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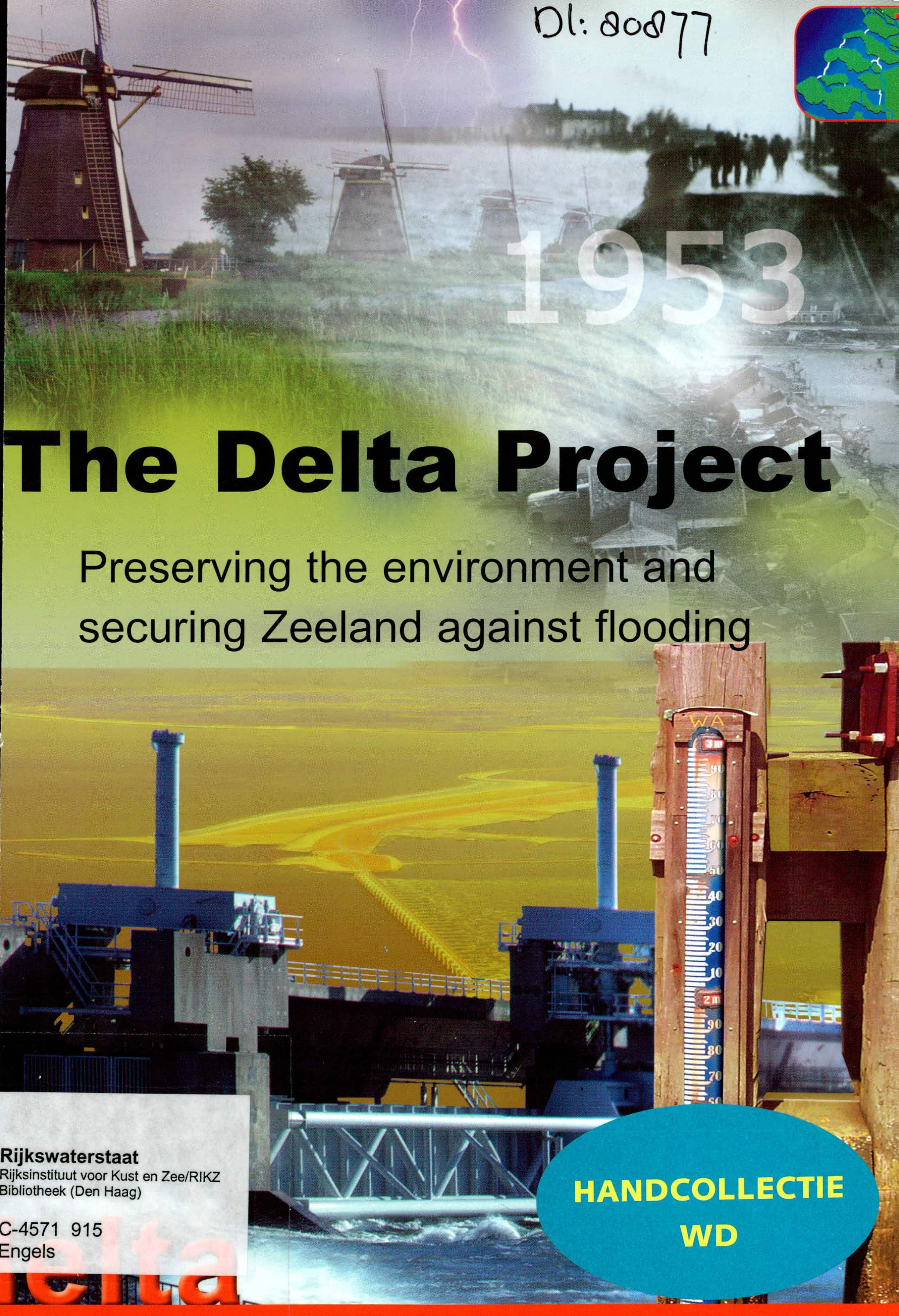

The Delta Project

Preserving the environment and securing Zeeland against flooding

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C-4571 915
Engels

HANDCOLLECTIE
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Colophon

Publication: WaterLand Neeltje Jans and
Florad Marketing Group
2002

Design: Florad Marketing Group
Text:: Voorlichting Verkeer en Waterstaat,
WaterLand Neeltje Jans
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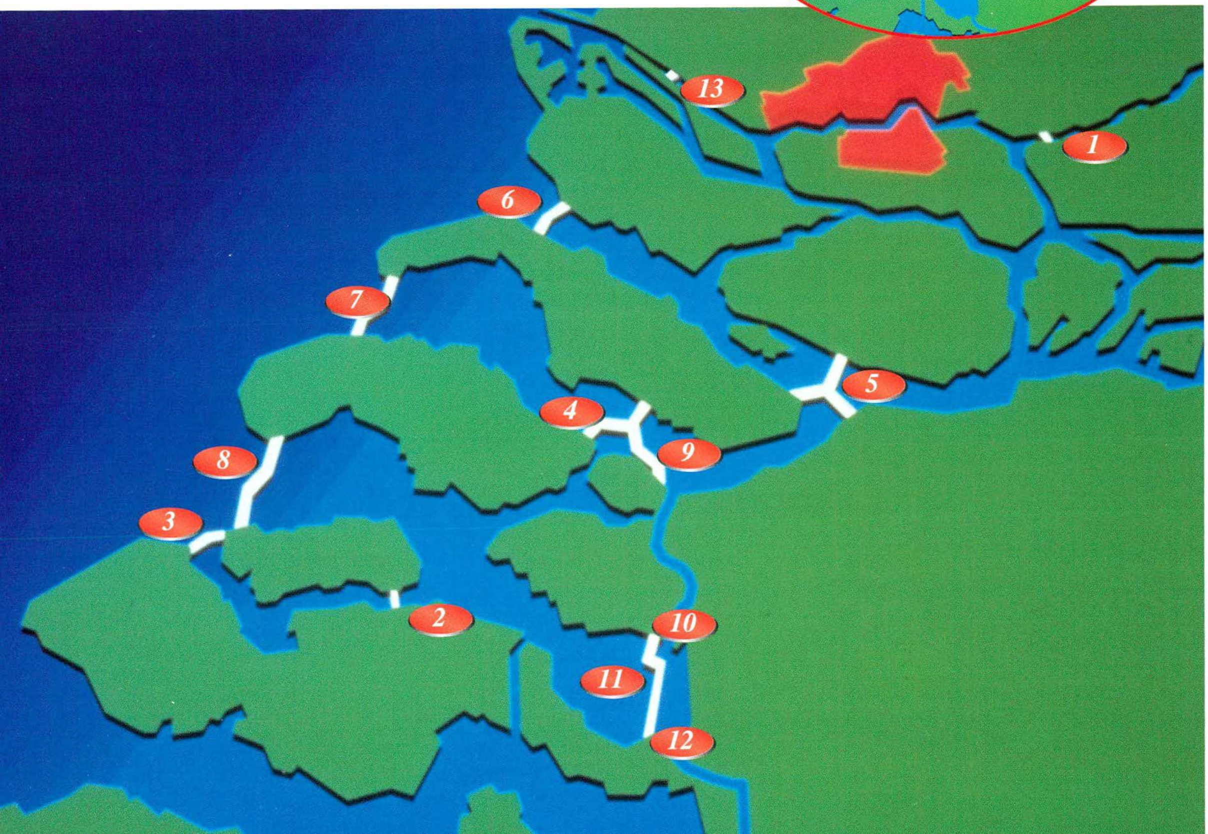
From 1953



A permanent struggle

The Netherlands is locked in a permanent struggle for survival. The country's name is self-explanatory: large areas of the Netherlands lie below sea level. Stronger dikes, dams and dunes are continually being constructed to keep the sea at bay and to ensure that this densely-populated country remains habitable. Half of the Netherlands would be flooded if it were not for the line of defenses that has been built over the centuries and the equipment to pump ground water and river water out of the low-lying polders.

The struggle is just as pressing today. The Netherlands is sinking in relation to sea level at a rate of 20 centimetres per century. Not only is the ground settling, but the sea level is also rising as the temperature of the earth increases, causing the polar icecaps to melt. Human activities such as burning coal, oil and gas produce carbon dioxide, creating the greenhouse effect and causing the temperature of the earth to increase ever faster.

At the end of the last ice age, around 10,000 years ago, the North Sea was formed and the area we now know as the Netherlands came to existence as marshland. The region was uninhabitable for many centuries, but with the passage of time peat bogs formed and people settled on the higher dunes, where they hunted, fished and practiced a little farming. They also built embankments to live on during periods of high spring tides. The first roads, canals and harbours were built by the Romans. The first dikes were built in the 10th century, and with them the defence of the land turned into a counterattack against the sea. Dikes were constructed to protect existing land from floods, and also to reclaim new areas from the sea, the polders. Reclaiming land was a profitable means of investing money that had been made in commerce and shipping.

