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River basins and deltas need a second game-change

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River basins and deltas can be considered as complex systems with dynamics resulting from natural processes. These dynamics have generated many ecosystem services, but they are also erratic in nature.

Since the industrial revolution, the belief has emerged that these systems can be controlled, thereby suppressing the erratic nature of rivers and deltas and maximizing economic benefits. This has led to a game change in the development of rivers and deltas: until the mid-19th century, the natural system was dominant and economic and urban development followed; after the mid-19th century, economic and urban development became dominant and the river and delta systems were increasingly adapted to the new economic and urban realities. The result of this first game change was the disappearance of sufficient room for the natural dynamics of river and delta systems. This has led to major problems in the current times of climate change, which can only be tackled with a second game change, which takes more into account the natural dynamics of the river and delta systems and offers more space for these dynamics.

An example of what this second game change could look like is a proposal for the reorganization of the main discharge of the Rhine and Maas rivers in the Dutch Rhine-Meuse delta. This reorganization has major consequences, but also offers new opportunities for the water system, as well as for the natural environment and for port development, urban development, and the necessary energy transition. For this new game change, design explorations are necessary to investigate how a new synergy can be achieved by combining all these aspects.[1]

INTRODUCTION: NOT JUST CLIMATE CHANGE

The 21st-century world is facing the enormous challenge of a complex combination of adaptation to climate change, of preventing an acceleration of climate change through energy transition, and of restoring biodiversity and the resilience of natural systems.

This complex combination of tasks occurs to an extreme extent in the catchment areas of the major river basins and in particular in the delta areas, where the rivers flow into the sea and where the greatest economic and urban growth has taken place worldwide over the past 150 years and continues to occur. The major rivers, and especially their deltas, are at the heart of the logistic processes of production, transport, and consumption of modern industrial societies. Adaptation to climate change in these delta regions seems to be extremely difficult but also extremely urgent.

However, it would be a mistake to look for the causes of these problems in climate change alone. In the search for effective long-term strategies, the changes in the physical conditions of river basins and delta areas, especially caused by human hands during the last century and a half, must also be considered. Although there were good reasons for these changes (economic development, urban growth, and prosperity), the downside is that the resilience and dynamism of the natural system in these areas has declined sharply. The effects of climate change, such as rising sea levels and increasing peak discharges of rivers, can have a greater impact on river basins and delta areas due to this reduced resilience.

In this paper I will argue that the transformation of river basins and delta areas during the 19th and 20th centuries can be considered a 'game-changer': the game changed from a dominating role of the dynamics of natural systems to a dominating role of man-made patterns of land use, manipulating natural systems with excessive engineering. The central hypothesis of this paper is that we need a second game-change, leading to a reactivation of the dynamics and resilience of natural systems in river basins and delta areas. For all urbanized delta regions in the world, it is necessary to discuss and determine whether such an approach is possible and effective. An important question is what consequences such an approach has/could have for economic and urban development, and how this approach can be combined with strategies for energy transition and making our economies, cities, and landscapes more sustainable.

This paper will start with a description of the character of the natural system of the delta (section 1), which is necessary to understand the essence of the first 'game change' (section 2). The section on this first game change will clarify why a second game change is necessary (section 3). The argument will be illustrated with examples from the deltas of the Rhine and Meuse (the Netherlands), the Yangtze (PR China) and the Mississippi River (USA).

THE DYNAMICS AND FORMATIVE POWER OF THE DELTA'S NATURAL SYSTEM

Deltas are the result of dynamic processes of rivers and sea, with regular and irregular changes in currents, tides, wave action, sediment transport and sedimentation, vegetation, wind, precipitation. Most del-

tas owe their present shape largely to the way in which these processes took place in the last 12,000 years, after the last Glacial Period. The large amounts of sediment that were brought in by rivers and the sea and subsequently became overgrown with vegetation led to dynamic processes of land formation (Kleinhans 2010; Teresa et al. 2021).

