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Living with Sea-Level Rise and Climate Change: A Case Study of the Netherlands

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ABSTRACT

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Based on historical hindsight, this paper shows that sea-level rise has played a fundamental role in the development of the low-lying environment of the Netherlands. It was beneficial in morphological terms during the mid-Holocene, but from Roman times, it has been a threat to the coastal zone evolution and human habitation. Collective human response started to play a role in coastal evolution as early as the ninth century, while its influence started to become a major factor during the nineteenth and twentieth century.

Throughout its history, Dutch society has always been receptive to new technologies, approaches, and policies in its dealings with the many water-related challenges. The success of concerted human response explains why the water boards were successful as the first democratic institutions in the Netherlands. Development of technology and increasing financial means (the Dutch Golden Age) gave rise to increasingly viable flood abatement measures and reclamation projects, which took place on increasingly larger scales. This culminated in large-scale works such as the closure of the Zuiderzee and the Delta Project in the twentieth century. During this project, a turning point in thinking emerged; while flood protection remained a top priority, human interventions were considered in a broader, more holistic context with natural values being weighed against socioeconomic interests.

In the face of the challenges of the twenty-first century, policy and management approaches as well as science and technology approaches need to be adapted further in accordance to the principles of working with nature in a transdisciplinary way. The success of this adaptation will to a large extent determine the viability of the Dutch society as a whole.

ADDITIONAL INDEX WORDS: *Adaptation, protection, accommodation, water management, flooding, reclamation, societal perception.*

INTRODUCTION

While the Netherlands is a small country (some 34,000 km^2), it is densely populated (some 460 inhabitants/km^2) and has a large active economy. Geologically, the coastal zone mainly consists of a series of deltas and flood plains of the rivers Scheldt, Meuse, Rhine, and Ems, bordered by coastal barriers (in the north in the form of barrier islands), a large (former) lagoon, tidal inlets, and coastal plains. The total length of the Dutch coastline is more than 400 kilometres, which can be divided into three different parts: the tidal inlets and estuaries in the south (now mostly controlled by open or closed barriers), the uninterrupted duned Holland coast, and the Wadden Sea area (featuring a series of barrier islands) in the north.

At present, almost one-third of the country is located below average sea level. A further third has to be protected against flooding by rivers in periods of high discharges. The shaded section of Figure 1 shows the current area of +1 m above the reference level NAP (Dutch ordnance level ≈ 0.5 m above current mean sea level). Low-lying countries such as the Netherlands, because of their physical characteristics, are highly vulnerable to the consequences of extreme climatic events such as storm surges and periods of extreme precipitation. As a consequence, sea level as an expression of climate change has been a dominant boundary condition for the existing land and its users for thousands of years.

This paper starts with an overview of the historical interaction between the Netherlands and the sea. This overview is based on BIJKER (1996), VAN DE VEN (1993), VAN VEEN (1962),

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Figure 1. Flooded area without dikes (van de Ven, 1993).

and ZAGWIJN (1986) (for the sake of readability, these authors are acknowledged here once rather than repeatedly at each of the numerous relevant passages in the following pages). Special attention is given to the way the Dutch have dealt with the associated natural hazards over the years. This includes a distinct turning point during the twentieth century, when more holistic approaches to management were first applied and important changes in the technical and institutional treatment of the coastal zone occurred. Finally, an overview is presented of the future challenges of dealing with water-related issues in general and sea-level rise in particular.

The attention given to the historical coastal evolution serves to illustrate the basic thesis of this paper, which is that the Dutch delta is the result of an ongoing, evolving, and dynamic relationship between people and sea-level rise. Hence, future problems of climate change and sea-level rise are part of this evolution rather than something fundamentally new.

THE ROLE OF SEA-LEVEL RISE IN THE HISTORICAL EVOLUTION OF THE NETHERLANDS

Pre-Holocene Landscape

By far, the greater part of the Netherlands' surface consists of geological deposits of the Quaternary, which began more than 2 million years ago. The Quaternary is subdivided into the Pleistocene, which covers the major part of the Quaternary with many glacial and interglacial periods, and the Holocene, the last and current interglacial period, which began only 10,000 years ago. During the Pleistocene period, large parts of the northern landmasses were covered with ice, which grew and melted alternately. During the first hundreds of millennia of the Pleistocene, most of the Netherlands was still submerged, and as such it formed part of the so-called North Sea Basin. This basin collected large amounts of sediments, which were deposited by the sea, rivers, ice, and wind successively.

The ice cap reached as far as the northeast of the Netherlands several times. The penultimate ice age (180,000–130,000 years ago) had the greatest geological impact on the Netherlands. The ice cap profoundly changed the landscape. The thrust of the ice caused the formation of ridges and lateral moraines. The highest lateral moraine, in the eastern Veluwe, is even today 100 m + NAP.

During the last ice age (110,000–10,000 years ago), the land ice did not reach the Netherlands. The ground top layer thawed in summer and froze in winter. Sparse vegetation allowed the wind to transport large quantities of sand to be deposited elsewhere. This material covers older layers of deposits like a blanket and is known as "cover sand deposits". Almost all of the eastern and southern regions became covered with these sands. Today, these Pleistocene layers can still be found on the surface in the east and south. In the west and north, Holocene deposits cover them.

10,000 BP to 2000 BP: Regression and Progradation of the Holocene Holland Coast

The Pleistocene topography of the western Netherlands' shore and the rapid relative sea-level rise during the first half of the Holocene (80 cm/century and more; see Figure 2) has led to an initially transgressive and later regressive coastal system, in which the river valleys acted as backbarrier sediment sinks. In waterlogged areas where fluvial and marine sedimentation was low or absent, large areas either accumulated thick layers of peat and deposits of organic detritus or remained open water with (hazardous) implications for future coastal development.

