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Interactions between water and land in The Netherlands

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Abstract. The Netherlands are one of the most densely populated coastal countries in the world and there is only limited space for living, working, transport and recreation, while there is also the need to preserve and expand valuable natural habitats. In order to solve many existing and future conflicts of interest, and in order to create 'added value', strategies are developed to optimize the use of water-land systems.

The principle of 'building with nature' is applied in order to integrate land in sea and water in land in such a way that future generations will be able to use coastal resources in a sustainable way, including a minimal effort to maintain the coastline and the promotion of a multiple-use system.

The concept of Integrated multifunctional sustainable coastal zone development is introduced. This concept deals with a balanced approach to the lack of space for present and future coastal uses in relation to each other, to the hinterland, and to the sea. Flexible master plans are developed, taking into account many functions of the coastal zone, and facilitating adaptation to future developments – e.g. impacts of climate change and relative sea level rise. In this regard increasing the flexibility of the coastal zone is of vital importance.

Large-scale coastal land reclamations in The Netherlands are dealt with, based on two different principles: (1) polder systems (low lying land reclamations surrounded and protected by dikes), (2) systems of 'building with nature' – land reclamation protected by man-made foreshores, beaches and dunes. In the latter type new flexible dynamic-equilibrium coasts are created with a minimum of 'hard structures'. In this way space is provided for many functions, while coastal vulnerability is reduced and a flexible coast is developed.

Keywords: Building with nature; Coastal zone; Integrated approach; Multifunctional sustainability; Land reclamation; Polder.

Introduction: The role of water in The Netherlands

The area of The Netherlands is 41 526 km^2, of which ca. 85 % is land (33 889 km^2) and ca. 15 % is water in the form of coastal sea, rivers, lakes and canals (only water bodies of > 6m width included). It has a population of 15.6 million (1997). About half of The Netherlands is situated below sea level, where about two thirds of the population is living.

The Netherlands is a typically lowland-coastal country, bordering the North Sea and with three main rivers (Fig. 1), the Rijn (Rhine; with the branches Waal and IJssel), Maas (Meuse) and Schelde (Scheldt). The North Sea (572000 km ^{2}) is a shallow epicontinental sea of the Atlantic Ocean. Most of the present 353 km long outer Dutch coastline, bordering the North Sea, is dynamical under the influence of tidal currents, waves and storm surges which remodel the accumulated river sediments. Of this coastline 254 km are dunes with beaches, 38 km sandy flats, 34 km sea dikes, and 27 km of seawall elements and two main storm surge barriers.

In the north, the Wadden Sea (3500 km^2) consists of tidal flats and salt marshes with tidal channels; it is largely protected against the North Sea by the Wadden islands, a series of sandy barrier islands. The Wadden Sea is an international natural park, combining nature conservation with diverse human activities like flat fish-, mussel- and cockle fishery, gas extraction and recreation.

In the southwestern part of The Netherlands, where the three main rivers enter the sea, islands and polders are surrounded by beaches and dunes and, further inland, by dikes, (salt) marshes, tidal flats, macro-tidal channels, lakes, rivers and canals. These low-lying islands have been severely affected in the past by many storm-surge floodings (van de Ven 1993). As a reaction to the latest major flooding (February 1953) the Delta Works have been executed, short-cutting the outer coastline with ca. 900 km and linking the islands with each other and with the mainland. The Delta coastal engineering works include sophisticated constructions in the estuary mouths such as the Eastern Scheldt- and the New Waterway Storm Surge Barriers. These barriers are only closed during high surge levels, providing protection and safeguarding economic as well as ecological developments (Hillen et al. 1993; Nienhuis & Smaal 1994).

Hydrological cycle

The major rivers in the Dutch deltaic landscape are: the Rhine, a melting-water/rain-fed river, and the Meuse and Scheldt as typically rain-fed rivers. The average water inflow at the Dutch border of Rhine, Meuse and Scheldt

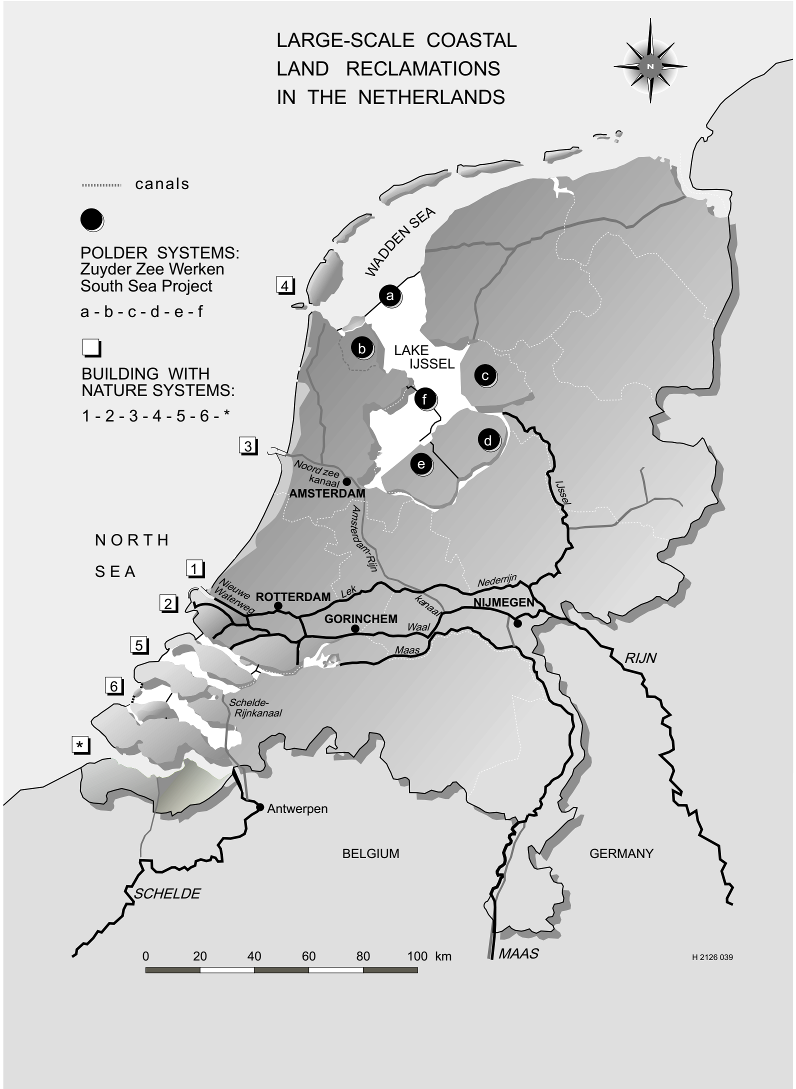

Fig. 1. Map of The Netherlands showing large-scale coastal land reclamations. Polder systems:
a =Enclosure Dike;
b =Wieringmeer Polder;
c =North-East Polder;
d =East Flevoland Polder;
e =South Flevoland Polder;
f =Compartment Dike Lelystad-Enkhuizen;