The dynamic nature of the natural system of deltas gave rise to three main characteristics of deltas: first, extraordinarily rich ecosystems. According to some, deltas and estuaries contain the richest ecosystems, with the most 'ecosystem services' of any ecosystem in the world (Costanza et al. 1997). Deltas include important intersections of migratory fish and migratory birds, which use deltas for foraging, spawning, and breeding.

Secondly, the dynamics of the delta led to the continuous formation of new (wet)land, which increasingly served as a protective buffer in the coastal landscape. It is true that these processes were erratic and in various places they also led to erosion and flooding of land. But the net result over the centuries was that the land in the delta grew with or even grew faster than the rise in the sea level (Seybold et al. 2007).

Thirdly, the dynamics of water and sedimentation also lead, with some regularity, to structural changes in the course of the main river outflow, and thus in the shape of the delta. The development of the Mississippi Delta shows a number of 'delta lobes', which are the result of changes in the course of the main river outflow since the last Glacial Period (Campanella 2006; Blum, Roberts 2012; Giosan, Freeman, 2014). These changes occur once every few hundred or thousand years and are the result of the silting up of the estuary by sediment supply and deposits by the river itself and the sea. At the moment that the riverbed of the main discharge starts to silt up, it starts to act as a blockage, and the water tries to find another, easier route to the sea, especially in the case of huge peak discharges. The development of the Rhine/Meuse delta shows a similar process. The main discharge of the Rhine has moved south in several steps over the course of 12,000 years (Vos 2011).

These processes continued in most deltas until around the mid-nineteenth century, when a series of major interventions began that radically changed the hydrological system and the spatial structure of the deltas.

THE FIRST GAME CHANGE: FROM DYNAMIC SYSTEM TO CONTROLLED MECHANISM

Two important developments during the nineteenth century are responsible for a fundamental ‘game change’ in the systems of river basins and delta: technology and the rise of nation-states. These two developments created the conditions for the era called ‘the Anthropocene’ (www.britannica.com ; Sijmons 2014).

The technological revolution of the nineteenth century includes the invention of the steam engine and later the electric and gasoline engine, and the discovery and use of coal and later oil and gas as energy sources. The new energy sources and technical equipment created the necessity as well as the possibility of making major adjustments to the water systems of deltas and rivers. The steam engine allowed for larger ship sizes; the larger ships required deeper waterways, which were made possible by

1 This paper is a rework of a start document for a working conference of the PBL (Netherlands Environmental Assessment Agency) and CCICED (Chinese Council for International Cooperation on the Environment and Development), written by the author. The working conference took place in October 2022.

steam and diesel-powered dredgers. Riverbed narrowing also took place on a large scale, resulting in deep waterways on the one hand and more available land for agriculture and urbanization on the other. The waters that mainly served as a transport corridor were separated from the land by high dikes, where urban, agricultural and industrial development could take place. Due to intensive drainage of the swampy lowland, subsidence occurred behind the dykes, increasing the vulnerability to possible flooding.

The new nation-states of the late 18th and 19th century created the institutional conditions for the large-scale, cross-regional interventions in the river basins, such as the Rijkswaterstaat (National Water Management Agency) in the Netherlands, and the US Army Corps of Engineers in the USA (O'Neill 2006; Lonnquest et al., 2014; Meyer 2017).

The deltas of the Rhine, Yangtze and Mississippi all experienced this development. It is true that there are many differences between the characteristics of these three deltas, but essentially the development process of each of these three deltas has the same characteristics. If we compare the maps of the three deltas from ca. 1850 with those of 2022, we can not only see a spectacular increase in urban and industrial land use, but also the consequences of large-scale river rectifications and normalisations, of new land reclamations, of countless waterworks such as new canals, dykes, dams, locks, of roads, railways, and pipelines. We also see what has disappeared: many dozens of square kilometres of intertidal areas: wetlands, mud flats, salt marshes, sandbanks, beaches, and dunes.

What took place during this period, which began with the deployment of the first steam-powered ships, dredgers and drainage pumps, and has in fact still not ended, can be called a first fundamental game-change. With the rise of the fossil fuel-based industrial society, compared to the previous centuries, a fundamental change of the game has taken place, with new players, new rules, and new outcomes.