The sea transgressed continuously, and around 7500 BP, the location of our coasts was approximately that of today (see Figures 3 and 4a). A sandy coastal zone with offshore beach barriers and dunes existed that was interrupted by coastal inlets giving access to (inter-)tidal basins consisting of mudflats, reed marshes, and peat-forming swamps (see Figure 4b). As the sea level kept rising, the coastline and the concomitant sedimentary environments shifted gradually inland until about 4000 years ago. Around 5000 BP, the rate of sea-level rise decreased. Based on geological interpretation (BEETS, VAN DER VALK, and STIVE, 1992), this caused a choking of the coastal inlets, and a strongly prograding barrier system developed (see Figure 4c). This prograded barrier system is still visible in the west of the Netherlands and is known as the "Old Dunes". Some of the former mudflats and tidal salt marsh areas behind this barrier system continued to fill with vegetation under the influence of a rising relative

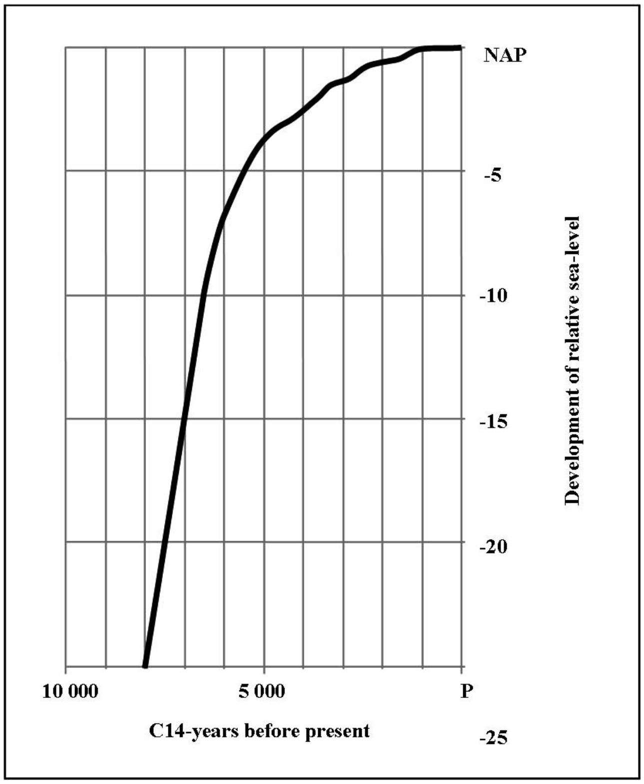

Figure 2. Relative sea-level trends in the Netherlands during the Holocene (Zagwijn, 1986).

sea level, while in other places, the sea transgressed, creating tidal inlets in which sand, silt, and clay were deposited. This Holocene transgressive period was positive in morphological terms because it created a Holocene sediment wedge up to 30 m thick in the western Netherlands.

AD 0 to the Ninth Century: Sea Transgressions and Invasions

Most of the prehistoric coastal settlements were constructed as "Flachsiedlungen", but later dwelling mounds, *i.e.,* "terpen" (*cf.* WATERBOLK, 1988) were constructed; the latter being the first attempts to put up defences to sea-level rise, of which the first date back to 500 BC. More systematic human settlement started from the first century AD. Just behind the closed coast in the south and east of the Netherlands, there were many areas with stagnating drainage. The cool humid climate was ideal for formation of peat, which covered extensive areas of the Netherlands. During the first centuries AD, the peat areas in the southwest of the Netherlands subsided supposedly due to man-induced drainage works (in the remaining peat area, this happened after 1000 AD). This human interference tapped the water table in the peat areas that became connected with the tidal channels, which caused peat growth to stop. As a consequence, marine influence increased, leading to a long period of coastal erosion in the areas not protected by a strong barrier (in southwest Netherlands from 300 AD and in north Netherlands from 1000 AD). Peat areas where the sea had broken through the embankments were washed away and, in other areas, clay was deposited on top of the peat. Much of the remaining peat cover later disappeared due to peat extraction for fuel.

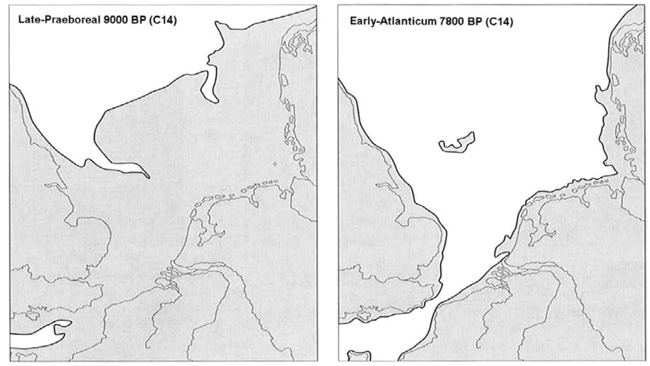

Figure 3. Coastlines in the southern North Sea area in 9000 and 7800 BP (Zagwijn, 1986).

From Ninth to Thirteenth Century: Initiation of Water Management

Significant physical changes continued after 800 AD, although the precise triggers and drivers are still not understood (BEETS and VAN DER SPEK, 2000). From about 1000 AD onward, an important physical change took place along the barrier coast: a redistribution process of sand along the western Netherlands' coast. Large amounts of sand were re-

Table 1. *Most important storms in the twelfth and thirteenth century (van de Ven, 1993).*

Date	Storm Surge Floods after 1100 AD
1134 AD	The storm surge wreaked havoc, particularly in the southwest of the Netherlands. During the years following this storm surge, the sea arms were enlarged considerably. To protect the remaining lands, comprehensive diking activities took place.
1163 AD	Floods ravaged Holland. Along the mouth of the river Maas, many dikes burst. Consequently, the mouth of the Oude Rijn, which had already been silted up to a large extent, was blown shut completely. In all probability, this storm surge also caused havoc in the northern part of Holland.
1170, 1196 AD	The north and the northwest of the Netherlands were hit by storm surges. These were a deciding step toward the further extension of sea influence in the north of the Netherlands. The Almere lake complex became a large sea inlet (the Zuiderzee). Following these storm surges, the peat area north of the present West-Friesland gradually changed into a mud-flat area. In addition, the large lakes in Noord-Holland were formed.
1214, 1219, 1248 AD	The north was repeatedly ravaged by storm surges, causing the Zuiderzee, the Noord-Holland, and Friesland lakes to be continually enlarged. Records of these disasters repeatedly mention transgressions along the Eems in the east of Groningen, flooding the low-lying peat area behind the levees of this river.

