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Research Article

Beyond the Limits of Present Adaptation Strategies: Exploring Strategies and Measures to Anticipate on Accelerated Sea-Level Rise in the Netherlands

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ABSTRACT

Accelerated Sea-Level Rise (SLR) may impose an existential threat to low lying densely populated coastal regions and delta's like the Netherlands. In 2019, the Dutch government started a research programme to assess soft and hard limits of present strategies on flood risk management and explore additional measures and alternative strategies. Model simulations were performed to determine the impact of SLR on the required coastal protection, and the potential combinations of dike reinforcement, peak storage and pumping capacity to manage extreme flood levels in estuarine areas. In cooperation with local authorities and stakeholders the impact of SLR and potential measures on present and future land use and investment agenda's on e.g., housing, agriculture and infrastructure was established. Different long-term strategies were defined and explored. There is substantial uncertainty regarding future SLR, and selection of a single strategy is not necessary yet. To deal with extreme SLR and to keep future options open, it is essential to reserve substantial space to expand future flood defences and increase peak water storage.

Keywords: Sea level rise; Water; Coastal zone; Coastal áreas; Floods

INTRODUCTION

Coastal regions, especially deltas are densely populated because of benefits related to productivity, fisheries, trade, water supply. As a result, they attract large populations and huge amounts of investments and show rapid growth. Presently, coastal areas are home to about 10% of the world's population [1]. However, these areas are also vulnerable to coastal erosion, floods, salinization and frequently suffer from related damages, casualties and societal disruption.

Sea-Level Rise (SLR) is expected to put additional stress to coastal zones and delta's, especially if a projected acceleration occurs later this century. As a result of global warming, the projected SLR at the end of this century ranges from 0.28 to 1.88 m relative to 1995, depending on the CO2 emission scenario, and will continue rising beyond 2100. Uncertain Antarctic land ice instability may aggravate this SLR [2].

In 2019, the Dutch government started a research programme to establish the potential impacts of this accelerated SLR on flood risk, fresh water supply and coastal management and to explore potential strategies to deal with this still uncertain challenge [3]. This paper presents the first results of this research programme: the potential impact of SLR on the Dutch delta, fundamental choices to be made in water and coastal zone management, potential strategies and related measures. And most importantly: A preliminary list of activities that are low-regret and should be started with.

The potential impact of SLR on the Dutch delta

Delta's are low-lying flat areas, characterized by the dynamic interaction of fluvial and marine processes like waves, tides, input and export of fresh water, sediments, nutrients, and extreme events like floods, droughts and storm surges. The morpho-dynamic behaviour of a delta is the result of the delicate balance between sediment supply, transport, sedimentation and erosion. SLR may have a serious impact on delta behaviour: a delta requires interventions that involve large volumes of sediment to keep pace with SLR, without adequate human interference erosion and finally drowning becomes inevitable.

The territory of the Netherlands largely consists of the delta's of the rivers Rhine, Meuse and Scheldt. Sediment availability, transport capacity and sedimentation conditions determine the deltas ability to rise with sea-level. Navigation works along the rivers Rhine and Meuse, like locks and harbours, in combination with embanked floodplains, dams and storm-surge barriers, have limited the natural supply and deposition of marine and riverine sediment to the Dutch delta, estuaries and coastal zone. Along the coastline this is partly compensated by periodic beach nourishments to eroding locations. The potential behavior of the

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present Dutch delta to accelerated SLR may result in the drowning of the intertidal areas and wetlands of the Wadden Sea (which is United Nations Educational, Scientific and Cultural Organization (UNESCO) world heritage) and Western Scheldt later this century [4], [5]. Maintenance of the coastline will require an increase of up to 10 times the current volumes of beach nourishments to combat erosion and to keep pace with SLR.

SLR not only increases the sediment demand, it also increases the intrusion of saline sea water into the estuaries and decreases the potential to discharge river water by gravity to the sea. The increasing salt intrusion requires more fresh water to flush brackish polders areas to enable fresh-water dependent agriculture [6].

MATERIALS AND METHODS

Strategies and measures to deal with SLR

Clearly, accelerated and large SLR may impose fundamental choices regarding coastal management, river discharge and fresh water supply. The last decade, with growing public attention for SLR, many plans have been developed for the Dutch delta [7]. Four different types of strategies can be distinguished in these plans [6].

