A Range of Options to Cope with Sea Level Rise

Two Case Studies — The Netherlands and the United States

Cnut the Great was a Viking king of Denmark, England, Norway, and some areas of Sweden in the early part of the 11th century. He met with repeated successes in politics, military affairs, and religion, but a pious legend tells us that, eventually, he met his match at the seashore. Henry of Huntingdon, a 12th century chronicler, assures us that Cnut purposively set up his throne at the very edge of the sea and, once seated, he ordered the rising tide to stop and not to wet his feet and robes. But when the tide failed to halt at his command, Cnut leaped backward, away from the water, and is said to have shouted:

> Let all men know how empty and worthless is the power of kings, for there is none worthy of the name, but He whom heaven, earth, and sea obey by eternal laws.[1]

Legend has it that Cnut then hung up his gold crown on a crucifix and never wore it again. The moral here an obvious one: even the greatest rulers are powerless when faced with a rising sea.

It is instructive at this point to look more closely at two highly-developed countries which will increasingly be faced with a rising sea and to learn what steps they may take to deal with this problem. The first country is the Netherlands, which has the most to lose from the rising sea and which, as a result, is taking an active role in efforts to deal with this issue.[2] The second country is the United States, which because of its enormous size and great range of topography, has much less to lose. Probably as a result, it has not moved very far beyond the "lots of talk, no action" option mentioned earlier. In this chapter, we shall discuss each the situation of each country in some detail.

The Netherlands

We have already referred to the Netherlands, especially the port of Rotterdam, several times in this book but a closer look is in order here.[3] The Netherlands is located on the western edge of the Eurasian land mass—on the North Sea and at the estuaries of the Rhine, the Maas, and the Scheldt rivers. It is flanked by Belgium on the south and by Germany on the east. The western and northern coasts of the Netherlands border the North Sea.

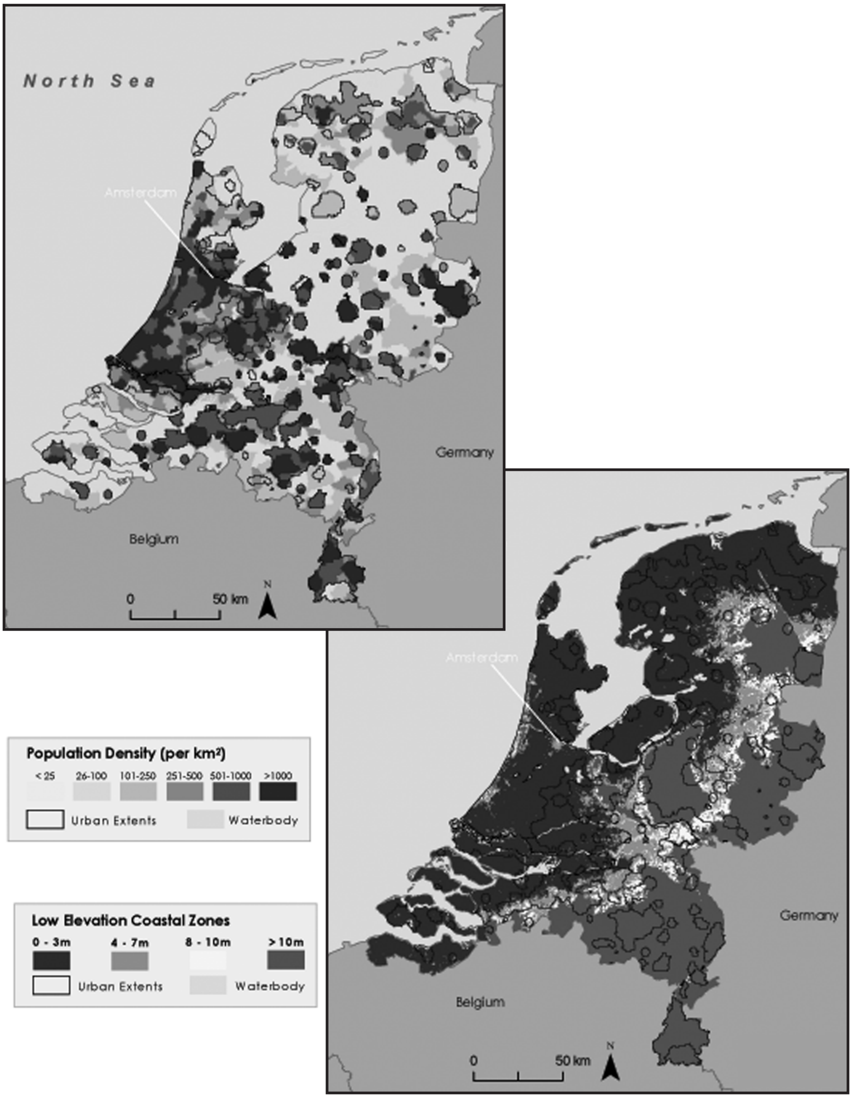
Some readers may remember the famous children's story of Hans Brinker, who is described as using his finger to plug a leak in a dike until help could come. This tale is much less well known in the Netherlands than it is in the United Kingdom or the United States because it is so far-fetched: if a dike threatens to give way, it takes much more than a boy's finger to hold back the water. As the Dutch author Han van der Horst has explained in *The Low Sky*, his excellent introduction to the Netherlands, if a break does occur,