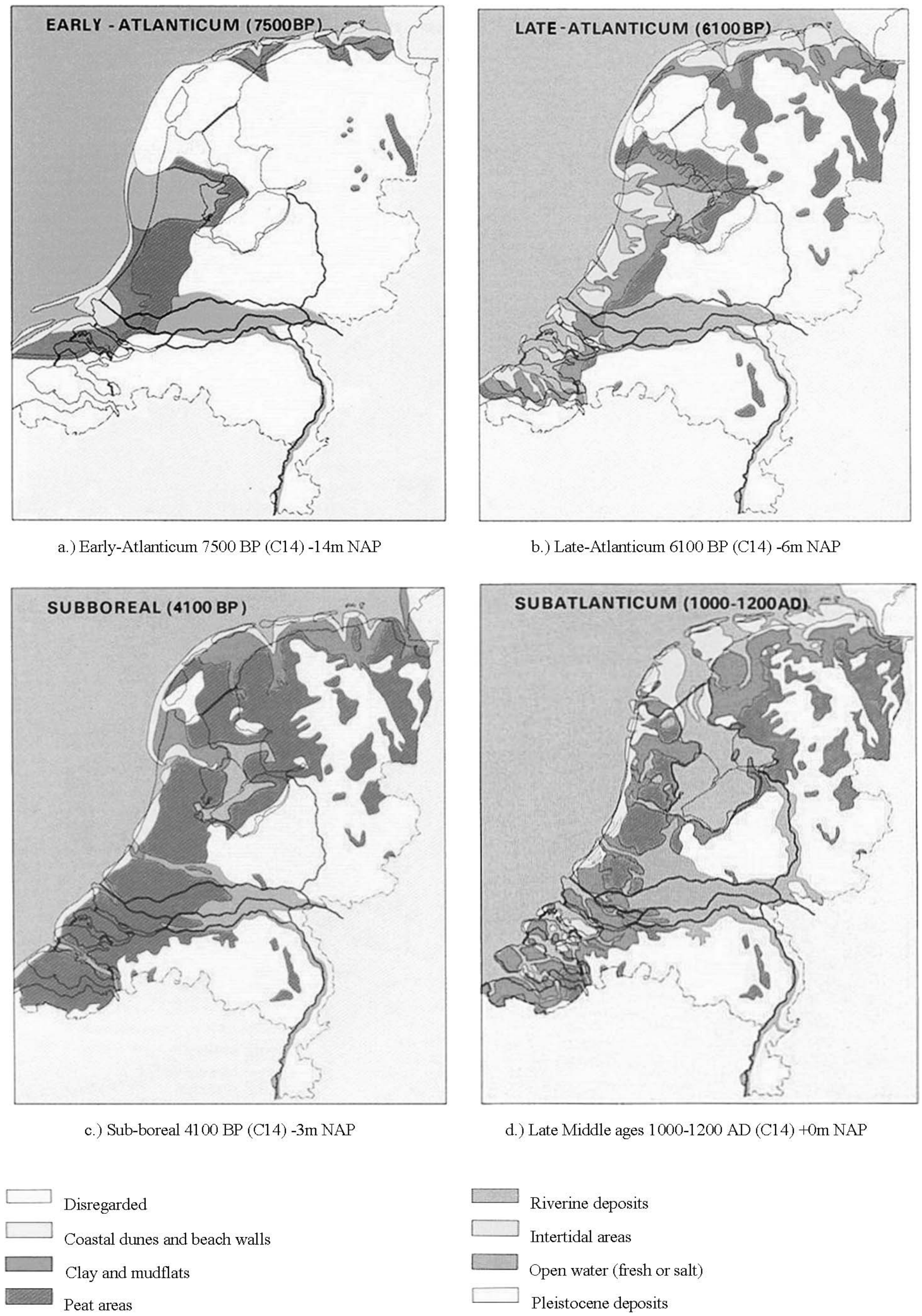

Figure 4. Development of the Netherlands during the Holocene (Zagwijn, 1986). **For a color version of this figure, see page 444**.

leased and worked into the back-barrier areas as well as blown inland, causing the formation of a new belt of large transgressive coastal dunes (the Younger Dunes), which became several kilometres wide. The Younger Dunes overlie part of the Older Dune landscape or, where the Older Dunes did not exist, lie directly on top of the clay and peat of the coastal plain. As a whole, the Holland coast stretched and straightened, reducing the number of coastal cells from more than three to just one.

Between 800 and 1250 AD, enormous losses of land occurred in the Netherlands, especially in the north and in the southwest (see Figure 4d). Although the combination of continuing sea-level rise with an increase in the frequency and magnitude of storm surges is sometimes suggested as a cause (GOTTSCHALK, 1971–1977), it is now known that in historical times, human occupation was the main cause of the loss of land (*cf.* VAN DE VEN, 1993). Peat cutting (for fuelling the early economic expansion of the southern Netherlands) led to significant land losses in back-barrier areas. Because of this land loss, large riparian areas in tidal basins became intertidal and sea inlets were scoured as tidal volumes increased. At the same time, storm surges penetrated deeper inland via the widened and deepened sea inlets (see Table 1), which encouraged further marine influence and accelerated the process of land loss.

Although sedimentation of sand and clay subsequently occurred in places, overall, the process of land loss prevailed. The Netherlands had changed from an area with a continuous protective barrier into an area that lay open to the influence of the sea from the southwest and from the northwest through the area of the former coastal lagoon (the "Zuiderzee"). For the first time, man, besides natural factors, had become an important factor in the evolution of the Dutch delta.

Flood Abatement, Reclamations, and Water Management

Increasing human interference on the coast is closely linked to historical trends in water management. Subsidence increased the risk of flooding and impeded the drainage of surplus surface water. To protect these areas, the dikes were strengthened continuously. By the thirteenth century, a major organizational step was taken by the introduction of dike rings in the majority of the threatened areas.

For effective reclamation, maintenance of the drainage system and the subsequent diking, proper administrative organisation of the population was essential. Using bylaws and inspections, drainage canals and dikes could be adequately maintained by landowners who were liable for maintenance. In some communities, a special board of permanent representatives was formed to carry out these tasks, and construction and maintenance of the drainage system became a local matter. This implied that each community carried responsibility for draining their surplus water into the outside waters although, in principle, it was not permissible to let surplus water flow into the drainage system of a neighbouring community. This gave rise to many disputes between bordering communities trying to solve the problems that arose. Conversely, these communities becoming involved in drainage has to a large extent been beneficial to Dutch water management and its infrastructure.

Probably the most important development in this period was the establishment of regional water boards. These were regional governmental bodies regulating water management, including the inspection and maintenance of hydraulic works. Thanks to the establishment of these water boards, the drainage system of an entire region or a dike ring could now be maintained. To this day, the water boards remain an essential element of water control in the Netherlands. As a result of local water management measures, the population in river areas grew considerably and a system of uninterrupted dikes was completed in the thirteenth century. Hence, the previous *accommodation* strategy (WCC '93, 1994) by means of dwelling mounds had changed into a *protection* strategy by the end of the thirteenth century; a remarkable turning point in the history of water management in the Netherlands. From then on, technology played an increasingly important role in water management, *e.g.,* outlet sluices constructed at that time are of a high technical standard. Without these sluices, construction of water barriers would have hindered drainage to such an extent that an intolerable situation would have been created. Every town and city with the suffix "dam", *e.g.*, Rotterdam, date from this period (VAN DE VEN, 1993), indicating another significant step in the protection strategy.