Protect: Two variants exist regarding the protection of river mouths: A permanent closure from the sea by dams or sluices, requiring large pumping stations to discharge river water to the sea. A second Protective option is to maintain open estuaries and raise the river dikes to accommodate flood levels along the rivers.

Accommodate: Adapt land use to increasing salinization, water logging and floods by flood proof buildings in combination with migration to higher grounds.

Advance: Reinforce the present coastline, or build a new coastline in front of the present one, with coastal lake, to temporarily store river floods.

Each strategy consists of specific measures and combinations, so called 'building blocks'. In total 28 building blocks were selected for flood risk management aspects of SLR, inspired on present plans and ideas (Figure 1).

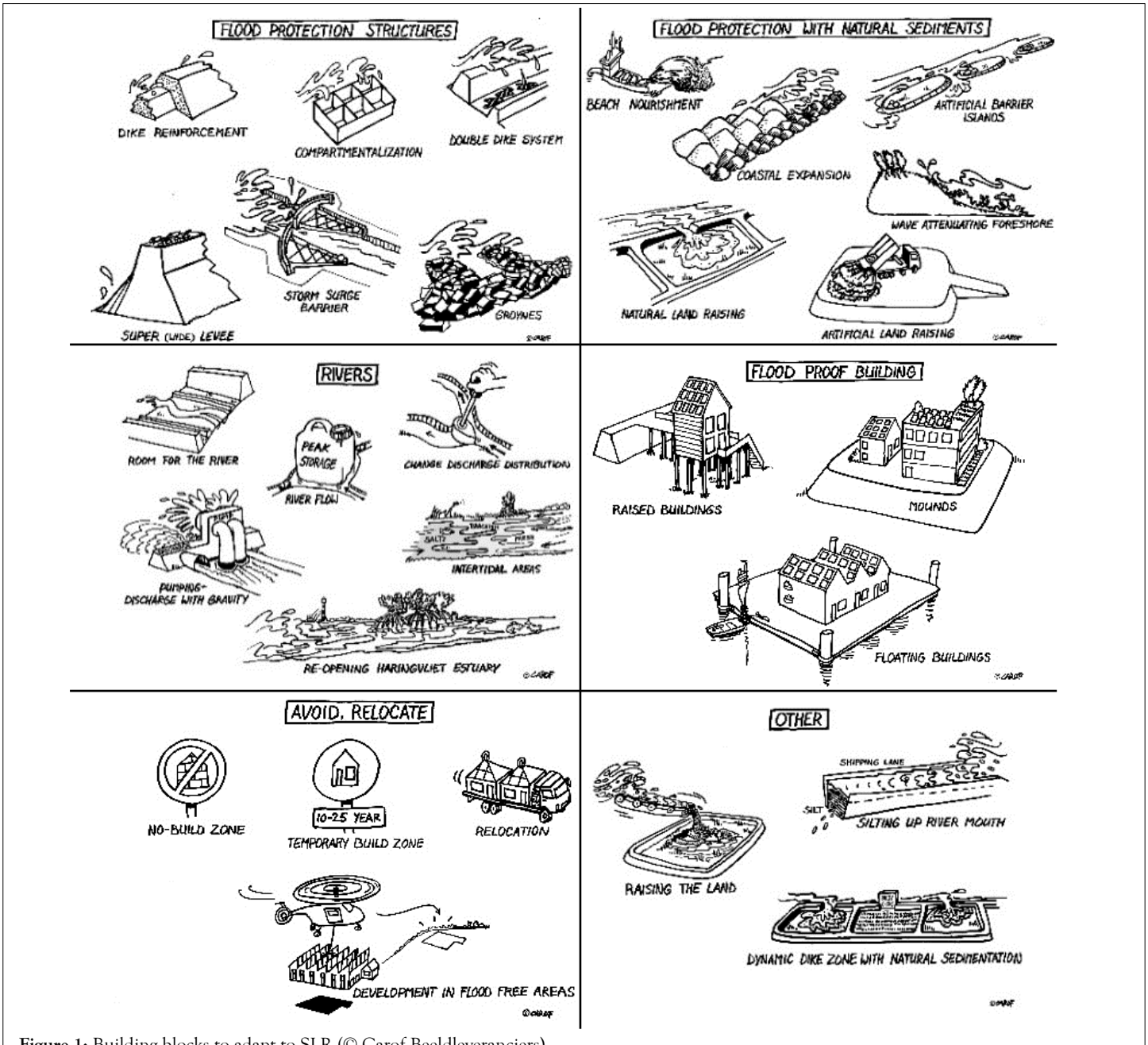


Figure 1: Building blocks to adapt to SLR (© Carof Beeldleveranciers).