> The water comes in like a wall ... boring a deep hole in the ground immediately behind the dike. It then spreads out, thundering and boiling, sweeping away everything in its part—trees, cattle, people....[4]

Although there is in fact a statue of little Hans in the village of Spaarndam, where his dike-plugging feat is supposed to have occurred, the only reason why the Netherlands is relatively dry today is that the Dutch have long excelled at non-stop feats of hydraulic engineering, i.e., water management. They need to be skilled at this undertaking because their country is, as they readily admit, *zo plat als een pannenkoek* ("as flat as a pancake"). They must always keep the sea at arm's length.

We mentioned earlier that about 27 percent of the Netherlands lies below sea level. Approximately two thirds of the country—one of the most densely populated on earth—is vulnerable to flooding. Its lowest point, near Rotterdam, is 22 feet (6.74 meters) below sea level. Its highest point, located at the southern tip of the country where the German and Belgian frontiers meet, has an elevation only 1,056 feet (322 meters).

Natural sand dunes and man-made dikes, dams, and floodgates protect the Netherlands from storm surges from the sea. River dikes prevent flooding from water flowing into the countryside from major rivers like the Rhine and the Meuse. An intricate system of drainage ditches, canals, and pumping stations makes the land suitable for homes and farms. This system is maintained by regional government bodies known as Water Boards, some of which date from the 13th century. They are charged with managing water barriers, waterways, water levels, and water quality in their respective areas of responsibility.[5]



Netherlands population density and low elevation coastal zones (Socioeconomic Data and Applications Center, 2009).

The Dutch experience with hydraulic engineering began in about 500 B.C., when settlers now known as Frisians heaped up piles of earth called *terpen* and lived on them not far above the level of the water.[6] They had a hard life: the Roman naturalist Pliny tells us that they were a "wretched race." In the period before the invasion by the Romans, the inhabitants of what is now

Friesland (located in the northwestern part of the Netherlands) were building low dikes to protect themselves against flooding by the sea. After 800 CE [CE = Common Era], when water levels at high tides increased significantly, the growing population had to intensify its efforts to prevent flooding. The first dike construction works on a large scale in the Friesland area began in the first half of the 10th century.

The earliest dikes were low embankments about 3.2 feet (1 meter) high, designed to protect crops in the fields from occasional flooding and to safeguard the small villages which had sprung up. As the population grew, there was a greater need for arable land and also a greater number of strong backs available to build dikes under the supervision of the major landowners and, later, the monks.

