Sigmaplan
Meet the Scheldt

Bergenmeersen

Construction of a Flood Control Area with Controlled Reduced Tide as Part of the Sigma Plan

Michaël De Beukelaer-Dossche
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COLOPHON

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CONTENTS

FOREWORD

Dear reader,

It is a true pleasure for me to present to you the Bergenmeersen Project Book. Bergenmeersen lies at the heart of our municipality, close to our town hall. From the very first plans, our municipality has therefore been closely involved in the development of that unique area. This involvement obviously has to do with protecting against flooding, but also with Bergenmeersen's many strengths. Local residents have also made many proposals for utilising these strengths.

The fact that there were also critical voices contributed to further modifications. Thus, any obstacle associated with the gradual rewilding was addressed. Both the municipal authorities and the promoters, Waterwegen en Zeekanaal NV (Waterways and Sea Canal) and the Agentschap voor Natuur en Bos (Agency for Nature and Forest), handled these concerns with the utmost respect.

The results speak for themselves: nature is developing rapidly. A few weeks after the opening, the area was already attracting numerous species of fish. And the walkway is also being used intensively by our residents and interested visitors from outside our municipality.

This book gives you a glimpse behind the scenes of this unique project. Hopefully it can inspire and challenge you to integrate river management and social factors to achieve outstanding results. You are always very welcome to visit Wichelen and see the Bergenmeersen project up close and personal. It is most definitely worth your while.

Kenneth Taylor

Mayor of Wichelen

INTRODUCTION

Bergenmeersen is one of the subsectors of the Kalkense Meersen Cluster, which in turn forms part of the updated Sigma Plan. This plan is an update of the original 1977 Sigma Plan, and is an ambitious project to improve water safety and nature around the tidal rivers of Flanders.

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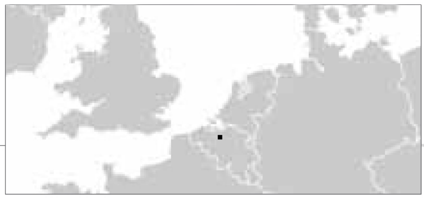
Where is Bergenmeersen?

The Kalkense Meersen Cluster consists of the subsectors Kalkense Meersen, Wijmeers (part 1 and 2), Bergenmeersen, Paardeweide and Paardebroek. These areas extend along both banks of the Scheldt on the territory of the municipalities of Wetteren, Laarne, Berlare and Wichelen.

Bergenmeersen lies on the right bank of the Scheldt, on the territory of the municipality of Wichelen. The area sits in a meander of the Scheldt adjacent to the centre of Wichelen.

Use tailored to water safety and nature

Bergenmeersen was already a functionally flood control area (FCA) that could accommodate water in the event of a storm surge. As part of the updated Sigma Plan, Bergenmeersen was reorganised as a flood control area with controlled reduced tide (FCA-CRT).



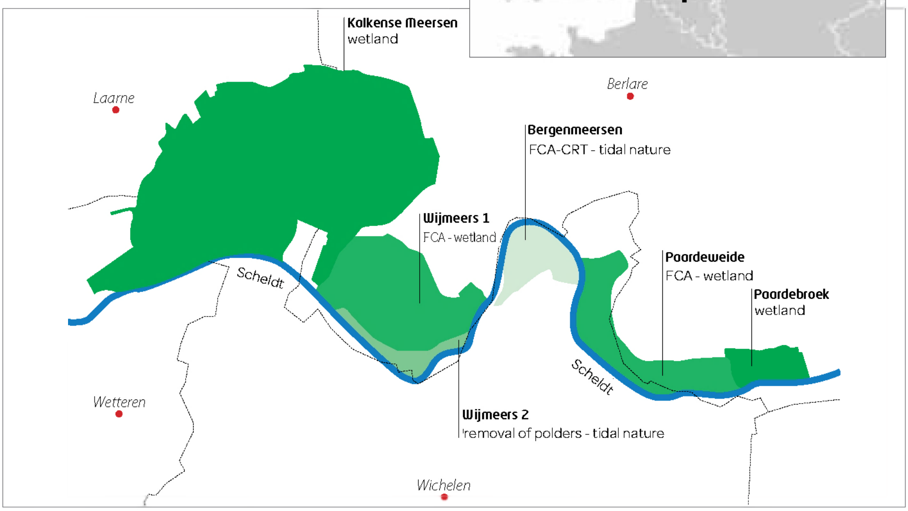


Figure 0.1. Location of Kalkense Meersen Cluster and the various subsectors

Figure 0.2. Bergenmeersen at low tide

Figure 0.3. Bergenmeersen at high tide

Figure 0.4. Bergenmeersen at spring tide

Figure 0.5. Bergenmeersen at storm tide

How does an FCA-CRT work?

An FCA-CRT is a variant of an FCA. It combines the safety role of a flood area with the restoration of rare tidal nature. Water flows into and out of an FCA-CRT twice a day to the rhythm of the tides.

The area is flooded at each high tide. A limited amount of water flows in through the inlet sluice. In this way, the tide is "reduced". When the tide ebbs, the water flows back into the river through the outlet sluice. The natural action of a tidal river is thus mimicked. The area effectively becomes part of the Scheldt ecosystem and a system of tidal marshes can develop.

The CRT principle was developed by Professor Patrick Meire (University of Antwerp). Before applying it on a large scale, an experimental CRT was constructed: the Lippenbroek trial project. The development and effect of tidal nature were tested here over recent years.

References

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PREFACE

This book is designed to fill a gap in communication within the Sigma Plan. In the project-based development of the Sigma Plan, various channels were developed to communicate with the local actors. This communication includes thematic folders, project-related newsletters, information boards and the Sigma Plan website (www.sigmaplan.be). In addition, there are the highly specialised studies and scientific articles by universities and research institutions. However, there has been no intermediate level to date.

This is why, when completing the Bergenmeersen FCA-CRT, the idea arose of documenting this new concept in hydraulic engineering and nature development in a "project book". The substantive objective: to explain the various aspects of the construction of the FCA-CRT, from the initial conception. The target public for this book was defined as interested professionals. The task of the authors was therefore to explain their specialist area and its application in the creation of the Bergenmeersen FCA-CRT for colleagues from other specialist areas.

The number of topics discussed has become fairly extensive. In addition to the construction and operation of the Bergenmeersen FCA-CRT, a number of more general aspects of the Sigma Plan are also outlined. The book therefore goes further than the ordinary folders, but still remains lighter than a scientific article, which means it satisfies the objective. An attempt has also been made, through a modern layout and the many illustrations, to make it an attractive work.

At the time the first draft of this book was completed (June 2013), Europe was battling with floods in several places. Making room for rivers is one of the solutions. With the development of the CRT concept, the Sigma Plan provides an innovative response to this problem in Flanders.

The authors

1. CONTEXT

For centuries, the Scheldt and its tributaries have ensured a well-watered country bursting with dynamism. But tidal rivers may also bring a great deal of water-based misery. Protecting Flanders more effectively against flooding by the Scheldt and its tributaries is the main objective of the Sigma Plan. All at once, the wonderful nature of the Scheldt will be restored in numerous places. Thousands of walkers and cyclists can then enjoy it to the fullest. The Sigma Plan also has an eye on the economic role of the Scheldt as one of Europe's busiest rivers.

In this chapter, you will find out all about the work in Bergenmeersen, a subsector of the Kalkense Meersen Cluster Sigma Project. You will discover how the Sigma Plan originated and how that progressive plan evolved into a smart project for the future that goes far beyond flood management.

Authors: Michaël De Beukelaer-Dossche (Waterways and Sea Canal) and Erika Van den Bergh (Research Institute for Nature and Forest)

1.1 Leading figure in the Sigma Plan: the Scheldt

1.1.1 The Scheldt and its tidal area

The Scheldt originates in northern France, on the Saint Quentin plateau. It is a small spring, which first forms a brook and is fed by other brooks and tributaries. All these brooks and rivers that flow into the Scheldt together form the Scheldt basin, along with the main river itself.

Up to Ghent, it is known as the Upper Scheldt; after Ghent its name changes to the Sea Scheldt. From this point on, the river is in fact already part sea. After all, unhindered by any barrage or dam, the tides can be felt 160 km inland as far as Ghent. Past Antwerp, the Scheldt flows into the Netherlands; there it is known as the Western Scheldt. At Bath, the river arcs in a large bend before emptying into the North Sea at Vlissingen. The effect of the tides can also be felt in the Durme, Rupel, Senne, Dyle, Kleine Nete and Grote Nete rivers. Together with the Sea Scheldt and the Western Scheldt, these tributaries of the Sea Scheldt form the Scheldt estuary, the tidal area of the Scheldt.

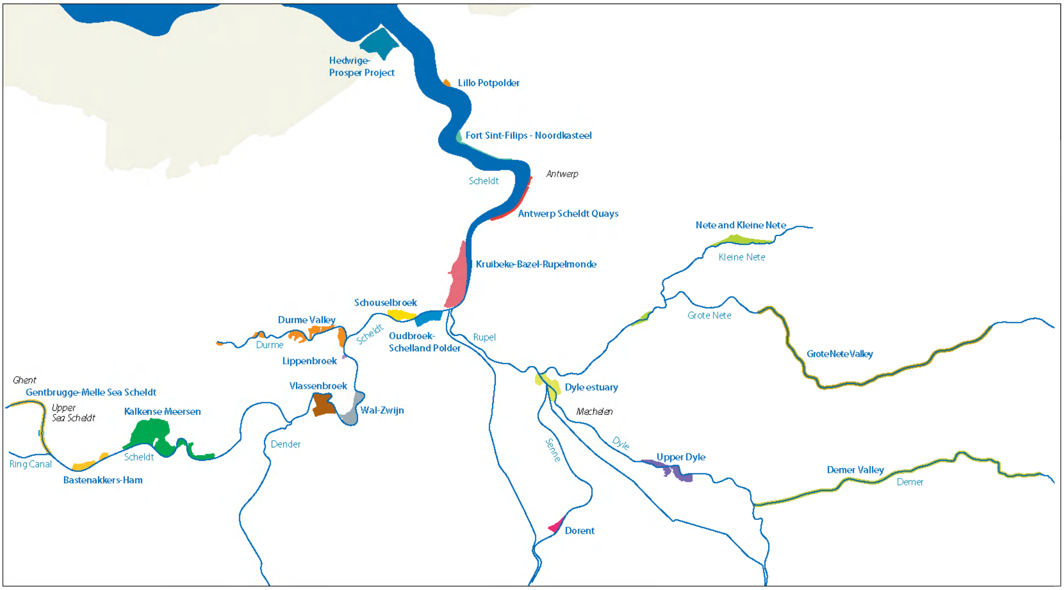


Figure 1.1. Map of the Sigma Plan project areas

1.1.2 The Scheldt as an economic artery

As one of Europe's busiest rivers, the Scheldt plays a prominent economic role. The river is a major shipping route, which carries millions of tonnes of cargo to and from the ports of Antwerp, Vlissingen, Terneuzen, Ghent and even Brussels each year. Via the Leie and the Upper Scheldt, the Scheldt links Flanders and the Netherlands with France. Past Antwerp, ships can join the Albert Canal eastwards, towards the Meuse river basin and beyond. Countless businesses are based in the ports and on the banks of the Scheldt. These employ tens of thousands of people and have a decisive impact on the economy of the whole of Flanders.

Figure 1.2. Inland navigation on the Scheldt

FLANDERS IN EUROPE

The Belgian federated entity, including Flanders, can act internationally with regard to their respective competences. They are active on international and European forums and can conclude treaties. That substantial right to conclude treaties is unique, as is the central position in Europe.

The European Union is a major influence on Flemish policy. After all, Flanders is also responsible for approving European treaties (such as the Treaty of Lisbon) and implementing European directives that concern Flemish powers. Flanders' foreign relations are also far-reaching. For example, Flanders enjoys bilateral relations with neighbouring countries and regions and signs treaties. Flanders also cooperates with multilateral organisations such as UNESCO, the OECD, the Council of Europe, UNAIDS, the International Labour Organisation and the World Health Organisation.