The net result is that, during the last century and a half, delta areas have been drivers of explosive economic growth and prosperity. Not only have the delta areas themselves become centres of economic growth and wealth, but this development has also been crucial for the hinterland. The Mississippi has become the main transportation corridor of the United States since the mid-19th century; 90% of what is shipped across the Mississippi and its tributaries goes to or comes from ports in the Mississippi Delta (O'Neill 2006). The Rhine basin is the economic artery of Europe, or the 'Blue banana' according to the French geographer Roger Brunet (Brunet 1989). The transformation of the Rhine delta into an efficient transhipment and distribution centre played a key role in developing the Rhine into the 'Blue banana' (Klemann, Wubs 2013).

In China, the Yangtze Delta and the Pearl River delta are the two most densely-urbanized regions of the country; together they are responsible for 40% of China's GDP (www.thinkchina.sg)

However, the flipside of this development is that the delta has changed from a natural system to something resembling a mechanical system. The entire water system of the river and delta has taken the form of an industrial machine. This also creates the illusion that rivers and their deltas can be controlled and monitored like an industrial machine. The toll that must now be paid for this illusion is threefold.

Firstly, we must note that the 'mechanisation' of the delta has led to a large decline in biodiversity. In some deltas, the specific features of the delta ecosystem have largely or even almost entirely disappeared. Not only has this led to a considerable impoverishment of fauna and flora in the delta landscape itself; this also has major implications for life on Earth in a much wider context. With the disappearance of large parts of the delta environment, an essential link in the food chains of countless birds, fish, shellfish and plants in our rivers, seas and oceans has been lost (https://www.worldwildlife.org/habitats/wetlands).

Directly linked to this is the second major problem: the disappearance of a large part of the formative capacity and thus of the resilience of the natural system of the delta. Instead of processes of siltation, land accretion and soil raising, other processes have come to the fore: erosion, subsidence, ever higher water levels in the river mouths, and a saltwater tongue penetrating deeper and deeper into the land. And although there is still a supply of sediment, as the most important building block for land formation, it is dredged away to ensure the rivers have the right depth for shipping (Ericson et al. 2006; Tessler et al. 2015; Hoitink et al. 2020).

Thirdly, the attempt of optimal control and fixation of the river and delta has led to the natural process of displacement of the estuaries appears to have come to an end. We emphatically state that this process 'appears to have come to an end', as we see that water management authorities over the past hundred years have been forced to build more and more engineering works in the river system in order to maintain the existing main drainage riverbed. In the Mississippi Delta, a series of dams, spillways and flood ways have been created around the connection between the Mississippi and Atchafalya Rivers to counteract the natural system's tendency to divert the main drainage to the Atchafalaya River. Nevertheless, it is feared that the time will come when this tendency will no longer be countered, with disastrous consequences for the city of New Orleans and the surrounding area (Barnett 2017; Day et al.2014). In the complex network of river courses of the Rhine/Meuse delta, a series of projects have also been carried out that counteract the tendency of the Rhine and Maas rivers to discharge more and more water via the Haringvliet and force this discharge out to sea increasingly via the Nieuwe Waterweg [New Waterway] near Rotterdam (Vellinga et al. 2014).

More than fifty years ago it became clear that maintaining this approach to the river system is harmful and unsustainable. The first large-scale protests against the loss of river and delta nature date back to the 1960s, and led to the first major adjustments in the Netherlands, such as the cancellation of the complete closure of the Oosterschelde [East Scheldt] and the construction of the Markerwaard [Marker polder]. Not coincidentally, the report of the Club of Rome, The Limits of Growth (1972), was published during this period. Although the main aim of these protests and changes was to prevent the disappearance of the delta nature, the need for a fundamental change in economic growth was already hinted at as a guiding principle in the development of natural landscapes (Buelens 2022). The American landscape architect Ian McHarg introduced an analysis and design method for wetland landscapes in the 1960s, in which he addressed the need to make a distinction between slow (climatic, geological, geomorphological, hydromorphological) change processes and faster, often

human-initiated, change processes such as infrastructure development and urbanization (McHarg 1969). His position was that it is important to take good account of the slow processes, to offer sufficient space for this, and to adapt infrastructure and urbanization accordingly. In practice, he saw exactly the opposite happening, with disastrous results. This method was later elaborated in the Netherlands and became known as the 'layer approach', which was advocated in various government memorandums of the 1990s and 2000s (Meyer 2017).