The clergy in particular supported the creation of new polders. The tools were very simple, no more than spades and baskets, and the first dikes were low embankments that were easily breached by the sea. Excess water in the polders was an additional problem and sluices had to be constructed to discharge it into the sea at low tide. With the invention of the windmill around 600 years ago, it became possible to keep increasingly deeper polders dry. Further-more, the mills could pump large ponds and lakes dry so that even more new land could be reclaimed. The dikes, however, remained a primitive form of protection, built according to traditional methods. It was not until the 19th century that new materials, techniques and tools such as concrete, stone embankments and steam-engines appeared.

Large pomds and lakes are drained with windmills.

Countless floods

The sea has had many opportunities in the past to determine the shape of the Netherlands. The line of coastal defenses shows where the water overpowered the people. Every century has witnessed floods. Many were given names, for example the Saint Aechten's Day Flood in 1288, the Saint Elizabeth's Day Floods in 1404 and 1421, the Saint Felix's Day Flood in 1530 and All Saints' Day Flood in 1570. Although the Dutch fought back, they often had to surrender large areas of land to the sea. The Verdronken Land van Saeftinghe (Zeeland Flanders), the Verdronken Land van Reimerswaal (South Beveland) and Zuidland (Schouwen-Duiveland), for example, were all lost to the sea. On balance, during the past centuries more land has been lost than reclaimed.

Floods have not been confined to particular periods or enabled to occur only by the limitations of technology. They have also occurred in the 20th century, for instance in 1906 and 1916. The greatest flood disaster in the country's history occurred on the night of 1 February 1953. The sea surged into many polders in the south-west Netherlands, inundating some 200,000 hectares of fertile farmland and flooding many towns and villages. The dikes were destroyed in 67 places and breached in over 400. 1,835 people drowned and 72,000 were forced to evacuate the region; more than 200,000 cows, horses, pigs and other livestock died and over 47,000 buildings were damaged.

The dikes had not been equal to the unprecedentedly high water level of 4 to 5 meters above AOD (Amsterdam Ordnance Datum, mean sea level as defined for Amsterdam). The flood was caused by a spring tide, when exceptionally low and high tides are produced as the influences of the sun and moon reinforce each other, in combination with a persistent north-westerly storm. The storm reached its peak in the middle of the night, and an hour of continuous wind force 12 coincided with the high tide. The water piled up against the dikes, spilled over the top of them and began to wash them away. Most people were asleep when the sea overtook them.

A great deal of assistance was offered from abroad. The people of the Netherlands were determined not to surrender the flooded land. Their thoughts first turned to repairing the damage and then to preventing a reoccurrence of such a disaster. They quickly resealed the dikes and pumped the water out of the polders. The experience they had gained in pumping the island of Walcheren dry after the bombing of its dikes in 1944, in damming the Braakman inlet in 1952 proved invaluable. Caissons, large watertight concrete structures, were indispensable as a means of blocking off the channels quickly. The last breach, near Ouwerkerk, was resealed in November 1953.

The dikes break in many places.

The attractions of delta regions

People have always been attracted to coastal regions. River estuaries in particular are obvious places for settlements; the river provides a communication route to the hinterland and also supplies alluvium that forms fertile soil.

The distributaries that branch from a river as it approaches the sea often form a triangular shape on the map. The mouth of the river Nile in Egypt is a very good example of this. The ancient Greeks called the mouth of the Nile a "delta" after the fourth letter of their alphabet, which was written in the form of a triangle. Nowadays the term delta is widely used to describe many areas where a river enters a sea or a lake. Apart from the Nile, other famous deltas include those of the Ganges, the Mississippi, the Rhone and the Yangtze. In the south-west Netherlands the estuaries of the Rhine, Maas and Scheldt also form a delta.

Low, flat deltas are vulnerable regions, and the inhabitants have good cause to construct dikes and embankments to protect themselves against the sea. As villages and towns flourish, though, and their economic importance as centres of trade, shipping and industry increases, the need to construct better forms of protection also increases.

Deltas often provide many of the conditions needed to support a rich and varied system of plant and animal communities. Algae and plants grow in the shallow, relatively warm water, which light can penetrate easily. Their growth and the supply of organic matter from the sea and minerals from the river enable deltas to act a nurseries for young fish. The driving force behind the delta's ecosystem is the tide. The regular exposure of mud flats and sandbars at low tide and their submergence at high tide is indispensable to the innumerable shellfish, worms and other fauna that live on them. These in turn are essential to the thousands of birds that feed on them at low tide. The lower animals and birds form a small food chain, one of the many that exist in the water, the mud flats and the higher-lying salt marshes.

However, the human settlement, transportation, agriculture, fishing, trade and industry that flourish due to the favourable conditions of the delta are a threat to the ecosystem. The increasing size of the ships requires the dredging of deeper navigation channels and the construction of larger harbours. Industry discharges waste into the water, and toxins discharged hundreds of kilometres upstream eventually settle with the alluvium at the mouth of the river.

Human activities put the ecosystem under pressure. Since the beginning of the 1970s there has been a growing awareness that this pressure cannot continue to increase unabated and a balance needs to be struck between the interests of ecology and the economy.

Securer flood defenses

New water sport areas created by the Delta Plan.

Shortly after the 1953 flood a specially appointed committee presented proposals for the prevention of another disaster in the future. The proposals centred on improving safety by strengthening the coastal defenses. A proposal to shorten the length of the coastline was enthusiastically received, as, after all, the strength of a defensive line increases as its length decreases. This has been the principle behind many other hydraulic engineering works, an outstanding example of which is the Barrier Dam which was constructed in 1932 across the mouth of the Zuyder Zee, now called the IJsselmeer, to protect it from the incursions of the North Sea. By constructing this single dam, the length of the coastline was reduced by 300 kilometres and the danger of flooding in a large area of the country was entirely eliminated.

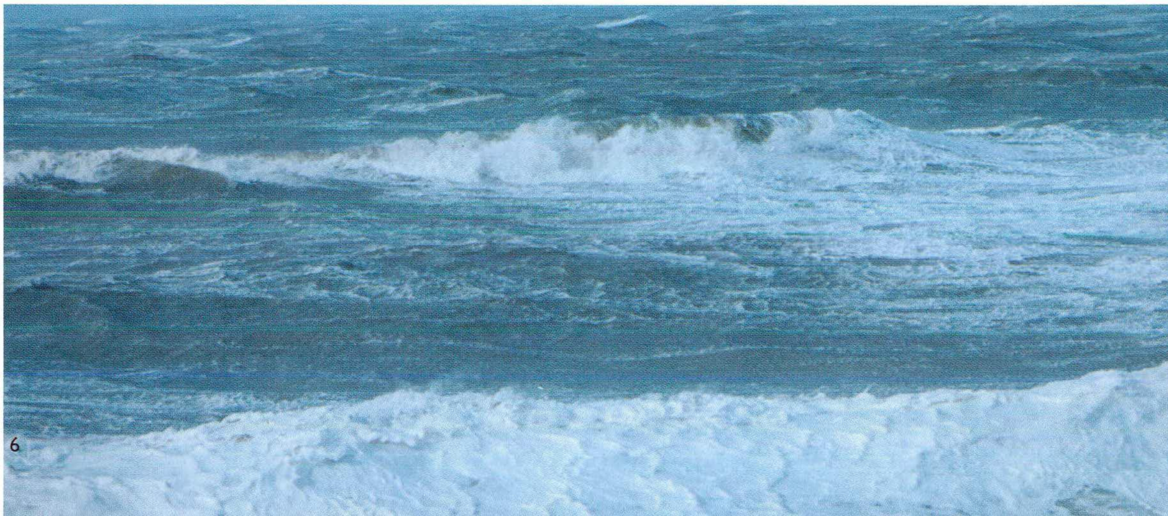
The committee recommended that the tidal channels to the Rhine, Maas and Scheldt Delta should be dammed near the coast and that the dikes along the sea and the rivers in the rest of the country should be raised to allow for a water level of five meters above AOD at the Hook of Holland. This would reduce the frequency of inland flooding to an average of once every ten thousand years and flooding in the inlets to once every four thousand years, which seemed quite safe enough for the time being.

The New Waterway and the Western Scheldt had to be kept open to shipping due to their economic importance to the ports of Rotterdam and Antwerp. The surrounding dikes would therefore also be raised to the same height as those in the Delta.