The central position and accessibility of Flanders are also extremely important. The port of Antwerp on the Sea Scheldt, for example, is one of the largest sea ports in the world. Brussels Airport is one of Europe's main airports for the transport of cargo and passengers. Flanders also has a dense network of railways, motorways and waterways. The various transport options make Flanders the ideal gateway to Europe.

But Flanders is more than a gateway to Europe. It is an economic engine with the world as its market. Around 75% of Belgian exports, or more than 150 billion euros, come from Flanders. Most of these exports are destined for the European market. What is striking is the sharp increase in exports to the new EU Member States, the BRIC countries (Brazil, Russia, India and China) and various other emerging economies. The chemical, pharmaceutical and automobile sectors traditionally account for a major share of Flanders' total exports.

The large volume of economic activity around the Scheldt seems irreconcilable with a rich and valuable inter-tide policy. However, through close cooperation between port companies, waterway managers and the environmental sector, Flanders is playing a pioneering role in estuary management. In various European projects, this Flemish expertise is being exchanged with actors involved in the integral management of estuaries in the rest of Europe.

1.1.3 Floods: also part of the Scheldt

The Scheldt Valley is no stranger to floods. They are the result of heavy storm surges in the North Sea, which send massive tidal bores up the river. As early as the Middle Ages, villages and estates along the Scheldt were permanently wiped from the map by severe storm surges. For older residents, the floods of 1953 and 1976 are still fresh in the memory. During the last floods, an area of 800 ha in Flanders lay under water. The municipality of Ruisbroek was particularly badly affected.

Figure 1.3. Ruisbroek in 1976

1.2 The Sigma Plan: an integral plan for a versatile Scheldt

Following the catastrophe in villages such as Ruisbroek, the Belgian authorities launched the Sigma Plan in 1977. This plan was intended to offer Flanders better protection against floods from the Scheldt. The 1977 Sigma Plan focuses purely on safety, by creating taller, stronger dykes (also known as Sigma dykes or dykes at Sigma height) and flood control areas.

Since then, around 500 km of dykes have been brought up to Sigma height, the agreed height of dykes along the Scheldt. Twelve flood control areas (FCAs) have now been proving their worth for years. These temporarily catch the water if a storm surge rushes up the Scheldt. The flood control area of Kruibeke-Bazel-Rupelmonde, the last flood area from the original Sigma Plan, will be operational by 2014. The strategic location and large capacity of that flood area make the Sea Scheldt basin considerably safer all at once. Meanwhile, the entire network of dykes is gradually constructed.

Figure 1.4. Scheldt water flooding over the overflow dyke in the Paardeweide FCA

The areas of Bergenmeersen and Paardeweide were laid out as flood control areas within the Kalkense Meersen Cluster in the 1980s, as part of the original Sigma Plan.

The Sigma Plan was updated in 2005. The update was needed to shore up the Sigma Plan against any future consequences of climate change, increases in sea levels, increasing tidal intrusion and heavier rainfall. Meanwhile, insight into the estuary's many functions has deepened and the vision of the water manager has developed to encompass a more integrated approach. Insofar as is possible, planned measures now take into account all aspects of the workings of the estuary.

A river needs room to flow and flood, but also to allow its ecosystem to function healthily. Safety measures can go hand in hand with the development of the nature that is needed for this purpose. These principles are now specifically defined in the updated Sigma Plan. After all, over the past 150 years a great deal of valuable nature has been lost along the Scheldt. Measures are being taken in the Sigma areas to restore this special nature. Firstly, tidal nature is being developed by moving dykes landward (de-poldering) and creating flood areas with controlled reduced tides (CRT), as in Bergenmeersen. Secondly, wetlands are being developed in the natural flood areas, some of them in FCAs that also absorb storm surges and reduce the impact of the rising water. European habitats are being developed in these wetlands, such as valuable grasslands, marshy areas and alder carrs, which provide a habitat for numerous species.

You can also enjoy the wonderful Scheldt landscape. The new cycle paths and trails, bird-watching hides and viewpoints being created by the Sigma Plan will make visiting the Scheldt an even more intense experience.

The Sigma Plan also takes into consideration the farmers who have suffered from the creation of flood areas. The Flemish Government developed a programme of mitigating measures for these farmers.

Figure 1.5. Recreation on the Scheldt dyke

The updated Sigma Plan is being implemented in several phases. The promoters want to have completed the update by 2030.

1.3 Arrangements with the Netherlands: framework for the Sigma Plan

The updating of the Sigma Plan also fits in with the Scheldt Estuary Long-Term Vision (LTV) (see box, p. 17). Both processes, the Sigma Plan and the LTV, influence each other and exchange information with each other. Various preliminary investigations and supporting studies have given shape to the Sigma Plan in recent years. These preliminary studies have provided vital information to draw up and evaluate workable alternative plans.

The environmental impact assessment plan (EIA plan) and the social cost/benefit analysis (SCBA) of the updated Sigma Plan were carried out parallel to and interacting with similar studies for the 2010 Development Outline (OS 2010) (see box, p. 17).

THE SIGMA PLAN: WHO IS WHO?

The Sigma Plan is the initiative of Waterways and Sea Canal (Waterwegen en Zeekanaal, W&Z), which manages the navigable waterways in western and central Flanders. Flood protection is one of this agency's main objectives. The Agency for Nature and Forest (Agentschap voor Natuur en Bos, ANB) is a key partner of the Sigma Plan. This government agency is responsible for the development of nature within the Sigma Plan.

The implementation of the Sigma Plan is centred on a multifunctional approach. W&Z and the ANB are therefore utilising a large number of partners. Flemish administrations and the Flemish Land Company (Vlaamse Landmaatschappij, VLM) and the Department of Spatial Planning, Housing Policy and Immovable Heritage (Ruimtelijke Ordening, Woonbeleid en Onroerend Erfgoed), as well as local authorities, agricultural organisations, environmental associations, hunters, fishers, and the tourism and hotel and catering sectors are actively involved in implementing the plans. Research institutions such as Flanders Hydraulics Research (Waterbouwkundig Laboratorium, WL), the University of Antwerp (UA), the Research Institute for Nature and Forest (Instituut voor Natuur- en Bosonderzoek, INBO) and the Flemish Institute for Technological Research (Vlaamse Instelling voor Technologisch Onderzoek, VITO), consultant firms such as IMDC, Tractebel Engineering, Antea, and hydraulic engineering contractors have all worked on that ambitious, innovative plan.

This meant the Sigma Plan, which is aimed at protecting Flanders from floods from the Scheldt, was optimised at an early stage. The general principles of this – in essence the maximum application of the "Room for the River" concept – were therefore carried over into the 2010 Development Outline produced by the project organisation ProSes.

However, the 2010 Development Outline goes further, integrating the pillars of "safety", "natural quality" and "accessibility" of the Scheldt Estuary LTV. The first two are closely linked in Flanders because the river needs room for both, a scarce commodity in a densely populated region. Therefore, the same areas are often eligible for safety measures and nature development. The Flemish Government therefore decided to incorporate the "natural quality" pillar of the 2010 Development Outline into the updated Sigma Plan. This gave the plan two similar objectives: safety and natural quality.

Figure 1.6. Het Verdronken Land van Saeftinghe (the Drowned Land of Saeftinghe) nature reserve (the Netherlands)

1.4 From safety plan to integral project

In 1977, the Sigma Plan was defined as a reaction to the heavy floods of the previous year. For a long time, the plan was aimed solely at providing adequate safety against flooding as a result of storm surges from the North Sea. "Hard" infrastructure, such as dykes, flood control areas and a storm surge barrier, were pushed to the fore as solutions.

In the meantime, however, a deeper insight developed into the estuary's many functions, and the concept of integral water management emerged. The safety issue remains prominent, but there has been a noticeable shift towards a more sustainable approach. The essence: respect the various functions of the water system, avoid negative consequences for the environment and seek added value and synergies. This philosophy is expressed in concrete terms in the safety concept "Room for the River": provide better protection against flooding by giving the river more room to breathe.

INCREASINGLY INTENSIVE FLEMISH-DUTCH COOPERATION IN RELATION TO THE SCHELDT ESTUARY

Cooperation between the Netherlands and Flanders in relation to the Scheldt estuary has come a long way in past decades. Even though interests do not always converge, this cooperation has become increasingly intensive.

The Joint Scheldt Policy and Management were accelerated by the development of the Scheldt Estuary Long-Term Vision at the end of the last century. The LTV – drawn up by the Technical Scheldt Committee (Technische Scheldecommissie) – outlines an integral vision for, on the one hand, the safety, natural quality and accessibility of the estuary, and on the other hand the cooperation between the Netherlands and Flanders on policy in the estuary.

To achieve these ambitious targets by 2030, the "2010 Development Outline for the Scheldt estuary" was produced between 2002 and 2004. This development outline indicates at a strategic level what projects and measures must be implemented to make the Scheldt safe, accessible and natural by 2030. The Flemish-Dutch Project Management for the Scheldt Estuary Development Outline (ProSes) prepared the outline.

Setting up the successor to the Technical Scheldt Committee, the Flemish-Dutch Scheldt Committee (Vlaams-Nederlandse Scheldecommissie, VNSC), was a key step in the communication and cooperation between Flanders and the Netherlands. The VNSC is focused on developing the Scheldt estuary as "a multifunctional estuarine water system that is used sustainably for man's needs". The joint objectives are protection against flooding, optimum maritime access to the Scheldt ports, maintaining a healthy and dynamic ecosystem and establishing common scientific research.

www.vnsc.eu

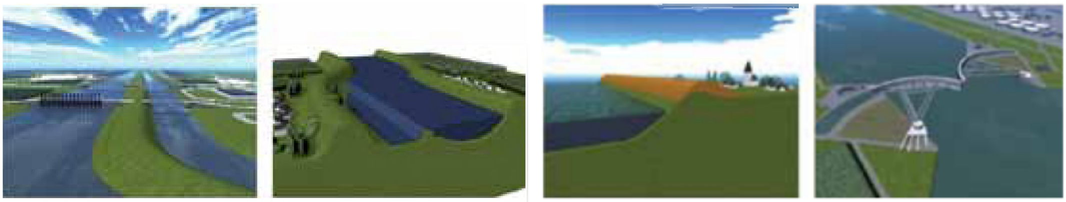
1.4.1 The preferred scenario for safety

The General Methodology was applied to estimate and predict extreme watercourse conditions. This was developed by the University of Leuven (KU Leuven) in collaboration with Flanders Hydraulics Research. Based on flow-duration-frequency relations (FDF), high water-duration-frequency relations (HDF) and wind intensity-duration-frequency relations (IDF), so-called composite hydrographs, limnigraphs (water level recordings) and windstorms are produced. Standard composite edges were produced for a total of 12 recurrence intervals (in years): 1, 2, 5, 10, 25, 50, 100, 500, 1000, 2500, 4000 and 10,000. Using hydrodynamic simulations with the one-dimensional water movement model Mike11, the water level associated with the recurrence intervals studied was then able to be estimated at each location in the Sigma area.

The (Flemish) risk methodology: input for the social cost/benefit analysis
The goal of the updated Sigma Plan is no longer protection against excessive water levels. The focus is now on limiting possible damage in a risk approach in which risk = probability X consequence. The updated Sigma Plan aims for an “acceptable” flood risk along the Scheldt and its tributaries. The acceptable flood risk was determined by a social cost/benefit analysis (SCBA). Creating even more flood control areas could contribute significantly towards protecting the entire Sea Scheldt basin. This emerged in 2002 from calculations with the hydraulic model (Mike11) for the Sea Scheldt basin,

Figure 1.7. The Western Scheldt (the Netherlands)

Figure 1.8. Some alternative plans



Overschelde (linking channel) *FCA* *Taller dykes* *Storm surge barrier*

performed as part of the update study for the Sigma Plan by the University of Ghent and Flanders Hydraulics Research. These calculations substantiated whether these areas could be reserved and organised for that purpose. These studies revealed 182 potential flood areas (PFAs) covering a total area of 15,700 ha.

The intention was obviously not to convert the entire 15,700 ha into FCA. The PFAs were evaluated using an environmental criteria analysis (ECA). Together with all the other components that lead to greater safety, they were then incorporated into a new hydraulic model of the Sea Scheldt basin. With the help of that model, various scenarios were studied, with different combinations of PFAs and lower/higher dykes. Storm surge barriers and an "Overschelde", a channel between the Western and Eastern Scheldt, were also considered.

