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*Opinion Paper*

# Changing estuaries, changing views

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## Abstract

During the design and the execution of the Delta project, carried out after the storm flood of 1953 in the SW Netherlands, the importance of the long-term effects of morphological and ecological developments driven by tides and currents, have been underestimated. Due to these processes the height of the dams will have to be increased for centuries to come, because the land behind the levees cannot grow in elevation anymore with the rising of the sea. Maintenance of the civil-engineering structures, and mitigating their unpredictable impacts on ecosystems, involve very high recurrent costs. The chance of flooding is reduced, but the potential damage after a storm flood is enlarged: seawalls and dykes provide a false sense of safety against flooding. Changes in the role of agricultural use in the European context, offer an opportunity to abandon arable fields and to retrocede them to the sea in order to absorb tidal energy and to allow the land to rise concomitant with the sea. A cost-benefit analysis of this approach should assess the direct and indirect economic values, as well as the non-use (intrinsic) values, whereby public engagement in management questions, facilitates decision-making processes. Reversible and resilient economic measures within the limits of the natural processes are preferable. A future, speculative perspective is an urbanised landscape, where people and investments are located in safe places, e.g. on floating, or sea-encircled artificial dwelling-mounds, surrounded by a landscape that is ruled by the forces of nature. New approaches such as developed in the Westerschelde offer flexible solutions to flooding problems, and are worth a broader evaluation. A worldwide platform of experts should be organised to study the future management of estuaries and deltas, and to develop and exchange new ideas and techniques.

## Introduction

The history of the SW Netherlands is marked by a continuous struggle between man and the sea. Since the year 1000 man reclaimed salt-marsh areas and transformed those into agricultural land. But irregularly occurring storm floods broke the man-built seawalls and recaptured parts of the gained land. Figure 1 illustrates the typical geomorphology of the delta system in the SW Netherlands between 1900 and 1950. The area of roughly 10,000 $km^2$ was characterised by a considerable number of small and larger islands and peninsulas, deep and shallow tidal channels, extensive intertidal sand and mudflats reaching up to 20 km off the coast, vegetated coastal plains, salt marshes and brackish marshes above mean high water. The most land inwards parts of the estuaries, where the rivers Rhine, Meuse and Scheldt enter the delta, were characterised by freshwater tidal marshes and willow coppice.

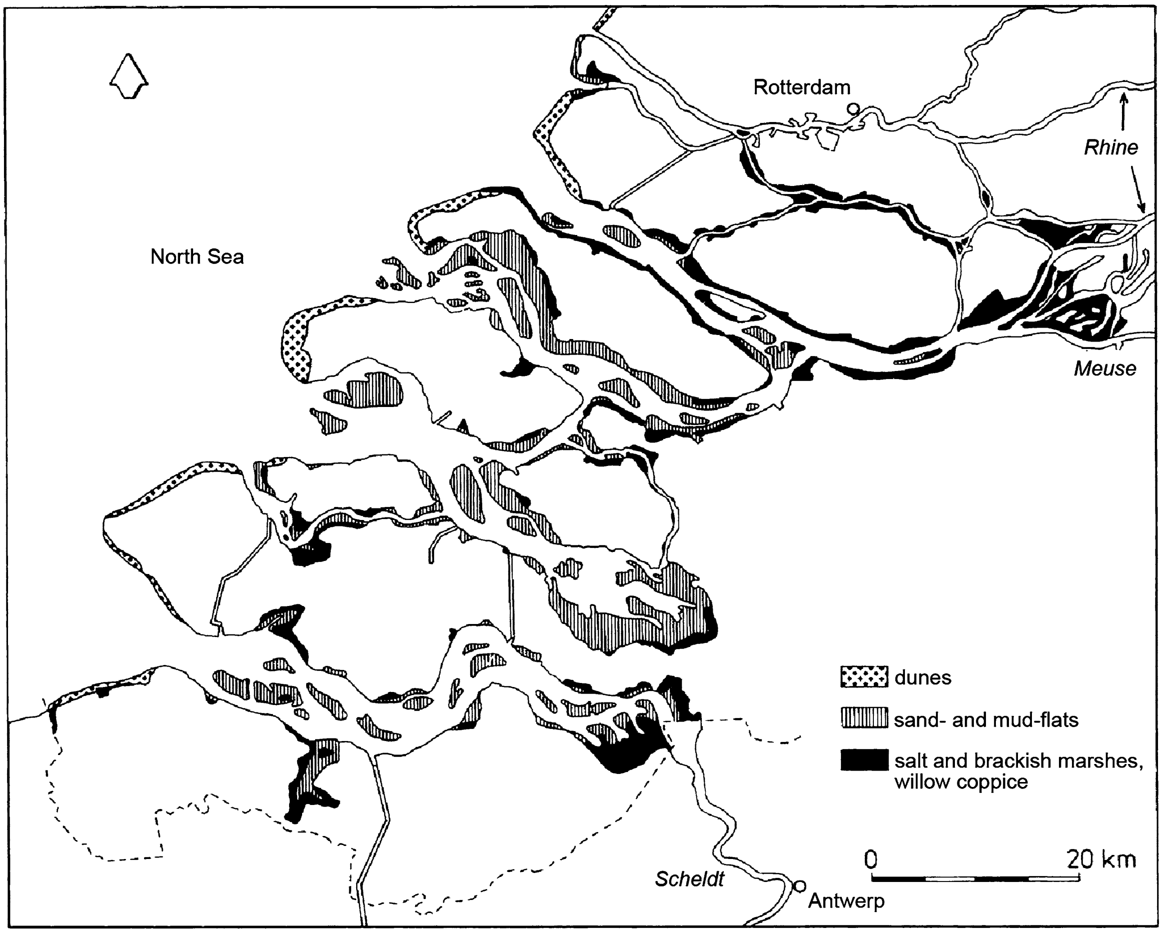


*Figure 1.* The Delta of the rivers Rhine, Meuse and Scheldt between 1900 and 1950; an extensive estuarine and coastal geo-morphological system (adapted from Nienhuis, 1982).

On February 1, 1953, a north-westerly storm induced tides to 3.4 m above normal levels, breached approximately 180 km of coastal-defence dikes and flooded 160,000 ha of polder-land in the SW Netherlands. 1835 people lost their lives in this large storm flood, more than 46,000 farms and buildings were destroyed or damaged, and approximately 200,000 farm animals drowned (Slager, 2003). The Delta project, formalized in 1957 by an act of the Dutch parliament, was conceived as an answer to the continuous risk of flooding, which threatens lives and property in this low-lying region. Because of the low mean elevation and premium on space in the Netherlands, the Dutch have a long tradition of coastal-defence construction and land reclamation. The need for continuous coastal construction has intensified over the years as a result of population growth, land subsidence and rising sea level. The potential threat of storm surges from the North Sea had already led to the closure of the Brielse Meer in 1950. The core of the Delta Project, to maintain a safe coastline as short as possible, called for the closure of the main tidal estuaries and inlets in the SW Netherlands, except for the Westerschelde and the Nieuwe Waterweg (Fig. 2). Along the Westerschelde the existing dikes have been raised, for reasons of continued international shipping access to Antwerp. In the Nieuwe Waterweg, the shipping route to the mainport of Rotterdam, the construction of the 'Maesland kering', a barrier protecting Rotterdam from storm surges, was finished in 1992. This enterprise was considered to be the final phase of the Delta project.

It is recognized that the decision, following the flood of 1953, to build a large, solid and inflexible 'wall against the sea', when placed in the cultural context of the time, was understandable. The aim of this paper is to show that this rigid project was not the best solution, in the light of modern standards and ways of thinking about sustainable water management. Focused on the Dutch delta, new insights in combination with advanced technological developments, call for a different strategy, comprising more flexible solutions. This paper will start with a short survey of the Delta project, and the underlying safety standards in the past and in the future, with regard to the risks of being hit by a severe storm flood. The lessons learnt from the Delta project are reviewed, ongoing solutions are discussed and new ideas are proposed, in order to mitigate and solve morphological and ecological problems. To stimulate the international discussion, alternative approaches and speculations about a society in balance with nature, coping with the tidal dynamics, will be given. The paper ends with a number of recommendations and views on future perspectives.

