CHAPTER 1

# *From a Defensive to an Integrated Approach*

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PRESENT WATER MANAGEMENT policy and practice in the Netherlands have been heavily influenced by a combination of the geological history of the country and the activities carried out by its inhabitants since about 2500 BP (years before present). The history of Dutch water policies began when the inhabitants of the coastal and floodplain areas tried to safeguard themselves and their livestock by building and living atop dwelling mounds. This was followed by the defensive and offensive periods, during which dikes were built, peat was excavated, and land was reclaimed for safety, living space, and agriculture. Quantitative water policy began in the 1200s, when farmers started organizing to combat flooding. Since then, local, and later also regional, water boards were formed. In the late 1960s, qualitative water policy was added to the existing quantitative policy. Two decades later, in the late 1980s, the focus of qualitative and quantitative water policies broadened to include the protection of aquatic ecosystems and sustainable economic development.

This chapter describes the geological history of the Netherlands, the impact of humans on its aquatic environments, and the history of water management in the country. It provides the foundation for more detailed discussions in the chapters to follow.

## GEOLOGICAL HISTORY

For a full understanding of the development of the Netherlands' water policies, knowledge of the country's origin and recent geological history is necessary. A combination of erosion, transport, and sedimentation processes created the basis for what is now the Netherlands. These processes were governed by wind, rivers, and the sea and were active during periods of marine transgressions (inundation of land due to a relative sea level rise) and regressions, in concert with the formation of ice sheets during glaciations and their melting in interglacial periods.

During the Pliocene epoch, between 2,500,000 and 2,000,000 BP, the present area of the Netherlands was mainly a seabed. Around 200,000 BP, in the Saalian glaciation, the southern part of the region consisted of a polar desert (tundra), while the northern part was completely covered by an ice sheet. Important glacial depositions occurred during this period. After the melting of the gigantic Saalian ice sheet in the interglacial period known as the Eemian, an area was left containing drumlins (hills of glacial drift), small and large stones, gravel, sand, till, boulder clay, and glacial water basins (de Mulder et al. 2003). The coldest period occurred circa 18,000 BP, during the end of the last glaciation in the Weichselian period. The entire North Sea area was a polar desert where, in addition to the previous role of water, eolian sediment transport (carried by the wind) was important.

The European shoreline of the shallow North Sea area was shaped during the subsequent melting of the ice sheet and then inundation of seawater from what is now the northern North Sea and in the south through what is now the Strait of Dover (Ingólfsson n.d.). A relief-rich deltaic landscape developed, featuring rivers, moraine deposits, drumlins, gravel, sand, till, boulder clay, and loess derived from areas other than the Netherlands. The interaction among these elements, the wind, and the ongoing rapid sea level rise, a concomitant marine transgression, resulted in new marine and fluvial deposits. In addition, favorable conditions for the growth of wetland vegetations created the basis for future peat formation. The development of the North Sea shoreline between 9000 and 7800 BP, at the beginning of the Holocene, shows an ongoing fast marine transgression in the area now known as the Southern Bight. Between 8700 and 8300 BP, the British Isles became separated from the mainland of the European continent. The Dutch territory was then the area where the sea met some of the main European rivers.

It was here, under increasing human influence and circumstances of sea level rise, tides, and river discharges, in concert with the growth of vegetation, that the landscape evolved into a dynamic coastal and delta area consisting of peat bogs and moors. According to Zagwijn (1991), these developments (see fig. 1.1) occurred over a relatively short period of 7,000 years. The post-Weichselian Dutch area changed from an open coast, with islands and tidal inlets connected to tidal flat water basins (5300 BP), to the mainly closed sandy coastline of today. A sea level rise between 7000 and 4000 BP inundated the lowest parts of the present Dutch territory, creating large lagoon and tidal flat systems fringed by extensive salt marshes (7000 to 5300 BP). Because of the ongoing sea level rise, this period was followed by further inundations. In the meantime, large peat bogs and moors formed on top of the Pleistocene sediments (3000 BP). Often marine clay was deposited on top of the peat and salt marshes, serving as a basis for the development of new salt marshes.

Between 3000 and 2000 BP, the sea level showed stagnation and sometimes even a slight temporal decrease, indicating both regression and transgression periods. The reduction in the rate of sea level rise allowed for important sand depositions in the main tidal channels that connected the estuaries and lagoons with

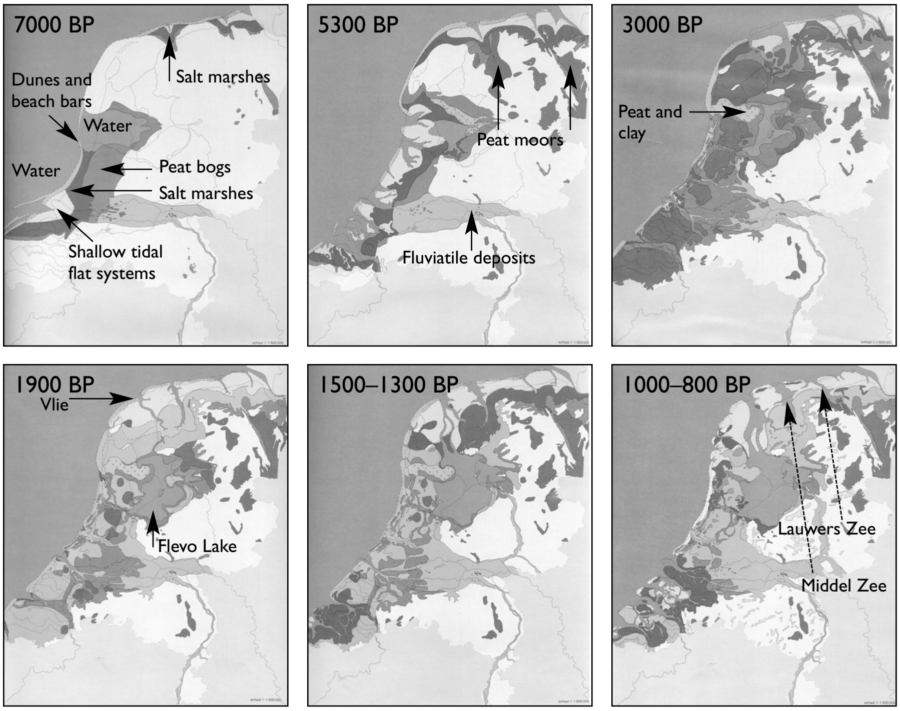

Figure 1.1 *Development of the Dutch area during the Holocene*

*Source:* Maps reproduced from Zagwijn 1991 with permission from Sdu Uitgeverij, 's-Gravenhage, the Netherlands.

the sea, diminishing the role of the tidal inlets. It also permitted the spread of vegetation to cover extensive coastal wetlands, contributing to the modification of the landscape and serving as the basis for later peat formations. Part of the former complex of estuaries and lagoons, such as the centrally situated Flevo Lake (later named the Almere; fig. 1.1), became completely isolated from the sea. At the same time, the western coast started to develop into one extensive single beach bar, extending to what is now the Vlie tidal inlet (fig. 1.1). The Wadden Sea was also created. While a long, dune-rich coastal barrier was forming in the western part of the country, a new breakthrough occurred in the north, by which the freshwater Flevo Lake became connected to the sea again (de Mulder et al. 2003). Permanent human habitation in the coastal area was presumably possible from 2700 BP onward.

After about 2000 BP, peat formation stopped as a result of drainage of the peat swamps both naturally, via the channel systems created during former sea inundations, and because of human activities related to cultivation and peat excavation (de Mulder et al. 2003). The ultimate result was that circa 1700 BP, the sea inundated deeply into the coastal part of the country. A combination of peat excavation to obtain sea salt, peat erosion, natural drainage, peat oxidation and compaction (surface lowering), and large-scale erosion changed the southwestern region of the Netherlands from a peat-rich area into a system poor in peat but rich in channels and intertidal sand- and mudflats (de Mulder et al. 2003).

## WATER POLICY IN THE PAST

When the river floodplains and coastal areas were first inhabited, water policy was nonexistent. Any action to safeguard people from flooding was realized locally by small, solitary groups of people and on an event-to-event basis rather than following an agreed master plan. This situation changed in the Middle Ages, when step by step the first flood defense measures were developed.

### *The Dwelling Mound Period*

The first inhabitants of the coastal and river floodplain areas had no means to defend themselves against the sea and therefore chose natural elevations in an attempt to find safe living areas. This was, however, difficult to realize when living in the middle of a river wetland or one consisting of coastal marshes and peat swamps. Initially, inhabitants actively elevated their own living areas for further protection. Around 2500 BP, they began to create dwelling mounds, basically human-made hills on which hamlets or small villages were often built. A marine transgression that started about 2550 BP served as the impetus for building this first generation of dwelling mounds. A second generation of mounds was built during another transgression in the late Roman period (1750 to 1400 BP). This was followed by two more generations of dwelling mounds, of which the last one dates from circa 1000 BP. These mounds basically consisted of every type of waste from their inhabitants. Very nice dwelling mounds can still be found along the coast in the north and on the river floodplains of the south and southeast where the Rhine River enters Dutch territory. The highest dwelling mound, part of which still exists, is the Frisian Hogebeintum in the north, which reached nearly 9 meters above the surface.