Building-with-nature systems:
1 =Plan 1: Scheveningen-Hoek van Holland;
2 =Plan 2: Extension of Euro-Meuse Plain;
3 =Plan 3; Seaport Marina IJmuiden;
4 =Shoal attachment to Texel;
5 =Potential pumped storage basin;
6 =Neeltje Jans Island;
* =Potential area for shoal development.

is 2200, 250 and 120 m^3/sec respectively (van de Ven 1993; Anon. 1997). Once, these rivers were freely meandering. Consequently, flooding occurred frequently and shipping was at times difficult. Therefore river dikes were built and small breakwaters perpendicular to the river banks, dams, barrages, sluices, locks, parallel canals and flood gates were constructed. In short: the rivers were tamed and regulated. However, river regulation went too far and the river's flexibility was lost. The recent combination of heavy rainfall and enhanced drainage towards the rivers caused very serious flood problems (Scholten et al. 1998; this volume). This led to the successful implementation of the 'Living rivers' project.

Ca. 50% of The Netherlands is drained to Lake IJssel (the former Zuyder Zee). During periods of summer drought, about the same land area can be supplied with fresh water from this lake. Mean rainfall is 725 mm/yr, and is, both directly and indirectly, evaporated again. The average evapotranspiration is 475 mm/yr, and the precipitation surplus in winter alternates with a precipitation deficit in summer. During a very wet summer a precipitation surplus of 500 mm may occur, while during a dry year infiltration and sprinkler irrigation is applied.

Groundwater flows in complex patterns with varying velocities underneath the surface. Fresh water from the surface and groundwater is flowing into the sea, while saltwater tongues protrude inland in the river mouths; fresh water lenses are formed under the coastal dunes resting on brackish water, while salt water intrusion occurs specifically where the dunes are narrow. All these fresh, brackish and salt water bodies and water flows play their own role in the hydrological cycle.

Fresh water is extracted from the surface water, groundwater and infiltrated water in dune systems, for drinking water supply and for agricultural use and process water and cooling water in industry and power stations.

For drinking water and industrial process water, a supply of ca. 1.3 $\cdot 10^{9}$ m^3 per year is needed, of which one third is being extracted from surface water and two thirds from ground water (Anon. 1996a). For agricultural purposes the precipitation surplus is used and during dry years up to 300 $\cdot 10^{6}$ m^3 is extracted from surface water and ground water. In wet years the excess water needs to be drained and discharged through pumping stations. Thus both drainage and irrigation are applied. Precise regulation of the groundwater levels for agriculture is achieved through intricate pumping systems.

Waste water is discharged after collection, transport, and mechanical, physical, chemical and/or biological treatment.

The Dutch have to protect their country at all times from flooding both from the sea and from the rivers, by natural and man-made dunes, dikes, solid seawall elements and storm surge barriers. Hundreds of diesel-electric pumps – successors of the original 10 000 wind mills– are working day and night to keep the country 'dry'. One day without pumping means a water level rise of about 10 cm in the polder canals. Water which is pumped out of a polder is collected in a main canal which ultimately enters into the sea (Fig. 2).

Economic functions

Sea routes and inland waterways are used as means of transport and distribution. Rotterdam and Amsterdam are linked directly to the sea via the New Waterway and North Sea Channel, respectively. Rotterdam is the largest port of the world in volume, handling ca. 300 million tons/yr. Rotterdam can accommodate ships up to 350000 ton. Both ports are linked to several European countries through the main rivers and inland canals. There are 2400 km of inland waterways in The Netherlands which can accommodate ships larger than 1000 ton.

In order to keep the harbour entrances and basins at sufficient depth, trailer suction hopper dredgers are used. To maintain the necessary navigation depth in the navigation channels leading to the harbour of Rotterdam ca. 15 million m^3, and to Antwerp ca. 10 million m^3, are annually dredged and combined, as far as possible, with sand mining activities (Misdorp & Terwindt 1997). The yearly amount of sediments to be dredged in The Netherlands will reach the level of 30 million m^3 during the period 1995-2015 (Anon. 1996a). The same equipment is used for foreshore, beach and dune nourishment (ca. 7 million m^3 sand per year; de Ruig 1998; this volume).

Commercial fishery is carried out in the sea and in the lakes and rivers. The seashores with their beaches and dunes are golden rims for tourism, recreation and nature conservation and so are the rivers and lakes. The capital city of Amsterdam and the port of Rotterdam are in themselves attractive for tourism using water as a transport route. Both cities offer facilities for cruise ships, intensive ferry connections and canal trips.

Nature conservation

The main coastal ecosytems, the North Sea, the Wadden Sea, as well as the main rivers and estuaries, Lake IJssel, and the smaller lakes and water courses, represent high nature values. In particular the coastal ecosystems of The Netherlands and other countries bordering the North Sea are very rich (Jefferies & Davy 1979; Beeftink et al. 1985). For many groups of plants and animals 60-80% of the Dutch species are found in the coastal zone. It is essential for soft coastal ecosystems that gradients in abiotic conditions are maintained or restored, e.g. variation in moisture, salinity, groundwater level, topography, microclimate, organic matter and carbonate content (Grootjans et al. 1997). Such gradients promote a high biodiversity. The concept of 'building with nature' is based on the widening of these gradients, thus creating resilient coasts. Resilience is defined here as the capability of a coastal system to maintain or enhance functions under changing hy-