In 1287, however, the Dutch nearly lost their war against the water, when big floods swept over the land and created the Zuiderzee ("Southern Sea" in Dutch), a large shallow inlet of the North Sea, located in the northwestern part of the Netherlands. (In 1932, a barrier dam would transform the Zuiderzee into the fresh-water Ijsselmeer, or "IJssel Lake" in Dutch.) The first drainage windmill was built in the Netherlands in 1414. After the St. Elizabeth's Day Flood of 1421, which killed some 10,000 people and inundated 20 villages, many more windmills were built. In the 17th century, the great hydraulic engineer Jan Adriaenzoon Leeghwater (fittingly, his surname means "empty water" in Dutch) used 43 windmills to help him construct polders north of Amsterdam. These windmills made it possible to regulate water levels by a series of drainage canals which crisscrossed the polders and thus dried out the land.

To prevent a recurrence of the disastrous flood of 1953, the Dutch created the Delta Works. Consisting of a complex series of dikes, dams, sluices, locks, and storm surge barriers, the overall goal of this ambitious and remarkable project was to shorten the Dutch coastline, thereby reducing the number of dikes that had to be raised in height. Most of the Delta Works were built between 1950 and 1997 in the southwest of the Netherlands to protect an extensive region of land around the Rhine-Meuse-Scheldt delta.[7] The final step in this project was only a small one — the official opening of a strengthened and raised water retaining wall near the city of Harlingen in 2010.

The last mega-undertaking of the Delta Works was the Maeslant Storm Surge Barrier on the Nieuwe Waterweg (New Waterway) near Rotterdam, which was finished in 1997.[8] This barrier, which closes automatically when needed, is one of the largest moving structures on earth and is designed to protect the 1.5 million inhabitants of Rotterdam and its surrounding area. The barrier is connected to a computer system which constantly monitors sea level data and controls the barrier appropriately.

Under normal sea level conditions, the two giant, hollow, semi-circular doors of the barrier remain open, giving seagoing ships plenty of room — a l,181 foot-wide (360 meter-wide) gap — to pass between them. When a storm surge of 9.8 feet (3 meters) above normal sea level is anticipated in Rotterdam, however, the doors close automatically. The Dutch now believe that, due to the rising sea level, the barrier will have to be closed about once every five years to keep the sea out, rather than once every 10 years as initially expected. The barrier first closed its gates for a storm flood during 2007. It is tested every year before the 1 October–15 April storm season begins.

In 2008, the Netherlands' high-level Deltacommissie (Delta Commission), reflecting on the lessons learned in New Orleans from Hurricane Katrina and on the certainty of additional sea level rise in the future due to continued global warming, reported that the Netherlands needed a massive new building program to strengthen the country's defenses against sea and river water. The likely cost of this work, e.g., broadening coastal dunes and strengthening sea and river dikes, was estimated at more than $144 billion (100 billion Euros).

In its studies, the Delta Commission evoked, among other scenarios, a worst-case, low-probability sea level rise (due in part to land subsidence) of 2.1 to 4.2 feet (0.65 to 1.3 meters) by 2100, and of 6.5 to 13.1 feet (2 to 4 meters) by 2200. Although no one can be sure be sure how high the sea will rise in the years ahead, the Dutch are certainly facing this problem head-on. The Delta Commission also made 12 recommendations, of which the first was arguably the most important. It stated:

> The present flood protection levels of all diked areas must be raised by a factor of 10. To that end, the new standards must be set as soon as possible (around 2013). In some areas where more protection is needed, the Delta Dike concept is promising (these dikes are either so high or so wide and massive that the probability that these dikes will suddenly and uncontrollably fail is virtually zero). With regard to special or local conditions, this will require a tailor-made approach. All measures to increase the flood protection levels must be implemented before. After 2050, the flood protection levels must be updated regularly.[9]

Plans for mass evacuations in the event of worst-case scenarios are also being refined. The current sea defenses of the Netherlands are continuously being strengthened and raised to meet the safety norm of a flood chance of once every 10,000 years for the western part of the country (this is the most densely populated and economically most important region), and once every 4,000 years for other areas. Primary flood defenses are being tested against this norm every five years.