Oyster beds in Yerseke.

In 1958, Parliament passed the Delta Act, which set out plans to ensure the safety of the south-west Netherlands, to the great enthusiasm of the public. In addition to reducing the risk of flooding by increasing the height of the dikes and shortening the coastline by 700 kilometres, the Delta Project would also create considerable economic benefits. It would improve water management in a large proportion of the Netherlands and combat the penetration of salt water into the ground water. Freshwater lakes would form and be an important source of water for farms. New recreational areas, particularly for water sports, would be created. The construction of dams would also considerably improve the road network in the south-west Netherlands.

One of the Projects drawbacks was that the saltwater fishing industry and the shellfish farms would disappear. The oyster and mussel farms centred on the town of Yerseke were an important source of income in the Eastern Scheldt region, but would be destroyed after the inlets were dammed. Shellfish cultivation would have to be transferred to other areas. In those days very little consideration was paid to the environment; flood protection and the economy were the main issues.



Fewer dikes

The original plans for the Delta Project entailed the construction of huge dams in four tidal inlets, the Veerse Gat, the Eastern Scheldt, the Brouwershavense Gat and the Haringvliet, which would reduce the length of the seadikes in the region from over 700 kilometres to just 25 kilometres. In addition, three dams were also planned further inland in the Volkerak, Grevelingen and Zandkreek channels. The Volkerak dam would separate the freshwater and saltwater environments, and the dams in the Grevelingen and Zandkreek would eliminate uncontrollable currents in the tidal area.

Some unusual civil engineering structures would be needed for specific purposes. A storm surge barrier was to be built in the Hollandse IJssel to protect the low-lying but densely-populated region of South Holland. A large sluice complex was to be built in the Haringvliet dam to discharge any excess water from the Rhine and the Maas into the North Sea. Locks were also to be built in several dams for commercial ships and pleasure craft.

The Delta area.

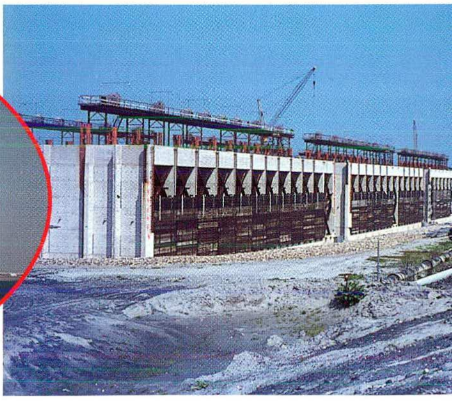
The Krammer locks in the Philips Dam.

New techniques

The Delta Project was a challenge to Dutch hydraulic engineers. It was evident that past experience and existing techniques would not be sufficient to enable dams to be constructed across the wide and deep tidal channels. The tidal range in the Delta approximately three meters and the water flows in and out twice a day with powerful currents shifting enormous quantities of sand. Weather conditions in the estuaries are often unfavourable and North Sea storms produce powerful waves. New techniques had to be developed quickly so that the Delta Project could be carried out.

The towering caissons were adapted and improved. Man-made fibres were used for the first time to protect the seabed and to clad the dikes. The traditional seabed protection method, which involved covering the seabed with large osier mats made of willow wood and weighted with stone, was gradually replaced. Changes took place step by step. It was decided to implement the Delta Project by working from small to large so that technological progress would keep pace with the growth in experience.

Prefabrication became a common technique and in addition to new materials, new equipment was also very valuable. Sluice caissons were developed to tip stone into the channels. Hydrodynamic study techniques were refined by developing laboratory tests. The computer gradually made its entrance. Measuring techniques and weather forecasts became more accurate. The Delta Project would take 25 years to complete. A new age was dawning for hydraulic engineering.



The implementation of the Delta Project

The storm surge barrier in the Hollandse IJssel 1958

The implementation of the Delta Project began with the construction of a storm surge barrier across the river the Hollandse IJssel, which forms an open passageway to the sea via the Nieuwe Maas. The barrier was built just to the east of Rotterdam and completed in 1958. It protects the lowest-lying region of the Netherlands from flooding. The 80 metre wide barrier consists of four piers towering over 44 meters above AOD, two gates suspended between the piers, a shipping lock and a road bridge. Under normal conditions the gates are raised high above the water so as not to impede shipping, but when the water level is dangerously high they can be lowered, effectively damming the river. When the barrier is closed ships can pass through the lock

Storm flood barrier in the Hollandse IJssel.

The Zandkreek dam 1960

The Delta Project really got underway with the construction of the dams. First on the agenda was the Three Islands Project, which would connect the islands of Walcheren, North Beveland and South Beveland with each other. Work began in 1959 on a dam with a lock between North and South Beveland in the Zandkreek channel. The 830 metre long dam was constructed using caissons and completed in May 1960. By this date the construction of the dam across the Veerse Gat between Walcheren and North Beveland was progressing well. Around 70 million m3 of water flowed through the Veerse Gat with each tide.

The Zandkreek Dam with lock.

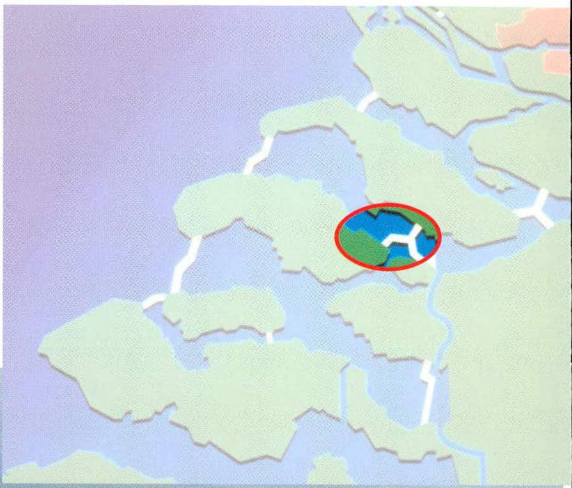
The Veerse Gat dam 1961

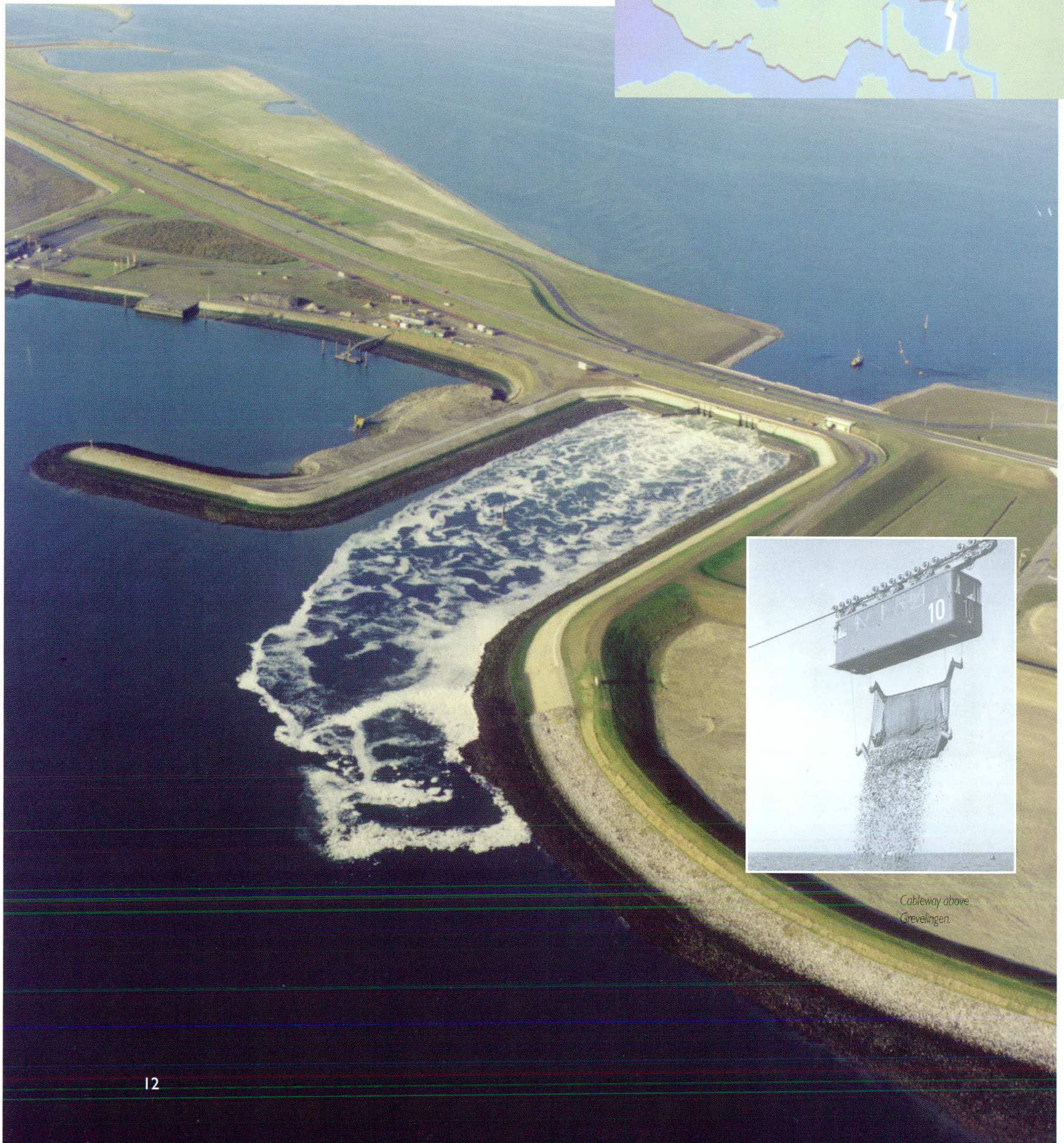
A new technique was needed to dam the Veerse Gat. The usual caissons were adapted and what are known as sluice caissons were developed. Sluice caissons have sealable openings so that at first water, it can flow through them freely while a dam is being constructed. Seven sluice caissons, each as high as a seven-storey building, were placed in the 320 metre wide channel on a sill made of tipped stone. The dam was completed in April 1961. The sluices were closed at slack water between low and high tide. The closure of the first inlet had been completed and a lake, the Veerse Meer, had been created. A dike was quickly laid over the caissons to finish the work.