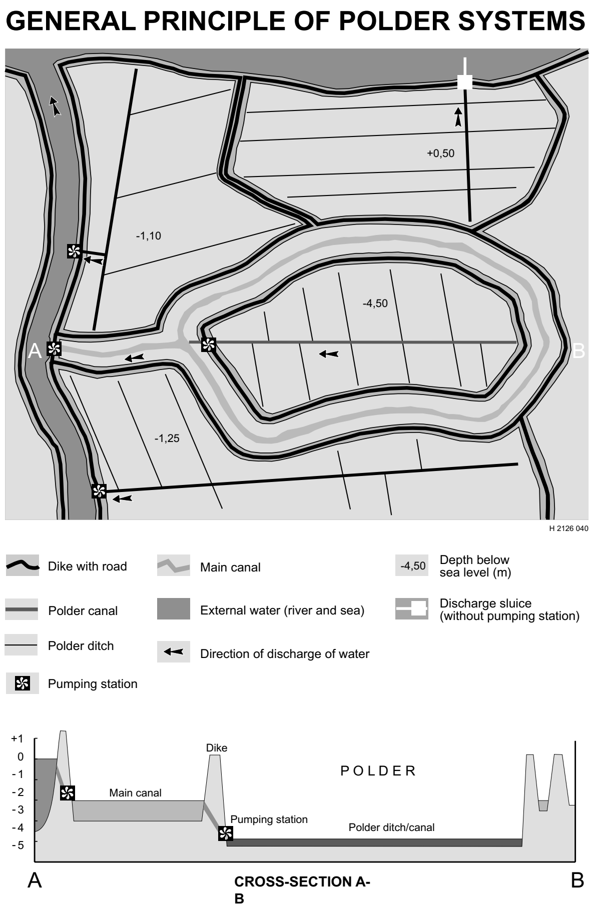

Fig. 2. General scheme of a polder system.

draulic and ecological conditions. These changes can be natural or man-induced such as climate change due to increased emissions of greenhouse gases. Nature conservation which is based on natural processes and accounting for socio-economic development, and on increasing the coastal resilience, will reduce the vulnerability of coastal areas to future changes like (accelerated) sea level rise.

Sustainable coastal zone development

Many civilisations had their origin in the border zone between land and water, both in coastal and deltaic regions. In the year 2000 ca. 80% of the largest population centres in the world will be found in lowland-coastal areas. Striking examples of coastal urbanization can be found in nearly all parts of the world, e.g. Alexandria, Bombay, Buenos Aires, Calcutta, Dacca, Hong Kong, Jakarta, Karachi, Los Angeles, Manila, New York, Rio de Janeiro, Shanghai, Singapore and Tokyo. The population in coastal urban agglomerations is growing much faster, both through birth and migration, than the world population as a whole (3.1% vs 1.7%/yr during the period 1980-1995 (Anon. 1995a).

In these densely populated coastal areas we have to deal with many existing and forthcoming problems in need of solutions, but also with challenging opportunities. A similar situation is found in The Netherlands.

The Netherlands have a high population density, but also a high motorcar density, a high waste production and a high energy use per capita. There is only little space available for living, working, transport and recreation, while at the same time we need to preserve or even enlarge natural coastal habitats. This lack of space is specifically apparent in the 'Randstad Holland', a rim of cities in the western Netherlands, including Amsterdam, Den Haag, Rotterdam and Utrecht, with a 'green heart' in the centre. Here, physical planning has to deal with lack of space for a growing infrastructure and the need for natural habitats.

Part of the solution can be found by a more efficient use of the existing areas, including the use of the third dimension in infrastructure and building, and in striving in due time for a stabilization of the population. The population growth of The Netherlands was 0.48% and 0.73% during the periods 1980-1985 and 1990-1995 respectively (Anon. 1995a).

Another solution is provided by land reclamation in front of the coastline by integrating new land in sea and water in the new land (in the form of tidal lagoons, lakes, harbour basins, fresh water lenses under dunes and water ways).

In all solutions, both in the hinterland and in the new land, water plays a crucial role. This should demand an integrated care of the condition and use of water systems, comprising the environmental compartments water, air, water-beds, banks and shores, soils and groundwater with their physical, chemical and biological aspects. In short: integrated water management.

Measures should be directed towards the sustainable development of water systems (preservation of production, biodiversity and self-regulation) and at the sustainable use of these water-land-systems for many purposes by man. This strategy should not only result in creating added economical values but should also increase coastal flexibility through reserving space and leaving options open for future responses to impacts of climate change and social developments in the coastal areas.

Integrated multifunctional sustainable coastal zone development, based on careful analysis of coastal regions and their climate and abiotic and biotic conditions and their present use, is a new approach to solving the above-mentioned problems, in relation to each other and in relation to the hinterland and the sea.

An important element of integrated coastal policy – including coastal protection and water resources management – is land reclamation using, as far as possible, the principle of 'building with nature'. This principle is based on the notion that coastal zones are highly dynamic areas and that one can make a more intelligent use of the existing materials and forces. In this way, most of the present and forthcoming problems in the coastal zone and the hinterland can be solved and new opportunities can be discovered – while learning from both the mistakes and the achievements of the past.

Along these lines, seaward extension of the narrow dune areas near highly urbanized regions forms one of the multifunctional solutions increasing the flexibility of the Dutch coast. By developing flexible coastal areas as buffers, we create space for living, working, recreation and nature, while in the mean time we prepare the adaptations to possible impacts of climate change. Such impacts will follow from the expected increase of the sea-level rise and storm frequency and intensity, which in turn will increase the frequency of flooding, coastal erosion and saltwater intrusion. In its 1995 Second Assessment Report (Anon. 1995b) the Intergovernmental Panel on Climate Change indicated that the sea level will probably rise globally with ca. 50-60cm (or may be even ca. 100 cm) during the next century. Locally, the rate of relative sea level rise will vary largely due to factors such as subsidence, tectonics and glacial rebound.