In response to the Delta Commission's work, a "Delta Commissioner" was appointed and given an appropriate staff. This official is tasked with making sure that a Delta Programme is drawn up and implemented every year and that progress reports are submitted. Thus, to use a metaphor from the sport of rowing, the Dutch are not resting on their oars. In its 2008 report, the Delta Commission concluded:

> Implementation of the recommendations [in the report] is a matter of urgency. The Netherlands must accelerate its efforts because, at present, even the current standards of flood protection are not being met everywhere. Moreover, the current standards are out of date and must be raised, the climate is changing rapidly, the sea level is probably rising faster than has been assumed, and more extreme variations in river discharge are expected. *The economic, societal and physical stakes in the Netherlands are great and growing still; a breach in a dike has seriously disruptive consequences for the entire country.*[10]

The United States

Although many shoreside East Coast and Gulf Coast cities are virtually certain to face serious problems from sea level rise over the coming decades, there is now no single, comprehensive national American program designed to deal with this issue. Some comparatively modest efforts are now underway at the Federal level (e.g., via the U.S. Geological Survey, the Federal Emergency Management Agency, and the U.S. Army Corps of Engineers), as well as at various state and city levels. But taking it all in all, the overall response by the United States to sea level rise has thus far been spotty and, on a national basis, not well coordinated.

Probably the most important reason is that, in the absence of any sea level rise disasters in the United States, the American public — and thus the American Congress— is unwilling to finance any major preventative measures (New Orleans excepted). Such measures are likely to be expensive and politically controversial. Many American decision-makers still function under the traditional assumptions that the level of the sea, and thus of the shorelines it washes, is inherently stable and that storms are a regular, normal part of nature.

At minimum, all of them know that no matter how important it may be in the long run, sea level rise is not now a problem that, in political terms, *simply must be dealt with this week*. Moreover, it is very difficult for legislators to convince Americans living in landlocked states in the middle of the country that their tax dollars must be spent to mitigate sea level rise along the distant coasts of the United States.

Nevertheless, despite these realities, at the technical level a good deal of in-depth research has already been conducted in the United States on sea level rise. One the best examples was a hefty (300-page) report coordinated by the U.S. Environmental Protection Agency in 2009.[11] This magisterial project, chaired by James G. Titus, focused on the mid–Atlantic region of the United States, e.g., on the coasts of New York, New Jersey, Delaware, Maryland, Virginia, and North Carolina. It remains the most thorough U.S. Government publication on the implications of sea level rise and is not likely to lose this heavyweight title soon. By drawing from it selectively and by allowing ourselves a little bit of editorial freedom in the process to improve readability, we can learn a number of interesting things[12]:

Perhaps the first and most important lesson is that although other coastal regions of the country (most notably the Gulf of Mexico and the Florida coast) are fundamentally more vulnerable to sea level rise, the mid–Atlantic coastal region, for its part, is a very prosperous, high-tech, densely-populated part of the United States coast that will be at greater risk as the sea rises in the years ahead. Farmlands, forests, wetlands, and developed lands in low-lying localities there will suffer the most from any future sea level rise of 3.2 feet (1 meter) or higher. When storm surges wash ashore on top of this kind of rise, there is going to be a great deal of trouble along the Mid-Atlantic coast.

Remarkably, however, the kind of comprehensive, high-resolution, precise analyses of the spatial distributions of population and infrastructure vulnerable to sea level rise in the Mid-Atlantic region which are essential for effective planning and response do not appear to exist at this time. Because of a wide variety of heavy financial, political, and bureaucratic restraints, most the public entities involved in this issue have not prepared for a rising sea. The Mid-Atlantic studies which do exist usually lack the required underlying land elevation data which is necessary for decision-makers to have full confidence in the results of possible efforts to deal with sea level rise.

Today, existing generalized data can give us only a very rough approximation of how many people may be affected by sea level rise in the Mid-Atlantic area. For example, between approximately 900,000 and 3,400,000 people (between 3 to 10 percent of the total population there) are believed to live on parcels of land or city blocks with at least some land less than 3.2 feet (1 meter) above monthly highest tides. As noted earlier, a sea level rise of about 3.2 feet (1 meter)—and perhaps even more—seems quite possible by 2100.

