coastal Development. Deltas maybe defined as low-lying areas where a river flows into a sea or lake. A delta is often considered a different type of river mouth than an estuary, although the processes shaping deltas and estuaries are basically the same. In line with the scope of the Aquaterra conference we have adopted in this research a broad interpretation of deltas which includes deltas proper, estuaries and the adjacent coastal zone.

Deltas are areas with major economic potential as well as large environmental values. The challenge for sustainable development of deltas is to strike a balance between economic development and environmental stewardship. The Aquaterra Conference will present and discuss the state and future of deltas world wide, with a special focus on eight selected deltas. All these selected deltas are densely populated and/or economically developed.

1. Yellow River Delta (China)
2. Mekong River Delta (Vietnam)
3. Ganges–Brahmaputra Delta (Bangladesh)
4. Ciliwung River Delta (Indonesia)
5. Nile River Delta (Egypt)
6. Rhine River Delta (The Netherlands)
7. Mississippi River Delta (USA)
8. California Bay (USA)

Another focus of the Aquaterra Conference is the response in deltas to a number of drivers such as economic growth and climate change as well as to a number of trends in society such as privatization and decentralization. Four themes are being considered:

- Natural systems (management and restoration)
- Infrastructure (extension and revitalization)
- Land and water use (development and adaptation)
- Governance (of delta development)

The research has explored the perspectives of and experiences with these themes. Some of these responses may already be classified as 'best practices' (at least in the local context), others are yet promising approaches. Anyway, the research aims to provide an overview of current practices in dealing with delta issues.

An effort has been made to arrange these practices into trends. Trends which are illustrated with examples taken from deltas all over the world, with an emphasis on the eight selected deltas of the Aquaterra Conference and in particular the Rhine River Delta. The examples presented are not necessarily the best illustrations of the trends. Own experiences of the researchers as well as easy access to information have played a role in the selection of examples. However, taken together, the trends and examples provide a comprehensive overview of the type of current activities and developments to enable delta life.

The research may be viewed as a first step in the description and analysis of state and future of deltas worldwide. The focus of the research has been on the identification of issues, trends and responses. The outcome is still qualitative and descriptive.. It may be worthwhile to elaborate on the current research. Such elaboration may include a more rigorous assessment of the functioning of deltas based on a set of indicators. Also an extension to other deltas should be included. This might be a nice challenge for future Aquaterra Conferences.

Trends and issues in the development of deltas

Deltas: economic and environmental hot spots

The major river systems of the world all have a unique delta region, with their specific challenges and opportunities. But there are also common characteristics. Deltas are usually areas with major economic potential because of their strategic location close to seas and inland waterways. Deltas provide also some of the world's most fertile lands important for food production. That is why navigation and port development, oil production and refinery as well as agriculture and fisheries have always been the engines of economic development of deltas. Attracted by these potentials, large numbers of people live in deltas; a development which has led to the growth of coastal (mega-)cities.

Trends and issues in the development of deltas

Deltas have been formed by the sediments brought in by their respective river and shaped by the interplay of tides, waves and currents. At the seaside of a delta, these forces tend to erode and disperse the sediments. But as long as the net input of sediments exceeds the rate of erosion, the delta will grow. Such natural processes are crucial in the long term evolution of a delta. A net deficit in sediment supply, for example caused by construction of dams upstream, will lead to coastal erosion.

The rivers that flow through the deltas are an important source of fresh water and nutrients that are critical for sustaining life in the deltas. The mixing of salt and fresh water in the estuarine part of the deltas creates environmental conditions for a unique flora and fauna. Delta and estuarine ecosystems are therefore valuable and among the most productive ecosystems on earth.

But, being low-lying areas, deltas are also vulnerable to flooding and have to cope with stagnating drainage. That is why living in deltas has always required human intervention. Land reclamation, irrigation, soil drainage and embankments have made many deltas a safe place to live and work.

Opportunities of deltas	Challenges in deltas
• strategic location close to seas and water ways • high potential for port development and oil industry • fertile soils and rich aquatic environment • large potential for agriculture and fisheries • valuable and most productive ecosystems	• areas vulnerable to flooding and drought • human intervention needed to safely live and work • filter or sink for upstream pollution • areas with high pressure on available space

Melting-pot of drivers and trends

Population growth, economic development and climate change are the main drivers for change in deltas. These developments pose extensive demands on the available natural resources of deltas. In addition to these drivers there are a number of societal trends which affect the organization and outcome of planning of delta development.

Of these trends decentralization and privatization may be viewed as autonomous developments. The challenge is to utilize the advantages of both trends, while minimizing their undeniable drawbacks. This calls for a selective enhancement of governance structures, reflecting the regional scale, integrated nature and long term perspective of delta development.

Drivers for change	Trends in society
population growth: the global population still grows with some 2% per year, although there are distinct regional differences. The number of people to be served and to be protected against natural hazards will increase.	***decentralization:*** brings delta issues closer to the stakeholders involved. Due to lack of national coordination there is, however, a sincere risk of uncontrolled and/or chaotic developments.
economic development: despite the current economic recession, economic growth may be expected over larger periods of time, resulting in larger demands to be met, higher values to protect, more energy to be generated and more goods to be transported.	***privatization:*** public-private partnerships are becoming the modus operandi for new infrastructural projects and services. Increased efficiency of tax payer's money is a key motive. The risk of privatization, however, is a focus on the short term as well as a neglect of the public interest.
climate change: although the extent of climate change may be subject of debate, there is general consensus that rise of global temperature is inevitable, with its associated (local) impacts on sea level rise and the hydrological cycle (larger and more frequent droughts and floods)	***participation:*** involvement of stakeholders and citizens is important to promote societal support of development projects as well as maintenance of infrastructure; planning may benefit from the tacit knowledge of stakeholders
technological development: innovations may open opportunities to enhance the functionality of infrastructural solutions, to extend the life time of infrastructure and/or to develop more cost-effective designs	***environmental concerns:*** worldwide concern over a changing climate and environmental degradation has raised the environmental awareness; it influences the valuation of impacts and the choice of measures
	risk aversion: acceptance of risk is decreasing in our modern societies; hence considerable efforts are made to further reduce or control the risks of natural hazards

Overview of pressing delta issues

The characteristics, which make deltas attractive areas to live and work, are under stress. Available space is under pressure, vulnerability to flooding is increasing and fresh water resources are threatened. Population growth, economic development and climate change will cause additional stress on deltas, unless appropriate measures are taken.