The relevance of this layer approach became apparent from the 1990s, when the first signs of climate change emerged, and it became clear that the channelled river courses did not have enough capacity to discharge the increasing amounts of melt and rainwater caused by climate change. The Dutch Room for the River program (2005-2015) was the first important implementation of the layer approach. Restoration of the river ecosystem was combined with the task of increasing the discharge capacity of the rivers and restoring and strengthening the resilience of the natural system (Sijmons et al. 2017).

Also, in and around the Mississippi Delta, the first ideas for major modification of the river drainage system date back to the 1990s and gained momentum after the 2005 Hurricane Katrina disaster. The wetlands of the delta have been subject to severe erosion since the 1930s. As a result of the channelling of the Mississippi river, all of the tributaries that fed sediment- and nutrient-rich freshwater into the wetlands were dammed. The wetlands form a buffer that reduces the force of hurricanes. Erosion of these wetlands is catastrophic to the survival of the city of New Orleans (Campanella 2006; Barnett 2017).

However, with the latest insights and predictions regarding climate change and sea level rise (Deltares 2018; IPCC 2022), the question is whether the aforementioned changes in the Rhine/Meuse delta, Mississippi delta and Yangtze delta are sufficient. The restoration of nature and especially the restoration of the dynamics and the formative power of the deltas requires a significantly more radical 'game change'.

TOWARDS A SECOND GAME CHANGE: REACTIVATING THE DYNAMICS AND RESILIENCE OF THE NATURAL DELTA SYSTEM IN COMBINATION WITH ENERGY TRANSITION

The need for a new ‘game change’, giving priority to nature-based solutions in delta areas, has already been addressed (Costanza 1997; Temmerman, Kirwan, 2015; Day et al. 2014). However, the major task in delta areas is twofold: (1) to restore the resilience of the natural system and provide room for its dynamics, and (2) to stimulate the transition from fossil to non-fossil energy sources. This means a combination of maximum mitigation as well as adaptation.

One of the main driving forces behind these changes in deltas is the port and shipping industry. In many cases, and certainly also in the deltas of Mississippi, Rhine and Meuse and Yangtze, the transshipment, storage and processing of fossil fuels plays a central role. Port development and shipping were the basis for the radical spatial and hydrological transformation of the delta, but also for the fact that the deltas have become central hubs in an economic system based on fossil energy sources. Due

to the large amount of space required and the many infrastructural systems, the port and shipping system also appears to be the most difficult to change. Because of this strategic role of ports and shipping in the delta areas, and in order to make the discussion more concrete, the consequences for ports and shipping will have to be explicitly addressed when discussing possible future prospects for these delta areas.

Discussions are ongoing in both the Netherlands and the Mississippi Delta about the most effective and desirable strategies for making the delta resilient to sea level rise. In the Netherlands, three approaches seem to emerge in the Sea Level Rise Knowledge Programme: (1) continue the development of the past century, with even larger-scale civil engineering projects, (2) a 'retreat' of cities and economic activity to higher ground, and (3) more room for restoration and reinforcement of the natural system, in the expectation that this will also lead to processes that make the delta less vulnerable to sea level rise and higher peak discharges (Haasnoot et al. 2019).

Also, in the Mississippi Delta, there seems to be a balancing of comparable alternatives, as reflected in the design competition 'Changing Course' (http://changingcourse.us/) .