Remarkable contrasts existed in the Netherlands 2,000 years ago. In the north, the local inhabitants focused on basic agricultural activities and constructed technologically simple dwelling mounds as a safety measure. At the same time, in the south, the Romans modified the natural water network by connecting main rivers via newly dug canals. Although this was done chiefly for navigational purposes related to trade and transport of their legions, these technological modifications heavily influenced the water distribution over the area. The Roman Drusus and his son built the Drusus Canal, or Fossa Drusiana, which connected the lower Rhine with what was until then a very small stream flowing north, the present river IJssel (see fig. 1.2). Huisman (1995) believes that Drusus also constructed a canal connecting Flevo Lake with the coastal area in the north and what is now the Wadden Sea. The Romans also built a dam to increase the flow of the IJssel, which now discharges more than 10% of the total Rhine water to the north.

The importance of the Dutch part of the Rhine River significantly decreased in 70 AD, when Claudius Civilis wanted the Waal tributary (fig. 1.2) to become

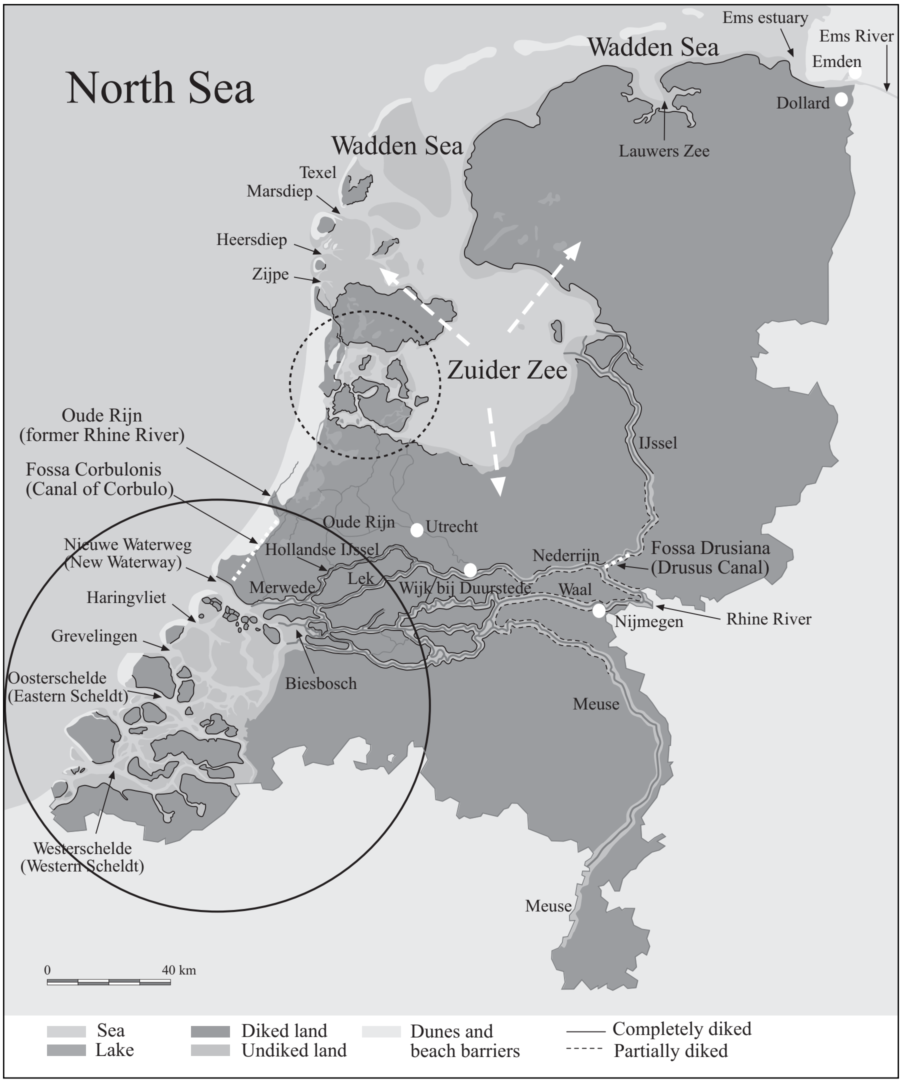

Figure 1.2 *Dike system in the Netherlands circa 1250 AD*

*Notes:* Dashed lines on the map indicate undiked areas around 1250 (750 BP), and arrows those hit by the 1916 storm surge in the Zuyder Zee. The large, solid circle encloses the area affected during the 1953 storm surge in the southwestern part of the Netherlands, and the smaller, dashed circle the region with big lakes that were emptied during the 17th century.

*Sources:* Information partly from www.livius.org. Geographic map reproduced from de Mulder et al. 2003 with permission from Wolters-Noordhoff BV, Groningen, Netherlands, and TNO.

more important than the lower Rhine. This decision might have been related to the place where Claudius Civilis lived, the civil settlement Noviomagum (Nijmegen), on the bank of the Waal River and also where the Roman legionary fortress was situated. The river flow was changed by the construction of a dam functioning as a water divider. Since then, the Waal has been the most important Rhine tributary in the Netherlands.

In 47 AD, the Roman general Gnaeus Domitius Corbulo ordered the construction of another navigation canal in the western part of the country, the Fossa Corbulonis (Canal of Corbulo). About 15 meters wide and 3 meters deep, this canal was built to connect the lower Rhine system (Oude Rijn) with that of the lower Meuse (fig. 1.2). Basically, part of this canal still exists as Vliet (Rijn-Schie Canal).

### *The Defensive Period*

In 1999, an archaeological team lead by J.G.A. Bazelmans discovered in Peins (near Franeker in Friesland) the remains of a 40-meter-long dike dating to 2100–2200 BP, the oldest dike remnant ever found in the Netherlands. Created from sod, the dike was a small one, presumably made to protect a piece of low-lying agricultural land on a salt marsh. It demonstrates that the dike-building technique was already practiced on a small scale more than 2,000 years ago.

Large-scale and well-organized dike building started much later, circa 1100 BP. This process was primarily stimulated by widespread peat excavations and accompanying drainage activities necessary for access. Sovereign lords such as the Bishop of Utrecht gave out permits and encouraged extensive cultivation of the peat moor "wildernesses" in the western and northern parts of the country. The cultivation was accompanied by the excavation of large amounts of peat for fuel and resulted in major erosion of the former coastal and inland peat swamp areas. Facilitated by the human activities, the freshwater Flevo Lake extended to the east, while peat erosion in the north improved the lake's connection with the sea (see fig. 1.1; lower panels 1900–800 BP). Not only were lakes formed, but considerable surface lowering (up to three meters) occurred as well, because the human-driven dewatering of the peat swamps led to further compaction and consequent surface lowering and oxidation of the organic material. When this human activity started around 1100 BP, the average height of the peat layers was three meters above mean sea level; by about 500 to 600 years later, the average elevation had been reduced to mean sea level. This enormous human-induced decrease in surface level forced the inhabitants to further increase their efforts in building efficient drainage systems with free water runoff to the sea. The so-called cultivations of the peat moor "wildernesses" thus basically started a never-ending struggle to maintain dry land in what is now the Netherlands. The necessity to have dry land for human habitation and cattle grazing in combination with the ongoing oxidation and compaction of the peat-rich underground of most of the country created an imbalance. The present formation of new peat is close to zero and thus unimportant.

Initially, the water could run off freely. Starting around 500 BP, however, because of the ongoing surface lowering, watermills had to be built to pump the water out to the sea. This illustrates that the water problem in the Netherlands is not new and is mainly related to human activity and definitely not just due to climate change. The surface lowering of the area not only had consequences for the local water drainage systems, but also made the coastal zone of the country ever more vulnerable to inundations by the sea. Storm events led to fragmentation of the coastal area, a situation that was further worsened by socioeconomic circumstances and wars. The result of the fragmentation between 1000 and 800 BP can be seen in figure 1.1. Between 1100 and 1000 BP, three new breaches occurred in the previously closed coastline in the north—Marsdiep, Heersdiep, and Zijpe—and two new ones in the south, Haringvliet and Grevelingen (see fig. 1.2).

### *The Offensive Period*

By around 1250 AD (750 BP; see fig. 1.2), large parts of the Netherlands were protected by dikes. Only in the higher elevated areas near the present German border were the rivers not diked. Yet despite the system of dikes, the country was not safeguarded from flooding. After 1250, flooding with dramatic effects still occurred on a frequent basis, including the years 1277, 1287, 1404, 1421, 1446, 1468, 1509, 1530, 1532, 1552, 1570, and 1584. These floods resulted in large areas of land being temporarily or permanently lost. Much of this can be attributed to bad or even improper technical dike maintenance; wrong priorities, in that dike maintenance was put too low on the agenda of the organizations responsible for a region's protection against flooding; and local quarrels or wars, as in the creation of the present Dutch Dollard area, part of the Ems estuary (fig. 1.2). In their historical treatment, Stratingh and Venema (1855, *68*) describe the factors leading to the formation of the Dollard: the ground on which the dikes were built was peaty and unstable, the seas sometimes rose very high, and governors responsible for dike maintenance disagreed with each other, resulting in poor dike condition. All these aspects led to the bursting of the Ems dike near Jansum opposite Emden (fig. 1.2) on January 13, 1277. A second catastrophic flood occurred later that year, on December 25. The local community was not able to restore the dike, and on December 14, 1287, a third big flood occurred. Within 10 years' time, an area of more than 300 square kilometers of land was lost, transformed into a tidal water body of which the present 100-square-kilometer Dollard is the remainder.