Main issues at stake in deltas

Pressure on available space: being a focal point of economic development population density is generally high and further rising. Coastal mega-cities have developed; their size and number are growing.

Vulnerability to flooding and drought: being low-lying areas, deltas are vulnerable to flooding. Subsidence of soft soils adds to this vulnerability. Accumulation of people and wealth will further increase the vulnerability with respect to climate change.

Shortages of freshwater resources: many deltas in the world currently face water shortages. Climate change may result in more frequent and prolonged periods of low river discharges. This will have profound repercussions on the delta agriculture, as well as on delta and coastal ecosystems.

Ageing or inadequacy of infrastructure: many deltas have irrigation and drainage systems which require an upgrade or major revision to improve their effectiveness. Other deltas have inadequate flood protection schemes or schemes that will require major upgrading.

Erosion of coastal areas: many deltas face a sediment shortage. This sediment shortage is often caused by regulation works in the upstream river. The sediment shortage causes coastal erosion problems. Sea level rise will aggravate these erosion problems.

Loss of environmental quality: Ecosystem functioning and biodiversity in deltas is under very high pressure worldwide. Main causes are a high population density and concentration of industrial, harbor and mining activities. Deltas are also receptor of pollutants from upstream.

Summary of issues in the eight selected deltas

In the research a quick assessment has been made whether the delta issues are a minor or major problem in the eight selected deltas. The table displays to what extent issues play a role. The classification distinguishes four types of problems. Problems are judged minor if they are either unimportant, small in magnitude or well controlled (•). A minor problem can become bigger in future (e.g. due to climate change or delta developments) in which case it is given two bullets (••). An issue is classified as a currently big problem if the issue is requiring significant management attention and is not (yet) controlled (•••). If the problem is likely to increase in the near future it is given four bullets (••••).

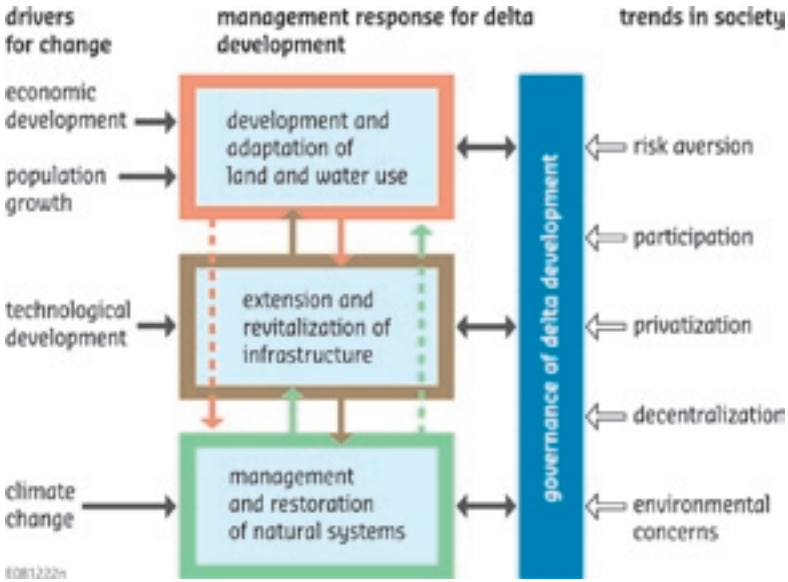
The outcome of this assessment is summarized here in a comprehensive table. The main report on trends and responses provides some short explanations for the assessments, whereas the delta descriptions provide further background on the issues at stake in the eight deltas. The assessment is certainly subjective and reflect *our* understanding of the issues at stake in the eight deltas. Within the short time span of the research we may have overlooked certain aspects; so individual assessments may need revision. The main purpose of the overview is, however, to show that there is a large variation between the eight deltas. For example vulnerability to flooding is a major issue in most deltas but not in all. The table also shows that some deltas have to deal with a range of major issues, whereas in other deltas most issues are minor or at least under control. A few revisions of individual assessments will not alter this overall picture.

deltas	issues					
	pressure on space	flood vulnerability	freshwater shortage	ageing or inadequate infrastructure	coastal erosion	loss of environmental quality and biodiversity
Yellow River Delta (China)	••	•	••	•	•••	•••
Mekong River Delta (Vietnam)	••	••••	••••	••	•	•••
Ganges–Brahmaputra Delta (Bangladesh)	••••	••••	••	••	••••	••••
Ciliwung River Delta (Indonesia)	••••	••••	••	••	•	••••
Nile River Delta (Egypt)	••••	•	••••	••••	••	••
Rhine River Delta (The Netherlands)	•••	••	••	•••	••	•
Mississippi River Delta (USA)	•	••••	•	••••	••••	••••
California Bay (USA)	••	••••	••••	•••	•	•••

Legend:
- • *relatively minor problem, now and in the near future*
- •• *currently a minor problem, but is likely to increase in the near future*
- ••• *currently already a big problem, future trend uncertain*
- •••• *currently already a big problem, likely to increase in the near future*

Linking measures with drivers and trends

To promote sustainable development of deltas a clear vision has to be developed on how to respond to the various drivers of change as well as on how to play along with the various trends in society. A strategy for sustainable development of deltas cannot be limited to infrastructural measures or restoration measures for natural systems only. A sensible combination of different kind of responses is required. This should include measures for management and restoration of natural systems, for development and adaptation of land and water use and for extension and revitalization of infrastructure. Furthermore enhancement of the governance structure is required to enable effective implementation of these responses. These are in fact the four major response themes distinguished in the Aquaterra 2009 Conference.