The first option (reinforcement of the existing system) only seems to cause more problems in both deltas in the longer term. Maintaining increasingly large-scale 'armour' to protect low-lying territory will encounter increasing technical, managerial and financial problems. It seems much too early for the second option ('retreat'); hopefully it doesn't have to come to that. To prevent this option, ‘something’ will have to be done in the delta areas. This ‘something’ should be a first step in the second game change, based on a new priority for space for the natural system.

AN EXAMPLE FROM THE NETHERLANDS: SHALLOWING THE NEW WATERWAY

The proposal for ‘The Rhine mouth as an estuary’ can function as an example of a possible starting point of the second game change (Deltastad, ARK, WWF, 2020; Deltastad, ARK, WWF,H+N+S, 2022). This proposal is based on an analysis of the dynamics of the Rhine and Meuse delta up to the mid-19th century. During this period, the main discharge of the Rhine and Maas rivers was increasingly shifting from the Nieuwe Maas (on which Rotterdam is located) to the Haringvliet river arm, further to the south.

The silting-up of the Nieuwe Maas created the problem of making the port of Rotterdam inaccessible for increasingly larger seagoing vessels. As a solution, a new river mouth was dug to provide the port of Rotterdam with direct access to the sea: the Nieuwe Waterweg [New Waterway] .

figure 01 — page 24

The result was an enormous growth of the port and city of Rotterdam. During the 20th and early 21st century, the port was expanded in a number of steps and the Nieuwe Waterweg was deepened further and further, while the main discharge was again artificially guided via Nieuwe Maas and Nieuwe Waterweg.

figure 02— page 24

figure 03— page 25

The downside of this development is that the influence of the sea on the river mouth region has increased. High water levels and salt intrusion have increased significantly. Moreover, more than 90% of the flora and fauna of the delta has disappeared, which has led to a dramatic reduction in biodiversity in the region.

Similarly, the salt water wedge occurs during the low water stage of the Mississippi River, threatening the water supply intakes of the area around and south of the city of New Orleans.

'The Rhine mouth as an estuary' is a proposal to investigate to what extent it is possible to have the main discharge run again via the Haringvliet and to make the Nieuwe Waterweg shallower. *figure 03— page 25*

This intervention is expected to be an important condition for the restoration of the flora and fauna of the delta, and to reduce salt-water intrusion and high water levels in the Rotterdam region. Research results by students from TU Delft and Rotterdam University of Applied Sciences have so far shown that the effects of shoaling on saltwater intrusion and high water levels are substantial (Hensen, 2021; Iglesias, 2022).

A shallowing and widening of the estuary can go hand in hand with a spatial reorganization of the port area, so that the estuary area becomes a central hub in a major landscape. and a significant ecological structure instead of a blockage. New ways of 'living on the water' will make the region more attractive as a place to live and work.

A strategy based on shoaling will also help to galvanise the necessary transition and transformation of the port area, whose land use is still largely (60%) determined by the storage, transshipment and processing of fossil fuels. When it becomes more shallow, the Nieuwe Waterweg can still remain navigable for inland vessels and smaller seagoing vessels, but no longer for the largest carriers. For the time being, the ports of Maasvlakte 1 and 2 and Europoort can remain accessible to the largest seagoing vessels via the parallel waterway, the Caland Canal.

CONCLUSIONS

This analysis of delta areas and the proposal for an approach for the Rhine and Meuse estuaries indicate that the current game change must entail a change of priorities: while in the past 150 years, as a result of the first game change, economic and urban development have taken centre stage and the water system has been adapted accordingly, this will now have to be completely reversed: attention must now be focused on a strategy for a sustainable water system, characterized by the reactivation of natural dynamics and natural processes of land formation, meaning that economic and urban development will have to adapt accordingly. The proposal for 'The Rhine mouth as an estuary' shows the results that can be achieved with a reversal of this kind.

This reversal is perfectly feasible at this current moment in time, because of the needs of the energy transition, which will have huge impacts on industrial land use.