## The Dutch Delta project

The Delta project formally started in 1957. A prerequisite for the construction of the primary sea-walls in the mouths of the estuaries was the need to reduce tidal-current velocities in the estuaries, before the construction of the primary barriers could be undertaken. Tidal velocities were lowered by constructing secondary compartmental barriers (Zankreekdam, Grevelingendam and Volkerakdam; Fig. 2) to reduce the extent of the Delta area subject to tidal influence. This resulted, in turn, in a reduced tidal volume and, therefore, lower current velocities through the main estuaries. The former (semi-)estuaries Veersche Gat and Grevelingen were closed off from the North Sea by high sea-walls in 1961 and 1971, respectively, and turned into non-tidal lakes or lagoons filled with brackish or saline water, whereas the Haringvliet was closed in 1970 by the construction of large sluices, meant to function as an outlet for the rivers Rhine and Meuse (Fig. 2).

The original plan for the Oosterschelde estuary called for a dam across the mouth of the estuary, a distance of 9 km, to be finished in 1978. The tidal basin would than have been changed into a stagnant lake filled with – polluted – water from the river Rhine. But the final form of the present barrier differs drastically from the simple dam that has been envisaged originally. Through the 1960's and early 1970's, conservationists and fishermen provoked an awareness in many people of the need, to protect the area's outstanding natural resources and its unique tidal habitat, including an extensive shellfish (oyster) industry, the only one in the Netherlands. The Dutch government decided to change the design of the dam in 1974. After several years of desk studies the Dutch parliament accepted in 1976 a compromise solution: a storm-surge barrier. On the one hand the barrier allows the reduced tides to enter the estuary freely, thus safeguarding the tidal ecosystem, including the plant and animal communities. On the other hand the barrier guarantees safety for the human population and for the properties of the inhabitants when storm floods threaten the area. This barrier design marked a turning point in the Dutch political decision-making process with regard to the natural environment. The storm-surge barrier was constructed between 1979 and 1986 in the western inlet of the estuary (Fig. 2; Nienhuis & Smaal, 1994).

The positive state of mind about the chosen solution for the Oosterschelde gradually tempered in the course of the years. The disturbed hydrodynamic tidal balance in the estuary enhanced the erosion of the tidal flats: all flats, managed as precious nature reserves, will gradually disappear under water. In fact, the closing of the four main branches of the Rhine–Meuse estuary brought the natural transitions between fresh, brackish and salt water to an end. The complicated interplay between deposition and erosion of marine and river sediments in all four estuarine areas was ceased, and large uncontrolled changes in long-term hydrodynamic and geomorphologic processes were set in motion. The original natural habitats disappeared, and were replaced by man-made habitats. This is reflected in the changes in biodiversity: characteristic estuarine species disappeared, as was the case with migratory species (e.g. fish species), used to travel between the rivers

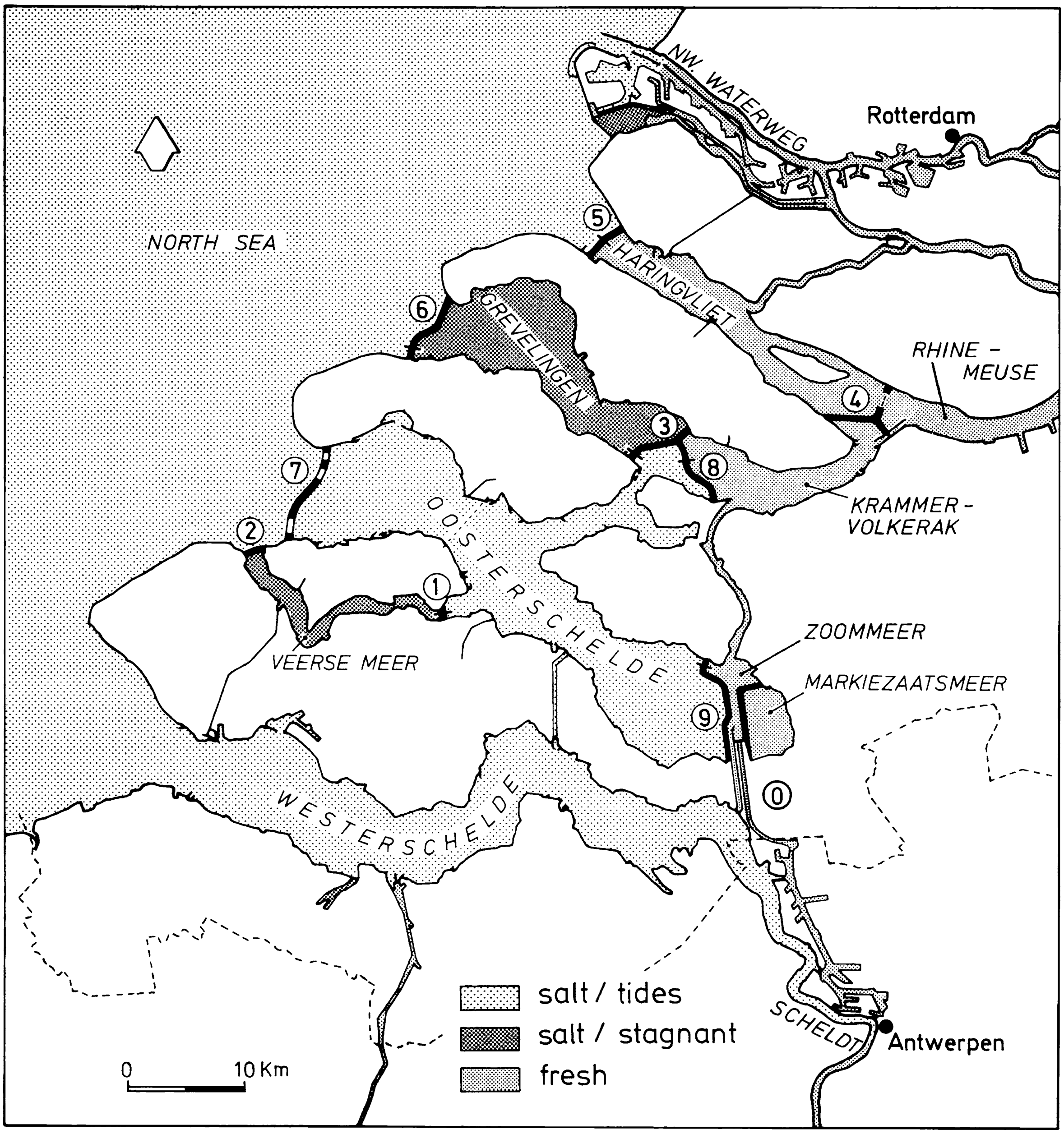


*Figure 2.* Map of the Delta area of the rivers Rhine, Meuse and Scheldt in the SW Netherlands, with various water bodies as resulting from the Delta project-engineering scheme. 1 = Zandkreekdam, 1960; 2 = Veersegatdam, 1961; 3 = Grevelingendam, 1964; 4 = Volkerakdam, 1969; 5 = Haringvlietdam, 1970; 6 = Brouwersdam, 1971; 7 = Oosterschelde storm surge barrier, 1986; 8 = Philipsdam, 1987; 9 = Oesterdam, 1986. Markiezaatsmeer has been closed off from Zoommeer by Markiezaatsdam in 1983. The connection between Oosterschelde and Westerschelde was already closed in 1867 (0 = Kreekrakdam). Projects preceding the Delta act of 1957, such as the closure of the Brielse Maas (1950), the Braakman (1952) and the construction of the flood barrier in the Hollandse IJssel (1958) near Rotterdam, have not been indicated (compare Figure 4; Nienhuis & Smaal, 1994).

and the sea. However, an increasing number of exotics have established themselves, covering large subtidal and intertidal areas (e.g. the Japweed, *Sargassum muticum* and the Japanese oyster, *Crassostrea gigas*; De Jonge & De Jong, 2002).