By developing resilient coastal areas as buffer zones, large gradient-rich areas consisting of valuable estuaries, dunes, lagoons and peat bogs can be formed. Such areas can more effectively withstand fluctuations in climate

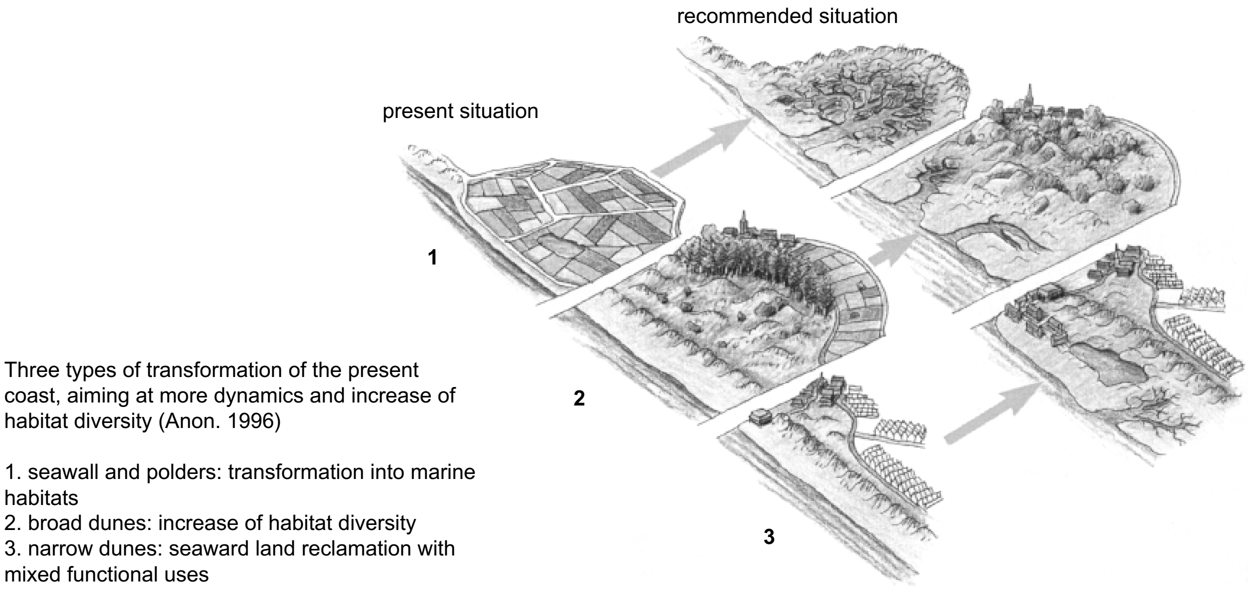

Fig. 3. Three types of restoration of coastal dynamics and -diversity (Anon. 1996). **a.** Polder protected by a sea dike can be developed into a marine environment; **b.** Broad dunes with woodland in the inner dunes can be diversified by creating inlets and opening up the woodland; **c.** Narrow dunes can be extended seaward by creating a beach landscape.

than narrow, fixed coasts. The restoration of natural coastal dynamic processes depends amongst others on broadening the dunes, as explained in the WWF-report: Growing with the sea (Anon. 1996b). In these areas not only space can be found for nature, but also for other functions, based on adequate zoning (Fig. 3).

In order to achieve integrated multifunctional sustainable coastal zone development, two aspects are essential. They will be discussed in some detail under the headings ‘Integrated approach’ and ‘Building with nature’.

Integrated approach

In order to deal, in an optimal way, with long-term coastal management issues, e.g. degradation of coastal habitats, changes in hydrological cycles, depletion of coastal resources and adaptation to sea-level rise, an integrated approach is desirable (Misdorp et al. 1990; Anon. 1993).

One of the basic elements of Integrated Coastal Zone Management (ICZM) programs is the arrangement of responsibilities. Horizontal (sectors and disciplines) and vertical (national, regional and local) institutional integration is required for the implementation of such programs.

Many coastal functions have to be considered carefully, involving many different academic disciplines, governmental sectors and non-governmental stake-holders (Table 1). As this table indicates, a wide spectrum of functions and elements are involved in the execution of land reclamation projects and consequently they all should be taken into account in the ICZM planning stage. During this stage a cost-benefit analysis of different alternative solutions should be carried out while taking into account the coastal functions affected. After a set of solutions has been chosen, financing mechanisms are identified whereby a combined public-private partnership could be a preferable option.

Building with nature

The essence of this principle is the flexible integration of land and water in the coastal zone with new land offshore, making use of materials and forces present in nature and taking into account actual and potential values of the natural environment (Waterman 1991,1997,1998). With regard to land reclamation, application of the principle is emphasized, both from the viewpoint of nature and from the viewpoint of cost-effectiveness.

According to this approach a new, flexible coastal zone is created using sand from the sea, consisting of a new primary range of dunes with a new beach in front of

Table 1. Coastal zone functions and management elements involved during coastal development projects (Waterman 1991).

1. **Safety** from: flooding (including effects from sea level rise), drought, coastal erosion, salt water intrusion, land subsidence; cyclones, storm surges, tsunamis, earth quakes, landslides, active volcanoes, human activities.
   To these safety aspects are linked the construction and maintenance of:
   - foreshores, beaches, dunes (built up by sand and vegetation);
   - dikes (consisting of clay, wood, grasses, seaweed, willow mats, asphalt, geo-textiles, etc.);
   - solid seawall elements, e.g. groynes perpendicular to the coast and breakwaters (above sea level and/or submerged) parallel to the coast, harbour moles, consisting of blocks of basalt, various types of boulders, concrete elements, gravel, etc.;
   - canals; sluices, locks, river regulation;
   - drainage and irrigation systems in general.
2. **Environment in general**: this includes the environmental compartments: air, water, land.
3. **Nature**: micro-organisms, flora, fauna, humans; eco-systems; nature conservation, nature development; bio-diversity.
4. **Landscape:** landscape conservation - landscape development.
5. **Water resource management:** water quality and water quantity; use of groundwater, surface water (rivers, lakes, sea), dune-infiltrated water; sewer systems and waste water purification.
6. **Energy:** energy supply and reduction of energy use:
   -natural gas, oil, coal, etc.;
   -biomass (wood, etc.), organic wastes; - nuclear energy
   -solar-, wind-, water-, geothermal energy;
   -combined cycle, isolation, etc.

7a. **Agriculture**: agriculture in general, also including horticulture and forestry, cattle and poultry breeding;

7b. **Aqua-culture, Mari-culture, Fishery**.