The result was approximately fifteen different alternative solutions to the flood problem, or put simply, alternative plans. Each of these alternative plans consists of one or more components and leads to greater safety up to a certain level (among others, 1/1000, 1/2500, 1/4000 and 1/10,000 years).

The advantages of these alternatives were compared with each other in an environmental impact assessment (EIA plan) and an SCBA.

The SCBA for the updating of the Sigma Plan estimates investment costs, avoided flood risks and costs and benefits relating to the impact of the alternative plans on, among other things, agriculture, the environment and recreation. Using these figures, the costs and benefits of the various alternative plans were able to be weighed up for the situations in 2000 and 2100, a process that also produces that so-called "optimal safety level". This is the level of safety against flooding that offers the most favourable ratio between social costs and benefits.

The risks of flooding will increase significantly over the next century as a result of rising sea levels. The safety benefits of the various alternative plans will therefore be great enough to earn back these investments. The alternative plans do not all have the same cost/benefit ratio, or the same environmental impact. Both the "taller dykes" and the "room for the river" alternative plans have a better cost/benefit ratio than the "storm surge barrier" and "Overschelde" alternative plans.

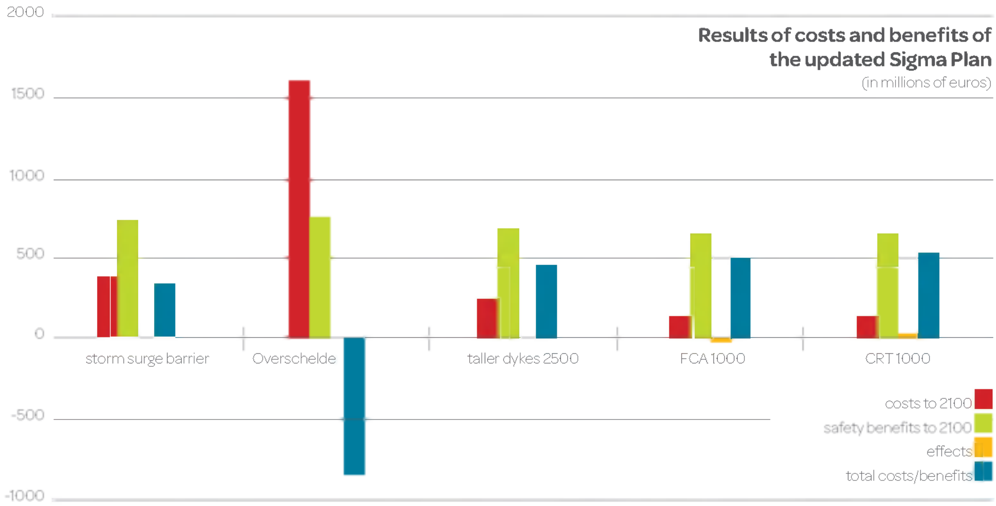


Figure 1.9. The alternative plans were compared with each other in an SCBA.

A large part of the avoided risk of flooding that is achieved by a storm surge barrier is obtained through the combination of local taller dykes and extra flood control areas, all at a much lower cost (investment + maintenance). The optimum solution therefore consists of a combination of local taller dykes and extra flood control areas.

The "storm surge barrier" and "Overschelde" alternative plans therefore no longer appeared to be part of the solution to the problem regarding protection against flooding in the Sea Scheldt basin, either in the short or medium term.

Optimising "safety" using the SCBA method

The best possible solution, "taller dykes and room for the river", was now known. The social costs and benefits of the many possible variants were gradually and systematically compared.

To this end, the study area of the Sigma Plan was divided into five zones, each characterised by its own flooding problem. The optimum solution is being sought for each zone, starting with the zone situated further downstream.

- Zone 1: the Sea Scheldt from the Belgian-Dutch border to the mouth of the Rupel
- Zone 2: the Sea Scheldt from the mouth of the Rupel to Dendermonde, the Rupel and Durme
- Zone 3: the Dyle between the Rupel and Mechelen
- Zone 4: the Sea Scheldt from Dendermonde to Ghent, which also includes Bergenmeersen
- Zone 5: the rest of the study area (Kleine Nete and Grote Nete, Dyle and Senne)

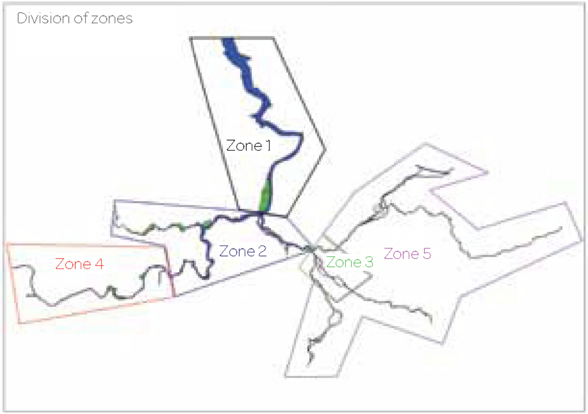


Figure 1.10. The study area of the Sigma Plan is divided into five zones, each characterised by its own flooding problem.

In each case, the optimum solution for a particular zone was included in the optimisation of the next zone upstream. The optimum Sigma Plan equates to the combination of optimum solutions from the five separate zones. This optimum solution was then subjected to a sensitivity analysis, which examined how robust the results of the optimum solution are in relation to other assumptions of crucial parameters (e.g. rising sea level, economic growth, etc.) and in relation to methodological choices (modelling of the formation of breaches).

The risks in each zone must be limited and spread as uniformly as possible. This involved seeking out the most profitable cost/benefit ratio, which in practice means reducing the risks in the so-called damage centres in particular. Damage centres are municipalities, towns or areas where there are major risks in the zero alternative, in which no additional safety measures are taken. In principle, many safety benefits (major risks avoided) can be achieved in these damage centres. Greater investments in safety are therefore justified. To put it in another way: from a cost/benefit standpoint, it is logical to first try and protect the damage centres as much as possible.

The optimised "safety" Sigma Plan developed on the basis of the method described above consists of:

- The zero alternative (Sigma Plan from 1977) is completed.
- The 24 km of additional taller dykes in the vicinity of Antwerp is completed: the flood barrier in Antwerp is raised to 9 m, the rest of the dykes between Oosterweel and the flood control area of Kruibeke-Bazel-Rupelmonde (KBR) (on both the left and right banks) to 9.25 m and the section on the right bank between the northern border of KBR and Hemiksem to 8.75 m.
- 1,325 ha of additional flood areas are created.

1.4.2 "Natural quality" in the Sigma Plan

The Flemish Government approved the 2010 Development Outline and the main objectives of the updated Sigma Plan at its meeting on 17 December 2004.

However, in an evaluation by the University of Antwerp (UA) and the Research Institute for Nature and Forest (INBO), the measures proposed for the "natural quality" component in the 2010 Development Outline were deemed inadequate to help achieve the objectives of the Scheldt Estuary Long-Term Vision. On the Flemish side, it was felt that this negative assessment could change if the updated Sigma Plan can also contribute optimally to the ecological recovery of the Sea Scheldt. This can be achieved by efficiently integrating the measures for protection against flooding and for ecological recovery, for example when organising the flood areas.

On 17 December 2004, the Flemish Government therefore decided that the "natural quality" component of the Scheldt Estuary Long-Term Vision on Flemish territory would also become an intrinsic part of the updated Sigma Plan. This also means that the nature development projects that have to be implemented in accordance with the 2010 Development Outline in the Kalkense Meersen, the Durme Valley and the Prosper Polder are part of the updated Sigma Plan. Investigations were also carried out to see which added nature development would best reach the natural quality objectives of the Scheldt Estuary Long-Term Vision. Building on the Scheldt Estuarine Nature Development Plan that was produced for the 2010 Development Outline (NOPSE), the Sea Scheldt nature recovery plan, the EIA plan, the SCBA, the agricultural impact assessments (AIAs) and other studies, the UA and the INBO are carrying out an ecological multi-trail investigation.

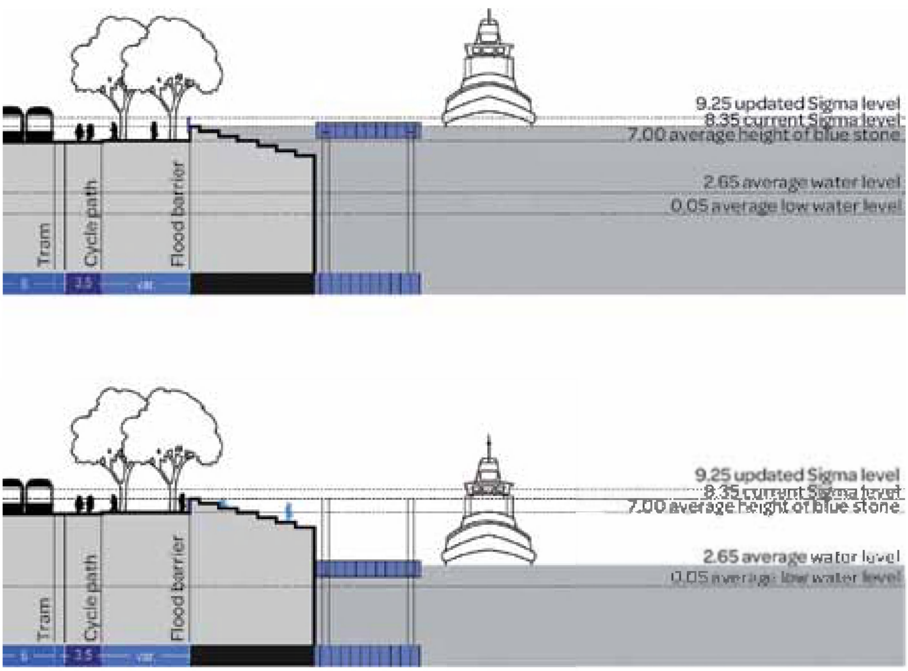


Figure 1.11. Flood barrier on the Scheldt quays in the city of Antwerp

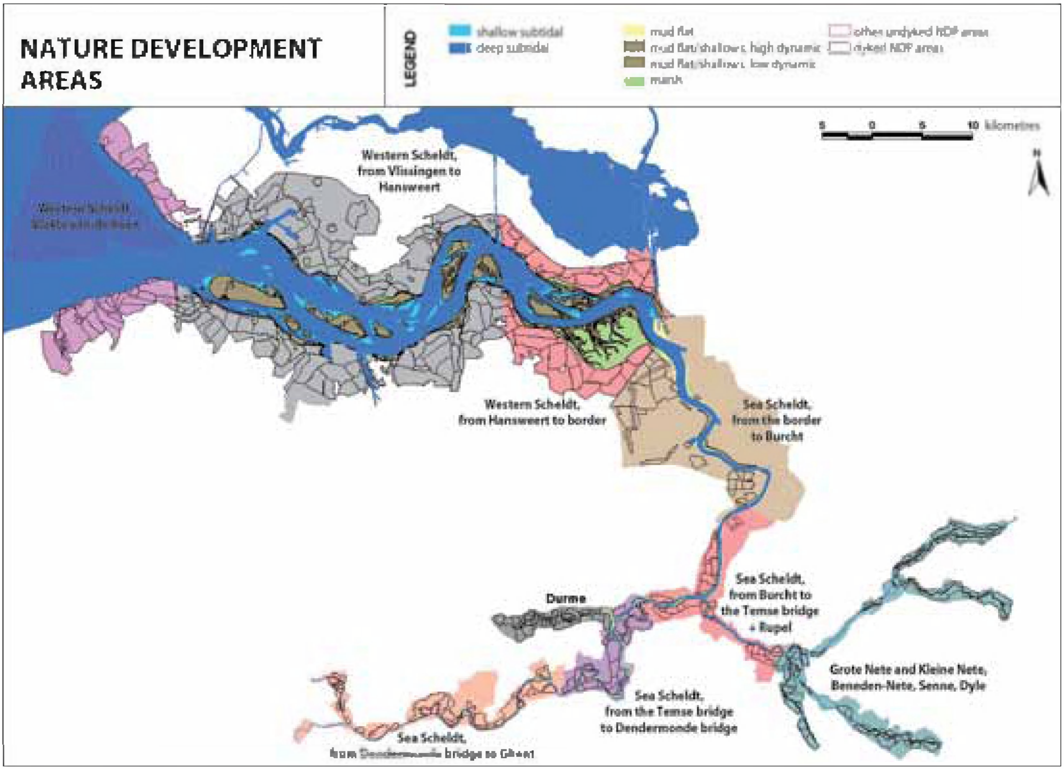


Figure 1.12. The zones of the nature development plan

The starting point was the functional objectives for the estuary, as proposed in the NOPSE: remedial measures for the chemical, physical and biological weaknesses in the functioning of the estuary. These are a conditio sine qua non for a robust ecosystem and for achieving a sound ecological position for the EU Water Framework Directive. In addition, those Natura 2000 and regionally important habitats were selected for which the Sea Scheldt is important. The possibility of achieving European conservation objectives (COs) for these biotopes was explored. An inventory was drawn up of the current natural values of the valley areas and it was determined where these could best be strengthened. At the same time, ecological models were used to investigate where, based on abiotic site characteristics, potential existed for what type of nature and what needs there were for nature connections. Finally, specific configuration requirements were also added to create a suitable habitat for the protected (bird) species for which the Sea Scheldt is important. This process was also based on the expertise in the field and visions of the Agency for Nature and Forest (ANB) and other land managers in relation to the areas managed by them.