From Thirteenth to Seventeenth Century: Institutionalisation of Water Management

Between 1250 and 1600, southwestern and northwestern coastal regions of the Netherlands were still strongly influenced by marine processes. Because sea-level rise rates had now decreased to approximately 10 cm/century (Figure 2), this influence was mainly due to storm surges. After 1250, many floods occurred, with the second Saint Elizabeth flood of 1421 being the most disastrous. Widening and deepening of the tidal inlets was primarily caused by these floods. They promoted the penetration of the tidal wave and of the storm surges, causing higher water levels especially where inlets were narrowing. Increasingly larger tidal volumes caused storm surges to overflow the dikes, giving rise to frequent dike breaches. There are indications that along the now completely closed Holland coast storm surge run-up levels reached increasingly higher than previously (JELGERSMA, STIVE, and VAN DER VALK, 1995).

The riparian coast of the shallow Zuiderzee lagoon (average depth of about 3 m in its southern basin) was also increasingly endangered. During long-lasting storm surges from the northwest and local wind-driven setup of the water, the Zuiderzee basin experienced high surge levels for a long period. Between 1250 and 1600, the breaching of dikes occurred frequently, and the flooded area increased in size; partly as a result of land subsidence in already drained peat areas and partly because natural peat moor cushions' water tables were tapped, causing them to collapse. In most places, dikes built in previous centuries were insufficient to withstand the surges, and dikes had to be repeatedly upgraded and/or rebuilt further inland. As a result, water management became better organised, but this could not stop coastal erosion in the Zuiderzee area. Only after another storm surge disaster in 1916 did plans to close off the lagoon became a reality (see later in this paper).

The river system had remained largely intact until around 1300. From then on, damming of some river branches increased marine influence. This altered the courses of the rivers, in particularly in the southwest, and several river branches switched to different tidal inlets. Apart from large floods, there was also widespread local waterlogging, (for a concise history of Dutch river floods, see TOL and LANGEN, 2000).

Figure 5. Drainage in stages by series of windmills (Courtesy of Rijkswaterstaat). **For a color version of this figure, see page 445**.

Water Management Aspects

Technologically, the consequences of waterlogging due to subsidence were now partly compensated for by the introduction of drainage by windmills starting from the sixteenth century (Figure 5). By digging drainage canals in much of the low-lying areas, an improved drainage system was created. This led, however, to an unstoppable subsidence in land levels relative to the still (slowly) rising sea level that induced an ever-growing need for more intensive drainage during later centuries. In the southwest of the Netherlands, loss of land was virtually brought to a halt in the sixteenth century after a gradual but steady loss of clay land overlying peat (termed "Old-Land") due to storm surges. A large number of new intertidal areas were reclaimed in the fourteenth and fifteenth centuries, and the soil structure of this New-Land was considerably better (for agriculture) than the lost Old-Land. In the north, more land was gained by reclamation/drainage than had been lost since the sixteenth century. Furthermore, the organisation of the water-boards became a constituent part of the government system in the various regions. The structure of the water management system, which had developed by this time, remained unchanged well into the nineteenth and twentieth centuries.

From Seventeenth to Nineteenth Century: Large-Scale Reclamations of Former Lakes

The seventeenth and eighteenth centuries were characterised by increasing human intervention because of technological and economic developments.

Technical Innovation

A range of technical innovations in drainage methods and a greatly increased capacity to manage water were the keys to the success of water management in general and reclamations in particular. This included bigger wind mills, better pumps, and better integration of drainage components. Reclamation of increasingly greater and deeper lakes and wide meres became possible thanks to such innovation. Toward the end of the eighteenth century, the first experiments were carried out with steam engines. Engines imported from England were used for drainage in the surroundings of Rotterdam (1776 and 1787) and near Mijdrecht (1793) although the major application of this technique came after 1860.

The seventeenth and eighteenth centuries were not without problems, as storm surges occasionally still had disastrous consequences (*e.g.,* 1625, 1686, 1717, 1775/76, and 1776/77). Equally severe river floods occurred in 1608, 1651, 1725, 1741, 1757, 1784, and 1799. Note that this list is by no means complete. Storm surges and floods, however, also had "positive" effects in terms of triggering technical and institutional development and innovation.

Technology, Economy, and Water Management

Despite the setbacks mentioned above, on balance the Dutch struggle against water turned out to be largely positive because of reactive management measures and a favourable socioeconomic context. The availability of innovative technology and the need for land played an important role. A strong growth in the population caused a rise in land prices, so investments in new land became a profitable venture. The strong trading position of the Netherlands' private ship companies between the Far East and Europe in the seventeenth and eighteenth centuries resulted in a large supply of capital whereas the possibilities for investment were limited. To protect investments, more robust protection works were installed. Wooden sluices were replaced by brick sluices, uniformity in dike design was established, existing dikes were significantly strengthened, *etc.* From then on, the condition of protection works was better managed.

Between 1600 and 1800, areas under reclamation increased dramatically, primarily driven by the desire to increase the area of productive agricultural land. Additionally, there was qualitative land reclamation—upgrading previously unproductive lands—thanks to the improvements in drainage techniques, such as the introduction of a system of high and low storage basins. In the eighteenth century, regulating the river flow of the Rijn and the Waal significantly decreased the danger from river floods.

Nineteenth and Twentieth Centuries: From Megascale Works to Paradigm Shift

Reclamation continued at a large scale during the nineteenth and twentieth centuries. The most spectacular lake reclamation scheme of the nineteenth century was that of the Haarlemmermeer in 1852, with a size of well over 18,000 hectares. Extensive coastal reclamations of the Wilhelminapolder (1809) in Zeeland, the Noord-Holland polders Koegras (1817), and the Anna Paulowna (1835) were carried out along with reclamation of the accretions along the Dollard and the Wadden coast (6,700 hectares). Between 1833 and 1911, a total of 350,000 hectares of land were brought into cultivation, of which 100,000 hectares were lands gained from the sea and drained lakes.

Figure 6. System of shipping routes developed by digging of channels in the nineteenth and twentieth century (van de Ven, 1993).

Although the risk of flooding in the river area had decreased significantly by extensive water management, it had not altogether disappeared. River floods occurred in 1809, 1820, 1855, and 1861. Ice dam formation on the large rivers was particularly dangerous, as it often resulted in breaches in dikes. While it started to be recognised that complete flood protection was unrealistic and some residual flood risk had to be accepted, further interventions were necessary for navigation and drainage purposes. Through extensive dredging, a coherent system of channels was developed in the nineteenth and twentieth centuries, both improving discharge and creating shipping routes (see Figure 6), such as the Nieuwe Waterweg (1868) and the Noordzeekanaal (1876). The impact of storm surges had also decreased after centuries of improved water management. However, two serious storm surges occurred in 1916 and 1953, triggering additional protective measures on a scale larger than any earlier projects.