The large-scale peat excavations in the Netherlands changed the coastal parts of the country from a peat landscape into a brackish tidal, sand- and mud-containing area and the Zuider Zee, (fig. 1.2) which is the extension of the former Flevo Lake. Originally the Zuider Zee had very long channel connections to the sea (fig. 1.1) and a collection of islands that are partly based on or connected to the drumlins and boulder clay–rich areas. In the northeast, in Friesland, the Boorne Basin, Middel Zee, and Lauwers Zee were formed by sea inundations (see fig. 1.1, *1000–800* BP panel). By building dikes, the local population was able to reclaim bit by bit the Boorne Basin and Middel Zee before 1600, but not the large Zuider Zee and Lauwers Zee (fig. 1.2).

Over time, the area near the mouth of the Meuse River in the southwest also changed dramatically (see the changes in rivercourse in figs. 1.1 and 1.2). The extensive former peat swamp areas in the southwest were already replaced between

1500 and 800 BP by a collection of islands (see figs. 1.1 and 1.2). In between the islands, intertidal flat systems developed. The mouth of the Rhine River moved so far to the south that it joined that of the Meuse. On the order of the Bishop of Utrecht in the first part of the 12th century, the course of the Rhine near Utrecht was rerouted to prevent the yearly "wet feet" in the town and its surroundings (as is still happening in places such as Cologne, Germany). The Rhine was dammed near the present town of Wijk bij Duurstede, and the water diverted into what are now the Kromme Rijn (further seaward, the Oude Rijn) and Lek River (see fig. 1.2). As a result of these infrastructural changes, the former river course lost importance. These changes have been beneficial to the later development of Rotterdam's harbors (cf. figs. 1.2 and 1.4), because the Lek, the "modern Rhine," flows along this city.

The peat excavations for fuel and salt continued and not only affected the landscape further, but also led to disasters for the inhabitants. An example of mismanagement related to peat excavation was that in the southwestern part of the country, this activity was carried out up to the foot of the sea dike, thus directly undermining its foundations. This was the main reason for the catastrophic effect of the St. Elizabeth flood during a storm on the night of November 18–19, 1421. The storm and related flood drowned a low-lying area of 300 square kilometers near the town of Dordrecht (see fig. 1.4). Centuries later, this area acquired fame as one of the most important freshwater tidal systems in Europe, named Biesbosch.

Starting in the 13th century, centrally organized protection against flooding by the government became one of the most important issues in the Netherlands.

## MODERN WATER POLICY

It became clear that the protection of the country against flooding had failed, and that a different organization and better measures were required to safeguard the country from this risk. Monasteries especially took the lead in this process, and this gave rise to the foundation of organizations that would later become water boards and an increasing role of the central administration. The continuing involvement of the central administration in combination with an improved organization to prevent flooding also resulted in strongly improved strategies and technical measures, which together ultimately led to the development of the Dutch water policy strategies of today.

### *Development of Quantitative Water Management*

Because of frequent catastrophic flooding of both rivers and the sea, it became evident that coordinated actions were required to prevent further loss of land. After the main engineering works of the Romans about 2,000 years ago, the monasteries started to play a major role in organizing the local dike building and related land draining around 1200 AD. Small organizations of farmers, often managed by the monasteries, were active at this time to combat the storm-related flooding. This development of the organization and management of the flood defense can be considered the start of structural quantitative water management in the Netherlands. These small, local organizations also formed the historical basis for the present modern water boards. Large-scale and sophisticated dike building accompanied by small-scale land reclamations began during this period. After 1480, stimulated by economic developments and flourishing international trade, dike building was professionalized and was now done by specialists and no longer by local farmers.

The first real water board in the Netherlands was founded in 1255 under the name Rijnland. It consisted of rich and powerful inhabitants who were led by the baljuw, the local administrator and judge, on behalf of the duke, Graaf Willem II of Holland. This administrative body also managed lower organizations known as "trades," which collectively were responsible for maintenance of the local dike systems. The existence of such local water boards was, however, no guarantee for success. Often governors had to intervene to guarantee the implementation of the measures necessary for flood prevention. Starting in 1504, quantitative water control was centralized when Philip I ("the Handsome") of Habsburg and his son Emperor Karel V took charge of the process, because they considered flood defense and quantitative water control as too important to leave to local people or water boards. Local authorizations were taken over by the central national administration, although the water boards retained some influence in the decisionmaking process. When, in the 17th century, trade with the Baltic states, Asia, and the West became a financially successful enterprise, foreign cash flow allowed for a definite policy change from defensive to offensive water management. The need for new land, the enormous amount of trade activities with positive cash flow, the combination of land dewatering and increasing sea level, and the concomitant decrease in land surface elevation strongly stimulated technical developments for maintaining dry land. These activities were all related to water pumping by windmills, because much lower land level no longer guaranteed free runoff of surface water. During this period, windmills were used on a large scale.

After these technical innovations, because of economic factors at the national level during the eighteenth and early nineteenth centuries, little changed in terms of water management for a long period of time, and the landscape in the Netherlands remained basically the same. The foundation on May 24, 1798, of a very influential technical governmental authority, the Rijkswaterstaat, however, marked the start of a complete and thorough transformation of the Netherlands landscape. At the beginning of the 19th century, Rijkswaterstaat initiated drastic changes in the landscape with the planning and subsequent construction of new infrastructure in the form of railroads, canals, and roads (Bosch and van der Ham 1998; Lintsen 1998). The completed infrastructure immediately led to the local development of urban and industrial areas, which began the still ongoing fragmentation of the original Netherlands landscape.

**Technical Developments between the 10th and 20th Centuries.** Originally small dikes were built by piling up sods. Over time, several types of substratum for dike building were applied, including clay, mud, reed, eelgrass, wood, or combinations thereof. The facing of cylindrical wooden piles as a technique to defend the coast against any form of erosion by flowing water and waves was widely developed along the Dutch coast. From the 15th century onward, windmills were developed and used to create new land areas or reclaim lost land by emptying lakes. Large inland lakes such as the Schermer, Beemster, Purmer, and Wormer in the western part of the country (province Noord-Holland) were transformed into land by pumping out the water (the dashed circle indicates the lake area in fig. 1.2).

After the introduction of the shipworm (*Teredo navalis*) in 1725 by wooden vessels from Asia, an explosive population growth of the species occurred in the brackish and marine waters of the European and thus also the Dutch coastal zone. These wood-boring bivalves caused severe damage, and by 1730, their spread led to a real disaster, because all the wooden structures with a function in flood defense were completely perforated and had been dramatically weakened. This led to the replacement of wood by stone as a new, and still existing, element in the coastal defense. At the end of the 18th century, another novelty was the introduction of "mattresses," an underwater gauze network constructed from willow twigs and covered by stones, as a mean to protect the dike foundations from erosion by currents and waves. To reduce dike "washover" during storm surges, the wave energy was reduced by rows of poles placed in the dikes. In addition, between 1906 and 1936, small, concrete Muralt walls were built on top of existing dikes in some areas as further protection against washover. These measures were taken to avoid reconstruction of the entire dike, which would have led to a significant widening of its foot to maintain stability.

**The Period of Big Closures.** During a period when politicians and the private sector were discussing how to obtain more valuable land for agriculture and better protect the country from flooding, two politically critical storm surges occurred. The first flood was in 1916, hitting the former Zuider Zee area, and the second in 1953, in mainly the southwestern part of the country (see fig. 1.2). These two floods were determinants in the further geographic development of the Netherlands.

The Zuider Zee flood of January 14, 1916, led to the final decision to execute the reclamation of the entire area. On June 13, 1918, the Dutch Parliament passed a bill to start the reclamation, known as the Zuider Zee works. The process started in 1919 and was completed in 1932 after finalizing the main, 32-kilometer-long closure dam called Afsluitdijk (see fig. 1.3). In 1929, while the closure of the Zuider Zee was still in progress, the Department of Waterways and Public Works (Rijkswaterstaat, which is still part of the Ministry of Public Works, Transport and Water Management) started to investigate the reclamation of the Biesbosch, formed by the November storm surge in 1421 and now a magnificent freshwater tidal area.