However, this reversal of priorities will not take place by itself. In most delta regions, port authorities and port- and shipping-related companies play a major role in the area of water management and spatial planning. However, in all these delta regions an analysis and public discussion is necessary if the economic values of ports and shipping are still in balance

with the increasing problems for humans and the other flora and fauna in the delta. In other words: are the profits for private companies still in balance with the public expenses for flood defence systems and related engineering systems, and for nature conservancy? Finally, strong political leadership at national and cross-national level will be necessary as a condition for implementation of the second game change.

But as a first step, exploring the possibilities and new potentials of a new game change will be necessary to start the debate. Design explorations, and the collaboration of designers with engineers and with ecological and hydrological scientists will be crucial in providing us with a vision of what the second game change can look like, how it can be implemented, and what kind of new conditions for economic and urban development can be derived from it.

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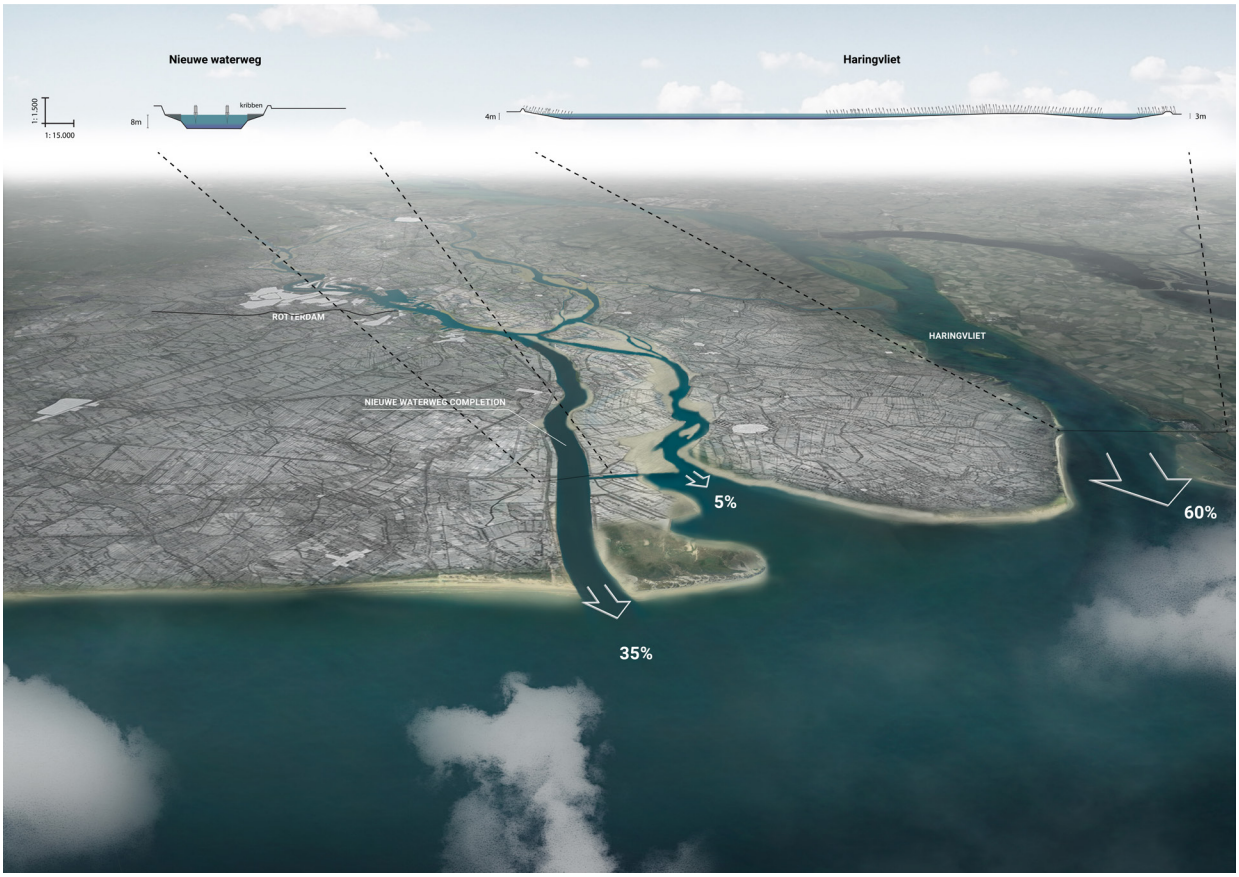