Zuiderzee Project

The floods of 1916 and the apparent vulnerability of the Dutch food supply during the First World War triggered a project to close the Zuiderzee lagoon. This shortened the coastline by 300 km, 220,000 hectares of land were gained, and a fresh water reservoir of 120,000 hectares was created. The enclosing dam of the IJsselmeer, called "Afsluitdijk", was completed in 1932, the Wieringermeerpolder (20,000 hectares) was dried in 1930, and the Noordoostpolder (48,000 hectares) in 1942. After the Second World War, the polder Flevoland (96,000 hectares) was also reclaimed. It is doubtful

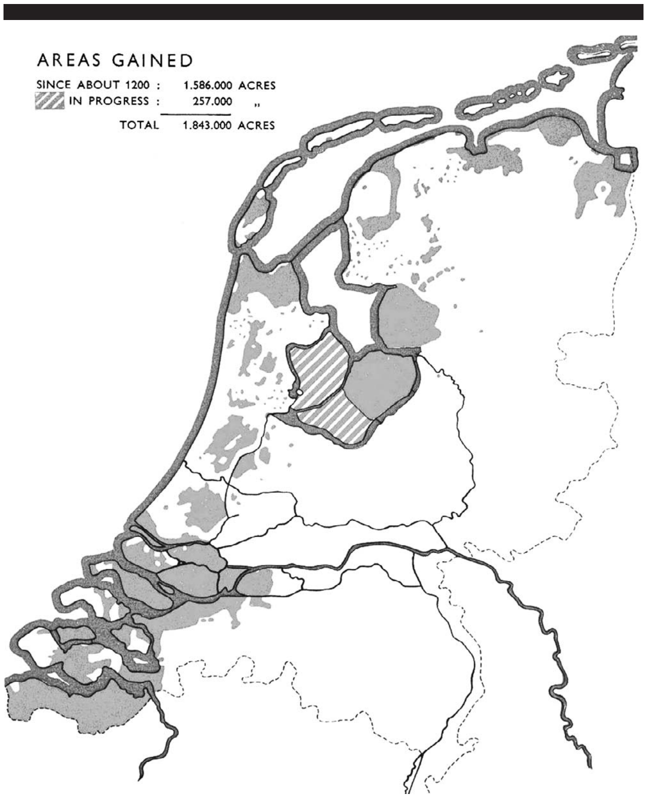

Figure 7. Original figure (van Veen, 1962) of areas of reclaimed and accreted land. *N.B.:* The western part of the area in progress, *viz.* the Markerwaard, was never implemented. **For a color version of this figure, see page 445**.

whether the originally planned Markerwaard polder (see Figure 7) will ever be realised. Since its planning, the need for new agricultural land has diminished, whereas the appreciation of benefits of the IJsselmeer as open water for water management and recreational purposes has increased. There was much fear as well that large-scale and very costly geotechnical and foundation problems on the old land would arise from the reclamation of such deep lakes (initial depth more than 8 m!) (DE MULDER *et al.,* 1994).

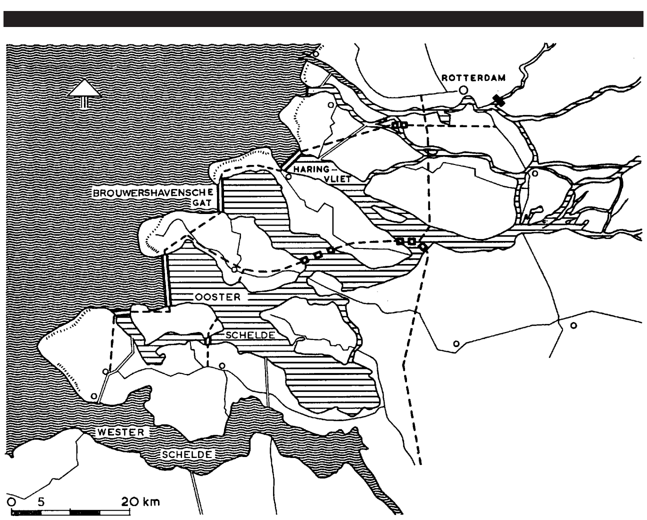

Figure 8. Original plan of the Delta Works (Courtesy of Rijkswaterstaat).

Delta Project

The 1953 storm surge disaster, which claimed 1835 lives and flooded 165,000 hectares of land in the Netherlands (GERRITSEN, 2005), triggered another huge hydraulic undertaking: the Delta Project (Figure 8). The Netherlands had to be secured against similar extreme disasters. In the contemporary (post–World War II) socioeconomic context, the only feasible solution seemed to consist of the closure of all sea inlets, except for the Nieuwe Waterweg (entrance to the Port of Rotterdam) and the Westerschelde (entrance to the Port of Antwerp). In 1958, the Delta Act was passed, and work started to shorten the total length of the coastline and thus the length of the potentially vulnerable coastal defences.

Extensive research work, carried out in the first decades of the Delta Project, focused on technical feasibility of the highly innovative engineering of the structures. This included research work on the hydrodynamics and morphology of the coastal zone in order to be able to guarantee the stability of the structures (see also Table 3; WATSON and FINKL, 1992). Safety levels of the new and/or reinforced coastal defence structures were defined based on the occurrence frequencies of extreme storm surge levels, which should lead to a small (say 10%) probability of failure. Occurrence frequencies were determined for each part of the coastline based on detailed water-level time series covering a period of more than 100 years. Relative sea-level rise of 10–20 cm/century over the last few centuries was taken into account in the design and construction of the coastal defences. A higher critical design level also incorporated the consequences of future sea-level rise, although no acceleration in sea-level rise was considered at that time.

Economically favourable conditions triggered a change in societal perception, which required the reconciliation of safety with environmental issues, and public pressure led to a revision of the Delta Plan. After the Haringvliet and Grevelingen tidal basins had been closed by dams according to the original plans, parliament decided (1979) to preserve the Eastern Scheldt's tidal flats and saltmarshes with their abundant flora and rich fauna and the high-yield shellfish fishery. This resulted in the construction of a storm surge barrier in the mouth of the Eastern Scheldt tidal basin that can be closed when storm surges approach (SAEIJS, 1982).

This marked a second turning point in the history of Dutch water management. After a thousand years of adaptation and another thousand years of protection strategies, the Netherlands would now adopt a more integrated approach. The Eastern Scheldt case shows the first signs of an upcoming paradigm shift affecting all three components of the triangle: policy, management, and knowledge.