Selection of project areas and their organisation

The areas defined by the Flemish Government Decree of 17 December 2004 were first examined to select project areas for nature development. These are the nature development projects in the 2010 Development Outline of the Scheldt Estuary Long-Term Vision, supplemented by the flood areas and reservation areas as defined in the optimum "safety" Sigma Plan defined in the SCBA. The existing flood control areas were added to these before the list was finally completed with the additional nature development projects required.

To select the most desirable type of organisation for each project area (removal of polders, FCA-CRT or wetland), a habitat analysis was carried out by combining various approaches and instruments. The aim of this approach: to uniformly assess, in addition to the estuarine ecological functions, the dyked and undyked natural values and potentials, with due regard for international and national nature policy. Public support for the proposed measures was also taken into consideration.

The results of the various approaches were brought together in a total analysis and weighed up against each other. The final result is a list of projects, with a proposal for organisation and habitat target type(s) for each project area and an overall picture for the entire study area that takes the different approaches into account as much as possible. Habitat requirements for specific species were not included in the provisional analysis, but were added to the scenario that was finally put forward at a later stage.

No.	Objective code	Objective	01 VlRaa	02 VlHan	03 HanGr	04 GrBur	05 BurTm	06 TmDem	07 DemGt	08 Durme	09 ZeDNe	10 sl+Sc
D1.1	buff_alv	maximise upstream drainage buffer	0	0	0	0	+	+	++	+	++	++
D1.2	diss_E	maximise tidal energy dissipation	+	++	++	++	++	+	+	+	+	0
D1.3	meerg	expand multi-channel system	0	++	++	0	0	0	0	0	0	0
D1.4	nat_hab	optimise natural habitat processes	++	++	++	++	++	++	++	++	++	0
D1.5	turb	minimise turbidity	0	+	+	++	++	++	+	++	+	0
D2.1	C	optimise carbon management	0	0	0	0	0	0	0	0	0	++
D2.2	N	optimise nitrogen management	0	0	+	+	+	++	++	++	++	++
D2.3	O2	optimise oxygen management	0	0	0	+	++	++	+	++	+	++
D2.4	P	optimise phosphorus management	0	0	0	0	0	0	+	+	+	++
D2.5	Si	optimise silicon management	+					++	++	++		0
D3.1	prim_prod	optimise primary production	0	+	+	++	++	++	+	++	+	0
D3.2	zoopl	optimise conditions for zooplankton	0	+	+	+	++	++	++	++	++	0
D3.3	benthos	optimise conditions for benthos	+	++	++	++	++	++	++	++	++	0
D3.4	vis	optimise fish migration	0	+	+	+	+	+	++	++	++	++
D4.1	ond_H2O	expand area of shallow low-dynamic water	+	++	++	++	++	++	++	++	++	0
D4.2	slikuit	expand area of mud flats	+	++	++	++	++	++	++	++	++	0
D4.3	slikdyn	reduce dynamic mud flats	0	++	++	0	0	0	0	0	0	0
D4.4	schoruit	expand area of marsh	+	++	+	+	++	+	++	+	++	0
D4.5	schorverj	rejuvenate marsh	+	++	++	++	++	++	++	0	0	0
D4.6	wetland	expand area of wetland	0	0	0	+	+	+	++	+	++	0

Table 1.1. Prioritisation of objectives per subsector. At the top are the zone codes for the entire Scheldt estuary. Bergenmeersen is situated in zone 7 (zone between Dendermonde and Ghent).

++ = very important
+ = important
0 = less important
blank = unknown

The *functional approach* is based on the ecological functioning of the estuary and indicates for each project area what organisational form would best contribute to all the estuarine processes. To do this, use was made of the ecological functions from the NOPSE and their relative importance per zone (Table 1.1). For each area, the table shows the elevation in the tide window and the associated flood pattern, as well as the location along the longitudinal axis of the Scheldt, with the associated location in the concentration profiles of relevant parameters.

The distribution of tidal energy and drainage energy along the longitudinal axis was also taken into consideration. This information indicates where the emphasis must be placed on estuarine or non-tidal nature, based on the energy distribution. For each project area, each function was given a score (0, 1 or 2) per organisational form (removal of polders, FCA-CRT or wetland). In each case, the organisation must make the greatest possible contribution to the most priority functions for a specific zone.

The determination of potential for the development of dyked nature types was estimated using a threefold approach:

- Current habitats: the area of Natura 2000 habitats and regionally important biotopes (RIBs) was calculated for Flanders, the project area (PFAs), the whole of the NDP zones and the habitat guideline area within.
- Habitat quality: based on the existing plant varieties, maps were drawn up that show the level of development per ecotope type for the kilometre grid cells investigated.
- Potential habitats: the areas were characterised abiotically using the POTNAT model of the INBO. The potentials for developing Natura 2000 habitats and RIBs were evaluated for each area.

Prioritisation of habitat types: based on the area available, an analysis was carried out to determine how important a habitat guideline area is for the habitat types for which it was reported: relative to Flanders and, where known, also on a European scale.

Connectivity in the NDP zones: fragmentation of natural habitats is one of the major threats to biodiversity worldwide. The formation of networks in which smaller core areas are linked by a system of connecting elements (corridors, stepping stones, etc.) is one alternative for preserving large habitat entities. The structural connectivity of a number of general habitats was visualised and analysed to estimate the scope of potential connectivity problems.

Four major habitat units or core areas are distinguished: (1) the salty grassland area in zone 4, (2) the core area of carr in zone 5, (3) the freshwater tidal habitat in zone 5-6-8, and (4) the tall oat-grass/marsh marigold grasslands in zones 7 and 8. The connecting network is supported by smaller habitat elements, mixed and spread out along the river. On the one hand, a buffer analysis shows that most places within the four habitat types are less than 1 to 2 km from each other. On the other hand, there is at least one interruption of 5 km or more for each type. The buffer maps provide a spatial picture of the main interruptions.

Management vision: in areas where nature will be strengthened, land managers are active who previously drew up nature targets and management visions for their area. A "manager vision" path was therefore developed with these managers. This examines where and to what extent the existing independent visions agree with or differ from the vision of the Sigma Plan.

Main objectives of the Sigma Plan "natural quality"

From the border to Burcht, the focus is on energy dissipation and filling in the gaps in the estuarine habitat as far as possible along the steep salinity gradient. The removal of polders and the recovery of undyked waste dumps are the main measures in achieving this. The zone around Antwerp will require permanent attention to improve connectivity. The increasing use of dyked area on the right bank threatens the overtide options for waterfowl.

Between Burcht and Temse and on the Rupel, additional estuarine habitat is required for energy dissipation, aeration and the silicon cycle. However, the polders around Hingene also hold the most important core of alder carrs (91EO) for the Scheldt Valley, a priority Natura 2000 habitat. Organisational measures focus on optimising both aspects. Upstream from the old lock at Wintam, the continuity of mud flats and marshes is a point of interest for the entire Rupel basin.

Between Temse and Dendermonde, the main areas of focus remain aeration and the silicon cycle. It is also the core zone for freshwater tidal areas in the Sea Scheldt. The potentials for developing land-based habitats are currently small.

From Dendermonde to Ghent, the main focus must be on buffering upper flow rates to reduce wash-out of pelagic populations. It is important to limit flooding of a regionally important core quaking bog (7140) behind the dykes in Weymeers as much as possible, and there are good potentials for forming cores for tall oat-grass/marsh marigold grasslands (RIB, 6150). The lack of continuity in the undyked habitat is also an area that requires attention.

The potentials for the Durme and its valley are considerable for optimising estuarine processes, for developing marsh marigold grasslands and low-lying meadows and for creating gradient situations. Sticking points are the lack of surface drainage and the sedimentation in the river. To optimise estuarine processes, it is important that estuarine habitat is expanded through appropriate phasing: from the mouth to Lokeren, not vice versa.

1.4.3 Three synthesis proposals for greater safety and natural quality

A synthesis proposal was able to be drawn up based on the existing preferred "safety" scenario and the knowledge of the areas and their organisation from a "natural quality" perspective. At the request of the agricultural sector, not one but three synthesis proposals were developed. This would leave several choices and the sector could pass comment based on balancing its interests.

Each of the three synthesis proposals satisfied the following conditions:

- In terms of net safety benefits, they are comparable with the optimum safety alternative.

- They each meet expectations in terms of "natural quality" (i.e. offer a guarantee of robust nature in the estuary and meet European nature targets for the estuary), albeit in different ways.

Each of the alternative plans obtained through this systematic approach is a cohesive whole that is difficult to split up. The alternative plans must therefore be viewed as one single project (consisting of sub-projects). For technical reasons, decisions about projects automatically also involved largely defining the other sub-projects. It was, however, clearly possible – and indeed the intention – to indicate in the memo to the Flemish Government of 1 July 2005 which sub-projects would be implemented on the ground first.

The characteristic features of each of the three synthesis proposals are briefly summarised below:

- **Scenario 1:** as regards nature, this alternative plan assumes the greatest possible separation of the nature function on the one hand and the functions of agriculture and recreation on the other. In this approach, the necessary area for nature was kept as small as possible and localised in optimally organised nature cores, preferably around existing recognised nature reserves or natural areas on the regional plan. Other zones were avoided, especially areas with a high agricultural and/or recreational value. From a nature point of view, this approach is strong, since it avoids disruption, for example through fragmentation, as much as possible, and because larger nature cores also lead to greater biodiversity.
- **Scenario 2:** this alternative plan opts for estuarine nature of lower quality, but over a greater area. Among other things, this translates into the creation of more FCA-CRTs instead of removing polders.
- **Scenario 3:** this alternative plan is also known as the interweaving scenario. In it, the interweaving can be both functional (e.g. basic waterlogging is organised that still allows marginal or suboptimal agriculture) and spatial (e.g. three quarters of the area become natural, one quarter remains agriculture). This alternative plan involves a larger area, which also includes all the priority areas for agriculture.

For each of the three synthesis proposals, three tests were performed: a nature test, a safety test and an agriculture test. These tests were carried out by experts in each of the three sectors and boiled down to ranking the three synthesis proposals according to relative preference.

The tests revealed that both the agriculture sector and the nature sector preferred scenario 1 because of the separation of functions, the higher quality for both agriculture and nature and the fact that, in net terms, less farmland had to be taken up. Where possible, additional comments from the agricultural sector regarding the choice of individual areas were also taken into consideration when producing the final Most Desirable Alternative (MDA). This MDA forms a derivative of the original scenario 1. The conversion of Bergenmeersen from FCA to FCA-CRT is a direct consequence of the choice for scenario 1.

1.4.4 The Most Desirable Alternative

The following is a map of the most desirable alternative plan finally proposed, which was produced using the method outlined above.