The research provides an overview of current practices in dealing with delta issues. An effort has been made to arrange these practices into trends, which are discussed for each of the four themes in the next sections

Natural systems: management and restoration

Functions and values of delta ecosystems

Deltas are relatively young landforms shaped by the interplay of coastal and riverine processes. These natural processes are crucial in the long term evolution of a delta. A net deficit in sediment supply will lead to coastal erosion. Besides sediments, the river also constantly supplies the delta with fresh water, nutrients and organic matter. Compared with the past five decades, both river discharge and sediment load will probably decrease for some large river systems with 30-40% in the next 50 years and up to 50% in the next 100 years as a result of human activities and dam construction.

The delta estuaries and its marine environs have the highest biological production of all natural areas in the world. Estuaries have also the highest economic value of all ecosystems. Nutrient recycling and food production contribute most to this high economic value. Coastal ecosystems can perform several functions simultaneously: a mangrove forest protects land from a storm surge, it provides a nursery area for fish and shrimp, it yields useful timber and serves as habitat for many species.

It is not surprising that these rich deltas attract migrating birds. Lying at strategic positions along flyways, delta nature sites are key stepping stones of millions of birds en route from north to south and vice versa. At this moment some 2,4 million hectares of delta wetlands have been given the official status of Ramsar Site, indicating that these wetlands are of international importance for the survival of many bird populations. In three instances, even the entire delta has been designated as official Ramsar site, viz. the Ebro, Danube and Volga delta.

Status and trends in delta values and functions

The most important direct drivers of change in ecosystems worldwide – and probably also for delta ecosystems – are habitat change, overexploitation, invasive alien species, pollution and climate change (in particular sea level rise). Habitats are converted to agricultural land or shrimp ponds and especially fish stocks are overexploited. Alien species and disease organisms continue to increase because of both deliberate introductions and accidental translocations through commercial shipping. With respect to pollution, particularly the high nutrient loading to regional seas is disturbing. Excessive flows of nitrogen and

phosphorous contribute to eutrophication of freshwater and coastal marine ecosystems. Indeed, compared to other types of ecosystems (such as forests, drylands and mountains), worldwide coastal ecosystems have been most impacted over the last century by all of these drivers, and current trends are increasing!

Loss of habitat can occur due to a variety of causes, but the majority of habitat loss in delta environments is the conversion of freshwater- and salt marshes into agricultural lands (e.g. through land reclamation) and – in the tropics – the conversion of mangroves into aquaculture. Worldwide decline in mangrove forest is estimated to be around 2% per year between 1980 and 1990 and 1% per year between 1990 and 2000. But also a more complex set of factors can lead to reductions in original delta habitats. For instance, the combination of subsidence, incidental hurricanes and the construction of levees and canals (for the oil exploration and navigation) has led to massive reduction in Louisiana's coastal wetlands.

Potential of wetland restoration

The good news is that delta ecosystems can be relatively easily restored. Because the delta environment is highly dynamic, delta nature has a remarkable adaptive and resilient capacity. In contrast to for instance tropical rainforests, which require centuries to reach a climax succession stage, delta ecosystems such as salt marshes, mangroves and dunes develop quickly into rich habitats once the environmental conditions are favorable. All over the world we see restoration ideas turning into reality. Of course not every initiative is an immediate success. The successful examples show the importance of:

- Good knowledge of the basic physical and ecological processes;
- Early involvement of local stakeholders leading to a participatory planning process;
- An integrated approach

Ensuring the integrity of downstream ecosystems

There are various ways to restore the integrity of ecosystems. This does not necessarily require a complete restructuring of the original situation, but can also lead to a rejuvenation or improvement of already modified ecosystems. A good example is the restoration of estuaries by reconnecting them with rivers and sea. Ensuring the integrity of the linkages between delta and river often requires measures upstream. Recently new insight has been gained with respect to the importance of freshwater inputs in coastal ecosystems.

Seasonal changes in river flow can temporarily change the 'normal' condition of an estuary. Usually the estuarine ecosystems and their species are adapted to this highly dynamic environment as long as these seasonal variations remain within the average natural dynamics. Upstream water diversions can permanently change this pattern with significant consequences for the estuarine ecosystem. Setting and maintaining an environmental flow requirement is being considered an important management measure to ensure the integrity of downstream ecosystems.

Room for rivers

Normalisation and canalisation have straightened and narrowed naturally meandering and braided river systems into a single channel system to support navigation. Embankments were raised to reduce flooding frequencies of the

adjacent lands. Over the past decades the adverse consequences of these river engineering measures became more apparent. Natural values have greatly declined and river beds have eroded. Narrowing of the floodplain gave rise to a rapid discharge of water and ice, increasing the risk of flooding. As climate change could result in higher peak discharges, river managers are confronted with the question to further heighten the dikes or explore other possibilities. The 'Room for Rivers' concept was born out of a belief that it is better to opt for a more resilient strategy than to go for resistance against the forces of nature. The Rooms for Rivers programme along the Rhine, giving back the areas of natural horizontal expansion during floods (i.e. wide floodplains and retention areas), is a showcase for this new philosophy and supports the paradigm shift from "fighting the floods" to "living with water".

Ecosystems approach to multiple use of wetlands

The use of the functions of coastal wetlands do not necessarily require special protection or denial of access. Using the ecosystem approach, wetlands can be used by the local people without compromising the integrity of these systems or overexploiting their natural resources. This approach is advocated by the Convention on Biological Diversity and denotes a strategy for the integrated management of land, water and living resources. The strategy promotes conservation and sustainable use in an equitable way. The approach focuses on levels of biological organization, which encompass the essential processes, functions and interactions among organisms and their environment. It recognizes that humans, with their cultural diversity, are an integral component of ecosystems. The world-renowned model for multiple use of wetlands, the East Calcutta Wetlands, is an example of this approach. Another example is the restoration of infertile, acid sulphate soils (a widespread problem in several tropical deltas and coasts) by replanting of the original vegetation, such as the Melaleuca trees in the Mekong Delta.

Infrastructure: extension and revitalization

Role of infrastructure in delta development

Living in deltas has always required human intervention. Infrastructure was developed to adapt the natural systems to create more favorable conditions for living and working. Demographic and economic developments will lead to a growth in the number of people and economic activities to be served and protected. As a consequence demands on the infrastructure will grow. Also environmental considerations play an increasingly important role in the design and construction of infrastructure. Traditionally the development and maintenance of infrastructure has been the task or responsibility of governments. A responsibility which is more and more shared with other parties through public-private partnership. The research has explored some trends in the development of infrastructure in deltas.