Development of a Water and Coastal Policy at National and EU Levels

The tendency toward a more integrated approach of water problems and an upcoming paradigm shift are reflected in

Table 2. *Summary of developments in water policy with special emphasize on the coast.*

Date	Policy Documents: High Lights
1968	First Water Management White Paper (MIN V&W, 1968): sectoral missions to develop the infrastructure for flood protection and to satisfy freshwater demand.
1984	Second Water Management White Paper (MIN V&W, 1984): water is a multifaceted resource.
1989	Third Water Management White Paper (MIN V&W, 1989): long-term strategy toward sustainable development.
1990	First Coastal Policy White Paper (MIN V&W, 1990): sustainable preservation of safety and of functions and values in the dune area by "Dynamic Preservation" of the coast line; start of a regular nourishment programme of 6 mm³/y.
1995	Second Coastal Policy White Paper (MIN V&W, 1996): Dynamic Preservation policy confirmed.
1996	Flood Defence Act (TK, 1996): legal liability to preserve the coast line.
1998	Fourth Water Management White Paper (MIN V&W, 1998): resilient coastal systems by working with nature.
2000	Third Coastal Policy White Paper (MIN V&W, 2000): long-term continuation of Dynamic Preservation requires compensation of sand losses in deeper water; yearly nourishment programme extended to 12 mm³/y.
	Nature Conservation White Paper (MIN LNV, 2000): dynamic coast with more space for natural processes and restoration of estuarine characteristics.
2002	Policy Agenda "Towards Integrated Coastal Zone Management" (MIN V&W *et al*., 2002): multisectoral paper formulating conditions for implementation of an IZCM policy.
	EU Recommendation on Implementation of Integrated Management of Coastal Zones (EUROPEAN COMMISSION, 2002): Definition of eight principles for integrated management.[1]
2005	National Spatial Planning Memorandum (MIN VROM, 2005): coastal policy is an integral part of spatial planning policy; sand is structuring principle; preservation of coastal foundation is basis for sustainable development.

[1] Eight principles for ICZM: holistic perspective, long-term approach, adaptive management, specification of local characteristics, natural processes, involvement of all stakeholders, and of all administrative levels, combination of instruments.

the development of water policy. Focussing on the coast, Table 2 illustrates this gradual development in policy thinking.

Although aggregated at a national level, the First Water Management White Paper (WMWP) (MIN V&W, 1968) was of a sectoral nature. The Second (MIN V&W, 1984) and Third WMWP (MIN V&W, 1989) made the connection between water management and economic and ecological development, introducing integrated water management and a water systems approach. The strategic objective of water policy was no longer limited to "a safe and well inhabitable country", but also to "healthy and sustainable water systems". Flood abatement, although still an important priority, would now be carefully evaluated in the context of all functions, values, and uses of water areas (*cf.* DE RUIG, 1998; TAW, 1995b). The Fourth WMWP (MIN V&W, 1998) intensified the connection with sociological developments by introducing an open plan procedure. An extensive governmental study into water management for the twenty-first century (WB-21, 2000), besides including technical adaptations, stresses the importance of creating public support, of alternative ways to exercise political authority and use of institutional resources, and of investments in the future.

Table 3. *Summary of characteristic research projects commissioned by the Dutch Ministry of Public works over the last decades (Van Koningsveld* et al.*, 2003). Abbreviations: FOW (Fundamenteel Onderzoek Waterstaat), TOW (Toegepast Onderzoek Waterstaat), GEOMOR (Geo-MORphology), VOORDELTA (the Zeeland foredelta area).*

Date	Research Projects: High Lights
1971–1975	FOW project: fundamental knowledge development (*i.e.*, on hydrodynamics and sediment transport) in support of the initial design stages of the Eastern Scheldt barrier.
1975–1980	TOW project: more applied knowledge development (*i.e.*, on coastal morphodynamics), amongst others, in support of the actual construction phases of the Eastern Scheldt barrier.
1982–1986	GEOMOR: monitoring, process-measurement, and modelling of geomorphological effects on the channels and intertidal areas inside the estuary.
1984–1988	VOORDELTA: monitoring, process-measurement, and modelling of geomorphological effects on outer deltas.
1986–1990	Studies supporting the First Coastal Policy White Paper: research programme addressing a wide range of items in support of the efforts to generate the First Coastal Policy White Paper. Main outcome was the policy decision of Dynamic Preservation of the coastline to counter structural coastal erosion. The preferred intervention method was sand.
1986–1989	Coastal Genesis—Phase 1: formulation and verification of hypotheses regarding evolution and behaviour of the closed Holland Coast. For the first time, other disciplines (*i.e.*, geology, historical geography, and physical geography) were involved to cover the wide range of time and space scales addressed.
1989–1993	Coastal Genesis—Phase 2: development of system knowledge at larger scales focusing on geological reconstruction, interrupted coasts, and uninterrupted coasts.
1994–1995	Coastal Balance 1995—Second Coastal Policy Document: research programme addressing a wide range of items in support of the efforts to generate the Second Coastal Policy White Paper. Main outcome was the intention to counter structural sand losses in deeper water as well as the dynamic preservation strategy from the First Policy White Paper.
1996–2000	Coast 2000: research programme to solve specific coastal management problems that came up after several years of experience with the Dynamic Preservation policy.
2001–2005	Coast 2005: research programme focusing on development of system knowledge in addition to the mere solving of previous specific coastal problems.

As a part of the water systems approach, in 1990 the First Coastal Policy White Paper (CPWP) (MIN V&W, 1990) was conceived, introducing sand nourishment as the principle proactive measure for sustainable preservation of safety and of functions and values in the dune area. Reconfirming this approach, the Third CPWP (Min V&W, 2000) extended the scale of nourishments, prescribing the compensation of sand losses at deeper water levels. The latter evolved into the definition of a coastal foundation for the Netherlands—the area including the dunes down to the −20 m depth contour (see, *e.g.,* VAN KONINGSVELD and MULDER, 2004)—and into the objective of preserving and improving it as a basis for sustainable safety and spatial quality of the coastal zone: the National Spatial Planning Memorandum (MIN VROM, 2005). Thus, coastal (and water) policy became an integral part of spatial planning policy in the Netherlands. This was a next step toward an integrated coastal zone management

(ICZM) that built on the exploratory steps of the Policy Agenda (MIN V&W *et al.,* 2002)—a cooperative effort of four ministries, the coastal provinces, Association of Water Boards, and several coastal municipal authorities—and that was in line with the Recommendations on ICZM (European Commission, 2002).