- Structural flood protection measures, like dams, dikes, storm surge barriers, groynes. They are robust, fixed and costly to construct and maintain.
- Non-structural, nature based flood protection measures benefit from natural sediment supply, transport and deposition processes. In general they are more flexible and less costly. Examples are beach nourishments, measures to stimulate natural sedimentation or reduce erosion.
- River related measures involve pumping stations and storage basins, in combination with raised dikes and sluices. In addition, in the Dutch situation adjusting the discharge distribution of the Rhine branches is also an important option.
- The above three categories of building blocks manage the increasing hydraulic loads related to SLR and reduce the probability of future floods. A fourth category of measures reduces the consequences of future floods on future land use, like floating, flood proof or raised buildings in flood prone areas, or land use planning aimed to regulate new developments in these flood prone areas and stimulate them in flood free areas.
- The last category consists of measures to influence land use by using natural sediments.

In future this selection of building blocks will be supplemented with fresh water supply aspects as well.

RESULTS AND DISCUSSION

Strategy development

The four types of strategies were elaborated on regional and local level regarding the types of measures, the potential to apply measures in combination and their specifications (like height, width, depth, area, volume, capacity). This was done in regional design-workshops, in which water-experts and stakeholders from other sectors participated. These regional design-workshops were aimed to increase awareness about the potential impact of SLR on future land-use and to explore opportunities for synergy (and potential conflicts) between SLR measures and the large investment agendas on e.g. housing, infrastructure and sustainable energy. The main purpose of this exercise was not to select a preferred strategy and start the elaboration, preparation and implementation yet, but to define 'low regret' do's and don'ts to safeguard space for future needs for flood defences, water discharge and storage.