8. **Mining**: Dredging (followed by transport and disposal) of sand/silt/clay/gravel from the seabed for the creation of soft sea-defence structures, for land reclamation, for the creation, deepening and maintenance of approach channels to ports, and for maintenance of the ports. Of importance for exploration and exploitation of oil, natural gas and other mineral resources (old land, new land, tidal flats, coastal seabed).
9. **Construction sites for living and working**: houses and facilities; industries and offices and facilities, city development.
10. **Recreation and tourism**
11. **Transfer/distribution centres and related activities**
    - seaport, river-port, lake port, airport, land-port.
12. **Infrastructure**
    - roads, railroads, waterways, airlanes, underground systems.
13. **Transport modules**
    - bicycle, motor-car, bus, tram, train, metro, ship, container, aeroplane, rocket.
14. **Telecommunication**
    Data acquisition; Data transmission; Data processing.
15. **Environment in particular:** Air-/Water-/Soil-quality improvement through pollution prevention, by improvement of conversion processes and by end of pipe purification.
16. **Environment in particular**: Solid and liquid waste by improvement of conversion processes and by absolute environment-friendly collection,transport, storage, processing, recycling of these wastes.
17. **Governmental institutions / Non-Governmental institutions / Citizen groups / Individual citizens / People's participation**
18. **Public health and welfare; Sport; Culture; Religion**
19. **Education and research**
20. **Defence**
21. **Economy and employment**
22. **Finance; Public private participation; Financial engineering**

the coast and with a minimum of solid seawall elements. The new coastline is designed in such a way that accretion and erosion are more or less in balance with each other. The method takes into account all the forces acting on the mobile sand, i.e. the action of tides, waves (specifically in the breaking zone), swell, river outflow (referring to water and sediment), estuarine and sea currents, gravity, wind and rain. Use is also made of the interaction between vegetation and sand. Another (complex) factor which can be considered is the interaction between marine organisms (such as benthic algae, diatoms, sea grasses) and sand/silt particles on the beach and near the shore.

The design aims at low maintenance costs for the new coastline; this is achieved by beach or foreshore nourishment, which fits the 'building with nature' concept. Only in those cases where erosion dominates accretion, solid seawall elements are preferred. In such cases measures for the reduction of hydraulic loading, e.g. (submerged) parallel breakwaters, sills, perched beaches using low-cost materials, or artificial drainage of beaches, can also be considered.

In cases of large-scale land reclamations, overall master plans are developed in such a way that nature reserve areas are included and that net nature gain is achieved, improving the economy and environment at the same time. A further advantage is that these land reclamations can be carried out phase after phase, segment after segment, all fitting in the master plan and allowing possible adjustments during the execution.

Within the master plan special attention should be paid, not only to integration of land in water but also of water in old/new land in the form of both salt and fresh water systems wherever necessary. This include tidal lagoons and inlets, harbour basins, lakes, canals, fresh water lenses under dunes, taking into account groundwater levels and water quantity and quality. It should be noted that the concept is not only applied in the field of land reclamation, but also in the existing hinterland by creating inland surface waters through inundation and excavation, for instance behind the coast and also in the river landscape. In these cases new and wide land-water border zones are created for nature development through activities such as mining of raw materials (clay, sand, gravel) and constructing storage basins for water (increasing river storage capacity for freshwater supply and diminishing risks of flooding). It is fascinating that if these activities are carried out (Waterman 1991, 1997) other positive effects follow, such as development of natural ecosystems, tourism and recreation, but also increasing safety against flooding, freshwater storage and providing building materials.

Remarkable examples of 'building with nature' are the development and execution of the plans: 'Living rivers' (Silva & Kerkhofs1992 ; Nijhoff 1998) and 'Resilient coasts' (Anon. 1996b).

'Living rivers' is a plan consisting of four sets of measures to increase the flexibility of river systems while at the same time safeguarding the essential function of shipping:

1. Widening the river bed by locally deepening of it, with the advantage that the storage capacity of the river increases and the danger of flooding diminishes.
2. Widening the river bed by dredging, which may give economically important materials (clay, sand, gravel).
3. By executing measure 1 in a special way, river wetlands can be created, which may become nature reserves.
4. Through zoning small marinas and other attractive areas for tourism and recreation can be created, including fishing, in such a way that nature is not disturbed.

The 'Living rivers' and 'Resilient coasts' plans are very similar. They are now being executed step by step and are of great importance in harmonizing functions and safeguarding options for future developments.

Another example of economic development in the framework of improving the environment in the coastal zone is found in the large harbour area of Rotterdam. In 1993 several agreements were signed by representatives of industry and the local, provincial and national government. These agreements provided a new impetus to the economic growth in the Rijnmond region (a 750 km^2 administrative region in and around Rotterdam) while they will also improve the environment. This twofold goal will be reached through implementing 47 conceptual plans and initiatives clustered in six themes during a period of 17 yr, on an estimated total budget of $4 \cdot 10^{9}$ USD (Anon. 1998). The existing conversion processes in the field of industry, power stations for energy-supply, agriculture and aquaculture and transport, cause tension between the economic development and environmental issues, and between coastal conservation and exploitation. (Waterman 1991, 1998).

Conversion processes will be developed in the near future and implemented in such a way that products are made at a higher yield with less raw material and with less energy, with less hazardous emissions to air, water and soil, and with fewer waste products. In case waste products are formed, they should be converted to environmentally friendly products, or safely stored.

One of the examples of this approach is the feasibility project aiming at recycling the residual waste heat-energy to the benefit of neighbouring partners in the Rijnmond area, the ROM-Rhinemond programme (Anon. 1998). Harmonious cooperation with all the relevant authorities at the various governmental levels and with non-governmental institutions and citizen groups is also here an essential prerequisite to achieve integrated and sustainable coastal zone development.

Large-scale coastal land reclamations

We shall now focus on examples of large-scale coastal land reclamation projects in The Netherlands, which are based on two different principles: Polder systems and 'building with nature' systems.

Polder systems

A large-scale example of a recent polder system is the 'Zuyder Zee Project'. It comprises a barrier dam and the transformation of the originally marine Zuyder Zee into the freshwater IJssel Lake, subsequently followed by the creation of four large polders (Fig. 4; Table 2). The enclosure dike ('Afsluitdijk') is 32.5 km long and connects the provinces of North Holland and Friesland. It has 25 gravity-flow discharge sluices and two sets of locks for shipping, complete with a nowadays four-lane motorway and a bicycle path.

The salt water of the former Zuyder Zee was gradually replaced by fresh water from the river IJssel, precipitation, and gravity drainage towards the Wadden Sea through the opening of the discharge sluices during ebb tides in the Wadden Sea.

Table 2. Characteristics of four polders in The Netherlands (Anon. 1995).