The Delta project is considered as the culmination of a long tradition of land reclamation and defence against the sea. Almost the entire area of the land around the estuaries was reclaimed from the sea in a trial-and-error process, over more than a millennium of constructing and repairing dykes in the muddy salt marshes and the former peat bogs. The combination of the rising sea level and subsidence of the reclaimed land (particularly the peat areas) dramatically changed the difference in surface levels between sea and land. Most polderland now lies far below the level of the sea (Fig. 3).

The flood disaster of 1953 has not been followed by an evaluation of the practice of traditional water and land management. Instead, the event worked as a catalyst for the decision to persist with large-scale measures in the existing tradition: to build larger and more rigid dams. There was a strong conviction that technology would always remain to be able to control the energy of the sea. The execution of the Delta project brought Dutch water engineers world fame. The skills and experience gained, became a significant export product of the Netherlands: Dutch engineering firms were asked to plan and execute similar large water projects in other parts of the world. For many countries the Dutch approach became the model for water management technology (www.rikz.nl).

From a socio-economic point of view, the impression of safety bestowed by the massive dykes, invited people to invest money behind them. Towns and villages prospered and tended to grow. Although the frequency of a potential disaster has diminished, the potential damage to lives and goods has increased: the impression of complete safety is therefore false. It is, in fact, the strong believe in technological solutions that made the Dutch population blind to the real risks. Particularly during periods of poor maintenance of the dykes (war, recession) that became only too obvious. The answer to a devastating flood has always been: build higher and stronger dykes. The effects have always been: more investments behind the dykes, but the repetitive consequences were: larger damage during a subsequent catastrophe. Concerning the Delta project, a cost-benefit analysis was carried out only after (and not before) the main decision to close off the estuaries was made (Tinbergen, 1959; Van Dantzig, 1959). Surprisingly, the analysis did not compare the different solutions; it simply calculated whether the costs of the chosen solution were in equilibrium with the expected benefits.

The chosen solution, to cut off the estuaries from the sea by large dams, will partly be irreversible in practice. The costs were so high that a

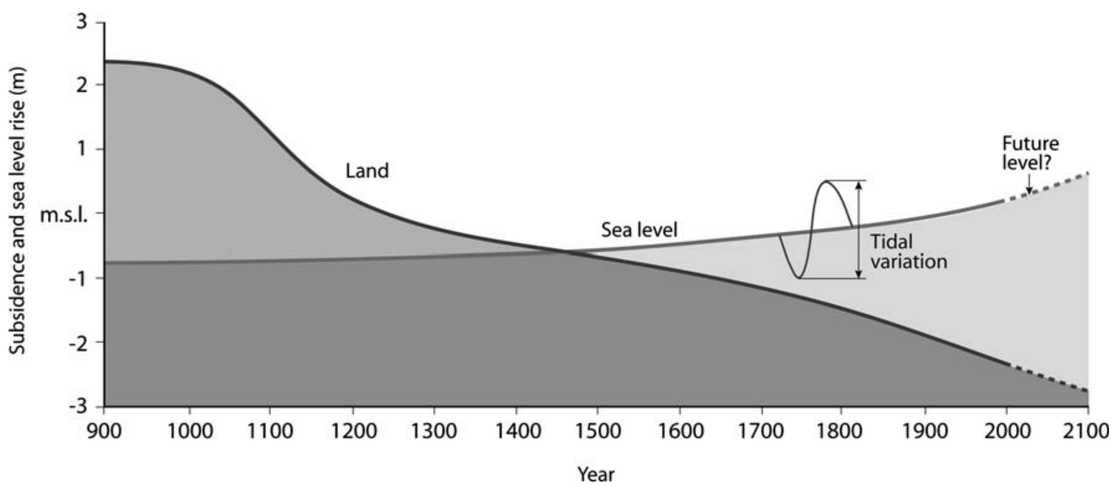


*Figure 3.* Scheme of the subsidence of the land in the western part of the Netherlands, and the simultaneous sea level rise over time (derived from Huisman et al., 1998).

reversal would mean a tremendous write-off of the investment: you cannot do the same job twice. Secondly, changes in the use of the lakes that originated behind the dams were far-reaching. New and strong economic interests developed, profiting from freshwater for agriculture and extensive tide-free shipping routes. These interests resist attempts to change the situation. The conclusion is that the decision to design and build large civil-engineering structures such as the Delta-dams, determines the pathway for the future. Rising sea levels will be countered by heightening the dams, thus increasing the potential damage.

**Accepted risks and safety standards**

A striking observation is that as soon as a dyke or dam is constructed, the inhabitants' relation with the natural dynamics of the system weakens and finally disappears. Shortly after construction, an embanked area will be used more intensively for living and working, usually to a degree which is out of proportion to whatever natural dynamics still occur in the area. Every improvement in 'safety' against the dangers of the natural environment is followed by new investments, and thus the risk is enlarged to, or beyond, the former level. The long history of transformation of the Dutch delta shows that spatial changes, very often comprise a series of small, apparently unimportant adaptations, such as the draining of polders and the expansion of a city near the river mouth. These processes take place gradually, and their impact on the environment is generally not perceived. At a certain moment, the development can no longer be stopped. At that moment, it can be postulated that economic growth can only be realised by more extensive and more radical alterations to the natural system. Apparently, it is extremely difficult to change strategies, once spatial plans have been executed, especially when it involves large engineering constructions such as the Delta project.

When dealing with a flood-prone area, the concept of risk is a central notion. Risk is often defined as the probability of the occurrence of an (unwanted) event multiplied by the consequences of that event: Risk = Probability × Effect. When we try to make this risk calculation for the year 1953, and roughly fifty years later for 2005, we find that the probability of a disaster has declined, but the potential effect has increased dramatically: more people and infrastructure will now be damaged by a major storm-flood than in 1953. However, it has to be recognised, that the effect of a flood disaster nowadays might be less severe than in 1953 as a result of improved communication and evacuation plans. Nevertheless, the rise of the water level in an inundated polder would occur faster than it did 50 years ago: the land has subsided and the dykes have been raised, which means that the polders would fill up more rapidly with seawater. While everybody feels safe in the shelter of the large constructions, it can be hypothesised that the risk has actually increased, not decreased. From this point of view, the Delta project was just a step forwards in a process, that had lasted for over 1000 years. The constant factor is that every measure to improve the safety of the area is followed by more investment and an increasing human population: greater technical safety (lower probability of flooding) is always cancelled out by the risk of larger numbers of deaths and more costly damage (RIVM, 2004).

In the Netherlands safety standards with regard to the risk of being hit by a flood are set by the Act of Defence against Flooding of 1996 (www.wetten.overheid.nl). Under this law the standards set by the execution of the Delta project, have been maintained (1/4000 to 1/10,000 per year). Three sets of arguments have shaped these standards. Firstly, arguments dealing with the predicted water levels should be mentioned, viz. the expected maximum impact of super-storms, including the tidal phase and the wind direction, the sea-level rise, and lowering of the land (due to man-induced subsidence as well as the autonomous sinking of part of the continental shelf). The quality of the dams, dykes and sluices constitute the second set. The expected loss of human life, and the value of the investments behind the dykes, is the third set of arguments. Although several of these factors can be calculated or standardised, others cannot. In the end, the standards are a political choice. The law says that every five years there must be an evaluation of the condition of dams, dykes and sluices. Whenever a shortcoming is found it has to be repaired. Whenever calculations derived from the first set, e.g. the rising sea level, make it necessary, dykes and dams must be adapted. There is, however, no obligation to reconsider the standard of safety against the arguments of the third set, the value of goods and human life.