On the technical side—and in parallel with an increasingly integrated approach—policy developments show a growing emphasis on working with nature. The coastal policy was named "Dynamic Preservation" (MIN V&W, 1990), referring to the principle of working with (and of preserving) the dynamics of the system as much as possible. This was the basic argument for selecting the mechanism of sand nourishments that could be administered in a flexible way. The governmental study into water management in the twenty-first century (WB-21, 2000) advocates a three-step strategy: (1) retention, (2) buffering, and (3) drainage. In order to do so, water will need more accommodation space, and this should become a governing principle in spatial planning. The National Spatial Planning Memorandum (MIN VROM, 2005) has formalized these recommendations on water. At the same time, the memorandum has formalized comparable principles for managing the coast, be it that the focus has shifted from water to sand. Availability of sand is a governing principle for spatial planning in the coastal zone (MIN VROM, 2005); in this sense, Dutch coastal management is sand management. Then, the three-step strategy for the coast is comparable to the water strategy, but in an inverted sense: (1) unhindered transport of sand, (2) buffering of sand by nourishments, and (3) retention of sand by hard structures (MIN VROM, 2005).

Working with nature implies a gradual paradigm shift moving from a perspective of water (nature) as an enemy toward a perspective of water (nature) as an ally; a reappreciation of aspects of an accommodation strategy as an alternative to a strict protection strategy (although safety remains a fundamental part of the overall strategy). Specifically for the coast, the paradigm shift implies moving from a water management perspective toward a sand (sediment) management perspective as the governing principle.

Management Guidelines: Standards, Indicators, and Test Procedures

The increasing complexity of water and coastal policies has called for clear management guidelines to facilitate their implementation by regional and local authorities. Some examples for coastal management, for flood defence in general, and for water management serve to illustrate this.

For coastal management, an important factor in the successful implementation of the Dynamic Preservation policy of the coast has been the clear definition of the Basal Coast Line as a standard of reference, part of a well-defined decision procedure for nourishments (see van Koningsveld and Mulder, 2004). The best known coast-related guidelines are those for flood protection of the hinterland and for dynamic preservation (TAW, 1995a, 1995b).

For flood defence in general, the development process of guidelines is guided, judged, and evaluated by an independent advisory committee named Expert Network on Water Defences (ENW), formerly known as Technical Advisory Committee on Water Defences (TAW). The guidelines concern the design and maintenance of both hard and soft defence structures, the establishment of hydraulic design boundary conditions, and the uncertainty issue in designing and managing the defence. To ensure integration of water aspects into the spatial planning process, the governmental study into water management in the twenty-first century (WB-21, 2000) advocated the active involvement of water managers in the development of any spatial plan from the earliest stages. This process, called Water Assessment (in Dutch "Watertoets command."), is legally liable since 2003 (Jorna and van Dijk, 2004).

Role of Knowledge and Research

The beginning of the twentieth century marks the end of the era of water management by trial and error. Since the Zuiderzee project, the role of scientific knowledge in support of the respective large engineering works as well as the major policy developments has become progressively more and more important. Table 3 lists a number of characteristic research projects commissioned by the Dutch Ministry of Transport, Public Works and Water Management over the last decades (after van Koningsveld *et al.,* 2003). An example of the role of knowledge in policy development is given by the Coastal Genesis research project (1986 to 1993).

In geological studies, the importance of an accurate reconstruction of the Holocene sea-level rise for the coastal evolution of the Netherlands was acknowledged after the 1953 storm surge disaster. Jelgersma (1979) did pioneering work in this respect. In the decades that followed, sea-level reconstructions became more accurate and geological borings supported by observations in excavations for new infrastructure helped with assessing the Holocene coastal evolution. At that stage, the Dutch Ministry of Transport, Public Works and Water Management realised the importance of the work to support long-term coastal evolution and stability, and stimulated the cooperation between geologists, historians, physical geographers, and coastal engineers: the start of the interdisciplinary research project Coastal Genesis from the mid-1980s.

The most innovative aspect of Coastal Genesis was the recognition that research has to be approached on a variety of temporal and spatial scales. Moreover, it became clear that to match knowledge across the various scales, the concept of process aggregation in a scale cascade was essential. This research resulted, amongst others, in geological reconstructions (*e.g.,* Beets, van der Valk, and Stive, 1992) and in coastal engineering findings (Louise, Stive, and Wiersma, 1990). The experience gathered was also used to develop the Intergovernmental Panel on Climate Change (IPCC) Common Methodology for the assessment of the vulnerability of coastal zones to sea-level rise (IPCC CZMS, 1992), which was widely applied around the world (Bijlsma *et al.,* 1996) and provided the methodology for one of the first global assessments (Hoozemans, Marchand, and Pennekamp, 1993).

In preparation of a national coastal defence policy (MIN V&W, 1990), different policy options were developed. The options were founded on a Netherlands-wide, dynamic sediment budget, with an orientation toward intervention scenarios and with predictions of the coastal evolution for several climate scenarios.

Among the wealth of information that was generated was a large-scale sediment budget study (Stive, Roelvink, and de Vriend, 1991) and a hindcast of the shoreface evolution from mid-Holocene up to recent times (Stive and de Vriend, 1995). Two important findings of the studies are: (1) near coastal inlets, the direct effect of sea-level rise (*cf.* Bruun, 1962) is often negligible compared to the indirect effect caused by the accommodation space of the tidal basins; and (2) on a larger temporal scale, the shoreface never attains equilibrium and is in a continuous transient state due to climate variation in general and sea-level rise in particular. These findings appear to be crucial for future management now that we are developing responses in the face of an acceleration of sea-level rise.

With rising interest in global climate change beginning some 20 years ago, more integrated approaches to the consequences of sea-level rise were developed (Wind, 1987). With the increased attention on the environmental consequences of damming estuaries and construction of large dikes, the emphasis of the research shifted toward ecology and water quality in the final decades of the Delta Project. To quantify the potential cost of adapting protective infrastructure to future sea-level rise, a study on the impact of sea-level rise on society (ISOS) was performed. The main conclusion of the ISOS study was that although a large part of the Netherlands is potentially affected by accelerated sea-level rise, the Dutch coastal zone is not considered vulnerable due to readily available natural and economical resources (Peerbolte, 1993; Peerbolte *et al.*, 1991).

In general, over the last century, the research scope has continuously widened from mono- and multidisciplinary knowledge of predominantly the natural sciences in the first three-quarters of the century through multi- and interdisciplinary knowledge of both natural and socioeconomic sciences during the last quarter, to transdisciplinary knowledge today (see, *e.g.,* van der Brugge, Rotmans, and Loorbach, 2004).

CHALLENGES FOR THE TWENTY-FIRST CENTURY

The paradigm shift in the approach of water and coastal management that is observable during the last decades represents a major challenge for the coming century: the challenge to adopt an approach according to the principles of working with nature in a transdisciplinary way. Some of the issues and dilemmas involved in this challenge are illustrated by the following examples.