A further study in 1934 showed, however, that this would have catastrophic consequences for the rest of the area, because the strength and height of the dikes were insufficient to cope with the expected increase in water height. A survey previously carried out in 1928 had led to the same conclusion. Both surveys indicated that something definitely had to be done about the condition of the dikes along the lower rivers. As an initial temporary measure, the Rijkswaterstaat decided to construct inexpensive concrete Muralt walls on top of dikes with insufficient water-holding capacity. Between 1906 and 1935, more than 120 kilometers of dikes in

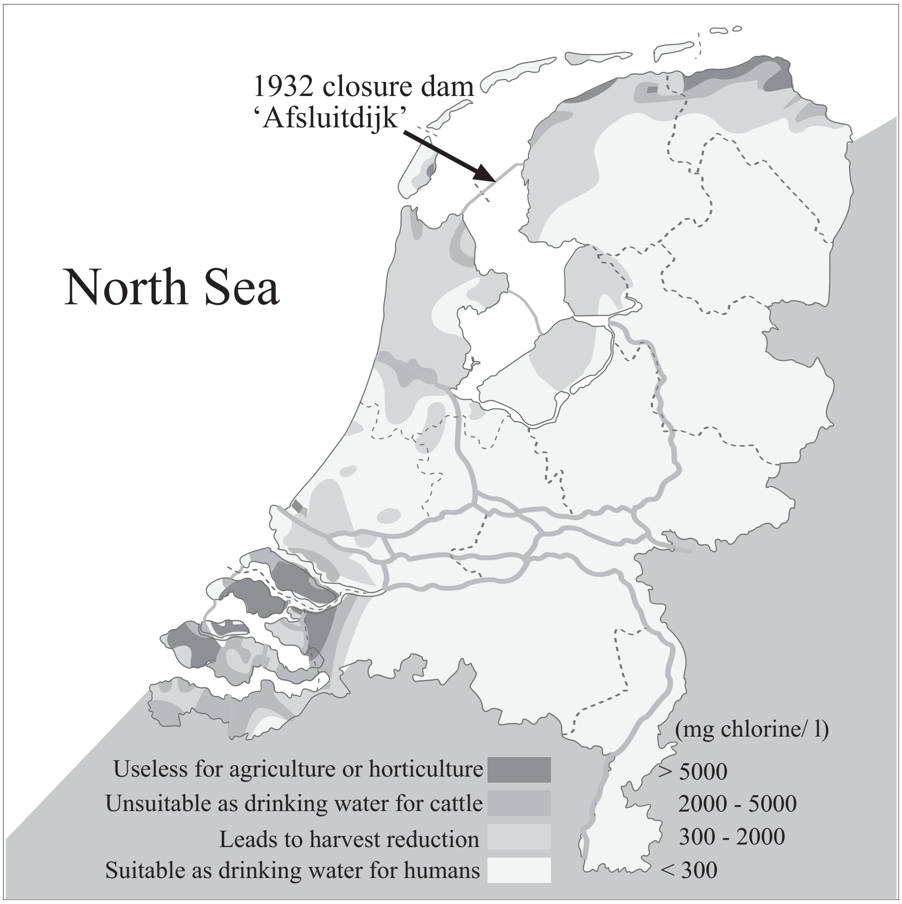

Figure 1.3 *Distribution of chlorinity in the groundwater of the Netherlands territory*

*Source:* Map reproduced with permission from Deltaworks Online Foundation, Sabine van Buuren, www.deltawerken.com.

Schouwen, Zuid-Beveland, and along the lower Rhine in Hollands Diep and Haringvliet (see fig. 1.4 for locations) were heightened.

The study service continued to emphasize the need to heighten the dikes but was unable to get political support. Meanwhile, in both the north and south (see fig. 1.3), the agricultural sector was coping with an increasing salt concentration in the groundwater, which was very costly to the farmers. Because of the importance of agriculture at that time, in an attempt to garner political support for the dike improvements, the study service changed its focus from flood defense to solving the agricultural salt problem. Interestingly enough, the solution for the agricultural sector was based on exactly the same plans as those for the dike improvements. The problem of increasing salt intrusion in the southwest was caused by the ongoing

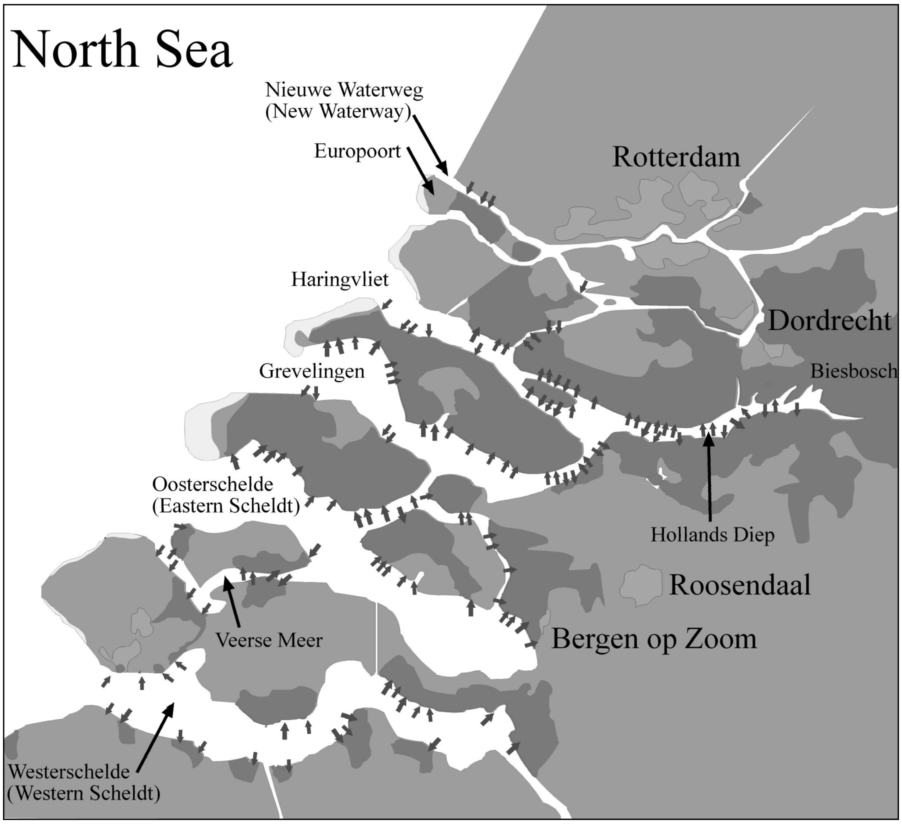

Figure 1.4 *Dike bursts and flooded areas in the southwestern part of the Netherlands as a result of the flood of January 31, 1953*

*Note:* Arrows indicate dike bursts, and flooded areas are in dark gray.
*Source:* Map reproduced with permission from Deltaworks Online Foundation, Sabine van Buuren, www.deltawerken.com.

deepening of the navigation channels, necessary for the further development of Rotterdam's harbors (fig. 1.4) but disastrous for arable farming.

Another problem, not recognized at the time, was that the deepening of navigation channels in estuaries affected the local gravitational water circulation. This in turn stimulated not only the upstream transport or flux of seawater, but also the transport and accumulation of seaborne mud in the river mouth at the low salinity zone. It was here, at the areas with the highest mud accumulation in the water, that Rotterdam's harbors developed (de Jonge and de Jong 2002).

The 1953 storm surge heavily affected the southwestern part of the Netherlands (the many dike bursts are indicated by arrows and the flooded areas by dark gray in fig. 1.4). Immediately after the extensive flooding, the first Delta Commission was created and charged with the task to safeguard this part of the country from future flooding (see de Haan and Haagsma 1984). The commission initially advised the construction of a movable storm surge barrier in the Hollandse IJssel (Dutch IJssel). It then developed a master plan to safeguard the area from further problems by closing all the tidal inlets except the Westerschelde (Western Scheldt) and Nieuwe Waterweg (New Waterway), the latter of which also got a movable barrier (see fig. 1.5; for locations of areas, see figs. 1.2 and 1.4).

In 1958, the government agreed on the Delta Law, which enabled the execution of the first Dutch Delta Plan and called for the reinforcement of all the national dikes and the closure of nearly all the former sea arms and estuarine areas

Figure 1.5 *The final design of the Delta Plan, with three movable storm surge barriers, one bridge, and nine dams*

*Source:* Map reproduced with permission from Deltaworks Online Foundation, Sabine van Buuren, www.deltawerken.com.

in the southwestern part of the country. This would lead to a dramatic shortening of the coastline, which, along with a nationwide increase in height and width of the sea dikes, would result in a much more effective coastal defense system than had existed before. Safety standards were dramatically strengthened to an accepted burst risk of the dikes up to 1 in 10,000 years. The closure of the sea arms would also greatly reduce the salt content of the lower rivers and groundwater by increasing the freshwater discharge via the Nieuwe Waterweg. Finally, as much land as possible would be reclaimed for agriculture.

The Delta Plan as implemented differed significantly from the original, however. Gaining more land for agriculture was no longer a goal, replaced by the formation of major freshwater basins: the Grevelingen and large parts of the Oosterschelde (Eastern Scheldt) (for locations of areas, see figs. 1.2 and 1.4). A powerful lobby consisting of scientists, environmentalists, recreational groups, bird societies, and fishermen ultimately led to the decision to keep the Grevelingen "salt" and not to close the Oosterschelde by a dam, but to build a storm surge barrier allowing the tide to go in and out. The final part of the Delta Plan was the construction in 1997 of the movable Maeslantkering (Maeslant barrier), in the mouth of the Nieuwe Waterweg (fig. 1.5). Once the plan had been implemented, the southern part of the Netherlands was declared protected against the marine influence, but only for the time being (see below).