Veerse Gatdam.

The Grevelingen dam 1965

A start had been made in 1958 on the six-kilometre dam across the Grevelingen channel between Schouwen-Duiveland and Goeree-Overflakkee, which would ultimately incorporate a lock and harbours near Bruinisse. A substantial part of the dam was constructed on the Oude Tonge sandbars using the well-tried method of dredging sand. Two channels remained open. The small southern channel was dammed using solid caissons placed on a sill constructed from new materials – nylon and mastic asphalt. A new method was used to dam the larger, northern channel: a cableway with gondolas suspended from steel cables nine centimetres thick was spanned across the channel and used to gradually dam it by tipping 170,000 tons of stone. The dam was completed in 1965 and a road along the top opened to traffic.





Passageway through the Grevelingen Dam.

Cableway above Grevelingen.

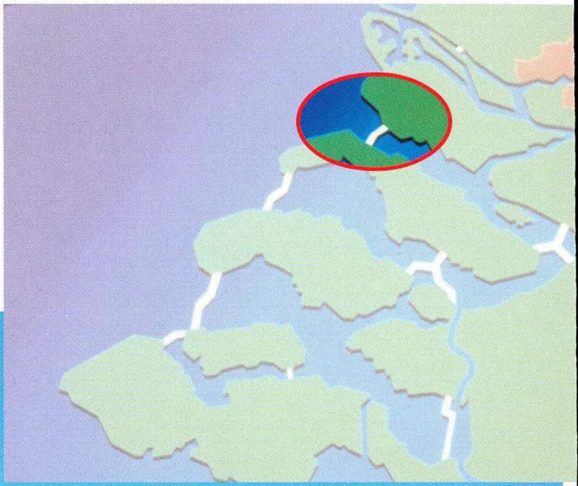
The Volkerak dam 1969

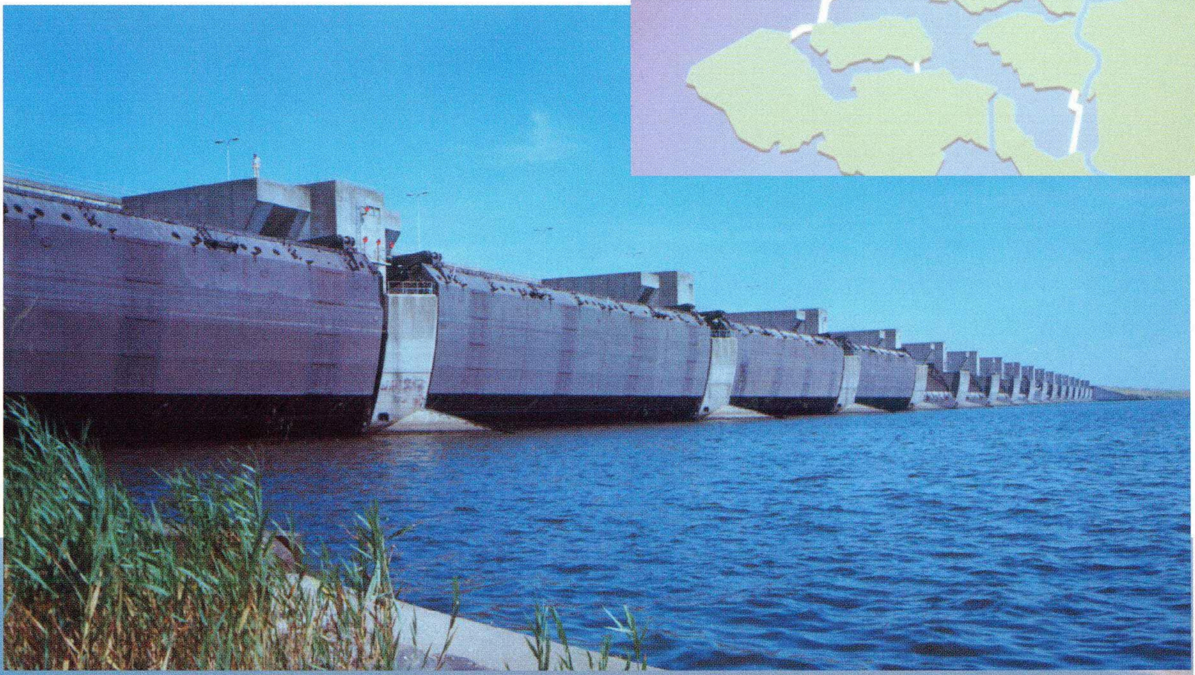
Taking advantage of the new techniques, the Volkerak channel between the Haringvliet and Hollandsch Diep channels was dammed to improve water management and the transport network. The work, which commenced in 1957, consisted of a dam across the Hellegatsplaten (a series of sandbars) and the Hellegatsplein (an artificial island), a bridge spanning the 1200 meters across the Haringvliet, and a large lock and sluice complex and a solid dam at the mouth of the Volkerak. The dam across the Hellegatsplaten and Hellegatsplein, the Hellegats dam, was constructed entirely of sand. The Volkerak was dammed in the spring of 1969 using 12 sluice caissons. By that date the locks, built near the town of Willemstad, were already being used by ships on the busy Scheldt-Rhine shipping route.

The Volkerak locks.