Period of creation	Name of polder	Area (ha)	Pumping stations Number	Pumping stations Power (Mwatt)	Initially pumped out (10^6 m^3)	Maintenance pumping Water (10^6 m^3 / yr)	Maintenance pumping Costs (USD/yr)
1927-1930	Wieringermeer	20000	2	3.28	700	160	200000
1937-1942	North East Polder	48000	3	6.10	1500	400	500000
1950-1957	East Flevoland	54000	3	5.94	1600	800 (East and South Flevoland combined)	900000 (East and South Flevoland combined)
1959-1968	South Flevoland	43000	1	3.53	1400		

ZUYDER ZEE WERKEN SOUTH SEA PROJECT

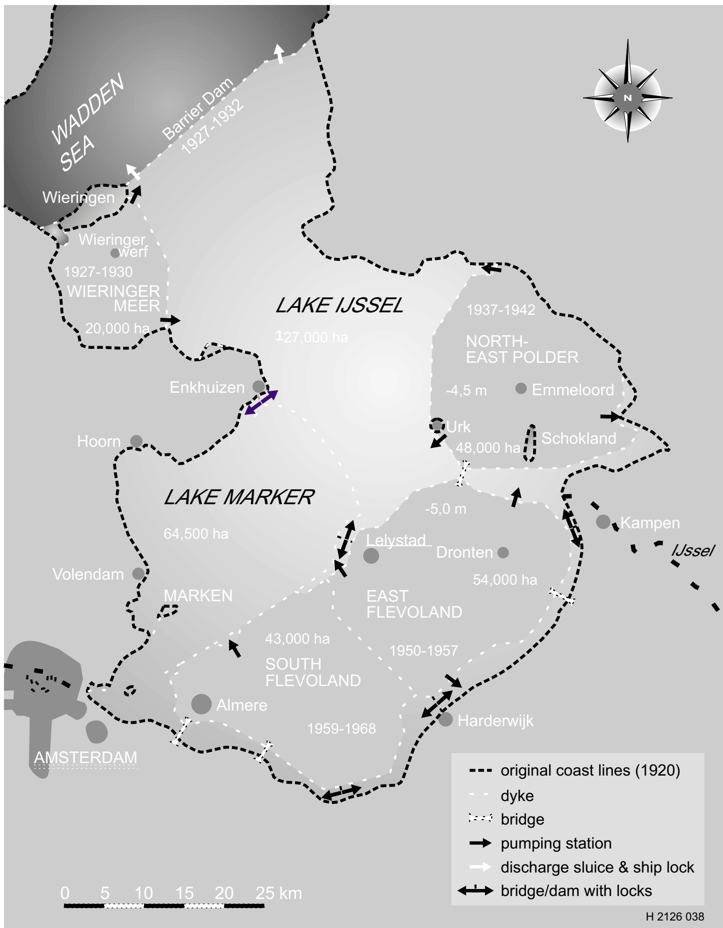

Fig. 4. Zuyder Zee Project.

The polders were initially formed through the construction of perimeter-dikes and pumping stations, followed by the pumping out of the enclosed water. The quantities of water pumped out (van Duin & de Kaste 1990) varied from $700\text{-}1600 \cdot 10^6 m^3$ for the four polders (Table 2). Then young soil of the polder was sown with reed (using aeroplanes) to enhance evapo-transpiration, followed by reed burning and the creation of canals, ditches, furrows and drainage pipes. The soil was ploughed and crops (rape-seed, winter wheat, barley) were planted to improve the initial soil structure and transform the former sea-bed in highly productive farm land as a base for living, working, infrastructure, recreation and tourism, and nature development.

The lowest level of the new land is ca. 6.5 m below mean sea level. The situation below sea level gives rise to seepage of water, mainly from the bordering lakes. In the case of the Wieringermeer Polder this seepage water has a considerable salt content caused by the proximity of the sea. The pumping stations of the Wieringermeer, remove about 750000 ton salt per year, while East and South Flevoland together remove about half this quantity (Anon. 1990-1995).

One of the consequences of draining is the subsidence of the reclaimed land due to the compaction of the clay and peat layers. The subsidence rate depends on the location of the polder and the soil type (clay, light clay, loam, sand or peat). The mean subsidence rate for The Netherlands during the last millennium is in the order of 40 cm/100yr, with a maximum of 100cm/100yr (van de Ven 1993). Another consequence is the need for daily pumping of large amounts of excess rain- and seepage water (Table 2) in order to keep the groundwater at the preferred levels. The total pumping costs for the four polders exceeds 1.5 million USD per year.

It is interesting to note that in the North East Polder two former islands were incorporated: Urk (an important fishery harbour) and Schokland. The design of this polder and the Enclosure Dike was such that the fishery was guaranteed and even augmented. Furthermore, several new urban settlements arose in the polders.

From 1930 to 1970 a remarkable shift in land use

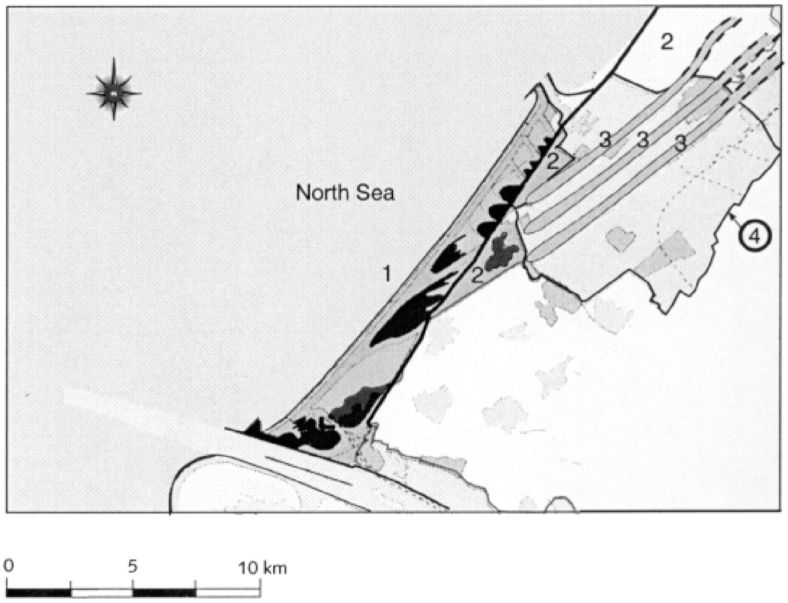

Fig. 5. Building with nature, Plan 1 (location see Fig. 1): Scheveningen / Hoek van Holland.
1. Proposed seaward land reclamation near The Hague with beaches, new dune ridges and lakes, and areas for marinas, horticulture and housing; 2. Younger Dunes (formed 1200 - 1600 AD); 3. Older Dunes (formed ca. 4000 BC) on a coastal barrier with three parallel dunes ridges; 4. City boundary of The Hague, which is partly situated on the Younger and partly on the Older Dunes; Note the alignment of the new dune ridges (in 1) with existing barrier system (3).

occurred: both urban and natural areas were created in the youngest polder (South Flevoland), while the agricultural area decreased (Table 3). This shift reflects the general urbanization trend, the increase of productivity in horticulture and agriculture per ha during the last decades, the increasing importance of nature conservation and development, and open-air recreation.