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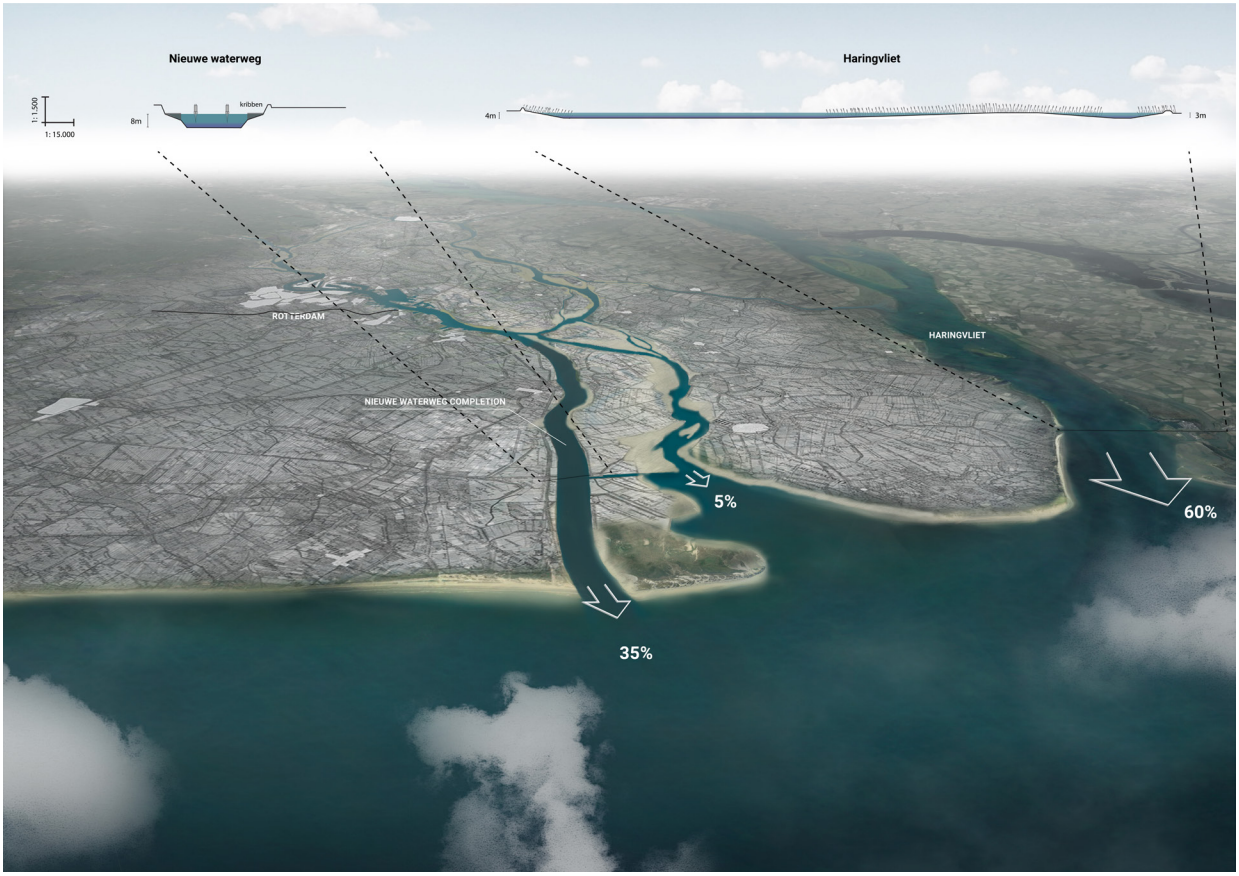