The closures definitely provided safety against floods but also resulted in unforeseen environmental problems. With the disappearance of the tide, the Haringvliet–Hollands Diep area, upstream of the Haringvlietdam and Volkerakdam (for locations of areas, see fig. 1.5), became a sink for contaminated riverborne sediments and associated phosphorus. The Grevelingen area, between the Brouwersdam and Grevelingendam, initially showed an exponential increase in eelgrass (*Zostera marina*) beds. These beautiful underwater meadows were widely appreciated, but after some time they collapsed for still unknown reasons. The Oosterschelde area, between the storm surge barrier known as the Oosterscheldedam and the Oesterdam, exhibited large-scale erosion of intertidal flats, with a significant decrease in the primary production and widespread deterioration of the eelgrass there. The navigation route between Westerschelde and the Rhine, east of the Oesterdam, developed extensive blooms of blue-green algae (Cyanobacteria). In 2007, it was decided to flush this area again with Cyanobacteria-free estuarine water. The area between Veersegatdam and Zandkreekdam (Veerse Meer) had excessive growth of sea lettuce (*Ulva* sp.) and deterioration of eelgrass beds, in combination with strong eutrophication-related problems such as low oxygen values. This lake has recently been reconnected to the Oosterschelde to combat these unforeseen problems.

The original political attitude, before 1974, was that after the completion of the Delta Plan in the southwest, the next step should be the further protection of the Dutch population by closing off and reclaiming all or parts of the Wadden Sea in the north (the area between the barrier islands and main coast in figs. 1.2 and 1.3), which would provide additional coastal defense because of significant shortening of the coastline. In 1970, the Mazure Committee was appointed and commissioned to study all the possibilities. The committee's report (Waddenzeecommissie 1974) was negative on nearly every aspect related to possible dam building or closures in the Wadden Sea. One of the most important arguments was the value of the sea as a natural area, which should be maintained for nature itself as well as forthcoming human generations (cf. the goals of all the EU directives below). This advice was a milestone in Dutch history, resulting in the environment as an issue temporarily gaining in importance and attention, until 2000. Because of this decision, all the sea dikes in the north had to meet the delta requirements and therefore had to be heightened and broadened. The necessity of the first Delta Plan was proven on November 1, 2006, when the water in the Ems estuary, in the northeast, reached a level never before recorded, at 4.84 meters above Dutch ordinance level and about 30 centimeters above the former record of January 28, 1901.

Attention also has focused on the main rivers. Several recent high river floods and near floods demonstrated that the river dikes also need reinforcement. This led to the declaration of Arles in 1995, which was to draft an action plan on flood control measures in the Rhine River basin. During a new convention on the Rhine in 1998, an action plan on flood defense was presented, and it entered into force on January 1, 2003. In the Netherlands, it was called the Delta Plan Main Rivers. The main proposals were that the rivers be widened and deepened. Further, secondary channels would be created to increase the discharge capacity during high river discharges. Attention was not restricted to the Rhine and other main rivers; rather, the plan covered the entire water network, from these big flows to the smallest ditches, pivotal in the Dutch network. It called for the creation of new wetlands to serve as overflow systems during wet periods, local widening and deepening of small and large waterways, and large-scale dike improvements. Except for the widening of the Waal River near Nijmegen (for location, see fig. 1.2), all parts of the plan have been realized.

Since the completion of the first Delta Plan and the Delta Plan Main Rivers, debate has again centered on where to go with coastal defense. Several options have been considered. One is to further increase the height of the dikes. Another is not to increase the height of each primary sea dike, but to build another one behind it and use the space between the double dikes for retaining any water that washes over. An experiment with the double dike system started in 2007.

While the first Delta Plan was still under execution, the Rijkswaterstaat prepared the *First National Policy Memorandum on Water Management* (1968). Although this document strongly focused on quantitative water management, and considered the effects of deepening the navigation channels and how to reduce the salt intrusion for the sake of agriculture, it also made some remarks on water quality. At this time, water quality concerns mainly centered on adequate oxygen content, coli bacteria as a quality measure for bathing water, biological oxygen demand to indicate pollution with organic matter, and radioactive substances.

### *Development of Qualitative Water Management*

Qualitative elements in coastal management issues can be subdivided into physical, chemical, biological, and ecological aspects. In this section, each will be treated in isolation as well as in combination. The physical and chemical components can be considered as setting the boundary conditions for ecological functioning, the results of which have to be judged by biological quality.

**The Start of International Cooperation to Combat Pollution of the Rhine.** The final act of the 1815 Congress of Vienna settled the future boundaries of the European continent. This act formed the legal basis for founding the Central Commission for Navigation on the Rhine and established the Rhine River internationally as a navigable waterway (Frijters and Leentvaar 2003). The first laws governing navigation on the Rhine date from 1831. As a regulatory body, this commission was not yet involved in real present-day water management, but it can be considered the start of it. Modern water management in western Europe, the Netherlands included, began in the early 1900s with some focus on quantitative physical aspects such as river discharges, water height, and current velocity.

Between 1831 and the early 1900s, little attention was paid to chemical and biological water quality aspects. But then, around 1935, salmon vanished entirely from the Rhine River. The water tasted salty and often had a carbolic acid smell. By the mid-20th century, the river had clearly lost all its original ecological functions and mainly served as a canal for navigation and a depository for the discharge of untreated organic waste, nutrients, and human-produced chemical compounds.

In 1950, the International Commission for the Protection of the Rhine against Pollution (ICPR) was established, and it was formalized during the Bern Convention of April 29, 1963. Its main tasks were to conduct research on pollution and define appropriate measures to the governments involved in order to reduce the pollution and prepare intergovernmental regulations. This led to the first Rhine Ministers' Conference in 1972, which resulted in charging the ICPR with elaborating conventions to reduce chemical and chlorine pollution. The ministers further decided to equip future power stations with cooling towers and instruct the ICPR to draft a long-term working program on pollution of the Rhine River. The European Economic Community (EEC) became a formal partner in 1976. In 1987, the ministers of the Rhine states adopted the implementation of the Rhine Action Program, and in 1998, a new, now EU-wide, treaty was adopted to protect the river. The document was ratified in 2000, and since then, the protection of the Rhine River system has been the full responsibility of the European Union.

**Development of Water Quality Issues in Freshwater Systems.** Until the *Second National Policy Memorandum on Water Management* (V&W 1984) was published, little interest existed in the quality of the majority of the Netherlands freshwater systems. This lack of interest held for all noninternational and thus relatively small water bodies.

The *First National Policy Memorandum on Water Management* (Rijkswaterstaat 1968) was concerned with water quality of the Rhine in terms of chlorinity, $BOD_5$ (biological oxygen demand in five days, measuring the amount of oxygen consumed during that period), and concentrations of ammonium, nitrate, oxygen, phenols, and radioactive compounds. For all the other water bodies in the Netherlands, based on the importance of agriculture at that time, only the chlorinity (salinity) of surface water and groundwater was an issue.

The *Second National Policy Memorandum on Water Management* covered both freshwater and marine systems, focusing not only on the quantitative distribution of surface water, but also on the excessive use of groundwater.

In a formal way, the situation changed with the publication of the *Third National Policy Memorandum on Water Management* (V&W 1989). This document paid attention to all the country's water bodies, with the aim of improving the water quality of its aquatic ecosystems.

**Development of Water Quality Issues in Marine Systems.** Just as for the freshwater systems, the history of water quality management of marine systems has been dictated by pollution events. In the northeast of the country, in the province of Groningen, the lack of interest in water quality led to one of the most dramatic organic waste problems in the world (Ribbius 1961). The pollution was estimated (Hopmans 1959) at about 15 × $10^6$ inhabitant equivalents (ie, where 1 ie = 35 g $BOD_5$). Later, Eggink (1965) provided a maximum estimate of 12 × $10^6$ inhabitant equivalents, of which about 50% were discharged to the Dollard (see fig. 1.2 for location). The problem was not only the discharges to the Dollard as the "end of the pipe," but also the enormous amounts of untreated organic waste from the potato flour and strawboard industries being discharged into small local canals as the first stage. From there, the mephitic water mass slowly flowed to the southeastern part of the Dollard, where it was sluiced out to the estuary. The odor in the area was unbearable during autumn and early winter, when huge quantities of potatoes were processed to make flour. As a contributor to the investigation of the effects of these discharges on the ecosystem of the Ems estuary, I witnessed the situation during the 1970s. The strawboard problem was solved as the market changed between 1977 and 1990, leading to closure of the factories. The number of potato flour factories was reduced from 21 to just 1 now, and 100% cleaning of the process water took place, heavily supported financially by the government.

According to de Jong (2006), who used the political life cycle developed by former Planning, Housing and Environment minister Pieter Winsemius, the history of water quality management was subdivided into four periods. During the period 1970–1975, and strongly based on the negative developments in freshwater systems, marine pollution was recognized as an issue by scientists and put on the political agenda. This was then followed by a relatively long period of monitoring and investigations to assess water quality and its relation to the discharges of polluted fresh water (1975–1984). The next important period, 1984–1990, was characterized by decisionmaking at the governmental level. The final one, 1990–present, has seen the implementation of strategies and management measures prepared earlier.

The introduction into the Netherlands of monitoring of nutrient levels and $BOD_5$ as quality aspects occurred nine years after the First International Conference on Water Disposal in the Marine Environment took place in 1959 at Berkeley, California, in the United States. Before 1970, pollution was internationally a subject only for disposal engineers and scientists (de Jong 2006). Despite the increasing pollution of the Netherlands' freshwater systems, estuaries, and coastal area, less than 5% of the 200-page *First National Policy Memorandum on Water Management* (Rijkswaterstaat 1968) was devoted to water quality.