Although legal obligations to maintain the agreed levels of flood protection exist, it is our opinion that this strategy cannot be sustained forever. Because of the subsidence of the western part of the Netherlands, the rising sea level and the more extreme fluctuations in river water discharges, due to climate change, we will end up living behind enormous dykes. Large pumps will have to be built to remove the continuous input of seepage water. The difference in surface level between the sea and the hinterland will further increase, enhancing the effects of a potential flood to catastrophic proportions. This situation can hardly be referred to as 'safe'. It has to be concluded that, seemingly, there is no way back: from the moment the first dyke was built by the monks, the endless spiral of 'fighting the waters' had begun. To our opinion, at some stage, the current approach of raising higher and higher dykes and building larger and larger dams will no longer be an option.

## Lessons learnt and solutions proposed

### *Changing views with regard to technological 'solutions'*

Decisions about managing the Dutch delta were based on contemporary knowledge, available in the 1950s and 1960s. This applies to the significance of the morphological and ecological attributes of the ecosystems, but also to the technical solutions chosen. In the 1950s it was clear: the struggle against the violent forces of the sea had to be won using physical barriers. Raising the existing dykes following the 1953 disaster, obviously, was no longer a convincing solution, considering the arrears of maintenance; it would take decades to reach the desired safety level. A statement had to be made, drastically shortening the coastline: the Delta Plan with its huge dams was designed with 'safety forever' in mind.

During extensive enterprises such as the Delta project (that took more than 30 years), it is common use that new ideas or concepts frequently displace those underlying the original project design (e.g. saline, stagnant Lake Grevelingen and the Oosterschelde with reduced tidal amplitude; Nienhuis, 1982). Over the past ten years, an increasing number of questions have been raised about the desirability and usefulness of rigid technological approaches. Are more and higher dams really the best solution to fight storm-floods? Are these measures not neglecting the rising level of the sea? Is an approach that opposes the natural behaviour of an estuary the best idea, or is it possible to envisage solutions that match with the forces of the sea and the characteristics of the estuary, rather than measures that counteract natural processes?

In 1953, the larger part of the affected area in the SW Netherlands had a rural destination, and agriculture was the dominant economic activity. The chosen solution (Delta project) was the best under the prevailing circumstances and within the cultural tradition. Agriculture, however, has since lost its pre-eminence in the now-urbanised Dutch society. Agriculture itself has been industrialised. Capital-intensive trades such as meat, vegetables and flower production need more and more investments, and less farmland. In the Netherlands, the future of types of agriculture that use large areas of land is very doubtful. Some economists predict an extreme decrease in land use for agricultural purposes, because the opening of the world market and the enlargement of the European Union to eastern European states makes it cheaper to produce elsewhere. Others predict a development towards more extensive land use: that is, fewer but larger farms that use more land and less intensive techniques. These two developments could occur at the same time. The outcome of a cost-benefit analysis depends to a considerable degree on the forecasts concerning the use of 'space'. It can be postulated that once the drive for more (agricultural) land has declined, a process opposite to that of the last 1000 years becomes possible: giving land back to the sea (Schuijt, 2001).

The maintenance costs of the Delta project are very high, much higher than estimated in the cost-benefit analysis (CBA) of 1959. Tens of millions of euros are spent each year to keep the civil-engineering constructions in good condition. The maintenance of the storm-surge barrier in the Oosterschelde alone, for instance, costs 15 million euros annually. Other costs were not foreseen (or accepted) at all, for example the projects to locally restore disturbed nature, and to control the water quality problems. To mitigate large-scale erosion of the foreshore of the former estuaries, bank protection over several hundreds of kilometres was put into place, at a cost of one million euro per kilometre. Moreover, considering the worldwide degradation of ecological quality, the economic value of ecosystems is being more widely recognized (Costanza et al., 1997). This added value was neglected in the past, and this concerns also the CBA framework used by Tinbergen (1959) and Van Dantzig (1959). Attempts are now being made to include the economic value of (aquatic) ecosystems in the decision-making process, when interventions are planned. Applying the economic values attached to an estuary, e.g. with regard to fisheries interests, it has been shown repeatedly that human intervention results in huge economic losses. Calculations along these lines, show that the economic value of the Dutch south-western delta has declined by 40% between 1900 and 2000 (Bouma & Saeijs, 2000).

In the end it is impossible to attach monetary values to all that nature offers. The ethical discussion should be added because intrinsic values are complementary to monetary values. What is it worth to be able to walk along a natural beach and leave problems and stress behind you? How much do we want to pay to let our children enjoy the sea and the wetlands without worrying about pollution problems? It is to society to decide what is the price to be paid to enjoy a healthy ecosystem.

*The values of a natural delta: bring back dynamics*

The execution of the Delta project, which followed centuries of smaller interventions, triggered several (unexpected) environmental problems. The building of the delta dams rigorously cut off the hydrologic and ecologic river continuum, both at the seaside as well as at the side of the rivers. The annihilation of the dynamic tidal gradient was foreseen by ecologists, but their voice was not heard in the 1960s when the provision of safety after the 1953 disaster was the main societal issue, and ecological arguments hardly played any role (Nienhuis, 2006). A primary function of the former estuaries was the discharge of river water to the North Sea. The closure of the Haringvliet and the Volkerak is obviously hindering the unrestrained discharge of river water during peak floods. The 1995 river flood has opened the eyes of the river managers for that problem, and measures are taken now to mitigate that problem, both along the rivers proper (core decision of physical planning 'Room for the River'; www.ruimtevoorderivier.nl; Van Stokkom et al., 2005) as well as in the delta region. A problem may arise when an extreme river flood coincides with a north-westerly storm flood at the North Sea, which requires the storm-surge barriers to be closed.

Sealing off the estuaries in the Dutch delta has led to the accumulation of polluted sludge in the northernmost river branches (Fig. 4). Although an increase in sedimentation was expected as a result of the closure of the Haringvliet in 1970, the large quantity of polluted sediments that settled in subsequent years in the Dutch delta overran all predictions. Biesbosch–Hollands Diep and Haringvliet became the downstream chemical depot for the Rhine and Meuse rivers. More than 150 million $m^3$ of highly polluted sludge have settled here. Fortunately, the quantity of pollutants in river effluents has steeply decreased in recent decades, and the toxic sediments are now being covered with relatively clean sediments, but the underlying potential negative effects are still available. It is likely that, even if the original sources of pollution should be removed, contaminated sediments would continue to deliver emissions over many decades (Smit et al., 1997).

The lack of tidal currents in the Delta compartments is the cause of many of the environmental problems that recently emerged. However, it is technically possible to bring tidal rhythms back into the area. If the Haringvliet sluice is to be turned into a storm-surge barrier (Fig. 4), and if both Lake Oostvoorne and Lake Brielle could be opened up again in a controlled, reduced way, (Fig. 4), it can be hypothesised that the natural dynamics of the northern part of the coastal delta, comprising tides, and a salinity and sedimentation gradient, could be restored. The opening of the two lakes mentioned, would nevertheless be difficult because of the intensive urban infrastructure and harbour developments in the area. A connection with the developing sandy islands in the coastal delta, where a new shallow sea is emerging, could upscale the natural values by a substantial