The youngest polder, relatively close to Amsterdam, contains the fastest growing city in The Netherlands, Almere, at present with 100000 inhabitants, which will ultimately grow to 250000. The second largest city (60000inhabitants), the capital of the Province of Flevoland is Lelystad, named after the originator of the Zuyder Zee Project, the engineer Cornelis Lely.

All in all we may state that the four reclaimed polders – the largest land reclamations in the world – are considered as a great success regarding the creation of space for people in a changing society.

With regard to the surrounding water areas of the polders we add that the remaining fresh water bodies are: the IJssel Lake: 127000 ha, Marker Lake 64500 ha, and the border lakes – east and south of the Flevoland polders: Veluwe Lake 5000 ha, Gooi and Eem Lake 4500 ha (Fig. 4). These lakes are very important as fresh water reservoirs, for inland navigation and for recreation. Especially the border lakes play an important part in the regulation and control of the groundwater levels in the adjacent hinterland.

Table 3. Changes in land-use over time in four successive polders (van Duin & de Kaste 1990). WI =Wieringermeer; NE =N orth East Polder; EF = East Flevoland; SF = South Flevoland.

Land use in %	WI	NO	OF	ZF
Agriculture	87	87	75	50
Nature (incl. woodland)	3	5	11	18
Cities	1	1	8	25
Dikes, roads, water	9	7	6	7

Building with nature systems

The principle of 'building with nature' is and will be used during the execution of land reclamation plans in the North Sea, where nature allows us to do so. As explained before, the essence of this principle is: flexible integration of land in the sea and of water in the new land, making use of materials and forces present in nature, taking into account existing and potential nature values (Waterman 1991, 1997). The locations of the Plans 1 - 3 are given in Fig. 1.

Plan 1 (Fig. 5) is a wedge-shaped addition of new land between Scheveningen and Hoek van Holland with an area of 4500ha, varying in width from a few metres near Scheveningen North to ca. 5 km near Hoek van Holland, consisting of a primary row of dunes with the new beach in front, and secondary rows of dunes parallel to old dune ridges in the existing hinterland. Actually two designs were made. The first segment of Plan 1 has already been created, the so-called Van Dixhoorn-Triangle near Hoek van Holland.

The plan aims at restoring a former coastal configuration (16th century), which was washed away by river outflow and sea breakthrough. The position of the new coastline is among others determined by the northern harbour pier of Hoek van Holland and the coastal

Fig. 6. Building with nature Plan 2 (location see Fig. 1): Land reclamation with industrial uses for the harbour of Rotterdam. In the foreground a depot for polluted harbor sludge. North Sea to the left.

segments inside this land reclamation plan are planned to be in alignment with the old coastal barrier system on which the city of The Hague was built (Fig. 5).

Plan 2 is a panhandle-shaped peninsula of ca. 2000 ha attached to the Euro-Meuse Plain of Rotterdam. This peninsula follows the shape and orientation of the already existing panhandle peninsulas of Goeree-Overflakkee and Schouwen-Duivenland (southwest of Rotterdam). Two designs were made. The first two segments of Plan 2 have been completed, including the so-called Slufterdam (Fig. 6).

Plan 3 (Figs. 7,8) is an addition of land, south of the (extension) of the southern harbour pier of IJmuiden. It has already been completed. This plan was initiated by nature itself as a reaction to the extension of the piers, caused by the littoral sand transport in northern direction. This process of sediment accumulation could be accelerated by creating a new primary range of dunes with a new beach in front. Within this plan a large yachting harbour was designed, with a boulevard, a tourism and recreation centre, a residential area, a fresh water lake and a new nature reserve area linked to an existing one. The creation of the yachting harbour and the lake provided the building material for this IJmuiden triangle.

All these plans consist mainly of dunes and beaches with a minimum of solid seawall elements. They are created by sand-extraction from the sea-bed, mainly using trailing suction hopper dredgers. They are all multi-functional with regard to the use, such as: residential areas; sites for the industrial and services sector; sites for tourism and recreation, including yachting harbours; areas for ports and port-related activities; roads, railroads, conveyor belts, underground systems including pipelines, cables, optic fibre; sewer systems and waste water purification; energy supply; the absolute environmental friendly storage and processing of various types of wastes; forms of agriculture and aquaculture; nature reserve areas. All these flexible, multifunctional plans can be created step by

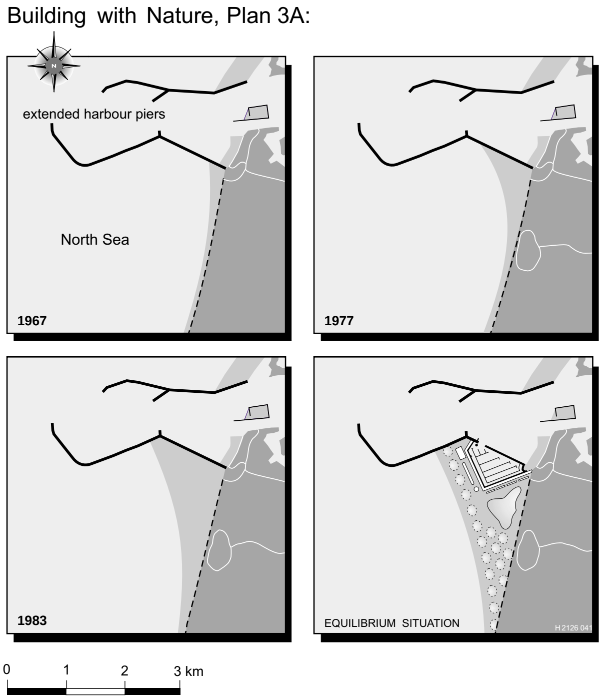

Fig. 7. Building with nature Plan 3a: equilibrium situation with IJmuiden on Sea, Seaport Marina IJmuiden and Kennemer Beach including initial dune fields (circles).

step, segment after segment, phase after phase, all fitting in a master plan.