Dealing with pressure on available space

Land reclamation has grown into a popular strategy in cases where the pressure on the available space is high. The land reclamation examples of The Netherlands, Hong Kong and Dubai are large scale and technologically advanced. Their implementation required large investments too. There are, however, also other ways of reclaiming land. In the delta of the Ganges / Brahmaputra in Bangladesh natural processes of river morphology are used to reclaim land on a local scale. The high dynamics of the rivers support a relatively cheap way of land reclamation. Another promising way to respond to the increasing pressure on space is through multifunctional use of infrastructure. Revitalization of infrastructure opens new opportunities for multifunctional use. Examples include the transition of conventional embankments into super levees in Japan and the ideas for rehabilitation of the Closure dam of Lake IJssel in The Netherlands. Multifunctional use of infrastructure may be especially promising for flood protection works. Linking flood protection to other development issues such as urban (re)development, water supply or nature development may be an attractive way to combine more immediate benefits of e.g. urban development with the long(er) term benefits of flood protection. Formed by the construction of a 350m-long Marina Barrage, the Marina Reservoir in Singapore will soon become a freshwater reservoir in the heart of the new downtown. In addition to flood control, the Marina Reservoir will provide a source of drinking water, as well as a stable water level for a variety of recreational water activities and events.

Securing future water supplies

In many countries shortage of fresh water is viewed as one of the most serious challenges in water resources management. The expected increase in water shortages is a major trigger for adaptation to climate change. In some countries the drought problems are so acute that emergency measures are taken. These measures are viewed as a kind of 'no regret' measures within a climate adaptation policy.

The challenge of servicing more people with water requires a critical look into water use practices. Balancing the demands for water between the various sectors will need to be accompanied by the use of new and alternative resources: 'security through diversity'. Hence it is important to develop innovations that promote increased recycling of wastewater that will ensure better access to safe water, reduced vulnerability to extremes and increased adaptive capacity.

Sea-ward extension of ports

Economic development implies among others a growth of trade. To accommodate the growing transport of goods, ports are relocated or extended in seaward direction, navigation channels are deepened, etc. Such developments are often objected because of environmental impacts. Compensation for such impacts through nature development outside the project area may promote the actual realization of plans for port development. The port areas left behind may offer opportunities for urban (re)development with waterfront access.

New impulses for hydro-energy?

In line with mitigation policies for climate change there is a growing interest in the potential of deltas for renewable energy. Specifically in deltas there are a number of ways in which water may serve as a source of sustainable energy, waiting to be tapped. These include energy from tides, from waves and from salinity gradients. To be feasible, energy generation from tides require a sufficiently large tidal difference as well as opportunities to develop a basin. In the UK a barrage In the Severn Estuary is now under serious consideration. If built, it would be the biggest renewable energy project undertaken.

Rehabilitation of infrastructure

Due to climate change the physical conditions for which the infrastructure has been designed will become more severe. Larger droughts to overcome, higher water levels to counter and larger loads to withstand. Climate change, without

adaptation or counter measures, will result in damage or a loss of functionality of the existing infrastructure. The adequacy of the infrastructure may be further challenged by physical / mechanical ageing of the infrastructure. Also inadequate maintenance may play a role. Quite some infrastructure is already present for decades or centuries and is in (urgent) need of replacement or rehabilitation. Such rehabilitation will require large investments in the near future. At the same time, rehabilitation may create opportunities to invest in new developments and new functionality, including multifunctional use of the infrastructure.

From building against nature to 'Building with Nature'

Environmental considerations play a major role in the sustainable development of deltas. Concerns on environmental degradation have been institutionalized into environmental regulation. Almost no infrastructural development takes place without a proper environmental impact assessment. It is, however, not always easy to specify the environmental requirements to be met. These requirements are often subject of debate, and are sometimes hard, if not impossible, to meet. That is why a different approach is being advocated. Not to try to minimize the negative environmental impacts, but in stead to make better use of the processes and materials present in nature. This approach reflects a shift in paradigm from building against nature to building with nature. Applications are found in sustainable solutions for the restoration of coastlines and habitats and in new approaches for land reclamation. The concept is, however, applicable in many settings.

Towards more robust infrastructure

There is a trend in how societies deal with risks, including those from natural hazards. Many societies show a growing aversion of risk. Although zero risk is impossible many countries are adopting strategies which aim at a (further) reduction of the probability of failure as well as the impacts of failures. The trend of risk aversion, together with the expected impacts of climate change, has triggered a demand for more robust flood defense works. The super levees in Japan are a good example of such more robust works. Similar to the concept of super levees in Japan Dutch engineers and landscape architects have developed the concept of climate dikes or delta dikes. These delta dikes, thanks to their height, width or structural reinforcements should be so strong, that uncontrolled flooding is practically excluded.

In addition to the trend of more robust infrastructure there is a need for more flexible systems. These are systems that are able to cope with uncertainties and will hence have the capability to adapt to new, different, or changing requirements. To develop these flexible systems, new design approaches and techniques are needed that recognize the value of flexibility and promote a more modular approach to water management. For example, in relation to storm-water management, small-scale decentralized measures, such as Sustainable Drainage Systems (SUDs) have the ability to respond more flexible to changes in boundary conditions.

Perspectives of technological development

Technological development may open new opportunities to enhance the functionality of infrastructural solutions. Technological development may also help to extend the life time of infrastructure and/or to develop more cost-effective designs and construction methods of infrastructure. An important 'source' of innovations are the developments in information and communication technology. Advances in sensor and simulation technologies may promote the development of more accurate warning and forecasting systems, which in its turn will enable a more efficient management of water systems. These technologies also support the development of local- and global-scale monitoring and diagnostic systems. Integration of knowledge from various disciplines may open new applications too. For example a synthesis of knowledge from soil mechanics, chemistry and biology may generate a whole family of innovations. Using bacteria as 'micro contractors' there may be new opportunities for 'on demand' adaptation of soil characteristics. New materials may also be eco-designed.