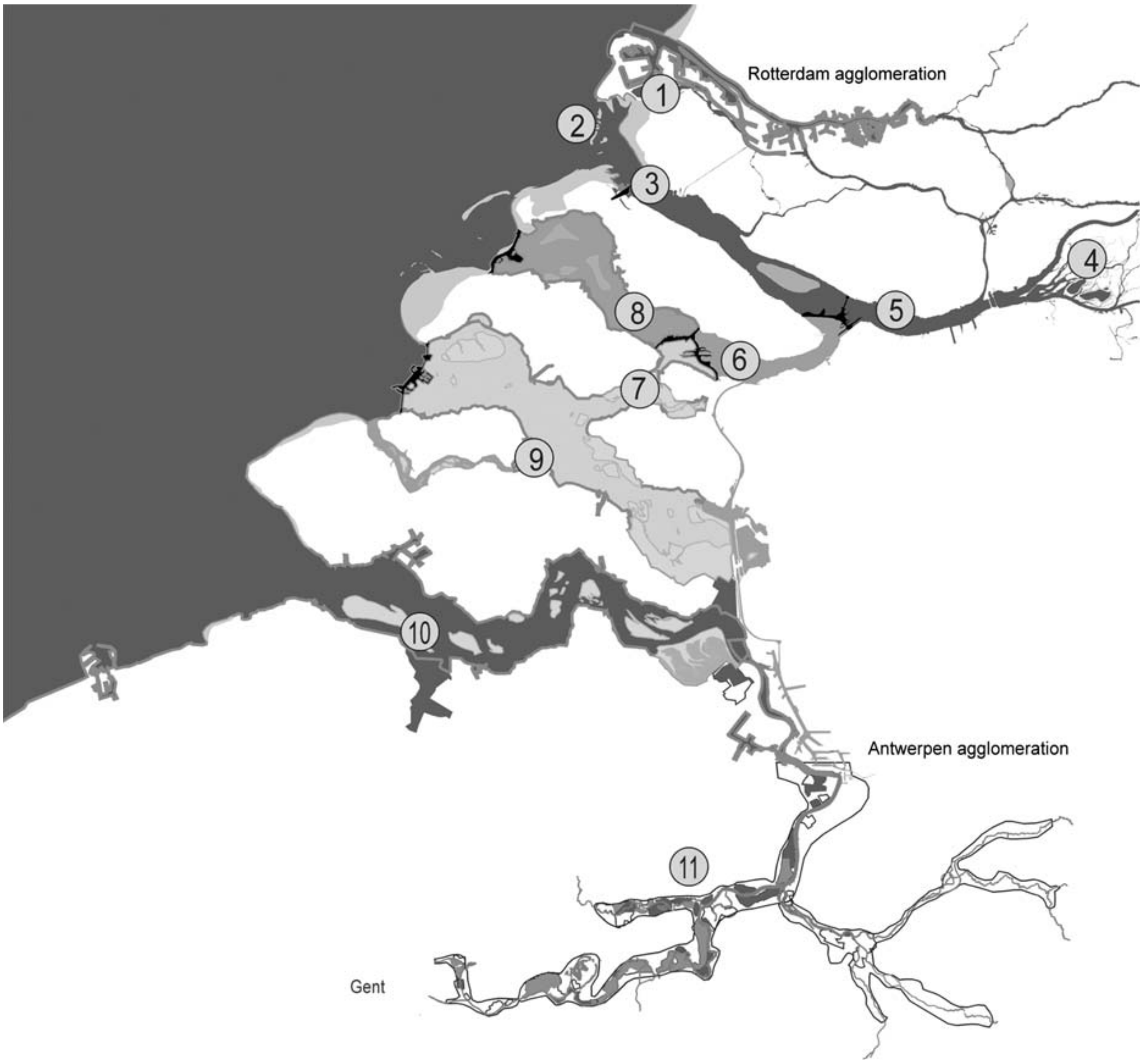


*Figure 4.* Changing estuaries, changing views: the return of the (lost) tidal dynamics. (l) Reconnecting Lake Oostvoorne and Lake Brielle to the sea and the tides. (2) Voordelta: undisturbed development of sandbanks alongside the coast, a new outlet for the rivers Rhine and Meuse. (3) Opening of the Haringvliet Sluices to restore the tides and the brackish gradient from freshwater to salt water. (4) Removing dykes and restoring the freshwater tidal area in the Biesbosch. (5) Sedimentation zone in the Hollands Diep branch for clean sandy sediments from the river Rhine. (6) Flushing the eutrophic Krammer–Volkerak with cleaner water from the river Rhine. (7) Connecting the Oosterschelde to the rivers Rhine and Meuse. (8) Connecting the Grevelingen both to the sea and to the river. (9) Connection between the stagnant Veerse Meer and the tidal Oosterschelde. (10) Returning the reclaimed Braakman area to the sea, for energy dissipation. (11) Controlled Inundation Areas, controlled reduced tides along the tidal river Scheldt (Saeijs et al., 2004).

amount (Fig. 4). If combined with the development of large natural tidal zones along the borders of Lake Oostvoorne and Lake Brielle, it would result in an extremely scarce and highly valued ecosystem, in the neighbourhood of one of the largest industrial concentrations of Western Europe (Stikvoort et al., 2002; www.rikz.nl; www.ecologisch-herstel.nl).

Experiments to re-introduce reduced tidal movements in the Haringvliet have been carried out and were successful. If the Haringvliet estuary is to be restored, this should be done as soon as possible, since irreversible geomorphological processes, combined with the extinction of migratory species (particularly fish species) are continuing. Opening of the Haringvliet sluice means also the (partial) restoration of tidal movements in the Biesbosch (Fig. 4), an area created during the giant storm-flood of 1421. In that year the former polder, the Grote Waard, was swallowed by the sea and turned into a shallow freshwater tidal area, and it took the river Rhine four centuries to fill up most of the area with sediments to above sea level. During this period, the Biesbosch was a vast and unique freshwater tidal area, the largest one in Europe (Kuijpers, 1995; Kerkhofs et al., 2005).

During the most severe period of pollution from the Rhine and Meuse, the Krammer–Volkerak (Fig. 4) was closed off from the Haringvliet in 1969, and this prevented the contaminated riverwater to enter the adjacent estuarine branch. The enclosed water mass, including the Zoommeer (Fig. 4) was conceived as a freshwater system, almost exclusively fed by the discharge from a few small rivers in Noord-Brabant, although some input of Rhine and Meuse water had to be accepted. Over the years, however, it became clear that nutrient accumulation, causing mass blooming of blue-green algae, nevertheless occurred, fed by agricultural run off, mainly brought by the smaller rivers. A recent survey of possible solutions to the eutrophication problem was carried out. One suggestion was to flush the artificial lakes with enough freshwater, in order to decrease the residence time of the eutrophicated water and hence to prevent the development of algal blooms. The problem is that this measure cannot be applied in dry summer periods when little river water is available, but algal blooms are at their peak. Creating a saltwater lake or a semi-tidal estuarine area are the suggested directions for a sustainable solution. The problem here is that the adjoining agriculture needs the freshwater supply (Tosserams et al., 2002; www.rikz.nl; www.ecologisch-herstel.nl).

In 1986 the building of the storm surge barrier in the Oosterschelde was finished. Owing to this enormous technical and financial effort, two thirds of the tidal movements have been maintained in this estuary. As this estuarine branch was cut off from the river, the connection with incoming nutrients, and the transition zone between salt and freshwater, were lost. The deterioration of the natural system, i.e, the irreversible erosion of the tidal flats, is continuing. Partial restoration of the estuarine gradient is a feasible option, however, by re-introducing a quantity of freshwater from the river Rhine via the Krammer–Volkerak (Fig. 4). The connection between the stagnant non-tidal saltwater Lake Grevelingen (Fig. 4) and the sea has already been restored in a restricted way. The flushing of the lagoon, however, can be enhanced by expanding the capacity of the already existing siphon in the eastern dam, connecting Grevelingen with the Oosterschelde (RIKZ, 2004). The connection between the stagnant, brackish Veerse Meer – suffering from massive blooms of the green alga *Ulva lactuca* – and the tidal Oosterschelde has already been accomplished in 2005 (Fig. 4; www.rikz.nl).