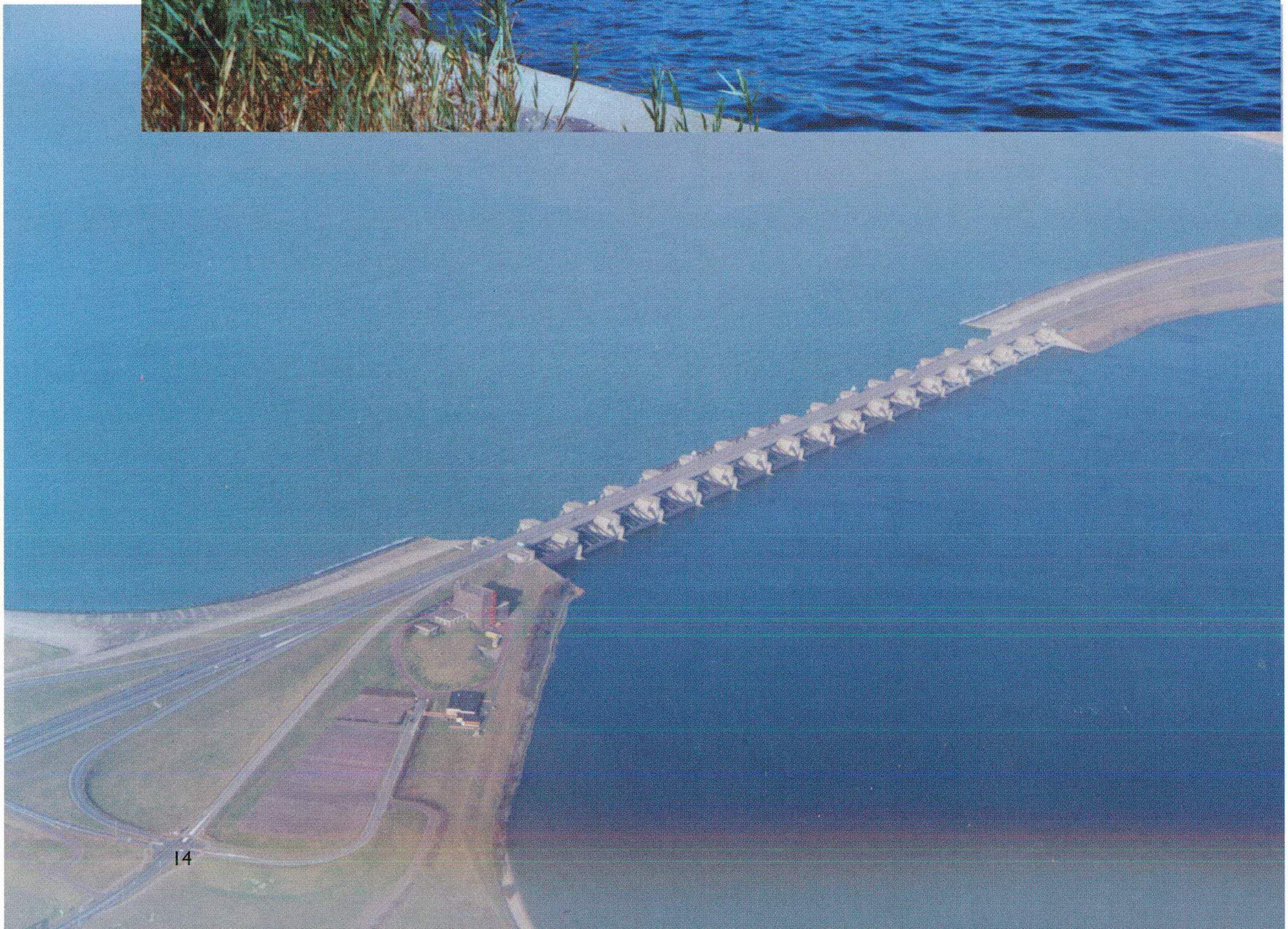
The Haringvlietdam 1971

It took 14 years to construct the Haringvliet dam, which extends 4.5 kilometres between Goeree and Voorne. A unique design was developed as the dam had to remain open for the purposes of water management and the discharge of excess water from the Maas and the Rhine: a sluice complex with a channel width of 1,000 meters and a lock for fishing boats. The 17 sluices can be closed with steel gates on both the sea and the river side. The gates were made in an excavated construction site surrounded by an encircling dike – similar to a polder – in the middle of the Haringvliet. The sluice complex temporarily functioned as sluice caissons, and the dam was completed in 1970 by tipping 100,000 concrete blocks using a cableway. A road built along the dam was opened in 1971.





Drainage sluices in the Haringvliet Dam.



The Brouwers dam 1971

The final rehearsal for the last part of the Delta Project, the Eastern Scheldt, was the construction of a dam across the 6.5 kilometre wide and 30 metre deep Brouwershavense Gat between Goeree and Schouwen. Work began in 1962 using various well-tried methods. Sand dams were dredged on the shallow Kabbelaarsbank and Middelplaten sandbars. The northern channel, Springersdiep, was dammed using sluice caissons, which had been constructed in a special construction dock in the Grevelingen. The southern channel, the Brouwershavense Gat, was dammed using the cableway method. The dam was completed at the end of 1971, creating a new lake, the Grevelingenmeer. A sluice was built into the dam ten years after its completion in order to flush the Grevelingenmeer with water from the North Sea to keep the salt content of the lake at an appropriate level.

Brouwers Dam.

Cableway at the Brouwershavense Gat.

The most difficult project

The Eastern Scheldt dam 1986

According to the original plans the dam across the mouth of the Eastern Scheldt inlet would have been completed in 1978, 25 years after the flood disaster. The construction of this dam, extending eight kilometres between Schouwen and North Beveland, would be the most difficult part of the Delta Project. The inlet had an average tidal range of three meters and its deepest channel was 40 metres deep. 1,100 million m3 of water flowed through the channels at each tide, considerably more that the 350 million m3 that flowed through the Brouwershavense Gat. Work commenced in 1967. The construction islands Roggenplaat, Neeltje Jans and Noordland were built on three shallow sandbars. Neeltje Jans and Noordland were later linked to each other by a three-kilometre dam.

Demonstration against plans to seal off the Eastern Scheldt completely

Approximately five kilometres of the dam had been completed by the end of 1973. Three channels remained open, the Hammen, Schaar van Roggenplaat and Roompot channels, with a total width of three kilometres. According to the plans they were to be dammed using the cableway method and prefabricated concrete blocks.

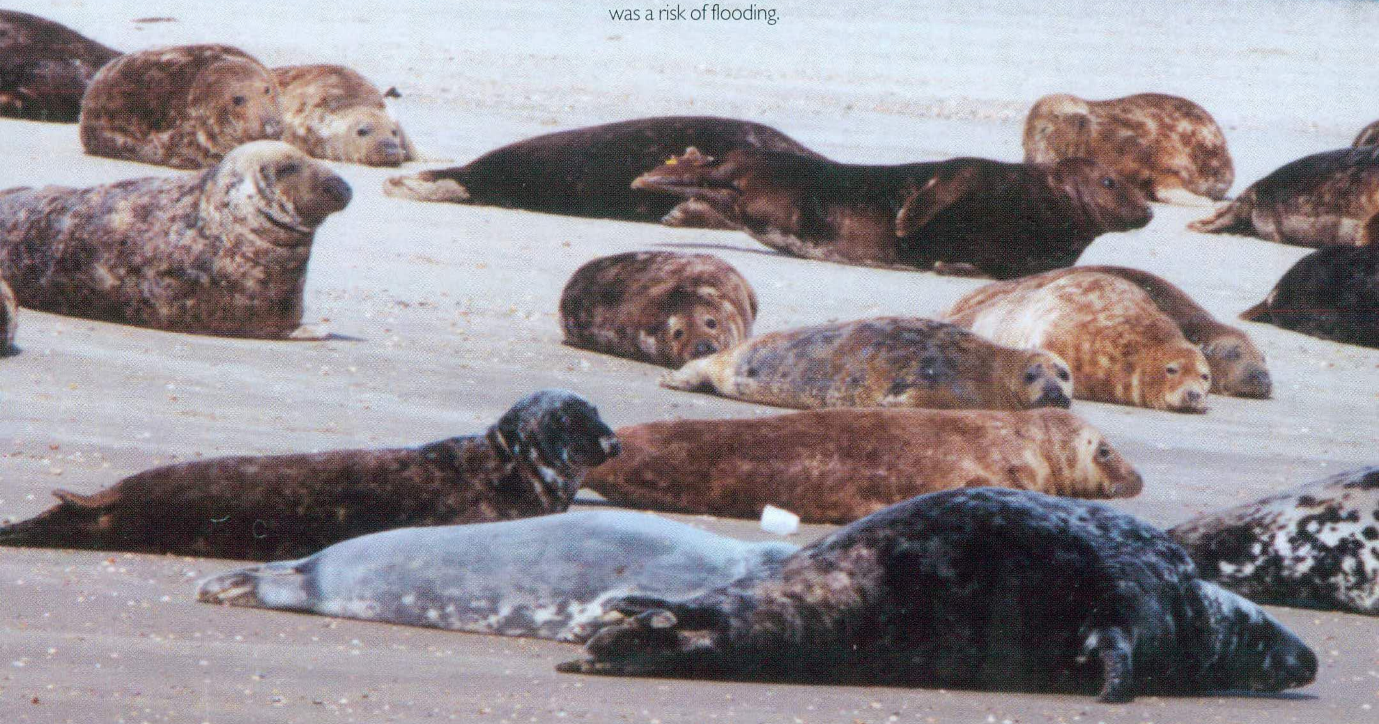
Steel towers for the cableway had already been erected in the channels, but they were never to be used. There was an increasing body of public opinion in the Netherlands which felt that the Eastern Scheldt should remain open to conserve the environment and the fishing industry. Social pressure forced trough a radical change in the Delta Project.