Land and water use: development and adaptation

Modes in adaptation of land and water use

One of the trends in the development of deltas is an increasing awareness that occupation should be adapted to changing environmental conditions. In particular the threat of climate change is an important trigger for adaptation of land and water use. This threat may be countered to some extent by spatial planning regulation: promoting that (new) activities are located in low-risk areas to minimize the (increase in) vulnerability to climate change.

If spatial planning offers little solace, solutions may be found in restructuring an area. For example: (re)structuring of urban areas may create sufficient space for storage of excess rainfall. Urban flood management is another example. Finally at the lowest scale, vulnerability may be reduced through adaptive designs and construction methods. This may include amphibious housing, shifts to more salt-resistant cropping patterns, etc. The research has explored some trends in the adaptation of land and water use.

Spatial planning and zoning

Historically environmental conditions have played a major role in the spatial 'planning' of land and water use. The available natural resources as well as the transportation potential were major reasons to occupy deltas. Infrastructure development was necessary to take full advantage of the benefits deltas had to offer. Unconsciously the idea developed that we can shape the world to our needs. Because of the debate on climate change as well as the occurrence of some major floods in the past few years, there is a trend to take better account of the risks of natural hazards. The awareness that deltas are potentially risky areas is growing. But in practice there are hardly examples of formal risk based spatial planning. The UK, however, has regulations for spatial development and flood risks. The Planning Policy Statement 25 (PPS25) on Development and Flood Risks defines what type of land use is compatible with particular flooding probabilities.

Urban (re)development

Economic development and population growth drive expansion of built up areas. This process is often leading to a reduction of available free space in cities and its surroundings. The augmenting rate of built up areas in cities leaves less space available for water storage functions. This is an unfortunate situation in deltas as it increases the vulnerability for floods and droughts. Often urban development means loss of agricultural land. In some cases, e.g. the delta of the Yellow River, agricultural land is so scarce and valuable that new land is reclaimed for urban development. In Japan super levees, apart from a more robust flood protection, provide usable space for urban (re)development with access to the waterfront.

Adaptation to climate change

In a few years time adaptation to climate change has developed into an important field of research and policy-making. Many countries have developed National Adaptation Strategies. As the resilience (the capacity of systems to adapt to other conditions through natural processes) of soil and water systems has deteriorated in many deltas, restoration of resilience is a key component of such strategies. Adaptation strategies should include measures to enhance infiltration, retention and/or storage capacities of water systems. Adaptation in densely populated deltas may also include multifunctional

use of areas, e.g. giving a water storage function to nature areas. Reducing the vulnerability of land use through adaptive designs is another important pillar of adaptation strategies, for example through urban flood management.

The development of adaptation strategies for climate-proof deltas requires an integrated method to assess the vulnerability of deltas and to determine adaptation paths for the different sectors in deltas. One of the key-elements in such method is the adaptation tipping point. An adaptation tipping point is a level where natural (physical) boundary conditions exceed technical, economic or societal acceptable limits. The adaptation tipping points method takes the requirements of key sectors of water management and spatial planning as a starting point to identify the need for adaptation to climate change. The degree of climate change each sector can cope with is determined. This provides insight into the vulnerability to climate change of deltas. Combining the adaptation tipping points with local scenarios for climate change will identify the possible need for and timing of new adaptation strategies.

Adaptation tipping points analysis for Delta Committee

The adaptation tipping point method has been successfully applied to the water resources system of the Dutch Delta to support the analysis and recommendations of the Delta Committee. Research findings adopted in the report of the Delta Committee include:

- Fresh water supply will be severely hindered through salt water intrusion; but it will not be an issue before 2040
- Speed of sea level rise (the higher scenarios) will come close or exceed the natural adaptive capacity of the Wadden Sea
- The Maeslant storm surge barrier in Rotterdam, has been designed for sea level rise up to 50 cm; hence this rise will not be an issue before 2060
- Current strategy for nature conservation will not be sustainable under climate change
- Salt water upward seepage through the ground water is a minor effect
- Coastal flood defense maintenance through sand nourishment will not be an issue, provided that sand can be taken from the North Sea bed
- In general it was concluded there are no limitations to technical adaptation measures, although these measures become increasingly expensive and space consuming.

Urban Flood Management

There is a growing number of floods in urban areas; climate change and rapid urbanisation will exacerbate this trend. Besides structural measures aiming at a reduction of the probability of flooding, new integrated approaches are being developed and implemented. Urban Flood Management aims to increase robustness as well as the adaptive capacity towards future flood impacts through flood-proof building and adaptive designs. Urban Flood Management still faces a number of bottlenecks that hamper the effective implementation of flood risk management in urban planning practices. These include lack of understanding of (residual) flood risks and their implications, inadequate steering of local authorities and the conservative nature of the building sector.

Adaptation to flood risks ('living with floods')

In the Mekong Delta, the awareness of flood risks is very high. This is partly due to the frequency of flooding (on average, there are major floods every three years). The strategy of the Vietnamese government is to look for ways of local adaptation to (risks of) flooding:

- the Land Use Law prohibits building in flood prone areas.
- in terms of land use planning, residences are planned on safest grounds (elevations) and preferably grouped together, which makes it easier to protect.
- change in cropping calendars, use of salt-resistant crops (in areas where salinity intrusion is present) and flood-resistant production (floating rice and aquaculture).
- investing in upgrading of infrastructure.

New agricultural practices to adapt to salinity problems

Salt accumulation in delta soils, resulting from intense irrigation and/or increased seepage, reduces the agricultural productivity. Hence alternative practices are introduced to changing environmental conditions. These include desalting of agricultural soils, genetic manipulation of existing crop species to enhance biological tolerance, cropping of salt tolerant species and mixed farming practices.

Governance of delta development

Role of governance in delta development

In the past few decades the development and management of deltas has become increasingly complex and often an issue of societal debate. A number of trends has added to this complexity, including decentralization of government and larger involvement of the private sector. Also interest groups and citizens have a stronger voice in development. They are able to delay or deter developments if these harm their interests. Management of deltas has to deal with this increased complexity. It requires comprehensive and qualified information on the state of deltas and possible development options to support participation and decision-making. It also calls for a selective enhancement of the governance structure reflecting the regional scale, integrated nature and long term perspective of delta development.