During the early 1970s, however, awareness of the deterioration of the aquatic ecosystems was increasing. The environmental situation at this time was exemplified by large kills of plankton, fish, and bottom fauna following spills. Causes ranged from the effects of increased nutrient levels (de Jonge and Postma 1974) to pollution by heavy metals such as copper sulfate (Roskam 1966) and pesticides such as dieldrin (Koeman 1971). The Dutch Pollution of Surface Waters Act (WVO) was adopted in 1970. Since then, strongly driven by international meetings, developments have been considerable.

In 1971, the Ramsar Convention on Wetlands took place in Ramsar, Iran, with the aim of conservation and wise use of wetlands and their resources. Several international events were held in 1972. An important one was the International United Nations Conference of the Human Environment (UNCHE) in Stockholm, Sweden. Also that year were the London and Oslo Conventions, on the prevention of marine pollution by dumping of wastes and other matter. During a summit of the nine EEC states that same year, the basis for a European environmental policy was created. An Environmental Action Program was formulated for 1973 to 1976, with the objectives of preventing, reducing, and eliminating pollution. It also introduced the "polluter pays" principle, which has successfully led to increased efforts by companies to reduce their waste loads. In 1974, the Paris Convention on land-based sources of marine pollution was held. Despite the developments, however, by 1985, the focus was still mainly on how to maintain the 1970 Dutch Pollution of Surface Waters Act (WVO).

In the early 1980s, the nutrient loads in the Rhine River and all other fresh waters in the Netherlands reached their maximum. This was due to the increasing use of artificial fertilizers and detergents since the mid-1960s. The ecological status of the majority of fresh waters had deteriorated. As a consequence of the natural seaward-flowing direction, the seas also suffered. In the North Sea and Baltic areas, large-scale oxygen depletion was reported for the German Bight, Kattegat, Belt Seas, and Kiel Bight (Gerlach 1984). These events alarmed society, and politicians decided to take action, resulting in a series of political conferences of the littoral North Sea states. The first three meetings, in 1984, 1987, and 1990, strongly stimulated the further development of the so-called science-policy network (de Jong 2006) in the Northeast Atlantic Ocean, the North Sea included. Based on the reference year 1985, a 50% load reduction was agreed upon for nutrients and harmful substances by 1995. The second set of conferences, in 1993, 1995, 1997, and 2002, were held mainly to discuss the progress and consequences of the reduction measures. The reduction was not achieved well for phosphorus and not at all for nitrogen.

Other international meetings also took place during that time period. The Paris Commission, held in 1988, recommended a 50% reduction in the concentrations of phosphorus and nitrogen for the entire Northeast Atlantic Ocean. In 1992, the Oslo and Paris Commissions decided to join and operate as the Oslo-Paris Commission (OSPAR), with the task of protecting the marine environment of the Northeast Atlantic Ocean. Also in the 1990s, the European Commission adopted the Nitrates Directive (91/676/EC) and Urban Waste Water Directive (91/271/EEC) as legal instruments to improve the environmental quality. Many more directives followed in the subsequent years. Meeting the goals on water quality is dependent not only on reducing human-driven pollution, however, but also on continental freshwater discharges and, for nutrients, global variations in ocean current patterns.

The Netherlands finally took a big step forward in 1988, when the Dutch government decided to change from simply maintaining the 1970 Dutch Pollution of Surface Waters Act (WVO) to considering all aspects of water management. Ecologists explained to the environmental engineers that concentrations of compounds had to be translated into a certain biological or ecological quality of the system under consideration, and thus integrated water management was introduced. This means that physical conditions and chemical concentrations are related to the structure and functioning of the aquatic ecosystem, and the quality of the ecosystem is considered along with the desired socioeconomic developments.

The preparations for what became the *Third National Policy Memorandum on Water Management* (V&W 1989) started in 1987 and took two full years. The main document was titled *Water for Now and Later* and was based on the exploration of several environmental options, among them the *Ecological Development Directions of Marine Waters* (Ten Brink and Colijn 1990). Covering a time period up to 2010, the document described historical trends in a large number of relevant aspects, including surface areas of salt marshes, occurrence of fish diseases, and a range of 32 species from algae to mammals. It also gave the outlook for all the above elements, depending on the developing direction or policy option. Finally, it presented a method describing and assessing the different coastal ecosystems, called the AMOEBA approach because it visualized the situation per factor in a radar plot resembling an amoeba in shape. For six different policy options, the ecological expectations or prognoses were described and compared with each other in what resembled an ecological Dow Jones index.

Based on this approach, the document concluded that a general 50% reduction measure for pollutants and nutrients would offer no improvement of the marine system in terms of sustainability. Even a general 90% decline was predicted not to result in the required improvement. The solution presented was the selective reduction of loads of compounds in combination with supplementary local measures, both physical (stimulating habitat-providing conditions) and biological (e.g., the rehabilitation of eelgrass beds). An insufficiently addressed general problem when assessing the effects of changes in water quality is that other resources and environmental factors besides nutrients are responsible for the production of organic material and a certain biodiversity. Among the most important of these are light, temperature, and the dilution rate of the water, including the nutrients, in the system.

The *Fourth National Policy Memorandum on Water Management* (V&W 1998) basically reconfirmed the previous one, with the addition of some further detailing.

**Effects of Political Decisionmaking on the Quality of the Environment.** At present, and from both a national and international perspective, there are two main streams of thought on environmental quality. One claims that the environmental successes in countries adjacent to the North Sea and Atlantic Ocean are so clear that, as for the Netherlands, the focus should now be more on economic development and slightly less on the environment. The other is that the necessary environmental quality levels have not yet been achieved, so we cannot become complacent.

Neither is completely true, although the situation has definitely changed. The countries sharing the river basins of, for instance, the Scheldt, Meuse, Rhine, Ems, Weser, and Elbe have been successful in reducing the main well-known pollutants, although we do not know all the new ones that have emerged more recently. In terms of eutrophication, these states have been successful in reducing the phosphorus loads and part of the nitrogen loads. But other issues have become evident that were overshadowed in the past by more problematic factors. One is the underwater light climate, with light reduction caused by turbidity resulting from suspended materials such as detritus, living plankton, clay, and other minerals. Since the phosphorus and nitrogen concentrations, which encouraged algal growth, have decreased, turbidity is emerging as a problem. Under excess nutrient conditions, algal growth may be high even under low light conditions. When, however, the nutrient concentrations are decreasing, the algal growth can maintain a relatively high level only when the light conditions are optimal. The present light conditions are not optimal, being much lower than the natural background situation (see de Jonge and de Jong 2002). This is largely due to human activities such as channel maintenance dredging (de Jonge 1983) and the disposal of harbor sludge in estuaries and the coastal zone (de Jonge and de Jong 2002).

Important remaining issues in the Netherlands are thus related to activities that disturb the light climate and further reduction of nutrients. Some people and economic sectors such as the fisheries are concerned about the decline of fish stocks, macrozoobenthos, low recruitment, and protection measures. Part of the fishery sector, for instance, blames the declining fish stocks on the reduction in nutrient loads as the main cause, rather than the actions of the fishery sector itself. Nevertheless, evidence on the role of additional factors apart from nutrients, such as light, indicate that other common environmental conditions deserve much more attention than they have received so far.

## EUROPEAN UNION DIRECTIVES

The EU has adopted a large number of directives meant to protect the environment and stimulate an integrated ecosystem approach to water management. Two important existing directives with respect to this are the EU Wild Birds Directive (79/409/EG) on the conservation of wild birds and EU Habitats Directive (92/43/EEC) on the conservation of natural habitats and wild fauna. Based on these two directives, an initiative to set up a network of nature conservation areas across Europe, called Natura 2000, has been started. This Natura 2000 network is meant to conserve natural habitats and species diversity. This is the biggest initiative so far on protection and conservation of nature in Europe. The Netherlands has designated 79 Birds Directive areas and 141 Habitats Directive areas. In combination with the National Ecological Network and Robust Corridors, the Natura

2000 areas contribute to combat the fragmentation of natural areas by coupling all terrestrial and wetland areas.

At the end of 2000, the EU Water Framework Directive (EC 2000) was introduced (see Chapter 11). In general terms, the requirements of the Water Framework Directive (WFD) are an analysis of the ecological characteristics of the different water types, a review of the impact of human activity on the status of surface waters and groundwater, and an economic analysis of water use. Ecologically, the WFD is one of the best directives produced so far; founded on a scientific theory and approach known as systems ecology, it has a very clear and understandable basis and goals.

Several years later, the EU Marine Strategy Directive (EC 2005) was published. Its aim is to "promote sustainable use of the seas and to conserve marine ecosystems." According to the directive:

> This will be achieved by control and reduction of pressures and impacts on the marine environment by a sector by sector approach which then should result in a patchwork of policies, legislation, programmes and actions plans at national, regional, EU and international level, which contribute to the protection of the marine environment. At the EU level, while there are a number of policies affecting the marine environment, and while a reflection has begun on a future all-encompassing Maritime Policy for the Union, there is no overall, integrated policy for the protection of the marine environment.