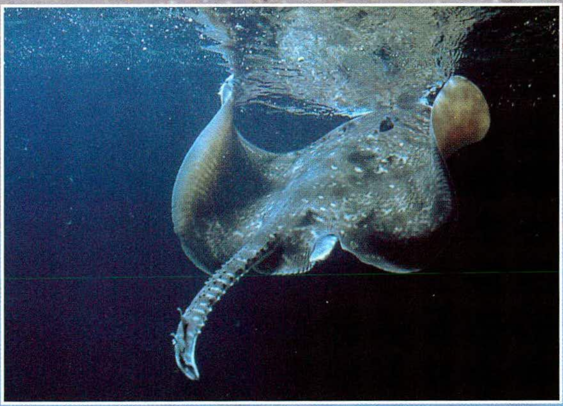
Increasing environmental awareness

The technical progress that had been achieved during the implementation of the Delta Project had not occurred in isolation. There had been a general and rapid growth in the economies of the western industrialised nations. Standards of living and levels of consumption had increased. The growth of opportunities, knowledge and power seemed to know no bounds. Cities were expanding, the road network was growing constantly, communications links were bringing faraway places closer to home and man was walking on the moon. With its emphasis on flood protection, increases in scale and the use of the very latest techniques, the Delta Project was a part of this era.

In the second half of the 1960s opinions about the environment changed. There was a growing awareness that the global assault on the environment could have a catastrophic results. The idea gained ground that there had to be limits to growth, and the optimistic view of the future began to fade. This ultimately led to a fresh approach being adopted for the Delta Project. The construction of a solid dam across the mouth of the Eastern Scheldt lost the general support it had once commanded. If the dam were built, the Eastern Scheldt would no longer be a tidal inlet, the salt water would become fresh and instead of rising and falling with the tides the water level would be constant. Moreover, the plant and animal communities would be transformed and the shellfish would disappear. More and more people realised that the Eastern Scheldt was an area of exceptional value and became concerned about the effects that damming the inlet would have on the flora and fauna.

Scientists, nature conservationists and fishermen spearheaded the protest against a solid dam. Their alternative was to raise the height of the surrounding dikes. Politicians initially refused to consider the plans. They had promised to dam the Eastern Scheldt, and they would keep their word. The fight to keep the Eastern Scheldt open, however, gradually received wider support, even in political circles. How people believed the inlet should be made safe became a yardstick for measuring their environmental awareness. The government decided to commission a special committee to perform a new study. In 1974 the committee recommended a compromise: the Eastern Scheldt should be kept open most of the time but closed whenever there was a risk of flooding.



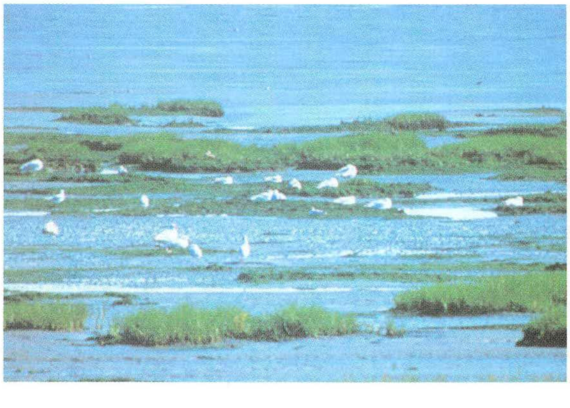


Seals return to the Eastern Scheldt estuary.

Unique wildlife area

The Eastern Scheldt is a rich and unique wildlife area. It is a tidal inlet entirely free of the influence of freshwater rivers and is thus completely saline. The tides generate fast-flowing currents as the water from the North Sea flows into the inlet through channels up to 40 metres deep and two kilometres wide. Sandbars and shallows lie between the channels. In the more inland section of the Eastern Scheldt the channels become narrower and shallower. The clean water, with its high salt content and relatively warm temperature, provides unusual conditions.

All kinds of plants and animals that usually live only in more southerly climes can be found in the Eastern Scheldt. The ecosystem is highly developed, with many organisms, both common and uncommon. Many valuable species of flora and fauna live on the stone and concrete-clad dikes, for example lichens, snails, sea acorns, sponges, anemones, crabs and starfish. There are dozens of varieties of seaweed, including some rare ones. The Eastern Scheldt is a rich store of food, plankton being the most important resource. A million tons of vegetation is produced each year, most of which sinks to the bottom where creatures living on the bed take full advantage of it. In their turn, fish, crustaceans and birds feed on the creatures living on the bed.



The Eastern Scheldt is a nursery for fish such as sole, cod, plaice and herring, which breed elsewhere but grow in the tidal inlet, and also a breeding ground for others such as gar, anchovy and pout. There are over 75 different species of fish in the inlet. The Eastern Scheldt enjoys an international reputation for its birdlife. Many thousands of birds rest there during migration or come to spend the winter, the summer or the breeding season. There is an abundance of food; the water is pure and rarely freezes in winter. The area is particularly important for water birds. The Eastern Scheldt is home to ducks, geese, oystercatchers, plovers and avocets. Many rare plants and animals live on the bed of the inlet. There are also mussels and oysters, which are economically very important.

Along the edges of the Eastern Scheldt there are extensive mud flats, which appear to be barren but are in fact teeming with life. Birds in particular take advantage of them. Towards the dikes, where the mud flats have gradually silted up, salt marshes have formed. Saltwater plants grow on the undulating land between the low and high tide marks, which is drained by countless streams. Some sections of the salt marshes are so high that they are submerged only during spring tides. There is a rich and colourful diversity of plants. Glasswort and sea aster are harvested for human consumption. A few of the salt marshes are grazed by sheep. The salt marshes form one of the few natural landscapes remaining in the Netherlands. This too is one of the unique features of the Eastern Scheldt.

The surface area of salt marshes and mud flats in the Eastern Scheldt estuary is reduced by the storm flood barrier.

The half-open dam

Creation of pitchings on the dike.

At the end of 1974 Parliament recognised the importance of keeping the Eastern Scheldt open and decided to change the plans for the Delta Project. It was not an easy decision to take and there were many opponents to it, so a compromise had to be reached. The plan for a solid dam was abandoned and the engineers were requested to design a reliable method of protection that would also preserve the valuable environment. A design for the half-open dam had to be worked out subject to several conditions: it had to be technically feasible; the additional costs had to be kept to a minimum; and the area around the Eastern Scheldt had to be protected from flooding by 1985. The hydraulic engineers were confronted with an entirely new problem, one at the very limits of their technical know-how. As there would no longer be a dam by 1978, the government provided funds to reinforce the weak dikes bordering the inlet. The reinforcement of the dikes considerably improved the safety of the area before the new barrier was completed.

Pushing back the frontiers

The engineers' problem was to design and construct a reliable, open barrier that would allow the tide to enter the Eastern Scheldt each day. Such a project had never been carried out anywhere in the world. The knowledge and experience gained during the implementation of the previous parts of the Delta Project were no longer sufficient and there was little time available. Of the various solutions that were proposed the engineers decided on a storm surge barrier across the mouth of the Eastern Scheldt. Parliament agreed to the project in mid-1976. The idea behind the storm surge barrier was simple: 65 concrete piers would be placed in the three channels, Hammen, Schaar van Roggenplaat and Roompot, and firmly anchored with masses of stone, and 62 steel gates that could be raised or lowered would be placed between the piers. Under normal conditions the gates would be raised so that the tidal movement in the inlet would be largely retained, thus preserving the environment. The gates would be lowered during storms when exceptionally high waterlevels were expected, damming the Eastern Scheldt from the North Sea and guaranteeing protection from flooding.

As the storm surge barrier would reduce the tide to some extent, it would be necessary to compartmentalise the Eastern Scheldt by building dams inland of the barrier. This would reduce the tidal area so as to maintain a sufficient difference in level between high and low tide, namely an average tidal range of 3.2 meters at Yerseke, which was important for the fishing industry. It also guaranteed that the Scheldt-Rhine shipping link would be non-tidal, as the Netherlands government had promised Belgium. Compartmentation had the additional advantage of separating salt water from fresh water, which was desirable for efficient environmental conservation and water management. Freshwater peripheral lakes were formed behind the Philips dam in the north-east and the Oester dam in the south-east. A discharge canal was dredged, leading to the Western Scheldt, to control the level and quality of these lakes. For technical and environmental reasons a further dike was constructed near Bergen op Zoom, which also created a new lake. The final part of the compartmentation works made the canal through South Beveland suitable for pushed barges.

Step-by-step construction

The storm surge barrier was constructed step by step. Solid foundations were needed in the sandy bed of the Eastern Scheldt, where enormous quantities of sand are continuously being moved, changing the location of sandbars and channels. The bed where the piers were to stand had to be improved. The first operation was to lay block mattresses made of concrete blocks attached to polypropylene sheets to protect the seabed around the area where the piers were to stand. At the site itself, clay strata were dredged out and replaced with sand covered with a layer of gravel to prevent it from being scoured out during storms.