*A useful approach: the Flemish view*

The southernmost branch of the delta, the Westerschelde, has remained in open connection with the North Sea, to allow sea going vessels to reach Antwerp harbour. Artificial deepening of the navigation channel for ever bigger ships enhanced the man-induced tendency of the Westerschelde to enlarge its tidal volume. The potential danger of this ongoing process was particularly felt in the narrowing, upstream part of the estuary, and it was modelled that the city of Antwerp experienced an ever greater risk of being flooded. The construction of a storm surge barrier in the Westerschelde (compare with the Oosterschelde dam) was financially and politically out of the question, and in the meantime the thoughts about the values of natural systems were evolving. After thorough studies, leading to better understanding of the tidal system, Dutch water managers responsible for the Westerschelde came up with a completely new approach within the limits of the natural characteristics of the estuary (Saeijs et al., 1993). During a centuries-long history, the medieval river upstream of Antwerp gradually changed into a tidal river, and large parts of the floodplain were reclaimed in the course of time. By constructing a new dyke more land inwards, and by subsequent removal of the old dyke, the original floodplain upstream of Antwerp could be given back to the river ('ontpolderen' in Dutch). These measures create more space for the river: the tides will come in twice a day, occupying the new floodplain, and hence changing the river forelands into freshwater tidal marshes, and increasing the tidal volume once again. The advantages are obvious: lower water levels would give more safety; more water exchange would lead to less dredging measures, and better quality of nature.

Flemish engineers, morphologists and ecologists adopted these ideas and came up with an adapted approach (Van den Bergh et al., 1999, 2003). To prevent flooding, the Flemish designed a system of Controlled Inundation Areas (CIA) along this estuarine river: giving back the floodplain to the tidal system in a controlled way (Fig. 5). Simply removing dykes in places where (uninhabited) floodplain were still intact would not have been effective. Instead, the dykes have been lowered in such a way that, during severe storms when Antwerp is in danger, the dykes start to overflow into selected polders (Fig. 6). Newly built, higher dykes in the hinterland protect the adjoining villages and cities. The top of the flood is thus removed in an 'elastic' way, playing with the natural forces instead of opposing them, within the limits of the natural system.

This system has some more advantages. Firstly, up to eight times a year the dykes of the controlled overflow polders may be overtopped, which means that the process of the sedimentation of silt during extreme tides may continue. In this way the area will slowly be elevated, following the rise of the sea level. A second advantage is that by using the in- and outlet devices of the polders, the opportunity will be opened to restore the natural conditions of a (internationally extremely rare) freshwater tidal system. At the moment, several areas covering a total of about 2000 ha are under construction (Existing Controlled Inundation Areas in Fig. 5). There are plans to enlarge the area to up to 4500 ha

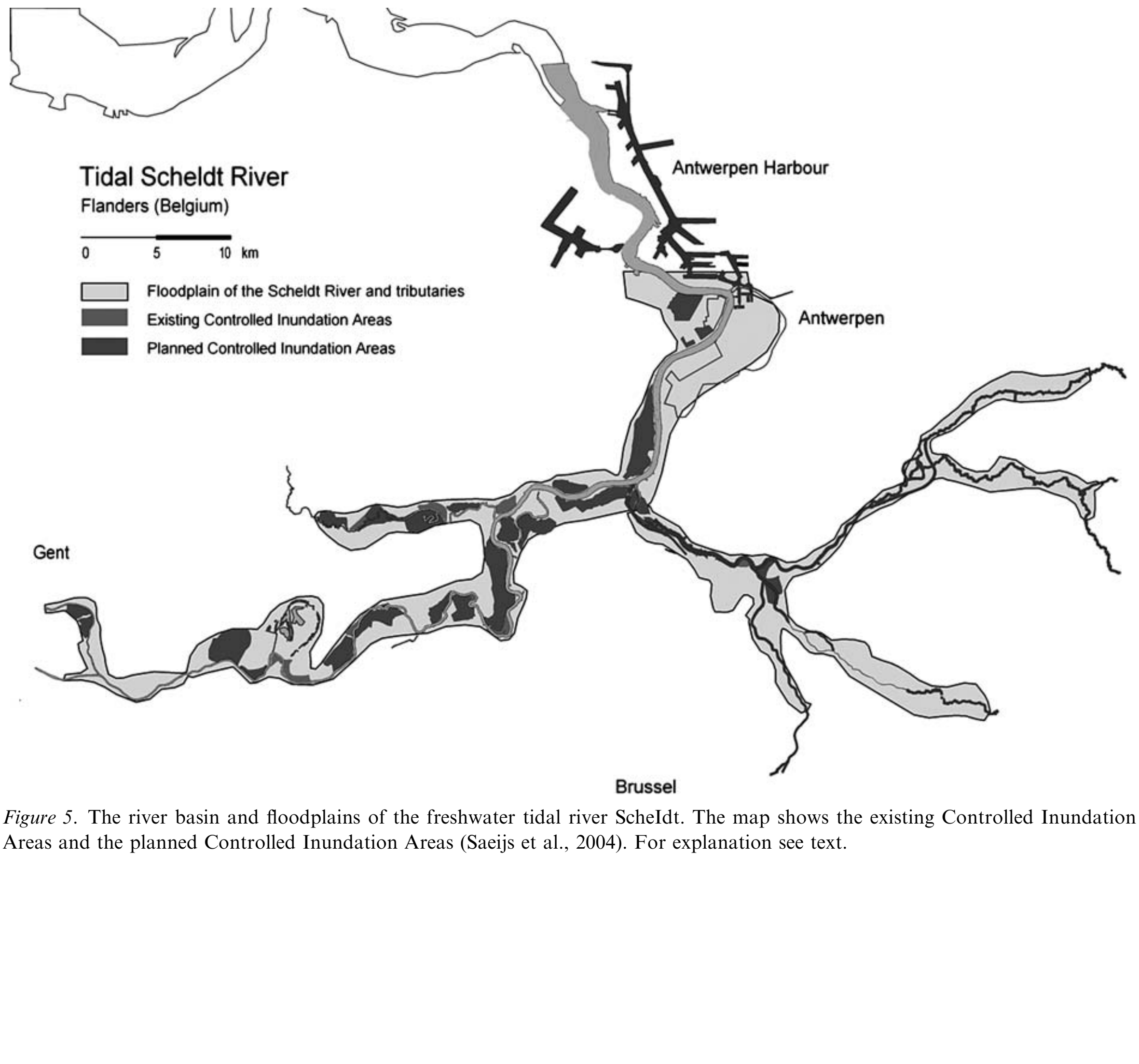


*Figure 5.* The river basin and floodplains of the freshwater tidal river Scheldt. The map shows the existing Controlled Inundation Areas and the planned Controlled Inundation Areas (Saeijs et al., 2004). For explanation see text.