02

01 Birds eye view of Rhine-Meuse delta in 1900, seen from the west, and sections of the waterways.
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02 Birds eye view of Rhine-Meuse delta in 1980, seen from the west, and sections of the waterways.
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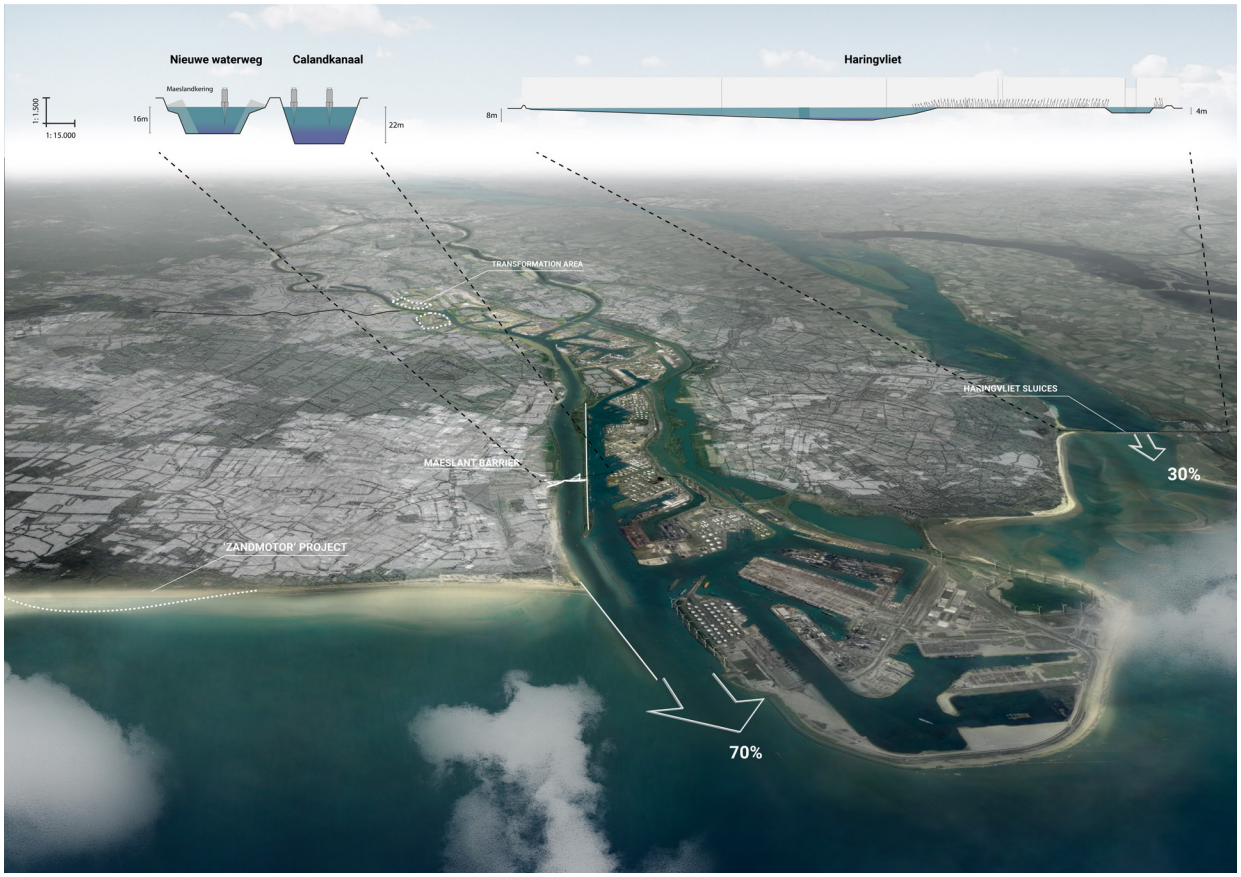

03

04

03 Birds eye view of Rhine-Meuse delta in 2020, seen from the west, and sections of the waterways.
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04 Birds eye view of a possible future of the Rhine-Meuse delta, seen from the west, and sections of the waterways.
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