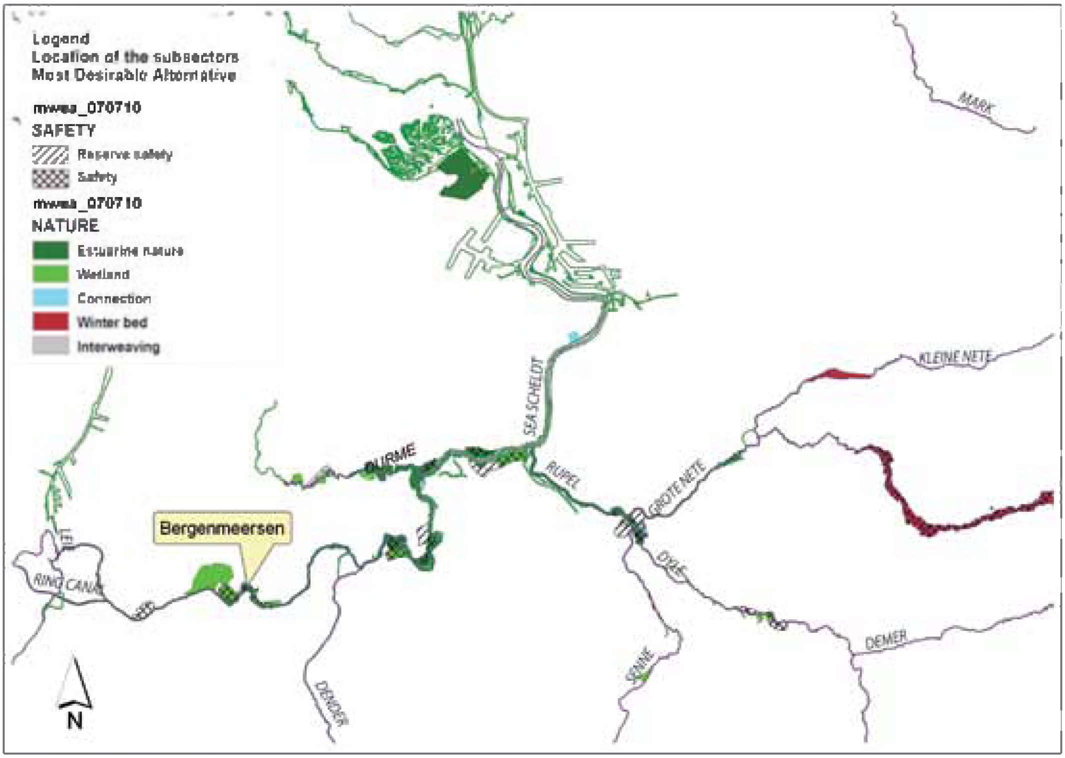


Figure 1.13. Map of the Most Desirable Alternative for the Sigma Plan, showing the areas that satisfy the safety and nature objectives

1.5 References

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2. PUBLIC SUPPORT

In a densely populated area like Flanders, space is a scarce commodity, with many interested parties and stakeholders. In such an environment the projects of the updated Sigma Plan have a tremendous impact. To develop and support the Sigma projects in a rational manner, a process and project structure was drawn up. Such a project structure was also devised and implemented for the Kalkense Meersen Cluster Sigma project.

This chapter examines the project structure, the various stakeholders and interests in the Kalkense Meersen Cluster project and dealings with the agriculture target group. Finally, it provides an overview of the various procedural steps gone through.

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2.1 A tailored consultation structure

The consultation structure developed specifically for the updated Sigma Plan is twofold. On the one hand, there is consultation at the coordinating level. At that level, the global principles for all Sigma areas are defined and feedback is also provided on the development of the various projects and clusters. The policymakers at Flemish level are represented in this consultation. Together with interest groups from the Flemish level, thematic work groups examine a number of topics more closely and reach agreements in that regard. These are the agriculture and nature organisations, touristic stakeholders and various federations, such as fishing clubs, hunters, weekend homes, etc.

In addition, a consultation structure is initiated at project level for each cluster. This consultation structure, the project-based work group, consists of a representation of the municipal authorities involved and the province, and the main local stakeholders, such as polder authorities, agricultural organisations, nature associations, etc. For specific topics, thematic sub-work groups are set up. In addition to the local authorities, these include the local associations of relevance to that topic. Bilateral consultation is also organised on specific subjects.

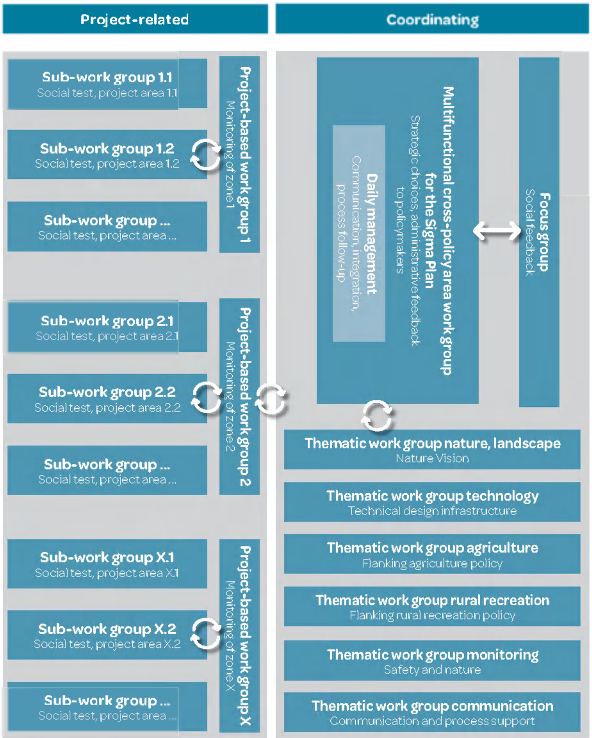

Figure 2.1. Consultation structure of the updated Sigma Plan

2.2 The consultation structure applied to the Kalkense Meersen Cluster

Various consultation sessions for the Kalkense Meersen Cluster, of which the Bergenmeersen project is a part, were held with the municipalities concerned. At an initial exploratory meeting in spring 2006, the Flemish Government's decision regarding the updated Sigma Plan was explained and the Most Desirable Alternative (MDA) presented. The flanking policy for agriculture, for which the Flemish Government also made a decision, was also examined. That flanking policy includes a set of measures to mitigate the effects of the project on the agricultural sector and the farmers involved as much as possible. To that end, work began on the agricultural impact assessment (AIA) in 2006 (see Section 2.4). The results of the AIA were presented to the municipalities in May 2007.

Between June and December 2007, intensive talks were held with the project-based work group and the various thematic work groups, during which the organisational proposal was discussed and developed. Wherever possible, existing weaknesses and opportunities were also included.

In November 2007, the members of the various work groups were invited to a guided visit of the Lippenbroek trial project in Hamme. This allowed them to become acquainted first-hand with the concept of a flood control area with controlled reduced tide (FCA-CRT). This concept is also applied in the (existing) FCA at Bergenmeersen.

The land use plan was presented to the general public at an info market in Berlare in December 2007. More than 300 visitors learned about the various projects of the Kalkense Meersen Cluster.

In spring 2008, the land use plan was brought closer to completion. Preparations also began for the first formal procedural step, the drawing up of the environmental impact assessment. Section 2.4 examines each formal procedure more closely.

Figure 2.2. Guided visit of the Lippenbroek trial project

2.3 Stakeholders

The municipality of Wichelen, the polder authority of the Bergenmeersen polder, the farmers and agricultural organisations involved, nature organisations, as well as local residents (district of Nederkouter) are all stakeholders in the project. Representatives of each of these were included in the consultation structure (see Section 2.1).

2.4 Agriculture and expropriations

2.4.1 The impact on the agricultural sector

By definition, the Sigma areas on the Scheldt and its tributaries mostly lie in the former winter bed. Since the river was dyked in during the Middle Ages, farmers have converted the winter bed into farmland, often in the form of hay meadows. On the one hand, the value of this land to modern farming has fallen sharply because the plots are relatively small, often with a high groundwater level. On the other hand, due to the scope of the Sigma Plan, a large area of this land lies within the project areas.

To limit the take-up of farmland, it was decided to assign at the same time a nature and a safety objective to most of the project areas in the Most Desirable Alternative (MDA). However, a number of safety measures, such as the removal of polders or FCA-CRTs, are incompatible with agriculture. The concentration of nature measures into so-called hard nature cores also leads to the loss of farmland. This is because some types of nature objectives, such as the creation of reed-land and forests, do not allow any further agriculture. Other zones are being organised as wet and/or rough grasslands, where a form of nature management will be applied that can only provide limited profits for agriculture.

The choices in the MDA therefore mean that economic, intensive agriculture will become impossible in the project areas. Concentrating the measures leads to a smaller take-up of farmland, but also to a greater impact for the farmers concerned. The drop in value for the owners and users of this land is so great that expropriation is an appropriate step. Due to the scope of the Sigma Plan, a large number of farmers are affected, some more than others. A flanking agricultural policy was therefore developed parallel to the updated Sigma Plan. This flanking agricultural policy was approved by the Flemish Government along with the MDA.

The flanking agricultural policy is based on expropriation and freehold purchasing, and sets out a number of measures to soften the impact. Some of these measures are existing schemes; others have never been used before and were developed in the course of the process. The Kalkense Meersen Cluster is acting as a test area for developing these new measures since the area contains a large proportion of farmland.

2.4.2 About expropriation and freehold purchasing

Various steps precede expropriation, such as the production of a regional spatial implementation plan (*gewestelijk ruimtelijk uitvoeringsplan* or GRUP) and an environmental impact assessment (EIA). When producing the MDA, the government assigned a "great social interest" to the updated Sigma Plan, as well as compulsory timing. Using these elements an expropriation order was drawn up and approved by the Flemish Government.

Expropriation is implemented by the Purchasing Committee, which is part of the Federal Government. In Belgium, it is not the expropriated owner of a plot of land who pays the land user. As a result, the Purchasing Committee has to negotiate with both parties to reach an agreement. This makes the expropriation process complex, especially if it involves large areas with a complex ownership structure and many users.

For Bergenmeersen, there are approximately 40 ha of land and around 125 plots that are being expropriated. A significant part of this is also leased to farmers.

A farmer who uses land without owning it is generally covered by the Farm Lease Law. Instead of expropriation, the phrase "freehold purchasing" is therefore used. The tenant farmer initially receives an "amicable" offer for the purchase of his freehold. The Purchasing Committee applies standard rules here, which evaluate the importance of the piece of farmland concerned within the farm in question and assign a monetary value to it: the freehold purchase allowance.

If the tenant farmer agrees with this allowance, this is known as an "amicable freehold purchase". If a compromise cannot be reached, a case is brought before the cantonal judge. This case may concern the amount of the allowance, but also the need for the expropriation. In this last case, the judge can declare the expropriation or freehold purchase invalid. This creates a stalemate, which can seriously delay the project. This is why an amicable expropriation is extremely important. The elements of the flanking agricultural policy aid in this process.

2.4.3 Measures of the flanking agricultural policy

Agricultural impact assessment
The Flemish Land Company (VLM) investigated the effect of the Sigma Plan on agriculture. It did so both at plan level and for the various sub-projects within the Sigma Plan. The agricultural sensitivity analysis mapped out the sectoral impact at plan level and helped determine the choice of project areas. The impact for individually affected farmers in a specific area is investigated in an agricultural impact assessment (AIA).

The VLM produced the agricultural impact assessment for the Kalkense Meersen Cluster in 2007. All farms (in the broad sense) were surveyed. According to this study, a total of 137 farms are affected within the Kalkense Meersen Cluster (Table 2.1). The AIA shows that the average size of farms in this area is fairly small and the age of the farmers fairly high. Converting the data from 2007 to 2013 (+6 years) indicates that the average age of farmers in the Kalkense Meersen Cluster is a little over 55. Fewer than 40% of farms are bigger than 40 ha (Table 2.3).