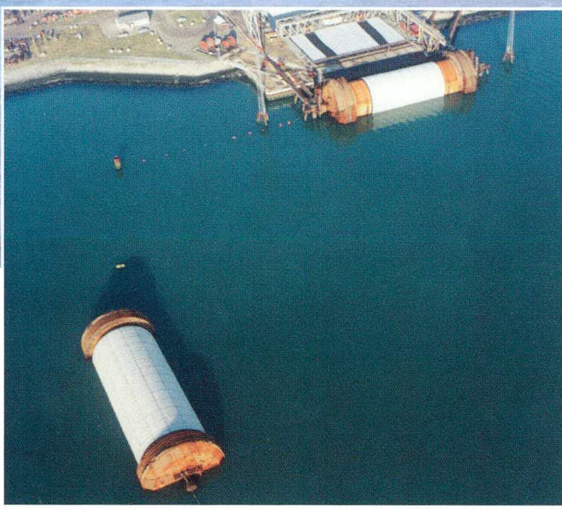
The barrier is very heavy and the seabed had to be compacted to a depth of 15 meters using a specially designed vessel, the Mytilus, to increase its bearing capacity. The Mytilus drove four steel tubes into the bed, which were vibrated to force water out from between the grains of sand, eliminating quicksand and thus strengthening the bed. It took three years to compact the bed in this manner. Bed protection, improvement and depth compaction, however, were not enough to ensure that the piers could be placed safely. A foundation had to be constructed on the reinforced bed to prevent the sand from being washed away and to guarantee that the piers would stand evenly.

The Mytilus sea-bed compaction vessel.

Polypropylene mattresses

The Cardium rolls off a mat.

Polypropylene mattresses filled with graded layers of gravel were used in the foundations. They were made at a factory that had been specifically built for their production. Two kinds of mattresses were made, lower mattresses 200 metres long, 42 metres wide and 36 centimetres thick, and upper mattresses measuring 60x31 metres. 65 mattresses of each kind were needed. As the mattresses were produced in the factory they were rolled onto huge floating drums and then placed on a specially-designed vessel, the Cardium, which laid them. The seabed was first levelled using the extra-wide suction nozzle on the bow of the Cardium before the vessel rolled the mattresses into position. It sounds a simple operation, but the mattresses had to be laid with extreme precision, which is not so simple in a



turbulent tidal inlet. Furthermore, they could only be laid during the short period of slack water between low and high tide, which lasts for just one hour. If a mattress had not been fully unrolled before the tide turned, it would have been destroyed by the force of the ebb tide. Fortunately, this never occurred.

Mat factory on the Neeltje Jans artificial island.

When the mattresses were being laid the Cardium was assisted by another specially-designed vessel, the Jan Heijmans. This vessel held the ends of the mattresses in place and sealed the seams between them with layers of stone. The piers were placed 45 metres apart, so there was a three-metre seam between them and the 42 metre wide mattresses. Laying the mattresses was a critical stage in the construction of the storm surge barrier: it determined the evenness of the seabed and the strength of the barrier.

The mattresses are filled with graded layers of sand and gravel and act as filters, trapping the sand in place on the seabed but allowing water to flow through them. The mattresses were laid quickly. In some sections a block mattress was laid on top of them to smooth out any unevenness. Another special mattress, a gravel ballast mattress, was finally laid over the seams to prevent the stone from being washed away. The final result was a flat "carpet", more level than most football pitches, across a 200 metre section of the mouth of the Eastern Scheldt.

The backbone of the barrier

The 65 enormous piers form the backbone of the barrier. They were constructed in three large construction docks 15 metres deep, which were kept dry by 320 underwater pumps. The piers are colossal structures made of prestressed concrete to keep their weight to a minimum. They are 30 to 40 metres tall and have a dry weight of up to 18,000 tons. The height of the piers depended upon their ultimate position in one of the channels. A purpose-built factory produced 450,000 m3 of concrete over four years. The piers were hollow and were filled with sand when they were in position. They are not featureless monoliths but contain many notches and indentations where the other concrete components and the steel gates are attached. It took just under one and a half years to construct each pier. As all the piers had to be completed in only four years, they were produced in staggered batches with work beginning on a new pier every two weeks. At the peak of activity 30 piers were being constructed simultaneously.

Piers in a building dock.

Serial constuction of piers.

Unusual vessels

When all the piers in a construction dock were completed, the dock was flooded and the encircling dike was opened so that they could be transported to one of the channels in the mouth of the Eastern Scheldt. This operation too required unusual vessels. The Ostrea was designed and built to lift the piers in the construction dock, transport them to the channels and then place them with great precision on the mattresses. The Macoma was specially built to moor the Ostrea while it was placing the piers and to clean the site immediately beforehand. The piers were positioned with pin-point accuracy at slack water using very sophisticated measuring equipment. It took a year to place them all.

Work on the piers was far from over once they had been placed. They still needed to be grouted, which involved filling the space between the foot of the pier and the foundation mattress with grout, a mixture of sand, cement and water, to achieve a perfect bond with the mattress. Once this operation was completed, the lower sections of the piers were filled with sand to increase their stability. They were then covered with a layer of concrete to protect them from damage. The foot of the piers was protected by stone/asphalt bags, each weighing 30 to 40 tons. These were necessary as each pier had to be embedded in a sill made of dumped stone.

The Ostrea crane vessel and the Macoma mooring and cleansing pontoon shortly after a piers has been installed.

Ten-ton stones

The sill increased the piers' stability and also helped dam the mouth of the Eastern Scheldt. The ultimate intention was that only that part of the barrier which could be closed by gates was to remain open. The sill was constructed of graded layers of stone. Lighter stones were placed at the bottom and huge blocks weighing as much as ten tons (10,000 kilogrammes) were placed on top. These blocks have to be so heavy in order to withstand the powerful currents that would build up if one of the gates refused to close during a storm. The largest stones could not be dropped into position as the risk of their damaging the piers was too great. The Trias was therefore designed to lay the top layer of stone. This vessel was equipped with a large crane with a long extendible arm that was used to place the heavy stones accurately. Five million tons of stone were used in the construction of the sill. It had to be imported over a period of four years from Germany, Finland, Sweden and Belgium as it was not available in the Netherlands.

The Taklift IV crane vessel with a road bridge box girder in its hoist.

When the work on the foundations, the piers and the underwater sill was finished, a large part of the battle had been won, although there was still a lot of work to be done to complete the barrier. In order of assembly, service ducts, pier capping units, gates, sill beams and upper beams had to be installed. These are all indispensable components for the efficient operation of the storm surge barrier. The concrete service duct, each section of which was 45 metres long, was placed on the piers by the floating crane Taklift 4. A major road now runs over the top of the service duct, while part of the space inside it has been used to house the operating and control equipment for the gates.

The Trias top-layer tipping vessels in action.

Ever increasing currents

The capping units were made of prestressed concrete and were installed to increase the height of the piers to accommodate the gate structure. The height of the 124 upper members varies from 4.3 to 10 metres and their weight from 250 to 450 tons. 62 concrete sill beams – hollow box girders 39 metres long, 8 metres wide and 8 metres high – were built in a construction dock to connect the piers to each other under water. After they had been positioned between the piers, thus reducing the cross-section of the channel and causing the speed of the current to increase, they were filled with sand. Above the water level the piers were connected to each other by concrete upper beams, which form the upper limit of the opening in the barrier.

The steel gates were designed to hold back the waters of the North Sea during storms. Their height varies from 5.9 to 11.9 metres depending upon their position in the barrier. The largest gate, weighing 480 tons, is located in the deepest channel, the Roompot. The gates were installed between the piers using the Taklift 4. When the gates are raised the Eastern Scheldt is open and sufficient water can flow into it to ensure a tidal range of 3.2 metres at Yerseke, the centre of the shellfish industry. That is just over three-quarters of the original tidal range and enough to preserve the existing wildlife and the fishing industry.

Positioning of lock hatches is precision work.

Gates closed

The gates consist of plating and tubular steel girders. The plating, which is on the Eastern Scheldt side, needs to be just one centimetre thick to withstand storms. The gates have been designed to resist the loads caused by different water levels on either side and can be raised or lowered in fast flowing water under adverse weather conditions. Each gate is opened or closed with the aid of two hydraulic cylinders, varying in length from 7.2 to 13.2 metres. The gates can be moved at a speed of three millimetres per second, which means that it takes an hour to open or close the largest gate.