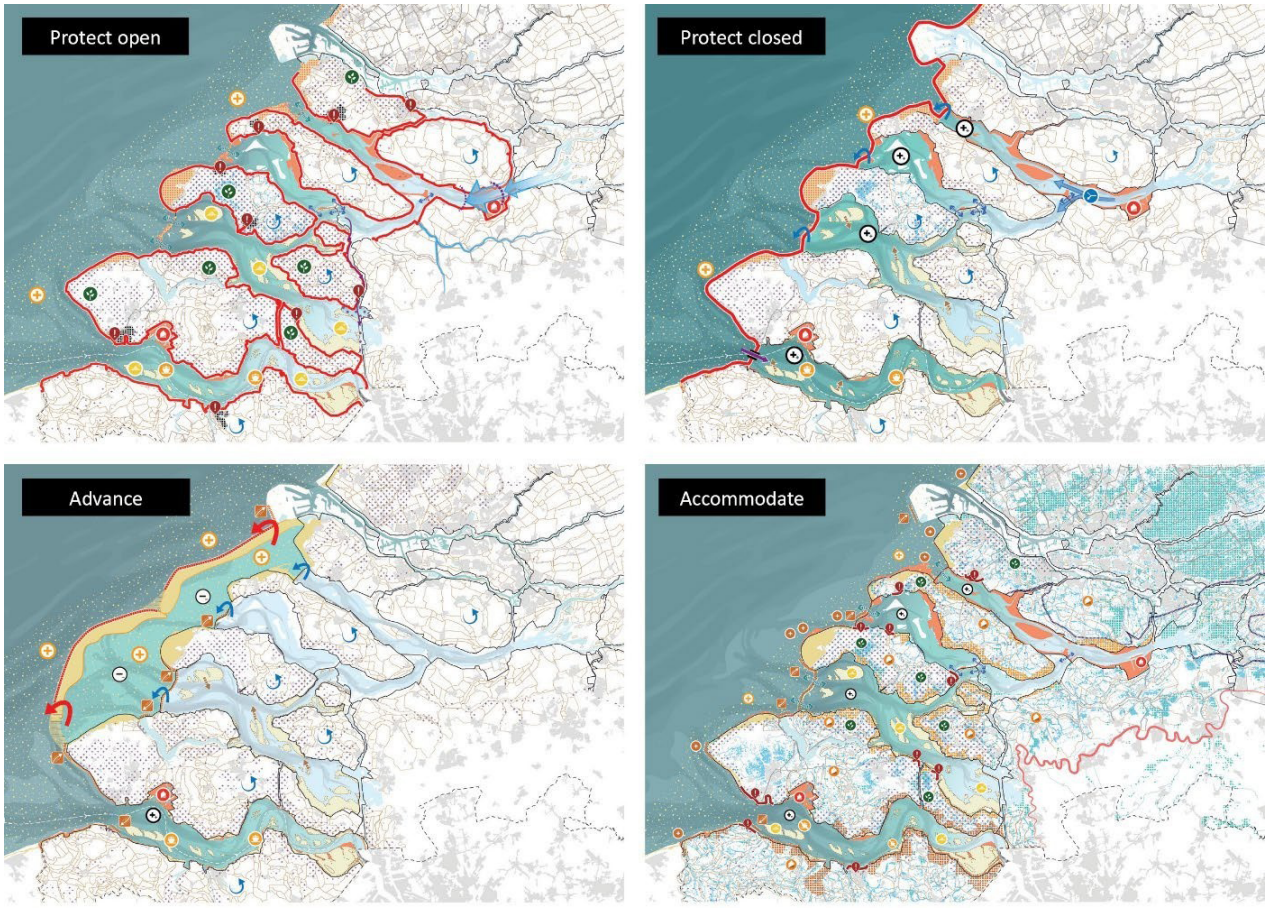
Case Southwestern delta

The Southwestern delta is the area between Rotterdam and Antwerp where the rivers Rhine, Meuse and Scheldt debouch into the North Sea. After the devastating flood of 1953, tidal inlets and estuaries were closed from the sea by dams, storm surge barriers and sluices, resulting in a complex and partly compartmented system of fresh and saline water systems. The coastal zone consists of natural sandy beaches and dunes. The area is bounded in the north by the vast harbour and industrial area of Rotterdam, and in the south by the Western Scheldt, the entrance to the Antwerp harbours. The former islands and peninsulas in the area mostly consist of rural and agricultural land, while the coastal zone is important for recreation. Up to 2050 large investments are planned related to housing (24 bln Euro) , sustainable energy (14 bln Euro), infrastructure (21 bln Euro) and climate adaptation (13 bln Euro) [8]. SLR will affect this area in different ways:

- It will increase coastal erosion, to be compensated by increased volumes of beach nourishments.
- It will reduce the discharge capacity by gravity of the Haringvliet sluices, requiring additional pumping capacity in combination with peak storage of river floods and raised flood defences.
- It will increase the closure frequency (and hydraulic loads) of the storm surge barriers in Eastern Scheldt and Rotterdam Waterway.
- Valuable intertidal ecosystems may drown when SLR exceeds their natural sedimentation capacity.
- Flood defence systems have to be raised along the Western Scheldt and the Antwerp harbours and urban areas.
- Increased salinization of ground and surface waters will challenge agriculture and drink water supply.

In a design workshop with water experts and stakeholders from local and regional authorities, NGO's and private organisations four different strategies were elaborated (Figure 2).

- In the Protect Open strategy estuaries, tidal inlets and river mouths maintain their open connection with the North Sea. SLR will result in increased flood levels and salinization of the coastal water basins and rivers upstream, requiring extensive dike reinforcement and measures for adapting to or reducing salinization. On the other hand, tidal action and natural sediment supply are maintained and partly restored, creating new opportunities for 'building with nature' processes.
- In the Protect Closed strategy estuaries, river mouths and inlets will be closed, shortening the coastal flood defences system. Rivers cannot discharge under gravity to the North Sea anymore. Instead, pumping stations with capacity of 10.000 m3/s or more are necessary to drain river water to the North Sea. Peak storage capacity in present water systems can reduce the required pumping capacity. Occasionally these water bodies will experience large influxes of fresh water river floods, resulting in rising water levels. A transition to permanent fresh water reservoirs of these former estuarine systems becomes an interesting option, having the advantage to combat salinization due to SLR as well. In this strategy natural tidal dynamics are blocked and navigation to the Rotterdam and Antwerp harbours is affected by a sluice complex.
- The Advance strategy consists of a new coastline, situated several kilometres offshore in front of the present one, creating additional protection against storm surges and a large buffer reservoir for river floods. The water level of this buffer reservoir has to be managed by pumping stations (and additional navigation locks) situated within the new coastline. The large buffer capacity of the reservoir reduces the required maximum pumping capacity significantly. The reservoir is fed by river water, creating a brackish environment that may reduce the salinization of the inland polders and water systems.
- The Accommodate strategy is based on the maintenance of the present flood protection levels, without expanding the flood defences and pumping capacity to SLR. As a consequence, the low lying western provinces will experience waterlogging and floods more often. Land use has to adapt into flood proof urban areas and saline rural zones. New investments in housing and economic activities will intensify in higher areas in the southern and eastern parts of the country (Figure 3).