This research has focused on governance as far as it is related to creating the proper conditions for a sustainable development of deltas. Good governance should promote that plans and visions for delta development are actually brought into practice through development projects. Governance should also provide adequate arrangements for maintenance of infrastructure to prevent early deterioration of the infrastructure. The research has looked into a number of ways, both institutional arrangements and enabling mechanisms, through which the governance structure of deltas may be strengthened.

Co-operation between levels and sectors of government

Lack of co-operation between different levels and sectors of government are a major impediment for implementation of development projects. The need to cope with the negative side-effects of decentralization constitutes a major trigger for the strengthening of the governance structure through multi-level governance. Moreover, deltas are mostly governed by multiple governing layers e.g. international, national, regional and local. The fact that there is no legal entity for deltas adds to the complexity.

Growing environmental concerns may lead to a standstill in economic development activities. Licenses for exploitation of natural resources may be denied in fear of jeopardizing sensitive delta ecosystems. Widening the policy arena with e.g. regional development may turn out to be an effective way to overcome objections against such exploitation. The extraction of natural gas

from the Dutch Wadden Sea and the establishment of a special 800 million Euros fund, to facilitate extra investments in ecological and economic projects in and around the Wadden Sea over a period of 20 years, offers a good example of such strategy. The same can be observed for port development. Widening the policy arena with the field of nature development (e.g. extension of the Port of Rotterdam) may open new opportunities, e.g. losses in environmental values in the project area may be compensated elsewhere.

Also the recent history of flood protection along the river Rhine has shown the strength of widening the policy field. In the case of the river Rhine impediments in the implementation of dike reinforcements were overcome through inclusion of nature development in the strategy for flood protection.

Cooperation between government and private sector

Co-operation between government and the private sector may cover various fields. Co-operation in the development of infrastructure through public-private partnerships is a well-known example. But co-operation may also include joint development and sharing of knowledge. A good example of the last form of cooperation is the innovation program on Building with Nature in The Netherlands. This innovation program was initiated by Dutch contractors and is carried out by a large consortium including government agencies.

In many countries public financing is unstable and rarely meets crucial expenditure requirements in a timely and adequate manner. Moreover, technical capabilities and capacities of public services may also be lacking, forcing governments to consider alternative options of finance and technical support. This may be achieved through associations with the private sector on a project-to-project basis. These public–private relationships include many options for co-operative provision of services as alternative to the delivery of traditionally public domain services. To mention a few:

- ***Service contract:*** Under this option, the private sector performs a specific operational service for a fee.
- ***Management contract:*** With this option, the private sector is paid a fee for operating and maintaining a government-owned business and making management decisions.
- ***Concession and build own transfer (BOT) / build own operate (BOO), build own operate transfer (BOOT):*** Under concessions, the private sector finances the project and also has full responsibility for operations and maintenance. The government owns the asset and all full use rights must revert to

the government after the specified period of time. BOT, BOO and BOOT arrangements are similar to concessions but in this case the private sector owns the asset and receives a fee for the service direct from the users.

Risk allocation is a very important aspect of the public private partnerships and this is often one of the decisive factors on the choice for the appropriate private sector participation. Although the principle is to transfer the risk to the party that is best able to manage them, risk sharing becomes more and more important.

Involvement of stakeholders and citizens in development issues

Involvement of stakeholders and citizens is important to promote societal support for development projects. If the success of proposed measures depends

on the active co-operation of stakeholders and/or citizens their participation is a precondition for a sustainable development. If people are requested to adapt their conduct in a more sustainable way, it is essential that they understand the need of such adaptation as well as their possibilities to do so. Stakeholders and citizens do possess of a lot of (tacit) knowledge on the functioning and use of water resources systems. Such knowledge constitutes important input into social learning processes for development planning of deltas.

Involvement of stakeholders is also of great importance in the maintenance of infrastructure. To prevent early deterioration of infrastructure, its maintenance should be well organized. Also sufficient funds should be (made) available for carrying out maintenance. Money for such funds should be raised from the people and companies that have a stake in the proper functioning of the infrastructure.

Dealing with uncertainties through adaptive management

Adaptive management is defined as an iterative process of optimal decision making in the face of uncertainty. It has the aim of reducing uncertainty over time via system monitoring. Adaptive management is often characterized as "learning by doing" although it is more about deliberate experimenting. Examples can be found in the large scale beach nourishment strategy proposed by the Dutch Delta Committee. This strategy is facing important uncertainties with respect to the effectiveness of large scale sand nourishment as well as the extent of sea level rise. The type of measure, however, lends itself good for adaptation based on the findings of monitoring. The Thames Estuary 2100 project in the UK is another example of adaptive management. It incorporates decision-making on possibly required changes to the existing flood management system, taking into account the uncertainties in the expectations of sea level rise.

Two perspectives on development of deltas

Basically there are two different ways to respond to the different drivers and trends. The first perspective is very much driven by the (liberal) economic perspective: the role of the (central) government is reduced through privatization and decentralization. Also there is less government influence in spatial planning, etc. The balance between central and de-central is a political issue. It is a response to a growing complexity in society and therefore a trend. The word privatization indicates that there is an existing public service that can be given to the market. There are also many new services to be developed. which require a vision on private sector development and involvement. The challenge is to find the right balance between governmental supervision and control, and the dynamics, innovation of free market forces. The conflicts that could arise out of this market-driven and less top-down controlled focus are generally solved in a typically technocratic way: i.e. by further development of infrastructure. This perspective reflects a high belief in our capabilities to engineer the world to our needs. The long term sustainability, however, is not guaranteed. Changing environmental conditions will require a regular upgrading of the infrastructure, as infrastructure does not adapt naturally.

The second, environmental perspective, is driven by global concerns on climate change and environmental degradation. It reflects a growing awareness that nature poses limits to development. These limits may be stretched to some extent through the development of infrastructure but at increasing costs. In this perspective land and water use should instead be adapted to changing environmental conditions through spatial planning regulation and adaptive designs. Natural processes should be utilized as much as possible to adapt to changing environmental conditions. The environmental perspective aims to make better use of the inherent adaptive capacities of nature.