A personal info sheet was drawn up for each farmer with the location of his or her plots and a description of the characteristics of the farm. This makes the agricultural impact assessment one of the most detailed ever

Table 2.1. Age distribution in the Kalkense Meersen Cluster in 2007

Age bracket (2007)	Number	%
Unknown	1	1
< 35	11	8
36-45	36	26
46-55	37	27
56-65	37	27
> 65	15	11
Total	137	100

Table 2.2. Proportion of farms as main occupation in the Kalkense Meersen Cluster

	Number	%
Main occupation	84	61
Side occupation	10	7
Hobby	5	4
Retired	14	10
Not surveyed	24	18
Total	137	100

Table 2.3. Size of the affected farms in the Kalkense Meersen Cluster

Farm area	Number	%
< 10 ha	32	23
10-20 ha	24	18
20-40 ha	43	31
40-80 ha	35	26
80-150 ha	1	1
> 150 ha	2	1
Total	137	100

produced. Thanks to the report, farmers can also be monitored individually.

Bergenmeersen is a small subsector within the Kalkense Meersen Cluster. In total, fifteen farmers are affected. Most of these farms are losing a relatively small proportion of their land (<20%); however, that figure is more than 20% for four farms (Table 2.4). That loss will be felt all the more so because co-use in connection with nature management is not possible on land where an unmanaged estuarine area is being developed.

Perimeter adjustments

Based on the detailed information for each farm, a number of farms and house plots located on or by the edge of the project areas were able to be removed from the

Table 2.4. Percentage of the farm affected by the development of Bergenmeersen

% in Bergenmeersen	Number of farms
< 20%	8
20-40%	3
40-60%	1
> 60%	0

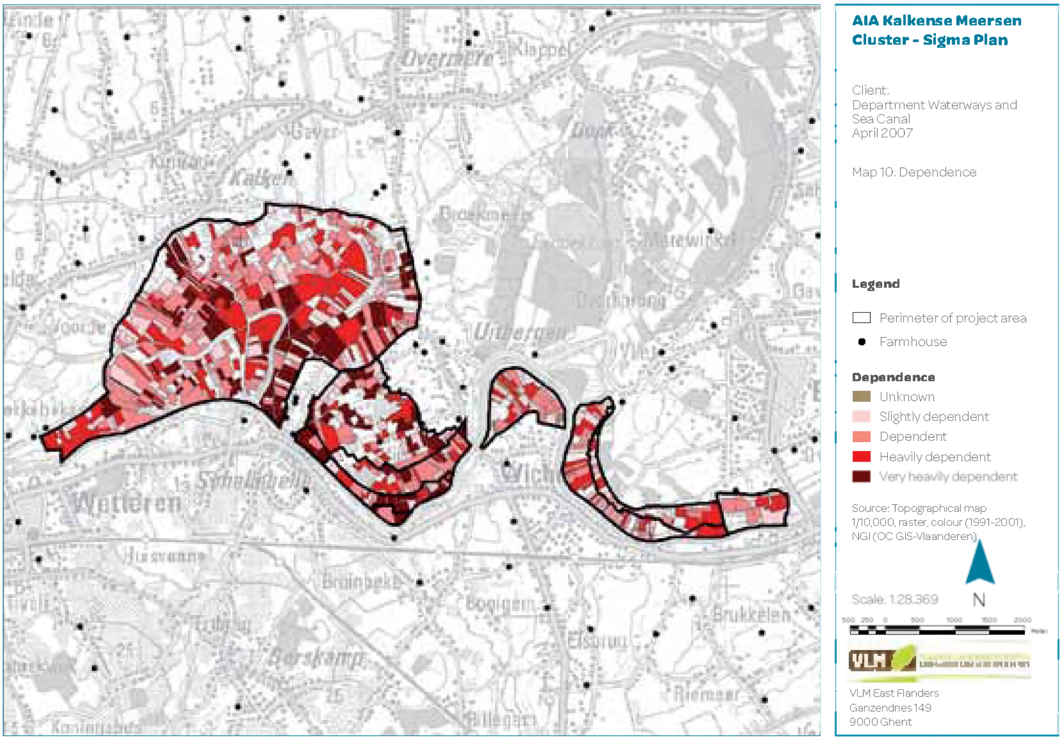

Figure 2.3. Dependence of agricultural plots in the perimeter of the project area as shown in the AIA

project perimeter. This measure can make a big difference for a farm, but also has a major impact on the project itself. Each perimeter adjustment (often a shrinking of the project perimeter) has to be tested against the safety and nature objectives. In a number of cases, a removal can be offset by extra extensions to the project perimeter. In the Kalkense Meersen Cluster, the perimeter was adjusted significantly in favour of five farms. In net terms, the project shrank by around 25 ha (2.5%).

No perimeter adjustments were possible for Bergenmeersen because the area had already been dyked as an FCA in an earlier phase. The borders were therefore already established.

Land bank and land exchange

The VLM was tasked with setting up a land bank with the aim of acquiring land that could subsequently be made available as exchange land. However, pressure on the land in the region is great. This is due to advancing urbanisation, hobby farmers (e.g. horse owners) and intensive land use in a number of sectors (e.g. arboriculturists and farmers themselves). The effect of the land bank is therefore rather small. The land bank managed to acquire far less land than the area to be expropriated. The land from the land bank was assigned to those farmers most affected, taking into account their age, absolute loss (in ha) and relative loss (in %), using a formula for apportionment.

Financial incentives

A number of financial incentives were developed to make the voluntary acquisition of land by the land bank possible. Both owners and users of land can utilise these incentives.

There is a reinvestment allowance of 20% for the owner. This compensates for the notarial fees associated with investing in new land.

For the user, there is – besides the standard freehold purchase allowance – a leaver's incentive of 2,000 euros per ha in the case of an amicable freehold purchase. This is a new incentive developed specifically for the Sigma Plan in connection with the flanking agricultural policy.

Farm relocation

The most radical measure is the relocation of a farm. This can be applied if the farmer

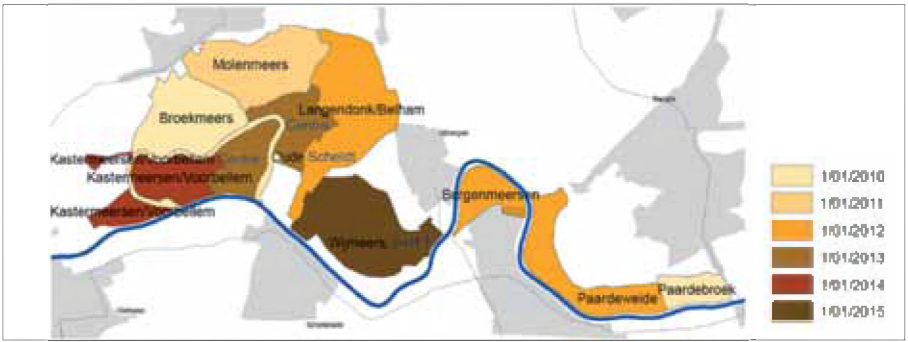

Figure 2.4. Phasing according to the GRUP

can demonstrate that the project affects his or her business to such an extent that it can no longer be viable.

One farm in the Kalkense Meersen Cluster was relocated. This freed up a significant number of plots in the project areas, as well as a number of plots of exchange land. The process was fairly difficult, and it became clear that the methodology for the "farm relocation" measure had not yet been fully worked out.

Following this case, a protocol for relocating farms was subsequently drawn up. This protocol describes the conditions the departing farmer must satisfy and what compensation the responsible authority must provide in return. The protocol will be incorporated into other major projects of the Flemish Government.

Phasing

Because of the scope of the updated Sigma Plan, it is impossible for all expropriations in a project area to take place simultaneously. This process takes several years. This means a certain amount of control is possible: some plots are needed straight away (e.g. for building dykes), while other parts can be expropriated and purchased at a later time (the bulk of a flood area). Thanks to this phasing, a number of farmers gain several years' respite.

The Kalkense Meersen Cluster was the first area for which such phasing was introduced. The phasing was incorporated into all relevant processes, including the GRUP. As a result, some farmers gained five years' respite. Given the age of the farmers, that is a significant intervention.

Service covenants

The Flemish Government's decision on the updated Sigma Plan also included the development of "service covenants" for affected farmers. This new instrument was further developed and applied in the Kalkense Meersen Cluster. It is an entirely new idea within the flanking agricultural policy.

The measure includes a transitional arrangement, with a twofold objective. Firstly, it is assumed that the farmer needs a certain amount of time either to adapt his business or buy other land with the money from the freehold purchase. A transitional arrangement is therefore desirable.

Secondly, within the context of nature development and apart from one or two exceptions, attempts are made to make the soil poorer ("diminishment"). The desired types of nature only develop in circumstances where the concentrations of nitrogen and phosphorus are much lower than on intensively managed agricultural plots. Nature development is therefore preceded by diminishment management. Here, too, a transitional arrangement is desirable.

The diminishment is achieved through mowing management (the cutting of grass). Once fertilisation is stopped, production is then expected to drop. The "sweet spot", where for nature management the diminishment is taken far enough to initiate specialised management, coincides with the time at which the yield for the farmer becomes sub-economical. It is estimated that this happens after approximately five years.

Based on that starting point, affected farmers are offered an extension on the use of their plots for a period of five years. Mowing management is imposed with the aim of removing as much plant material as possible from the plot. In return, there is a limited financial compensation of up to 355 euros per ha per annum (or 1,675 euros per ha over five years).

This measure has been very successful in the Kalkense Meersen Cluster, but is not being applied in Bergenmeersen. This is because the area is being developed as an estuary, with no room for mowing management.

Ease of payment

Farmers who lose land they formerly leased can offset that loss by buying new land. However, the amount they receive for the leasehold purchase is less than the cost of a new, equivalent plot of land. This means the farmer is forced into making an extra investment. This investment is partly offset by an "ease of payment" scheme (low interest, deferred payments).

Lease acceptance incentive

Another measure developed in connection with the Sigma Plan is the lease acceptance incentive. This incentive is paid to owners of free land who are willing to accept a tenant. This measure encourages tenant farmers to relocate. The allowance is the same as the leaver's incentive (2,000 euros per ha). In this case, however, no leaver's incentive is paid (the tenant farmer is relocated, but does not lose any land). The measure does not therefore cost any extra.

In practice, however, little use is made of this measure. This is probably because little lease-free land is available, due to the demand for land.

Compensation for loss of production

Farming remains possible in a limited number of project areas, for example in an FCA with no specific nature objectives. The frequency of flooding is low (from once to twice a year to once every 50 years). In addition, these FCAs are generally active in the winter period. In that case, the agricultural activity is largely unhampered. Compensation is paid for any damage suffered.

2.5 Procedures and participation

Various steps are required to implement the projects of the updated Sigma Plan on the ground. Sections 2.1 and 2.2 describe how and with what parties the land use plan was drawn up that gives substance to the objectives in relation to safety and nature. That land use plan formed the cornerstone of an initial, informal phase. After all, up to that point, no formal procedure had been begun or completed.

In a second phase, various formal procedures were followed:

- production of an environmental impact assessment (EIA),
- production of a regional spatial implementation plan (GRUP),
- production of an expropriation plan,
- application for an urban development permit.

Participation is possible in each of these procedures. This means that the point at which the public can inspect the plans and also knows when participation is possible is laid down in law. In addition, Waterways and Sea Canal and the Agency for Nature and

Forest have produced project brochures and project newsletters to provide regular information about the planned project and the current situation. Each formal participation was also complemented by an accessible info market for the general public.

The environmental impact assessment mapped the project's expected environmental impact. In accordance with the EIA procedure, the notification was made available in June 2008 for inspection at the municipal authorities. The aspects to be investigated and the methodology used for each discipline were also described. After the period of participation, the EIA Service of the Flemish Government bundled the advice and comments from the public together into guidelines. Based on these guidelines, the team of EIA experts produced the actual EIA. The EIA was approved by the EIA Service on 11 June 2010. The GRUP adapts the legal purpose of the Kalkense Meersen Cluster, so that the land use plan can be implemented. In accordance with the law, the preliminary draft RUP (spatial implementation plan) was submitted to all government bodies involved for advice. The draft RUP was subjected to a public inquiry (June-August 2009). During that public inquiry, an info market was organised on 19 June 2009. The RUP was finalised by the Flemish Government on 26 March 2010.

The technical aspects of the various interventions of the land use plan, which formed the basis for the environmental impact study and the spatial implementation plan, were subsequently developed further. Based on that technical design, an application was made for an urban development permit (25 June 2010). A public inquiry was also held, and an info market for the general public was organised on 17 June 2010.