Flood protection

- Reinforcement coastal flood defences
- Expanding coastal dunes
- Navigation lock Western Scheldt
- Primary flood defences
- Regional flood defences
- Complex dike reinforcements in urban areas
- Non- protected areas adapt to more frequent flooding
- Expanding pumping capacity to discharge river floods
- Raising water level to continue discharge by gravity
- Restoration of tidal action at former closed estuaries

Protect open

- Adaptation of non-protected areas to rising water level
- Adaptation of discharge distribution

Advance

- New coastline
- New pumping stations
- New coastal lake to buffer river floods
- Discharge under gravity of river water into the coastal lake

Accommodate

- Double dikes
- Double dikes to stimulate natural sedimentation
- Protection of urban areas
- Flood proof buildings and shelters
- Flood free boundary (hoog en droog)

Salinization and fresh water supply

- Saline-brackish-fresh water
- Increasing salinization due to SLR (and subsidence and increased water extraction)
- Saline intrusion at navigation locks
- Storage of rainwater

Protect open

- Saline-fresh water boundary, depending on river discharge
- Saline resistant crops

Drainage

- Pumping to drain low lying polders
- Areas are getting wetter (accommodate)

Sediment

- Beach nourishments to maintain shoreface
- Drowning of intertidal areas
- Increased erosion of intertidal areas
- Increased dredging to maintain navigation channels
- Increased erosion of former coastline (advance)

Accommodate

- Intertidal areas keeping pace with SLR
- Navigation channels silting up without dredging
- Flexible coastline with natural erosion and sedimentation

Figure 2: Strategies to adapt to SLR for the South-western delta of the Netherlands.

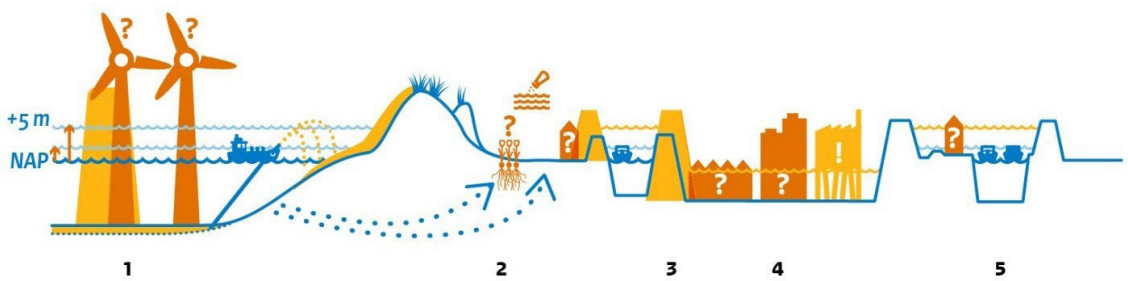


Figure 3: 1: Required space for sand extraction and new coastline, 2: salinization, 3: expanding flood defences, 4: water logging an storage, 5: river water discharge. NAP is present water level.

CONCLUSION

These strategies differ very much in their character, assemblance of building blocks and effects on other interests like navigation and nature values. However, they all have in common the necessity to maintain space for future drainage and water storage, flood defences and sand extraction (for raising land, beach nourishments or construction of a new coastline).

The present large investment agendas on housing, sustainable energy, infrastructure often include constructions with a life time of 50-100 years or even more. Furthermore, such developments often attract additional developments in the same area. As such, these agenda's determine the future land use and remaining options for measures to adapt to SLR. Spatial reservations now are required to maintain this necessary space for water, and prevent high adaptation costs for future generations (see Figure 3). This will require short term actions to align the need for reservations for long term water management with short term developments.

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