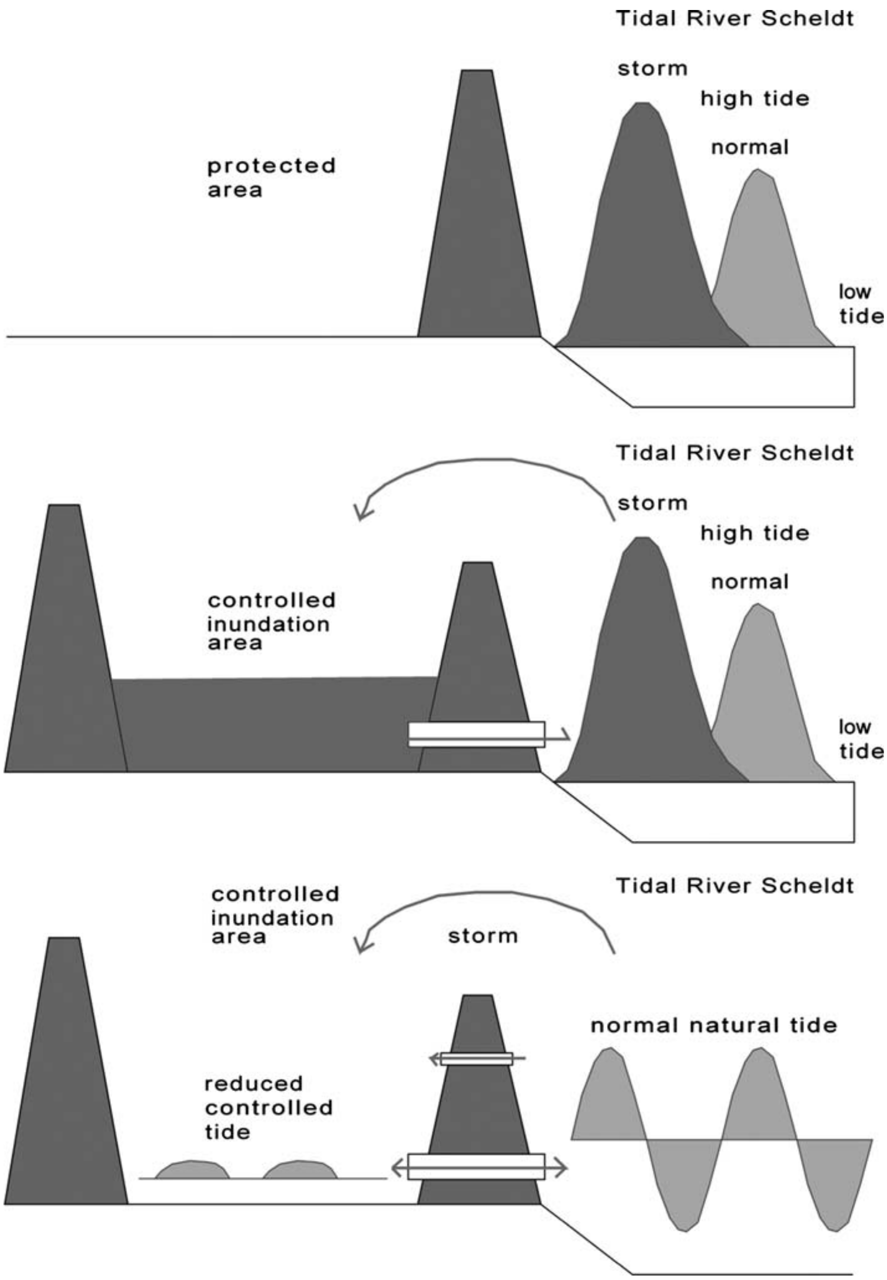


*Figure 6*. Controlled Inundation Areas along the freshwater tidal river Scheldt. Upper panel: Scheme of the tidal river Scheldt, existing situation, danger of uncontrolled flooding. Middle panel: Controlled Inundation Area along the river Scheldt provides protection against flooding. Lower panel: Reduced controlled tides: freshwater tidal areas along the river Scheldt (Saeijs et al., 2004).

(Planned Controlled Inundation Areas in Fig. 5). Apart from the improved safety conditions, and the possibility to keep pace with the sea level rise, a natural tidal freshwater river will reclaim its tidal plains. In the very densely urbanised area of Flanders, including Antwerp, Ghent and Brussels, a beautiful natural park will be created with unprecedented ecological and recreational potentials.

In 2003 Flemish and Dutch experts formulated an outline of a common sketch for sustainable development of the Scheldt estuary over its full length of about 160 km, based on an earlier accepted long term vision for the Scheldt-estuary. The Flemish Controlled Inundation Area solution was presented through an international body (ProSes), and similar solutions for the Dutch part of the estuary were presented as well. A new idea was formulated by the ProSes study (Van den Bergh et al., 2003), viz. dissipation of tidal energy. According to this idea the energy of the tidal wave is absorbed by its contact with the soil of the permanent water bodies and of the (periodically) inundated areas. In wide and shallow systems the energy of the tides is absorbed to a much higher degree than in waters with limited contact with the streambed and banks of the channel. In terms of energy dissipation, the 1000-year technological development of building dykes, cutting of shallow branches from the sea, and deepening the navigation channel, have diminished the energy absorption capacity greatly, allowing the floods to develop more force and cause more damage. Serious drawbacks of dredging measures in tidal navigation channels on the erosion–sedimentation cycle (in the Ems estuary) were discussed by De Jonge (1983).

Dykes are not entirely safe, and decision makers in the harbours and industries of Westerschelde area had no intention to rely on the 1:10,000 or 1:4000 per year safety standards. The huge investment in heavy industry and, even more crucial, the existence of three nuclear plants (two in Flanders and one in the Netherlands), put the value of potential damage very high indeed, and called for additional solutions. In order to survive extremely high tides, artificial dwelling mounds were in use in the estuary already in the early Middle Ages (Bloemers & Van Dorp, 1991). Even the highest floods obey the rhythm of the tides so that on an artificial mound, the worst that could happen was a shallow covering of water for a few hours. Along the estuary most places are situated below Mean Sea Level, sometimes several metres. Industrial managers made a partial return to the safest possible strategy for flood prevention: large-scale artificial mounds. In fact, many of the large harbour facilities and industrial estates were built on mounds. Even in the worst case, i.e. a flood exceeding the 1:10,000 level, the mounds will remain dry or only suffer from shallow flooding during a short period. Curiously enough, urban planning did not follow this strategy (Saeijs et al., 2003).

## Alternative approaches: a society in balance with nature

For centuries the primary economic drivers in the Dutch delta were agricultural interests. Since globalisation has enlarged the trade markets, the rationale behind the fight against the sea, to maintain reclaimed land for regional food supply, has lost much of its value. Keeping in mind agricultural over-production in Europe, it is easy to conclude that there is even too much land used by farmers. Resource-use strategies should be looked for, which are compatible with the characteristics of the geographic region. It may be postulated that an economy based on marine and estuarine fisheries and aquaculture is in better harmony with the resources of the delta than forced agricultural practice.

The delta area could become even more important for recreation than it is already nowadays. Leisure time and spending for amenity reasons have grown during the last decades, and the millions of people living in the densely populated western part of the Netherlands provide a ready market. The recreation industry could be expanded by changing land use; for instance by returning the ancient agricultural lands to nature. These lands have settled over hundreds of years of use, lowering and compacting the ground. Here, freshwater could stagnate, leading to interesting freshwater nature reserves. As these lands are situated near picturesque old towns, a perfect combination of culture and nature could be created. Recently, a computer model has become available which simulates varying conditions related to land and water management and climate change (*SimDelta: a spatial model for coastal morphology on mega-time scale*; www.rikz.nl). Application of the model allows an exploration of possible morphological changes in the south-western delta area under specified conditions. Within the context of this paper, although speculative, two scenarios are intriguing.

1. No dykes, open estuaries, and no forced drainage of the dry land. If the inhabitants of the Dutch delta had not been focused on land reclamation but on aquaculture and fishery, the south-western estuary would be much larger than it is today. In this scenario only the villages and cities would be embanked or otherwise protected from, or accommodated to, high water levels. The importance of the wetlands and open estuaries as nurseries for fish and molluscs, and breeding places and feeding grounds for waterfowl would have been recognised and preserved. The number of flood events would have been larger, but the impact – both socially and economically – is assumed to have been lower. A disaster on the scale of the 1953 flood would probably not have occurred because estuarine sedimentation processes, and the growth of peat in isolated river-fed areas would have matched the irreversibly rising sea level, caused by geophysical and climate changes. The model assumes that the population density could have been approximately at the same level as it is nowadays. All the costs linked to dyke construction, closing of the estuaries, water pollution and nature restoration would have been saved.
2. Embanked islands, open estuaries, and no overstrained drainage of the dry land. If the inhabitants had decided to embank the islands without applying intensive drainage programs, the total area of land above mean sea level would have been larger than it is now, but smaller than in scenario 1. In scenario 2, the inhabitants would have been focused on trading, tourism and, to a smaller extent, on aquaculture and fishery. The spatial planning of the islands would have catered for the storage, handling and transport of goods. After embankment, sedimentation processes would have ceased but peat growth would have prevented subsidence of the soil. The weakness of the soil structure would, however, have required specifically adapted construction methods for housing, buildings and infrastructure. Flooding frequency would have been higher than in scenario 1 because the embankments would have raised the water levels in the river branches. However, the impact of incidental flooding would have been relatively low in the absence of soil subsidence. Hypothetically, it is unlikely that the damage of a flood of the dimensions seen in 1953 would have happened. All the costs linked to closing the estuary, water pollution and nature restoration would have been saved.