In this way integrated, multifunctional, sustainable coastal zone development is realised in relation to the hinterland on one hand and in relation to the bordering sea on the other.

Concluding remarks

Ca. 80% of the largest population centres in the world are found in coastal and deltaic areas and the growth of these already densely populated coastal areas exceeds the growth rate of the world population. There is only limited space available for living, working, recreation and transport, and at the same time there is the need to preserve or expand valuable coastal ecosystems. To solve the existing and future problems in these areas and to create added value there are basically four main solutions: (1) to use more than before the third dimension, e.g. with skyscrapers and underground solutions, linked to multifunctional uses; (2) to use more than before the existing hinterland; (3) to integrate land in sea and water in land, with methods such as 'building with nature'; (4) to stabilize the population in due time. In

Fig. 8. Building with nature Plan 3: Complete realisation with beaches, initial dunes, lake, marina, car parking and condominiums.

The Netherlands these principles are being carried out, providing space for many functions, while at the same time a flexible coast can be achieved. Increasing coastal flexibility simultaneously allows adaptation to amongst others impacts of climate change and sea level rise. The Netherlands are subject to continuous changes. There is a need to find answers to future developments such as sea-level rise, increasing occurrence and intensity of storm surges, periodical increase of flooding by rivers, local drying-out of soils, damage to the environment including nature and landscape. Solutions such as: 'Living rivers' and 'Resilient coasts', are examples of integrated management of water systems.

References

Anon. 1990-1995. *Annual Reports of the Polderboards HollandÕs Kroon (Wieringermeer), North East polder and Fleverwaard (Flevoland)*.Wieringerwerf, Emmeloord, Lelystad (In Dutch.)

Anon. 1993. *Preparing to meet the coastal challenges of the 21st century.* Conference Report World Coast Conference, pp. 1-117. Coastal Zone Management Centre, The Hague.

Anon. 1995a. *World resources report 1994-1995*. World Resources Institute, Washington, DC.

Anon. 1995b. Second Assessment Report – Impacts, adaptation and mitigation of climate change. In: Bijlsma, L. (ed.) *Working Group II, Chapter: Coastal zones and small islands*. Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

Anon. 1996a. *Future for water and its basic documents. Dutch aquatic outlook*. Ministry of Transport, Public Works and Water Management, The Hague.

Anon. 1996b. *Growing with the sea, creating a resilient coastline, an exploratory study on the future of the Dutch coastline*. World Wildlife Fund for Nature, Zeist.

Anon. 1997. *Annual report of the water company Brabantse Biesbosch*. Brabantse Biesbosch, Dordrecht. (In Dutch.)

Anon. 1998. *Internet site: www.rom-Rhinemond.nl. ROM Ð Spatial planning and environment) programme municipality of Rotterdam and Province of South-Holland*. ROM-Rhinemond, Rotterdam.

Beeftink, W.G., Rozema, J. & Huiskes, A.H.L. 1985. *Ecology of coastal vegetation*. Dr. W. Junk Publishers, Dordrecht.

de Ruig, J.H.M. 1998. Coastline management in The Netherlands: human use versus natural dynamics. *J. Coast. Conserv.* 4: 127-134. (This issue.)

Grootjans, A.P, Jones, P., van der Meulen, F. & Paskoff, R. (eds.) 1997. Ecology and restoration perspectives of soft coastal ecosystems. *J. Coast. Conserv.* 3: 3 -102.

Hillen, R., Smaal, A.C., van Huijssteeden, A.J. & Misdorp, R. 1993. The Dutch Delta - aspects of coastal zone management. In: *Proceedings of the World Coast Conference 1993: ÔPreparing to meet the coastal challenges of the 21 st centuryÕ* p. 653-659. Coastal Zone Management Centre, The Hague.

Jefferies, R.L. & Davy, A.J. (eds.) 1979. *Ecological processes in coastal environments*. Blackwell Scientific Publications, Oxford.

Misdorp, R. & Terwindt, J. 1997. Coastal zone management experiences in the Netherlands. In: Haq, B.U., Haq, S.M., Kullenberg, G. & Stel, J. (eds.) *Coastal zone management imperative for maritime developing nations*, pp. 233-253. Kluwer Academic Publishers, Dordrecht.

Misdorp, R., Dronkers, J. & Spradley, J.R. (eds.) 1990. *Strategies for adaptation to sea level rise.* Intergovernmental Panel on Climate Change - Coastal Zone Management Subgroup. Ministry of Transport, Public Works and Water Management, The Hague.

Nienhuis, P.H. & Smaal, A.C. (eds.) 1994. *The Oosterschelde estuary: a case study of a changing ecosystem.* Kluwer Academic Publisher, Dordrecht.

Nijhoff, J. 1998. Integrated plan for the river Meuse. In: *Water of The Netherlands*, pp. 145-150. Netherlands Hydrological Society, Delft.

Scholten, H., LoCashio, A. & Overduin, Th. 1998. Towards a spatial information structure for flood management in The Netherlands. *J. Coast. Conserv.* 4: 151-160. (This issue.)

Silva, W. & Kerkhofs, S. 1992. Ecological recovery of the river Meuse in The Netherlands. In: *Ecological rehabilitation of floodplains*, pp. 125-130. International Commission for the Hydrology of the Rhine basin, Lelystad.

van de Ven, G.P. (ed.) 1993. *Man-made lowlands, history of water management and land reclamation in the Netherlands.* Matrijs Publisher, Utrecht.

van der Maarel, E. 1979. Environmental management of coastal dunes in The Netherlands. In: Jefferies, R.L. & Davy, A.J. (eds.) *Ecological processes in coastal environments*, pp. 543-570. Blackwell Scientific Publications, Oxford.

van Duin, R.H.A. & de Kaste, G. 1986. *The pocket guide to the Zuyder Zee project*. Ministry of Transport and Public Works, IJsselmeerpolders Development Authority (RIJP), Lelystad.

Waterman, R.E. 1991. *Towards an integrated coastal policy via building with nature.* Meinema, Delft.

Waterman, R.E. 1997. *Integrated coastal policy via building with nature*. Ministry of Transport, Public Works and Water Management 1989 (appendix 1998), The Hague.

Waterman, R.E. 1998. *Sustainable coastal zone development in harmony with the natural environment.* Waterman & W.L./Delft Hydraulics, Delft.

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