There are several ways—none of them perfect—to cope with sea level rise. These options include:

- In-shore protection (i.e., protecting buildings, etc., which are situated immediately inland of the shore).
- Shoreline armoring, for example, the use of seawalls, bulkheads, retaining structures, revetments (walls whose seaward side follows a slope), dikes, dunes, tide gates, and storm surge barriers.

- Beachfill (also called beach nourishment or sand replacement), which adds material to a beach to make it higher, wider, and less vulnerable to the sea.
- Physically raising existing structures: for example, after a severe hurricane in 1900, most of Galveston, Texas was elevated by more than 3.2 feet (1 meter).
- Erecting groins (hard structures placed offshore) and/or converting eroding mud or sand beaches to a cobble or pebble beach, which is more stable.
- Retreat (also known as relocation). The most ambitious relocation program in the Mid-Atlantic region was moving the Cape Hatteras Lighthouse about 1,475 feet (450 meters) inland in 1999.

A basic problem here is that almost all coastal communities and public structures in this region (and elsewhere, of course) were conceived, designed, and built without any realization that sea level would rise substantially. Although these communities probably expect that the Federal or state government will somehow stabilize their shores and maintain the coastal status quo, the economic costs of shore protection over a very long period of time are now unknown. Similarly, the long-term economic and social costs of retreat still remain to be quantified.

The need to prepare for a rising sea level is a function of numerous complicated and interrelated factors. Some of them are:

- the length of time over which a decision will have continuing consequences
- how rapidly the sea is expected to rise
- the degree of uncertainty about the pace of this rise
- levels of risk tolerance among the tax-paying and shore-using publics
- levels of risk tolerance among the decision-makers responsible for community action or inaction
- the implications of doing nothing at all at a given time.

Within the Mid-Atlantic region, most governmental organizations are not yet taking specific measures to prepare for sea level rise. Congress has given neither the U.S. Army Corps of Engineers nor the U.S. Environmental Protection Agency a mandate to change the present administration of wetlands by focusing on a rising sea. Understandably, these agencies are not able to move ahead on this issue without a green light from Congress. On the other hand, some private organizations that manage land for environmental purposes, e.g., The Nature Conservancy (the largest private holder of conservation lands in the Mid-Atlantic region), are now moving ahead unilaterally on this front.

Looking ahead, what can we say about the implications of sea level rise for the United States as a whole? Here are some of the ideas mentioned in the Environmental Protection Agency's report:

- More than one-third of the U.S. population now lives in the coastal zone, which continues to attract new residents and commercial development. Fourteen of the 20 largest U.S. urban centers are situated along the coast. Sea level rise, especially if accompanied by more frequent storm surges, will have significant and uniformly negative economic and social impacts.
- Some portions of the U.S. coast will be subject to inundation from sea level rise over the years leading to the next century. In a relatively early (1989) study, the U.S. Environmental Protection Agency forecast that a rise of only 3.2 feet (1 meter) could drown approximately 25 percent to 80 percent of the U.S. coastal wetlands. Such a rise would also inundate 5,000 to 10,000 square miles (12,949 to 25,899 square kilometers) of dry land if shores were not protected, and 4,000 to 9,000 square miles (10,359 to 23,309 square kilometers) of dry land if only developed areas were protected.[13]
- A great deal still remains to be done to quantify the likely effects of this rise and to spell out the dominant coastal change processes for each region of the U.S. coast. Understanding, predicting, and responding to the environmental and social effects of sea level rise will therefore benefit from a national program of integrated research that includes both the natural and social sciences. The findings of such a program (which does not yet exist) would be of great value to other coastal nations, too.
- In the process of such research, the historic and geologic record of coastal change should be used to improve our understanding of natural and human-influenced coastal systems. We need to increase our knowledge of sea level rise and coastal change over the past few millennia; to identify possible thresholds or tipping points in coastal systems; and to relate past changes in overall climate to specific changes along the coasts.