The expropriation plan for Bergenmeersen was published in the *Belgian Official Gazette* on 23 January 2008. In April 2013, Waterways and Sea Canal had acquired almost all the plots in Bergenmeersen. After the urban development permit for Bergenmeersen was issued (4 February 2011), preparations for carrying out the work could begin. Thus, a specification for carrying out the work was drawn up and a call for public tenders was issued in 2010. In 2012, the work was assigned to the contractor Herbosch-Kiere from Antwerp.

2.6 Flanking recreation policy and less nuisance

During the various participatory sessions, both the public and local authorities raised a number of weak points. Solutions to these points were sought during the planning phase of the project. Aspects of better recreational services and mitigating measures for the public were both considered. The chosen solutions often appeared to encompass aspects of both problems. They are therefore dealt with together here.

2.6.1 Mosquito ridge

For its organisation as an FCA-CRT, the land had a profile in which the lowest-lying parts were located close to the ring dyke. With these land conditions and an operational CRT, the deepest water would be close to the ring dyke and therefore close to homes. If pools were left behind between tides, these could become breeding grounds for mosquitoes. This seemed to be a genuine fear for several people from the neighbouring area.

This was addressed by extensively altering the land profile of the FCA-CRT. Stagnating water by the ring dyke was avoided by creating a raised zone against the toe of the dyke. This structure was quickly named the "mosquito ridge". The mosquito ridge is sufficiently high so that it is only flooded during the most extreme tides. Stagnating water by the dyke is thus a thing of the past. As a result, the homes are further from the water and the threat of mosquitoes has been removed.

2.6.2 Supply of earth during the work

The reinforcement of the existing ring dyke to Sigma standards involves raising and widening the dyke. To do so, a large amount of construction material (sand, heavy soil) is needed. Transport by road with many hundreds of lorry journeys would place a severe burden on the surrounding villages, and local authorities lodged protests against it. The construction of an extra mosquito ridge made the problem even worse. A request was made to make as much use as possible of transport by water or obtain soil locally to avoid transport by road.

The solution was found in the creation of the onset of a creek system (see Figure 4.3). A channel was dug by the CRT sluice that can serve as main creek when the CRT is operational. Digging such a creek onset facilitates the outflow of the water and promotes the establishment of a pattern of creeks. Excavating a broad, deep channel could provide a large volume of soil and avoid road transport.

However, the archaeological study revealed that a number of zones in the area should be better saved because of the presence of artefacts (see Chapter 5). As a solution, a creek onset was designed with a western and eastern branch. The archaeologically sensitive parts of the area were thus avoided. The western channel was dug broad and deep, allowing as much construction material as possible to be obtained for the creation of dykes and the construction of the mosquito ridge.

2.6.3 Walking infrastructure

Together with the design of the stream source, thought was also given to the area's accessibility. Experience with the Lippenbroek trial project teaches us that, on the one hand, a working CRT sluice has a high amenity value for passers-by. On the other hand, local residents indicated that

Figure 2.5. The walkway in Bergenmeersen with bridge over the eastern stream arm

they perceived the view to be had from the raised ring dyke into their homes and gardens as a breach of their privacy.

A plan was drawn up for the recreational aspect, in which all forms of recreation were kept away from the ring dyke. However, walking and cycling on the overflow dyke remain possible, and is being strengthened.

A walkway was planned in order to make the area accessible to walkers. This follows the eastern stream from the eastern corner of the FCA-CRT (link to Wichelen churchyard) to the CRT sluice and crosses the eastern stream via a bridge. Opposite the sluice, the walkway opens onto a platform; from there, the incoming water can be observed and there is a panoramic view of the CRT (see Figure 3.9). Recreation is therefore concentrated around the CRT sluice and the eastern stream. This creates the necessary quiet in the centre of the area for any breeding or foraging birds, which in turn could act as a new magnet for bird-lovers (see Chapter 8).

The walkway was designed to be wide, and creates a monumental impression. It is also accessible to wheelchairs from Wichelen. Very soon after the walkway was built, it seemed to be greatly appreciated by the local population, birdwatchers and the municipal authorities of Wichelen. Thanks to its unique character, the FCA-CRT can be an added attraction for the municipality. In time, a learning path will be created here, with information about the area's nature and safety functions. A bird-watching hide is also one of the options.

2.6.4 Cycling infrastructure

The overflow dyke forms part of recreational routes along the Scheldt, but is also heavily used as a functional link-up between Wichelen and Wetteren, for example by children going to and from school.

The link with the N416 did not exist before the reorganisation as a CRT; bicycles had to be pushed up a steep set of steps. This created a serious bottleneck for cycling traffic.

The construction of the new ring dyke provided a new cycle ramp, so that the road along the Scheldt now joins the N416 at Uitbergenbrug. This is a considerable improvement for cycling through-traffic. In time, an uninterrupted cycling link will be created on both the left and right banks for functional and recreational purposes.

2.6.5 Trash screens

The Scheldt contains floating material of varied origin: reed stems, branches and unfortunately also rubbish (plastic). Most of this material is not wanted in the FCA-CRT. Branches, for example, can block the sluices and affect the operation of the CRT. For safety's sake, they must be kept out. Local residents also indicated that they found floating plastic and other "pollution" to be a real nuisance. They did not want a "trash can" at their back door.

Trash screens were therefore fitted to both sides of the sluice. The width of the openings is a compromise that took account of the need to hold back the rubbish, avoid blockages and allow fish to pass through.

2.7 References

- ***Brochure Onteigening (2009)*** *(Expropriation Brochure) (2009) / www.sigmaplan.be/nl/files/download/ Onteigeningen.pdf*
- ***Brochure Flankerend Landbouw-beleid (2010)*** *(Flanking Agricultural Policy Brochure) (2010) / www.sigmaplan.be/nl/files/download/ Brochure%20Flankerend%20landbouw-beleid.pdf*

Figure 2.6. Recreational plan for Bergenmeersen

3. CONCEPTUAL CHOICES

Flood areas are sophisticated, strategically chosen places. After all, not every point along a river is suitable to be organised as a flood area. The location of the flood area must ensure that the area makes an efficient contribution towards safety. The impact on agriculture, local residents and the economy must also be kept to a minimum. The Flemish Government established the contours of the Sigma areas in 2005 and 2006 in the Most Desirable Alternative.

This chapter outlines the contours of the Most Desirable Alternative for the Kalkense Meersen Cluster and the various sub-projects. It then explains how this Sigma project contributes towards the safety and nature objectives. Finally, it looks in greater detail at how the project satisfies the concerns of users of the areas in question and interprets the land use plan and the GRUP for this Sigma project.

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3.1 Most Desirable Alternative for the Kalkense Meersen Cluster

3.1.1 Situation of the Kalkense Meersen Cluster and the various sub-projects

Chapter 1 describes how the Most Desirable Alternative came into being. The Kalkense Meersen Cluster is part of that, and belongs to the group of projects for which implementation must have begun by 2010 at the latest. The Kalkense Meersen Cluster and the sub-projects in this cluster contribute significantly towards the safety and nature objectives of the Most Desirable Alternative.

The purpose of the safety functions is to keep the risk of flooding in the Scheldt basin to a minimum. Dyke heights are being increased along the entire length of the Scheldt. In addition, there are various types of construction – some of them temporary – to help buffer high water levels. The area around Wijmeers, Bergenmeersen and Paardeweide is one of the most strategic points for absorbing extreme high waters in a controlled fashion within the Sea Scheldt basin. Populated areas behind the dykes are thus better protected against flooding.

Wijmeers 1, Bergenmeersen and Paardeweide will function as flood control areas (FCAs), absorbing water from the Scheldt via overflow dykes in the event of a storm tide. Ring dykes at Sigma height protect the hinterland behind the incoming water. When the tide ebbs, the water will flow back into the Scheldt. Table 3.1 provides an overview of the different subsectors of the Kalkense Meersen Cluster.

The other subsectors, Kalkense Meersen and Paardebroek, will function as wetland. Wetlands are wet areas of significant natural value. They can be wet grasslands, marshy areas or wet forests. Safety is not the primary function of wetlands. They do not accommodate water from the Scheldt. The drainage of upstream areas is, however, an important safety aspect. A higher groundwater level is needed for the development of wet nature.

Wijmeers 2 is being de-poldered, as a result of which the area will again come under the influence of the Scheldt's tides. This means the area will be watered on a daily basis.

The operating principles of the various subsectors are illustrated in Figure 3.1.

Kalkense Meersen: wetland

The aim in the Kalkense Meersen subsector is to raise the groundwater level by raising groundwater tables in reservoir basins. Because the subsector is already a natural basin and the adjoining zones are higher, damming up in the area has no effect outside the subsector. The level of the Kalkense Vaart, which is responsible for draining a

Table 3.1. Overview of the different subsectors of the Kalkense Meersen Cluster

Subsector	Area	Use
Bergenmeersen	41.37 ha	FCA-CRT
Kalkense Meersen	606.16 ha	Wetland
Paardebroek	27.77 ha	Wetland
Paardeweide	84.73 ha	FCA-wetland
Wijmeers part 1	158.75 ha	FCA-wetland
Wijmeers part 2	27.85 ha	Removal of polders
Total	946.63 ha	

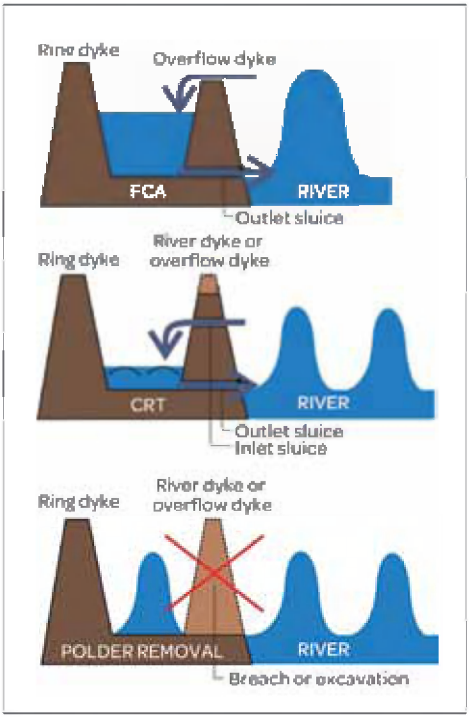

Figure 3.1. The operating principles of an FCA, FCA-CRT and the removal of polders

significant area of hinterland, is being cut off from the reservoir basins. Adjustable weirs are being installed in the side basins and channels that open into the Kalkense Vaart. The drainage of the Kalkense Vaart itself is controlled by the pumping station.
The purpose of this project is to raise and strengthen the dykes to +8 m TAW (Tweede Algemene Waterpassing - Second General Levelling) instead of the current +7 to 7.5 m TAW. The raised Sigma dyke will form part of the reference situation.

Wijmeers 1: FCA-type wetland
For Wijmeers 1, the ring dyke already constructed around the de-poldered Wijmeers 2 area will partly be converted into an overflow dyke. To do this, the dyke will be lowered from +8 m to +6.8 m TAW and reprofiled (overflow dykes have a shallower profile). Outflow constructions will be built in the existing Scheldt dyke to the Scheldt, but there will be no direct outflow constructions to the de-poldered area. A new ring dyke will be constructed around Wijmeers 1 at Sigma height (+8 m TAW). The ring channel is being built to ensure the drainage of Wijmeers 1 for development as an FCA. This ring channel will be shoaled or partially filled to create the rewetting that is required for the desired nature development in Wijmeers 1. A compartmentalising dyke will be constructed in the Wijmeers 1 area at +5.5 m TAW between the eastern and western sections.

Bergenmeersen: FCA-CRT
The existing Bergenmeersen FCA is being converted into an FCA-CRT. The area will flood daily in a controlled manner at high tide. A limited amount of water will be let into the area at each high tide via a new inlet construction in the dyke. At low tide, the water flows back into the Scheldt via the low outlet pipes. This creates a CRT in the polder. When water levels in the Scheldt are normal, the inflow of water is extremely limited. This is the only way the desired mix of mud flat and marsh can be created.
The existing ring dyke (+7.6 to 7.8 m TAW) is being raised to Sigma height (+8 m TAW). The height of the existing overflow dyke (+6.4 to 6.5 m TAW) will be retained. The area will continue to serve as an FCA in extreme storm tides.