The storm surge barrier is operated from the Tops-huis, the central control building standing high above the North Sea at some distance from the barrier. On average the barrier has to be closed twice a year due to extremely high water levels. The Tops-huis also accommodates the Delta Expo, a permanent exhibition on 2,000 years of hydraulic engineering. On the southern part of the Neeltje Jans construction island the Roompot lock was built because ships can no longer pass freely through the mouth of the Eastern Scheldt. A road has been built on a viaduct above the barrier.

On 4 October 1986 Her Majesty Queen Beatrix officially declared the storm surge barrier in the Eastern Scheldt open.

The Ir. J. W. Tops-huis, the storm flood barrier service building.

New peripheral lakes

The compartmentation dams necessitated by the building of the barrier were constructed on the border between the provinces of Zeeland and North Brabant. Interconnected peripheral lakes formed as a result of the construction of the Oester and Philips dams. From north to south these lakes are the Krammer/Volkerak, the Zoommeer and the Markiezaatsmeer. A sophisticated salt/freshwater separation system has been built into the Krammer lock complex to prevent the fresh water of the lakes mixing with the salt water of the Eastern Scheldt. Water can be discharged from the Zoommeer via the Bath canal into the Western Scheldt so that the level of the peripheral lakes is kept constant. The Oester and Philips dams were constructed using sand and are the largest sand dams in the world to have been constructed in flowing water.

The Philips dam 1987

The Philips dam was constructed between Sint Philipsland and the Grevelingen dam. A large lock complex, the Krammer locks, was built on a construction island in the middle of the dam. Two locks were built for commercial shipping and are suitable for four-barge pushtows. A separate lock was built for pleasure craft. A salt/freshwater separation system was built into the lock complex to prevent large quantities of salt water entering the freshwater Krammer/Volkerak whenever a ship is locked through from the Eastern Scheldt, and conversely to prevent dilution of the Eastern Scheldt with fresh water. It works on the principle that salt water is denser than fresh water. During the lockage of ships to the Krammer/Volkerak the salt water of the Eastern Scheldt is replaced with fresh water, and the procedure is reversed for ships travelling in the opposite direction. This system has also been used in the Kreekrak locks to prevent the brackish and polluted water from the industrial area around Antwerp entering the Zoommeer.

Philips Dam.

The Markiezaat dike 1983

A special dike had to be constructed to prevent strong currents building up during the construction of the Oester dam, which would have caused problems for shipping and weakened the banks. This dike was built along the edge of the submerged former marquisate of Bergen op Zoom; hence its name, the Markiezaat dike. A serious setback occurred during the construction of this dike, which extends five kilometres between the Kreekrak locks and the Molenplaat near Bergen op Zoom. 1982 it had been virtually completed and only the finishing work needed to be done when a storm surge 3.7 metres above AOD breached the dike. The dike was finally completed a year later. A freshwater lake has formed behind the Markiezaat dike, most of which will remain a wildlife area.

Markiezaatskade quay.

The Oester dam 1986

The Oester dam was built between Tholen and South Beveland. Extending nearly 11 kilometres, it is the longest of all the dams in the Delta. It separates the Scheldt-Rhine shipping route from the Eastern Scheldt, so that this important link is now non-tidal. The dam lies close to the Scheldt-Rhine link in the most easterly section of the inlet and therefore the majority of the Eastern Scheldt remains tidal. A lock, the Bergsche Diep lock, has been built in the dam near Tholen for pleasure craft and fishing boats moving between the Zoommeer and the Eastern Scheldt. The dam was built in an area where man had often done battle with the sea in the past. The composition of the bed was so erratic that it had to be improved in many places.

Oester Dam.

A simple technique

The mouth of the canal running through Zuid Beveland at Hansweert.

A sluice has been built in the Grevelingen dam just south of the point where it meets the Philips dam. It uses a simple principle: that of the siphon. It does not need expensive gates. The siphon allows water to flow between the Grevelingenmeer and the Eastern Scheldt. The siphon and the discharge sluice in the Brouwers dam enable the Grevelingenmeer to be flushed with water to keep its salt content at an acceptable level.

Water from the land inland of the compartmentation dams drains into the peripheral lakes and the level and quality of these lakes have to be controlled. Inlet sluices have been constructed in the Volkerak dam and when necessary water from the Rhine and Maas can enter the peripheral lakes via the Hollandsch Diep. As there are often toxins in the rivers, though, the river water is only rarely allowed to enter the peripheral lakes; otherwise the beds of the Krammer/Volkerak and the Zoommeer would be covered with a layer of highly polluted alluvium.

The Bath Discharge Canal 1987

The eight-kilometre Bath discharge canal has been excavated across the neck of South Beveland to discharge excess water from the rivers and polders. It runs parallel to the Scheldt-Rhine link and can discharge 8.5 million m3 of water per day. At the outlet in the Western Scheldt there is a sluice made of concrete tunnels that forms part of the sea wall. The sluice gates are closed when the water level in the Western Scheldt is high, thus preventing salt water from the Western Scheldt entering the Zoommeer. The existing canal running through South Beveland was also improved as a part of the compartmentation works. New locks were built at Hansweert, the canal was widened and a lock-free mouth was created near Wemeldinge.

The Delta project completed

The bold programme of hydraulic engineering works in the Delta produced enormous changes affecting people, animals, plants and the landscape. Dams, locks, and roads were constructed and new lakes and residential and recreational areas were created. Sweeping changes have occurred in the age-old rhythm of ebb and flow. The environment has altered in may places and in many ways. In addition to protecting the south-east Netherlands from flooding and producing economic benefits, the implementation of the Delta Project increasingly took account of ecological requirements. A delta is a very rich and varied system of plant and animal communities: an ecosystem that is also economically important and very sensitive to human intervention.

The Netherlands was willing to spend a lot of money on the Delta Project. The cost of ensuring protection from flooding, radically improving the communications network, distributing the scarce supplies of fresh water more efficiently and preserving the unique ecosystem came to Fl. 12,000 m. The work in the Eastern Scheldt was the most expensive part of the Delta Project, costing Fl. 8,000 m.

During the official opening ceremony of the storm surge barrier, Queen Beatrix declared the Delta Project completed. The work in the south-west Netherlands may be over, but there is still a lot of work for the hydraulic engineers. Shallows and sandbars are developing in front of the dams and headlands, and gradually becoming higher, promoting the formation of new channels. This area can offer new opportunities to the fishing industry and the environment. Plans are therefore already under consideration in connection with the Delta Project for the future of this area. The steady rise of the sea level also indicates that the protection of the Netherlands against the sea will remain a permanent struggle. Dutch hydraulic engineers believe that the knowledge and expertise they gained in the thirty years it took to complete the Delta Project should also benefit other countries in addition to the Netherlands.

The storm flood barrier is complete.

New Waterway storm surge barrier

The Maeslant storm surge barrier 1997

The original Delta Plan was based on raising the height of the dikes around the New Waterway. This would ensure that Rotterdam remained accessible by sea. In the 1970s there were protests by the local population. In many places traditional buildings such as dike houses would have to disappear. In addition, raising the dikes was an expensive business. Studies carried out in the Eighties showed that a mobile storm surge barrier would be technically and financially feasible. This solution would have no detrimental effects on shipping. The way was now open for the Maeslant storm surge barrier.

The Maeslant storm surge barrier rose from the New Waterway near the Hook of Holland between 1991 and 1997. It now protects more than a million people in and around Rotterdam from floods. Never before was a storm surge barrier built that had such huge, moving parts. Both gates have a ball and socket joint with a diameter of 10 metres and a weight of 680 tons. This joint is embedded in a colossal foundation block weighing 52,000 tons.

The trusses are 237 metres long and are made of three linked metal pipes. The barrier gates are 22 metres high and each one is 210 metres long. Each gate, including the ball and socket joint, is almost as high as the Eiffel Tower (300 m).

How it works

When sea levels are normal the gates are in the parking dock in the bank of the New Waterway. Shipping can pass unhindered. If high water levels are anticipated the docks are filled with water and the gates starts to float. The gates are moved towards the middle of the New Waterway by the so-called locomobiles. When the gates approach one another the hollow cavities are filled with water and the sink to the bottom. In this way the gates close off the 360 metre wide New Waterway.
If a water level of 3 meters above NAP is anticipated for Rotterdam the storm surge barrier has to be closed. This water level occurs on average about once every five years.

The Netherlands is locked in a permanent struggle for survival. The country's name is self-explanatory: large areas of the Netherlands lie below sea level. Stronger dikes, dams and dunes are continually being constructed to keep the sea at bay and to ensure that this densely-populated country remains habitable. Half of the Netherlands would be flooded if it were not for the line of defenses that has been built over the centuries and the equipment to pump ground water and river water out of the low-lying polders.