The first perspective is visible in most deltas of the world. The second perspective is, as yet, less visible, but is gaining momentum. We see this for instance in integrated water management and coastal zone management programmes. Ideas to reconcile human development with nature are emerging in various fields. Building with nature is for instance practiced in the form of beach nourishments as opposed to hard structures to control erosion. Multifunctional use of infrastructure is being implemented in densely populated deltas, to save space and money. Restoring the natural purification

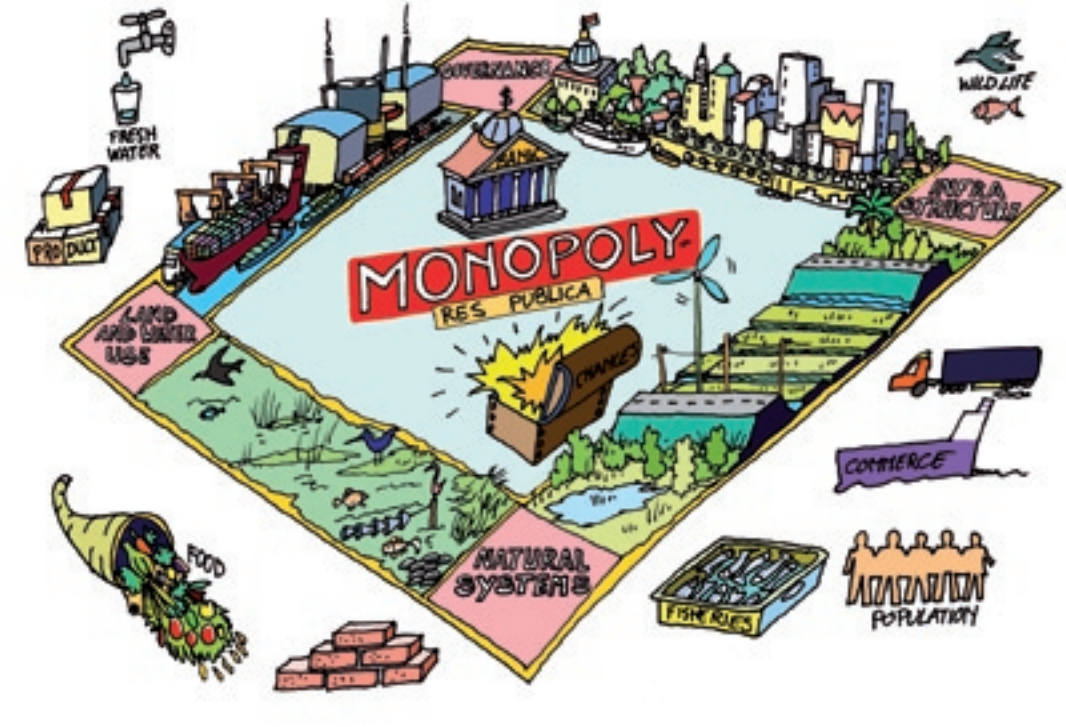
capacity of wetlands and estuaries are being considered in highly modified deltas, as in the Netherlands. Renewable energy from waves, tides and salinity gradients is being studied.

The two perspectives are basically conflicting. The main challenge therefore is to combine elements of both perspectives into a strategy which is both economically viable and ecologically sound. It requires among others harmonizing and balancing on the axes government – market and on the axes central – de-central.

The way forward

The characteristics, which make deltas attractive areas to live and work, are under increasing stress due to population growth, economic development and climate change. The management of delta development has also become increasingly complex, due to among others decentralization and privatization. World wide concern over a changing climate and environmental degradation has raised the environmental awareness that nature poses limits. A more sustainable development of deltas, however, requires not only acceptance of the limits posed by the natural system but also making use of or even enhancing its enabling conditions. A few questions need to be answered in this respect:

- what development are we pursuing, how do we strike a balance between economic development and environmental stewardship



- what are our technical capabilities and how much confidence do we have in them (knowledge/science/engineering experience) and
- how are we organizing these capabilities vis-à-vis the social and institutional environment (governance).

To promote sustainable development of deltas a clear vision has to be developed on how to best respond to the various drivers of change as well as on how to play along with the various trends in society. Innovations are required to implement such a vision, including social, institutional and technological innovations.

Delta vision: a shared view on sustainable development of deltas

A shared vision on sustainable delta development should deal with all drivers for change in a delta (population growth, economic development, and climate change) as well as with the relevant societal trends (decentralization, privatization, participation, growing environmental concerns and growing risk aversion). Such a vision should be developed in close co-operation with all parties that have a stake or a say in the development of the delta. A good example of such vision is 'Delta in Sight' which was developed for the southwestern delta of the Netherlands and which presents an integral view on problems and possible solutions for the Dutch Delta waters.

Next the delta vision should be elaborated into a policy or delta programme. Such a programme cannot be limited to infrastructural measures or restoration measures only. A sensible combination of different kind of responses is needed. This will include measures for restoration of natural systems, adaptation of land and water use, extension of infrastructure as well as measures to strengthen the governance structure. Extension of infrastructure may be needed; in particular in those cases where the adaptive capacity of land and water use and/or the potentials of the natural systems are insufficient. In order to be more sustainable, the development of infrastructure should be tuned to these (new) demands, for instance through more robust infrastructure and multi-functional use of infrastructure. Also the development of infrastructure has to be in harmony with the potentials and limits of the natural system, for instance through building with nature.

Establishing the most suitable combination of measures requires a strategic analysis of the potentials and limitations of the different types of measures. The analysis should also look into the coherence and timing of these

measures. Moreover, such analysis should take account of the many uncertainties associated with delta development, including the impacts of climate change. Strategic Environmental Assessment (or Strategic Impact Assessment), being a systematic process for evaluating the environmental consequences at the earliest stage of decision-making on a par with social and economic considerations, may constitute a suitable instrument for the development of the shared delta vision and the associated delta programme. Strategic Impact Assessment should be applied at all levels, to assess strategic decisions at plan, program and policy level in key sectors with potentially significant effects such as transport, energy, agriculture, water management, fisheries, infrastructure, spatial planning and nature.