This strategy has resulted in the introduction of the term the "ecosystem approach," which is meant to follow in practice the Driver-Pressure-State-Impact-Response (DPSIR) model as an analysis framework for the development of management strategies. Like the Dutch Natura 2000 designations, this is all meant to contribute to ensuring quality of life for nature and humans and also provides chances for socioeconomic developments. Just as in the WFD (Annex V), it aims to protect structure and functioning of aquatic ecosystems in an ecosystemwide approach based on a sound scientific foundation. Here, structure refers to species, and functioning to processes such as the production, consumption, and degradation of organic carbon, fluxes of organic material among species groups within the food web. Although the idea has been presented, a clear basic concept of how and what to use, further develop, or implement is lacking at the moment. Thus the Netherlands still has a long way to go before the foreseen policy and management instrument is operational at the required levels of quality and detail. An additional step in applying measures to control human impact at sea can be found in the EU Maritime Development, whose goals are continued technical development while at the same time taking measures to safeguard coastal and marine ecosystems.

## TOOLS TO JUDGE THE QUALITY OF AQUATIC SYSTEMS

Ecological quality objectives (EQOs) have to be defined for nearly every regulation today, both for national purposes and for legislation in international frameworks such as the Trilateral Wadden Sea Cooperation and the EU directives. EQOs can vary widely from vague development directions, as in the EU Habitats Directive, to precisely defined concentration levels to be reached, as in the Dutch policy on nutrient reduction. In Dutch national policy, the first time a real objective was defined was during the preparation of the *Third National Policy Memorandum on Water Management* in 1987–1989. Since then, EQOs have been part of environmental and international policymaking and management.

The most important EQOs at the moment are those dictated by the European Union, which are under development with OSPAR (e.g., OSPAR Commission 2005) and the International Council for the Exploration of the Sea (ICES) as advisory body to OSPAR (ICES 2004). When going through the recent documents of these organizations, it is evident that despite all the directives and regulations produced nationally and at EU level, the discussion on EQOs has just begun. The current discussion is more focused on starting points than on how to judge success, and it thus has not yet been finalized by the production of a suitable applicable instrument or technique for judging the system's condition objectively. It is also apparent that at all levels, advisors are struggling with hard and rational objectives in terms of an index or a clear value or number. This all indicates that people worldwide are on the way to another sort of rational or soft decisionmaking that should be based on an ecosystem approach, of which the contours are as yet vague and unclear.

Monitoring is generally acknowledged as a suitable means to collect the data for assessing the status of an aquatic system. These data may be helpful in establishing a coherent and comprehensive overview of water status within each river basin district. From a biological and ecological point of view, however, and considering what we know about the structure and functioning of coastal and marine aquatic food webs, the WFD monitoring requirements include a rather arbitrary set of factors (see Chapter 11) and a frequency schedule that does not make sense (de Jonge et al. 2006). For the Dutch situation, organism groups such as microalgae cells are monitored twice a year, but the species composition may change completely within one to two weeks. It also does not make sense to monitor the species composition of these algal cells without taking into account their activity (growth expressed in organic carbon) or considering the most important removal process, done by grazing organisms such as copepods. These aspects are listed in table 1-1 and illustrate that against the background of an ecosystem or integrated ecological approach, with required quality objectives, ecological potential, and ecological status, the fact that the microbial food web and everything smaller than one millimeter mesh size, notably the grazing zooplankton, are not monitored seriously handicaps both the WFD and the ecosystem approaches.

In the Netherlands, the monitoring of marine waters is more extensive and also more intensive (high frequency) than required by the WFD (see de Jonge et al. 2006). Nevertheless, for coastal and marine waters, it is still not possible to fulfill the ecological requirements of the EU's ecosystem approach. For freshwater systems with a long history of monitoring quality, this does not seem to be a real problem. Based on the above-mentioned uncertainties as well as the often strong interannual variation in species composition and abundance, de Jonge et al. (2006) proposed to work on an integrated index or set of indices covering both the func-

Table 1-1 *Environmental elements, means and symptoms, and parameters to be measured during monitoring programs as required by the WFD*

| *Quality elements* | *Means and symptoms* | *Parameter and frequency* |
|---|---|---|
| ***Morphology*** | | |
| Geomorphology of system | Means for realizing optimal habitat providing conditions | Soundings once per six years |
| ***Physicochemical conditions*** | | |
| Temperature, oxygen, salinity, nutrients, pH | Means for realizing optimal habitat providing conditions | Water sampling once per three months |
| Other pollutants | | Sampling once per three months |
| Priority substances | | Sampling once per month |
| ***Biology*** | | |
| Phytoplankton | Toxic blooms | Species composition and countings twice per year |
| Macroalgae | Algal mats | Species composition and countings every three years |
| Macrophytes | Loss of habitat | Surface area of eelgrass beds and salt marshes every three years |
| Macrobenthos | Anoxia | Species composition and countings every three years |
| Fish (transitional waters) | Migration barrier | Species composition and countings every three years |

tioning and species structure, or biodiversity, of the aquatic ecosystems. Such an approach may be possible when we are able to integrate, for instance, a flux analysis of marine food webs with the species responsible for these fluxes. A suitable basis could be to apply and further develop ecological network analysis as developed by Ulanowicz (1980, 1986, 1997).

When applying the implementation requirements of the WFD to the ecological reality, it is evident that the directive fails to follow its own clear starting points, because in practice, only parts of the systems' ecological principles are applied. The directive also neglects to set the scene for a real ecosystem or holistic approach. This is an extremely important point, as the EU Marine Strategy (EC 2005) builds further on the fundamentals of the WFD. In addition, politicians ask for indicators that are easy to measure and understand, inexpensive, representative of the system's condition, and appealing to decisionmakers and the general public. This is asking a great deal when working with such a complex system. Moreover, the government bodies serving the politicians often find it difficult to translate the political aims into practice and to handle the associated concepts or principles, and also may have a hard time convincing the responsible politicians that achieving these aims requires sufficient funding for the scientific community.

## CLIMATE CHANGE EFFECTS AND WATER MANAGEMENT

Apart from direct human impact at local and regional levels, we are also dealing with large-scale natural changes that cannot easily be regulated. It has widely been accepted that because of widespread global changes in land use and related activities resulting from increased population, humans are contributing to climate change. This term can be defined as an alteration in the state or condition of the climate system. The present climatic changes are ascribed to increased concentration of trace gases, such as carbon dioxide ($CO_2$) and chlorofluorocarbons (CFCs), in the atmosphere, resulting mainly from the oxidation and burning of fossil organic material and industrial production of CFCs. These alterations in gas composition affect the amount of radiation absorbed by the atmosphere because of a depletion of the ozone layer. The most important aspects related to climate change are global warming, with an expected increase in temperature of 2.0° to 4.5°C by circa 2050; more precipitation at the Netherlands' latitude, resulting in higher freshwater discharges; a changed wind climate, which at this latitude may lead to greater average wind speed; and more frequent occurrences of extreme weather conditions. One of the main results of the expected temperature increase is a sea level rise due to the thermal expansion of oceanic water. The rise projected by the Intergovernmental Panel on Climate Change (IPCC) varies from 0.09 to 0.88 meters over the period 1990 to 2100. The consequences of this sort of forecasting for safety against flooding have prompted the Dutch government recently to commence a new, second Delta Commission with the task of briefly formulating what has to be done to safeguard the Netherlands from problems related to increased future sea level rise (Deltacommissie 2008).

The recorded steady increase in the tidal range around the North Sea, which influences the semidiurnal variations in water height, is an issue that is not clearly attributable directly or indirectly to climate change. For the Netherlands, the most important anticipated short-term changes are the expected increases in precipitation and wind speed, on top of which the country has to be prepared for an unknown sea level rise and increased tidal range.

Some of the necessary management measures related to the expected increase in precipitation and consequently higher water discharges are those discussed earlier: widening and deepening of waterways, from ditches and canals to the main rivers; creation of wetlands as overflow systems; and reinforcement of the dikes. Not yet mentioned is the need to enlarge the sluices in the sea defenses, channels that allow free runoff of fresh water during low tide, and create large freshwater basins just in front of these sluices. The rising sea and lowering land have already led to big problems, as the difference in elevation between the freshwater and seawater levels during low tide is decreasing. In the short term, this problem can be solved by enlarging the sluices in conjunction with providing for sufficient water storage in front of them. As a long-term solution, large-scale infrastructural adaptations are necessary and pump capacity must be increased significantly.

From a safety management point of view, an increase in the mean wind speeds will lead to longer and higher waves, with a greater risk of washover during storm surges. In combination with a higher sea level, measures are needed to reduce the size of the waves. This is technically possible by building structures in the sea to diminish the fetch and consequently reduce the capacity for gigantic waves to build up. These structures may be used for economic purposes (e.g., airport, wind power, harbors, or fish culturing) or recreation (e.g., boating or bathing in a sheltered lagoon system).