Working with Nature

In a critical evaluation of the morphological, ecological, and socioeconomic effects of the Delta Project (see above), Saeijs *et al.* (2004) advocate working with nature in any future flood protection project in estuarine and coastal environments. A number of their recommendations exemplify this:

> (1) If there is still is a choice, leave untouched estuaries and deltas alone. . . . (2) If there is already a history of human intervention, try to adopt the most flexible approaches to safety and development. . . . (3) Reversible and local measures within the limits of the natural processes are preferable.

The recommendations of Saeijs *et al.* (2004) regarding working with nature are in line with today's policy (*cf.* the coastal policy to maintain the coastline with soft solutions). Nevertheless, implementing the recommendations appears to be complex. For instance, sea dikes may hamper natural processes, but from an economic viewpoint, let alone from a socioemotional viewpoint, it is generally not justifiable to remove dikes. The complexity may be further illustrated by comparing the Saeijs *et al.* (2004) statement with the conclusions of Jonkman, Stive, and Vrijling (2005) drawing lessons to the Dutch from the New Orleans flood disaster of 2005. The latter observe a tendency in Dutch policy to head toward the U.S. model of mitigating the consequences instead of strengthening the flood defences, while prevention of floods is receiving gradually and relatively less attention. Then, arguing that (1) the protection standards are over 40-years old and have not evolved with the increase of economic value of the protected area over time and (2) the societal risks associated with flood defences on a national scale are larger than in other domains of the Dutch society (Ten Brinke and Bannink, 2004), they conclude that a fundamental debate on the required safety levels of Dutch flood defences is necessary.

However, considering the postmodern plea of Saeijs *et al.* (2004), it is obvious that the format of such a fundamental debate is not trivial. Coping with the dilemmas involved is an example of the major challenge for the near future. It illustrates that working with nature does not simply imply the use of methods from natural sciences, but involves a range of different disciplines and asks for a transdisciplinary approach.

Transdisciplinary Approach

Present water problems, besides technical adaptations, ask for the creation of public support and alternative governance (WB-21, 2000). In the background to this recommendation is the observation that the water problem is typically a so-called unstructured problem: different actors have different problem perspectives, uncertainties are large, and relevant knowledge is under debate. These are typical characteristics that according to Hoppe and Huijs (2003) ask for a transdisciplinary approach: a specific type of interdisciplinarity transgressing borders between disciplines and integrating knowledge and perspectives of different scientific disciplines as well as nonscientific sources (Pereira and Funtowicz, 2005).

An example of the practical implications—or if you like, of the major challenge—for coastal engineers is formulated by Kamphuis (2005, 2006):

> They must participate. They need to understand, discuss and explain uncertainties openly and clearly. They must realize that they do not provide some final proof, but only the best possible insight for an optimum solution. They must also recognize that they are not in competition with the approval process, but complementary to it.

DISCUSSION AND CONCLUSIONS

Sea-level rise has played a structural role in the development of the low-lying, deltaic environment of the Netherlands. Over time, human response developed from individual protection to collective action against flooding. Initially, this was modest, but it has evolved toward large-scale interventions such that coastal evolution and human response interact (KLEIN and NICHOLLS, 1999). The Netherlands has learned to live with the fact that sea-level rise is ongoing and accepts that associated impacts are a continuous issue. The history of water management in the Netherlands can be seen as a demonstration of policy cycles evolving toward integrated coastal zone management. In hindsight, one may conclude that this transition process from individual/local toward public/regional/national responsibility was not trivial. It took two millennia to arrive at a national coastal defence strategy. A growing population and economy asked for organisation of infrastructure for transportation, land reclamation, and protection works on a national scale. In 1798, a national organisation, Rijkswaterstaat, was established to develop and maintain all water related works on a national level. Today, responsibilities for water management are defined by the constitution, laws, and bylaws, and are vertically integrated from national to local level.

The vision of the functions of the coastal area and the way that they should be managed has gradually, but consistently, changed. Just after the 1953 flood disaster, guaranteeing the safety of the hinterland was the most important coastal policy objective. For decades, the Delta Plan was the predominant element in coastal management. Many engineering works were carried out to guarantee a legally determined safety level. However, before the Delta Plan was completed, the vision of coastal management was shifting toward the integrated use of the coastal area under national and sociopolitical pressure by, *e.g.,* nongovernmental organizations (NGOs).

Given projections of acceleration of the rate of sea-level rise, the traditional strict protection strategy has come under even stronger debate. Working with nature, with a reappreciation of an accommodation strategy in combination with a hard protection strategy, is being gradually considered to be a sustainable alternative, as illustrated by the adoption of soft protection to maintain the coastline where applicable. This moving perspective requires a shift in approach involving the integration of knowledge from different scientific disciplines and from nonscientific sources. An important challenge here is learning to deal with, at first sight, inequitable outcomes of different perspectives, such as technological/economic and social/political perspectives.

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□ SAMENVATTING □

Op basis van geologische inzichten laat dit artikel zien dat zeespiegelstijging een structurele rol heeft gespeeld in de ontwikkeling van het laag gelegen landschap van Nederland. Deze rol heeft een controversieel karakter, in het mid-Holoceen bevorderlijk en vanaf de Romeinse tijd bedreigend voor de ontwikkeling van de kustzone. Collectieve respons begint vorm te krijgen vanaf de 9e eeuw, maar de invloed van die respons wordt echt merkbaar in de 19e en 20e eeuw. Gedurende haar historie is de Nederlandse samenleving altijd in staat geweest om nieuwe technologieen, benaderingen en beleidsuitgangspunten te incorporeren in haar worsteling met het water. Het succes van collectief handelen verklaart het succes van de waterschappen als eerste democratisch instituut van Nederland. Ontwikkeling van technologie en financiele middelen, zorgt ervoor dat veiligheid tegen overstroming en het aanwinnen van land op structurele wijze en steeds grootschaliger kunnen worden aangepakt. Dit resulteert uiteindelijk in grootschalige ingrepen als de afsluiting van de Zuiderzee en de Delta werken in de 20e eeuw. Tijdens de uitvoering van het Delta project vond een belangrijke verschuiving in het denken plaats. Hoewel veiligheid prioriteit één bleef, werden menselijke ingrepen in een breder, meer holistische perspectief geplaatst, waarbij meer aandacht werd gegeven aan natuurlijke waarden gewogen tegen socio-economische belangen. Met het oog op toekomstige uitdagingen in de 21e eeuw, blijft de ontwikkeling van nieuwe technologieen, benaderingen en beleidsuitgangspunten in overeenstemming met de principes van het werken met de natuur op een transdisciplinaire manier actueel. De levensvatbaarheid van Nederland hangt voor een groot deel af van de mate waarin we deze ontwikkeling succesvol kunnen vormgeven.