Delta technology: innovations in science and technology

Sustainable development of deltas requires innovations in the knowledge of natural systems behavior as well as in the approach to planning and design. A number of required breakthroughs have been identified in the Dutch innovation program 'Building with Nature' with respect to knowledge of natural system behavior and the approach to planning and design. For example we should move from an engineering approach to 'integral thinking'.

Knowledge of natural system behavior:	Approach to planning and design:
• static approach → dynamic behaviour	• engineering-centered → integral thinking
• descriptive → predictive	• mitigating adverse environmental effects → adaptation to the natural system
• species → ecosystem dynamics	• construction → life cycle management
• false certainty → living with uncertainties	• reactive → pro-active

An important 'source' of innovations are the developments in information and communication technology. Advances in sensor and simulation technologies may promote the development of more accurate warning and forecasting systems. These technologies also support the development of local- and global-scale monitoring and diagnostic systems. Integration of knowledge from various disciplines may open new applications too. For example a synthesis of knowledge from soil mechanics, chemistry and biology may generate a whole family of innovations.

Delta governance: social and institutional innovations

For development of deltas to be more sustainable, it is important to obtain societal acceptance and support for this development. Good governance should promote that shared visions are developed on sustainable development of deltas. Moreover proper conditions should be created for the actual implementation of such a vision through development projects. Governance should also provide adequate arrangements for maintenance of infrastructure to prevent early deterioration of the infrastructure.

Societal trends have to be taken into account in creating these conditions, in particular the trends of decentralization and privatization. Decentralization and privatization may be viewed as autonomous developments. The challenge is to utilize the advantages of both trends, while addressing their undeniable drawbacks. This calls for a selective enhancement of governance structures, reflecting the regional scale, integrated nature and long term perspective of delta development. The enhancement may take different modes:

- Promotion of a better co-operation between different levels and sectors of government, balancing the trend of decentralization and the need for (national) coordination.
- Facilitation of the cooperation between government and the private sector, taking into account trends of privatization but also the need to safeguard the public interest in the long term.
- (Better) involvement of stakeholders and citizens in development issues to promote the societal acceptance of development projects as well the long term sustainability of development projects (arrangements and incentives for maintenance).
- Creation of arrangements for sharing of risks (insurance) and financing (securing funds for maintenance and broadening the base for investments).

Delta dialogue and forum: establishing best delta practices

Sustainable development of deltas is an increasingly complex field which requires the contribution and co-operation of many parties. Although there is no general recipe on how to best deal with many delta issues, it is important to learn from experiences elsewhere. To this end, exchange of knowledge and experiences should be stimulated. Such exchange may take various forms:

- The draft National Water Plan of The Netherlands (December 2008) proposes to set-up an active and longstanding co-operation on water safety and water quality with some four delta areas in the world. This co-operation may serve as a vehicle for exchanging experiences in planning and design approaches.

- The Aquaterra conference has the ambition to develop into a biannual forum on delta and coastal development. The conference may offer a platform to discuss the various challenges in deltas and the possible approaches to deal with these challenges. Through a process of dialogue, these approaches may be elaborated into best delta practices.

Emerging 'best practices' for dealing with delta issues?

Deltas have characteristics in common, but there is also much diversity in physical conditions, governance structure and cultural background. Hence, there is no general recipe on how to deal with delta issues. Nevertheless, some broad perspectives may be distinguished on dealing with these issues: emerging 'best practices' for deltas? Such practices should comprise a balanced mix of measures from the different response themes and reflect the integrated nature and regional scale of delta development. Enhancement of the governance structure is an important component of such practices.

Relieving the pressure on available space.
Spatial planning regulation may relieve some of the pressure by redirecting urban development and economic activities to less 'crowded' and/or low risk areas. In cases where spatial planning offers little solace, land reclamation has proven to be an effective way to relieve some of the pressure on space. Land reclamation offers also good opportunities for implementation of the Building with Nature concept meanwhile easily applying new safety considerations. Multifunctional use of areas, e.g. giving a water storage function to nature areas, may further assist in relieving the pressure on space.

Improving resilience of delta areas
Vulnerability of societies to future climate change (such as flood risks, droughts and salinity intrusion) should be reduced, preferably by making societies more resilient. Resilience can be improved by: preparedness, coping strategies and adaptation to changing conditions. This requires a combination of willingness to change, appropriate technology and community participation. Increasing the robustness of infrastructure is another promising way to respond to the increase of the vulnerability of delta areas as well as the growing aversion of risk.

Securing fresh water supplies.
Many deltas in the world currently face water shortages which may aggravate due to climate change and pollution. Adaptation of land and water use will be an important way to respond to these shortages. This may include more efficient water use and/or changes in cropping pattern and fertilization in agriculture. Pollution reduction programmes and establishment of environmental flow requirements for deltas are needed. Their implementation may benefit from involvement of river basin agencies.

Upgrading of ageing infrastructure
Many deltas have irrigation and drainage systems as well as flood protection works, roads, water supply and treatment facilities which require upgrading. Public private partnerships could provide a solution in those cases where farmers, industries and communities directly benefit from these infrastructure investments. But for protection schemes against floods and storm surges other options could be more appropriate, such as introducing financing mechanisms. Rehabilitation of infrastructure offers also opportunities for multifunctional use of infrastructure.

Coastal erosion management
Many deltas experience coastal erosion problems due to a sediment shortage Solutions should preferably include a restoration of the sediment balance. If this is not feasible, sand nourishments are preferred over hard engineering structures. Also other 'Building with Nature' options should be looked into, e.g. mangrove restoration. This is primarily a task for coastal management agencies, who should work closely together with local stakeholders and the private sector.

Biodiversity protection and restoration of ecosystems
Worldwide estuarine ecosystems and biodiversity in deltas are under severe pressure. Effective action must be taken to protect nature areas from local habitat destruction, external disturbance and adverse inputs (pollutants). This requires adhering to the national and international obligations such as Habitat Directive, Ramsar Convention and Biodiversity Convention. Biodiversity protection should be effectuated at the local level through cooperation and involvement of all stakeholders. Ecosystems in deltas can be relatively easily restored. An integral approach and early involvement of stakeholders contributes to the success of restoration efforts, The integrity of (modified) estuarine ecosystems may be enhanced through reconnection with rivers and seas.

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