From mainly a technical point of view, the second Delta Commission (Deltacommissie 2008) formulated 12 recommendations. Some of these are interesting. Sand is essential for the morphological developments along the coast and in the Wadden Sea. A presently ongoing technique in coastal defense is beach nourishment, actively transporting sand to compensate for any sediment deficit in front of the coast. The Delta Commission recommends extending these activities on a very large scale, termed "foreshore nourishment," to let the vertical morphological growth of the Dutch coastal zone, the Wadden Sea included, keep pace with the sea level rise in a seminatural way. Another recommendation is to build dikes that are not necessarily able to keep all the water out, but are technically "unbreachable," so that the damage caused by any flooding due to extensive washovers will be restricted.

Ecologically, more fresh water, increased wind, higher temperatures, and a sea level rise may result in complex changes in the functioning of estuarine and coastal ecosystems, which includes the majority of Dutch territorial waters. Changes in wind climate may result in wind-induced resuspension of mud, creating greater water turbidity. This turbidity as well as the rising temperatures may stimulate the production of organic matter by mainly benthic microalgae instead of phytoplankton, which then serve as an alternative source of food for the other aquatic organisms (de Jonge et al. in preparation). An increase in temperature may also trigger changes in the biogeographic distribution of species and thus lead to the introduction of invaders, something that has taken its toll already. The use of coastal areas and rivers for navigation necessarily is accompanied by dredging activities, and the disposal of the dredged material may be another cause of turbidity of the water column (de Jonge 1983; de Jonge and de Jong 2002). The decrease in the light climate as a function of suspended material (SPM) follows a power function. This means that a slight increase in SPM in basically productive and clear coastal waters will strongly reduce the total light penetration in the water column and thus the production of food by algae. With respect to the WFD, light (SPM) is acknowledged only as a natural boundary condition and not as a pollutant that reduces the functioning of the ecosystem. This should be corrected, because the effects of climate change on the functioning of coastal ecosystems may be dramatic, with a complex mixture of human-induced and natural changes. On top of that, we are dealing with often nonlinear feedback systems that are not all known and whose outcomes cannot be predicted.

## NATURAL VERSUS HUMAN-DRIVEN SIGNALS

The concept of integrated water management is a complicated one. Depending on the factor we are interested in, the data we collect may be a mixture consisting of a natural trend, including its natural variation, and a human-driven signal (see fig. 1.6).

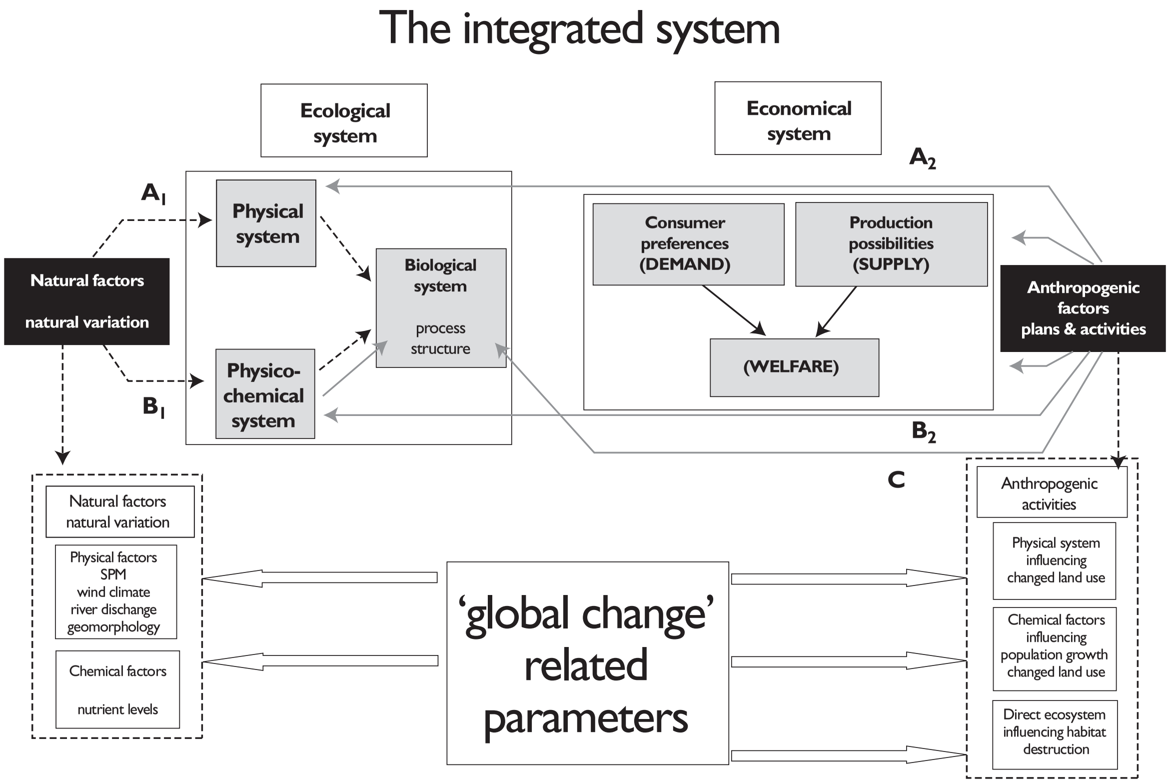

Figure 1.6 *The structure of the integrated system*

*Notes:* Dashed lines indicate natural influences, and solid lines denote anthropogenic influences. $A_1$ and $A_2$ refer to influences of the physical system, $B_1$ and $B_2$ to those of the physicochemical system, and C to direct human impact on the biological system. SPM = suspended material.

*Source:* Modified after de Jonge et al. 2003.

Examples of such trends in physical factors are the sea level rise, the development of the tidal range (including low and high water levels), and temperature (represented by $A_1$ and $A_2$ in fig. 1.6). A trend may be partly natural ($A_1$) and partly caused by human activities ($A_2$), as is the case with estuarine tidal range, where low and high water levels can be influenced by channel maintenance dredging (de Jonge 1983) or engineering works.

Comparable influences hold for physicochemical factors, such as the natural discharges of river water and society-related discharges of nutrients and contaminants. Changes in these factors may indirectly influence the biological subsystem ($B_1$ and $B_2$ in fig. 1.6), resulting in a change of the ecological quality of the ecosystem under consideration. It is also possible to change the biotic subsystem directly, as fisheries do (C line in fig. 1.6). This all illustrates that a good basis exists for the use of the term "biocomplexity" in these sorts of systems.

It is a challenge to society to manage the whole integrated system as visualized in figure 6. This is possible only when the scientific basis is solid and concepts have been developed that are suitable for application in the policymaking and management arena. Before developing measures to effectively combat undesired situations or developments, we need to know how our systems function. We also need to know how they will respond when basic conditions change (e.g., changes to SPM and thus light by dredging, eutrophication by nutrients, temperature by trace gas production, and residence time by engineering) and how important the relative contribution of human-related changes is to the total change.

Considerable improvements have been made in our understanding of aquatic systems. It is clear that we need to continue to manage these environments with the information we have while striving for better understanding of their functioning. With reference to all available national and international agreements, legislation, and directives, the ecological and biological quality of these systems currently has to be judged against ecological quality objectives that often seem unsuitable. The big management issue is how to determine suitable indicators and their levels. This will be possible only when we have sufficient knowledge about the complex, nonlinear responses of our aquatic ecosystems to changes in environmental factors.

## CONCLUSIONS

Water management in the Netherlands has transformed from the simple flood protection of the past into a combination of managing water in terms of its quantity, quality, and biocomplexity. The history of coastal defense and water management in this country spans more than 2,000 years and is therefore among the longest in Europe. Large-scale peat excavations since the beginning of the 12th century, with related dewatering, peat oxidation, and sediment compaction, caused a dramatic decrease in surface elevation all over the country, and the combination of sinking land and a rising sea hampered the free runoff of fresh water to the sea and dramatically increased the risk for flooding.

Several milestones in water management can be recognized. The first were the decisions in 1974 not to reclaim the present Wadden Sea and not to close the

Oosterschelde by a dam, but to build a storm surge barrier instead. The second was the presentation in 1989 of the *Third National Policy Memorandum on Water Management*, which introduced integrated water management after ecologists explained successfully to the environmental engineers that concentrations of compounds had to be translated into a certain biological or ecological quality of the system under consideration. This decision brought the Netherlands a strong and well-respected reputation in the fields of coastal defense and integrated water management, which included both water quantity and quality.

Despite the significant advances to the coastal engineering works, some new problems arose. The large closures of the Zuider Zee and southwestern part of the Netherlands provided a greater level of safety against flooding. Environmentally, however, the country has largely failed to manage these waters according to plan. Every closed former estuarine system in the southwest now has at least one major environmental problem, ranging from large-scale erosion of intertidal flats to massive algal blooms.

The Water Framework Directive, based on systems ecology, is in practice a fragmented approach, because only portions of the system's ecological principles are applied. The directive also neglects to set the scene for a real ecosystem or holistic approach. Policymakers have failed to understand that complex coastal ecosystems cannot be represented by simple indicators.

The present water policy developed step by step, from flood defense to quantitative and then qualitative water management, and on to integrated water management in the late 1980s. It is notable that every new topic addressed built on an existing program, which led to integrated water management. Since about 2000, water management has been returning to a sector approach, exemplified by the recent presentation of the new second Delta Plan, in which coastal defense strongly prevails. Nevertheless, increasing internationalization has strongly stimulated debate on quantitative and qualitative aspects of water management, including the complex functioning of its biology.

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