Again, although it is speculative, it can be concluded from the above model exercises that a delta without dykes is safer than a delta with dykes, because natural processes will weaken the effects of extreme storm floods. A dynamic delta is more sustainable and robust, while it is flexible enough to adapt to changing situations. A static delta, on the contrary, is not safe and increasingly vulnerable to severe flooding. Projected into the future, this insight means that, in the Dutch case, if the importance of agriculture diminishes (as expected), new choices will open up. A modern, sea-oriented society could be developed, with (large) harbours, sea-oriented industries, shipping and fisheries and aquaculture trades. Housing on islands would be safe against flooding and surrounded by a shallow sea. We have every opportunity to do this moderately and wisely, by keeping the land we need and giving back to the sea what is necessary, to turn the environment into a more safe natural system.

This line of thinking opens a new perspective for different approaches to spatial planning in areas that are at risk of flooding. The delta of the rivers Rhine, Meuse and Scheldt is an example of an area where people could live and work in places that are sometimes inundated. Dykes could be displaced, enabling (temporary) inundation and sedimentation processes to take place again. The surface level of the land will be raised by natural sedimentation processes, providing a durable alternative for the unreliable dykes. When the natural dynamics are used in an optimal way, the effects of sea level rise, climate change and land subsidence can be partially counteracted. Maintenance will always remain necessary, however, because unpredicted and unwanted erosion and sedimentation processes have to be managed and guided. At sheltered localities houses could be built in the floodplain, constructed in such a way that the water cannot affect them, for example floating during floods or built on small artificial mounds as was practised in past centuries. While the 'mound-strategy' is already used in the Dutch delta by large investors, the private inhabitants should be offered the same advantage. Risks to life would be reduced compared to the situation in which an unexpected breach of a dyke could take place.

Implementing the measures described above would introduce a sustainable way of rehabilitating nature and developing the specific characteristics of the estuaries, so that ecological productivity and biodiversity will be optimised. Economically, this type of development needs less maintenance, leads to lower costs for flood defence, fulfils the precautionary principle and decreases flood risks. Next to the people economically bound to the region, the environment would be very attractive for retired people: Zeeland could become the "Florida" of the Netherlands, providing unique living conditions in harmony with the natural water environment. It could grow into an example of spatial planning in accordance with the natural system instead of a defensive planning against the basic characteristics of the ecosystems (cf. Van den Born et al., 2001).

As we have seen in the section '*A useful approach: the Flemish view*', along the Westerschelde, proposals have been launched to give land back to the sea in order to dissipate tidal energy, and to enhance the quality of the natural environment. Another successful example of changed land use can be found in England (European FRAME project). Dykes that were raised on the Alkborough flats along the east coast after the 1953 storm, are being removed. As a result, part of the Humber estuary (440 ha) will be changed from agricultural land into natural salt marsh and other estuarine habitats. An additional advantage is that the intertidal flats will break the incoming waves. The saving in maintenance and building costs of the surrounding dykes is estimated at 18 million euros (www.frameproject.org).

## Recommendations

Drawing on contemporary experience and knowledge, it would be easy to point the finger at past mistakes and wrong decisions. We cannot change history, but we can adjust our own future and share with other countries the Dutch experience and changing views, related to the exploitation of estuaries. In summary, the lessons we have learned from the design, execution and follow-up of the Delta Works in the SW Netherlands have led us to the following recommendations and visions:

1. The Delta Works approach has underestimated the importance of long-term hydromorphological and ecological processes and changes: the height of the dams will have to be increased for centuries to come, and the land behind the levees cannot grow anymore with the rising of the sea.
2. Realise that on-going costs for maintenance and mitigation of side effects are ultimately higher than those for the original building of the civil engineering constructions. Maintenance costs for technical constructions and mitigation costs of hydrological and ecological negatively valued moves are a perpetual expense. In this context the Dutch taxpayers are charged for several tens of millions of euros each year, and these costs will not decline but will only rise, due to the progressing deterioration of the engineering works.
3. 'Look before you leap': safety declines! There is only a toilsome way back after land reclamation and dyke construction, and it is therefore better not to start this process. The 1953 flood was a disaster waiting to happen, and it might happen again. The dependence on dykes and other infrastructure will intensify over time, which means that opting for short-term safety is inevitably connected to increasing long-term vulnerability. Moreover, once a sea-dyke is built, people will use the new land to the maximum: new investments are made, so the economic damage of a flood disaster increases steadily.
4. Better to be safe than sorry. Dykes can never guarantee full safety; they provide a false sense of safety against flooding. The huge dams may be technical masterpieces for control of the dynamics of the sea, but society fails to control the socio-economic processes the dykes unleash during a flood disaster, and their existence is to a large extent irreversible. The chance of flooding has been reduced, but the potential damage is enlarged, so the net

economic result is probably negative. Risk assessment should focus not only on minimising the risk of a prevailing flood disaster, but also on minimising the impact by not allowing large investments at vulnerable locations.

5. There is a call for reversible and flexible solutions. When modifications of the natural system seem to be inevitable, try to use reversible measures. As knowledge develops, other solutions might be found which could than be applied. The hydro-morphological and ecological changes that will occur when an estuary is modified are still poorly understood, and predictions have to deal with a great amount of uncertainty. Changes in the importance of agricultural land in the European context, offer an opportunity to give arable fields back to the sea in order to absorb tidal energy and to allow the land to rise concomitant with the sea.
6. Look for suitable economic drivers. Each (semi-natural) landscape has its own characteristics and, considering the fact that the values of the existing ecosystems are recognised and integrated into economic development strategies, extreme disturbance of the environment should be avoided. Try to develop economic drivers that are compatible with the conditions of the natural environment, in the delta e.g. fishery, aquaculture, salt-water crops, and marine-wetland oriented recreation and trades. Reversible and resilient economic measures within the limits of the natural processes are preferable.
7. A future perspective is a new urbanised landscape, where people and investments are located in safe places, surrounded by a landscape that is ruled by the forces of nature. Industry took refuge on artificial mounds, the most ancient and the most modern way to survive storm-floods. Floating, or sea-encircled artificial dwelling-mounds deserve full attention as a long-term strategy for safe building in the lowest parts of the Netherlands and Flanders. New approaches such as developed in the Westerschelde offer flexible solutions to flooding problems, and are worth a broader evaluation.
8 Try to make a complete environmental cost-benefit analysis, including the direct and indirect economic use values, and the non-use (intrinsic) values. The use and non-use values of (unaffected) ecosystems, and the long-term value of the safety that nature provides if we do not interfere, should be included in cost-benefit analyses
9. Create public awareness related to ecosystem functioning and safety for people and their goods. Public participation may result in better understanding of the structure and functioning of ecosystems. When the short- and long-term consequences of, for example, obstructing the connectivity of the river-estuary–sea continuum is explained, people will better understand the importance of an intact ecosystem. The result may be greater goodwill for sustainable developments, even if unpopular measures have to be taken such as giving land back to the sea.
10. Consult a world-wide group of estuarine experts, from the natural as well as from the social sciences. As shown in this paper, lessons can be learned from countries that have experience with interference in estuaries. As water management practices are traditionally exported by Dutch experts, the Netherlands and Flanders (Belgium) could take the lead in such an initiative.

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