Paardeweide: FCA-type wetland
The existing function of Paardeweide as an FCA will be retained, but will be adapted to the stricter safety standards. To this end, the existing ring dyke will be raised to +8 m TAW. No changes will be made to the existing overflow dyke along the Scheldt. The FCA becomes operational if the level of the Scheldt exceeds +6.3 to 6.5 m TAW. Calculations by Flanders Hydraulics Research show that statistically, this flood area will be operational once a year.

Paardebroek: wetland
The objective in the subsector of Paardebroek is rewetting. This is possible due to the existing relief and without waterlogging the areas upstream, just as in the Kalkense Meersen.

Wijmeers 2: polder removal
This polder removal is being implemented as the first sub-project, as a result of which there are two different implementation situations: the situation as a de-poldering area

without an adjacent FCA, and the situation with an adjacent FCA.

In a first phase, the existing Scheldt dyke will be locally breached, allowing the Scheldt water to flow freely into the area at high tide. A new ring dyke at Sigma height (+8 m TAW) will prevent the water from continuing into the area behind. Drainage of the dyked areas is being ensured by the construction of a ring channel. This will partly follow the current course of the Sompelbeek and the Oeverbeek, with a new section of ring dyke being constructed in between. This brook will drain into the Scheldt at the Bellebeek outlet sluice. The adjacent ring channel will be modified so that the nature objectives can be achieved.

3.1.2 Contribution of the Kalkense Meersen Cluster to the safety objectives

The following paragraphs outline the frequency of flooding for each subsector. The effect on the rise in the water level if the flood areas are not created is described for several recurrence intervals (T10, T100, T1000, T2500 and T4000 (situation in 2000)), without taking into account the possible formation of breaches. In each case, the planned interventions within a clus-

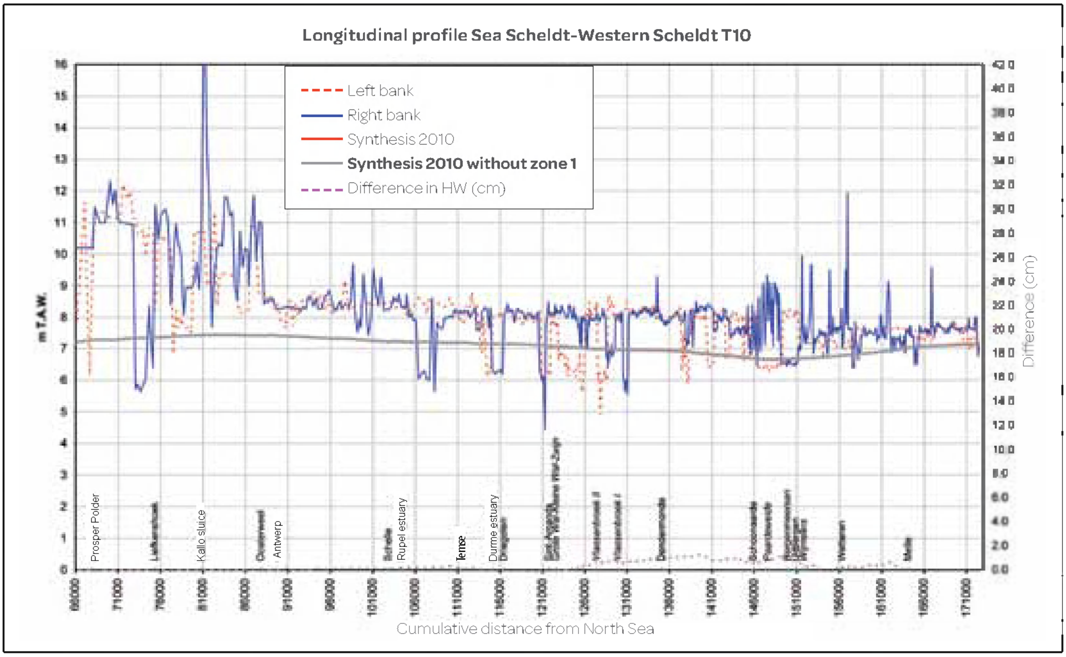

Figure 3.2. Longitudinal profile of the Sea Scheldt, maximum water levels during a storm with a recurrence interval of 10 years

ter were rectified in the synthesis model. All calculations were performed without taking into account the function as an FCA-CRT.

Frequency of flooding

The flood control areas of Bergenmeersen and Paardeweide will come into operation during a storm with a recurrence interval of one and two years respectively. Only the eastern section of Wijmeers 1 will be filled via the overflow dyke for storms with recurrence intervals longer than 25 years. The western section of the Heisbroek FCA, Wijmeers 1, will be fully protected from flooding up to a recurrence interval of 100 years (T100). At T100, only the compartmentalising dyke between the eastern and western sections will overflow. At T500, both the compartmentalising dyke and the actual overflow dyke of that section of Wijmeers 1 will overflow.

Increase in the water level if the Wijmeers FCA is not put in place

Figures 3.2 to 3.7 show the longitudinal profile of the Sea Scheldt with the maximum water levels for different recurrence intervals.

- Because the Wijmeers 1 FCA and the Heisbroek FCA only flood in storms with a recurrence interval longer than 25 years, the disconnection of the Wijmeers flood zone

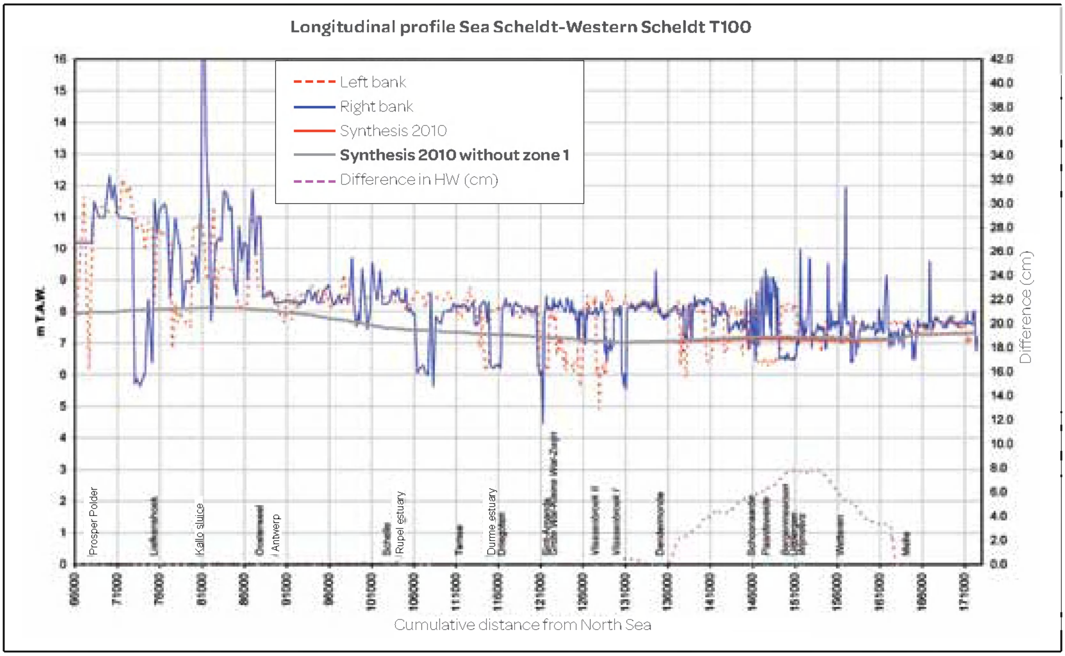

Figure 3.3. Longitudinal profile of the Sea Scheldt, maximum water levels during a storm with a recurrence interval of 100 years

(through the de-poldering of Wijmeers 2) only has a limited impact on the water level in the Sea Scheldt at **T10**.

- However, if the Kalkense Meersen Cluster is disconnected, the water level in the Scheldt will rise at **T100**. The maximum water level in the Scheldt will rise by approximately 8 cm at Wijmeers and Bergenmeersen, and by approximately 6 cm at Paardeweide. The rise in the maximum water level in the Scheldt will only continue to a limited degree, upstream to Melle, downstream to just before Vlassenbroek I. At Vlassenbroek, the (expected) increase will be completely absorbed by the extra filling of the FCAs. The Vlassenbroek I FCA in particular will then receive more water (lowest overflow height).
- In storms with longer recurrence intervals, this rise will increase further, as will its range. Upstream, the rise will always continue as far as the edge of the model area. Downstream, it will continue to just past Vlassenbroek at **T500**, where it will always continue further for longer recurrence intervals, as far as the mouth of the Rupel at **T4000**. At Vlassenbroek, the increase is partially absorbed by the extra filling of the FCAs.
- At **T500**, the maximum water level in the Scheldt will rise by approximately

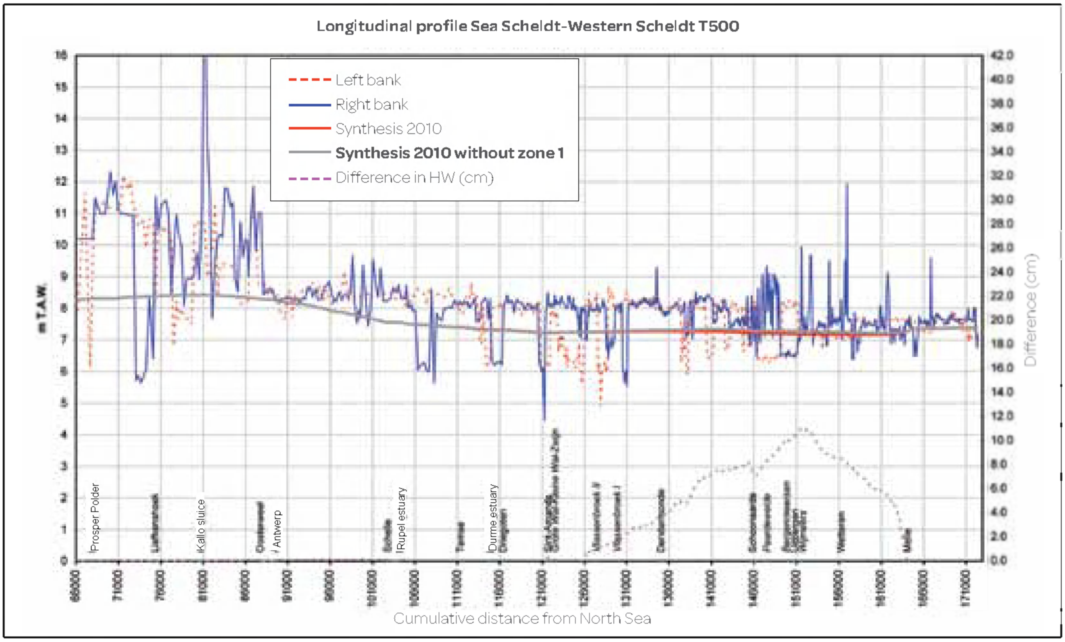

Figure 3.4. Longitudinal profile of the Sea Scheldt, maximum water levels during a storm with a recurrence interval of 500 years

10 cm at Heisbroek, Wijmeers and Bergenmeersen, and by approximately 8 cm at Paardeweide.

- At **T1000**, the maximum water level in the Scheldt will rise by approximately 11 cm at Wijmeers and Heisbroek, and by approximately 9 cm at Bergenmeersen and Paardeweide.
- At **T2500**, the disconnection of the Kalkense Meersen Cluster will cause a rise in the maximum water level in the Scheldt of approximately 32 cm at Heisbroek, Wijmeers and Bergenmeersen, and of approximately 27 cm at Paardeweide. In a storm with a recurrence interval of 2500 years, the water level will remain below +7.5 m TAW if the Wijmeers flood zone is put in place. But if the Wijmeers flood zone is not established, the maximum water level at T2500 will be higher than +7.5 m TAW, where +7.5 m TAW is the design water level to be held back in the area around Wijmeers.
- At **T4000**, the maximum water level in the Scheldt will rise by approximately 27 cm at Heisbroek and Wijmeers, by approximately 33 cm at Bergenmeersen and by approximately 35 cm at Paardeweide.

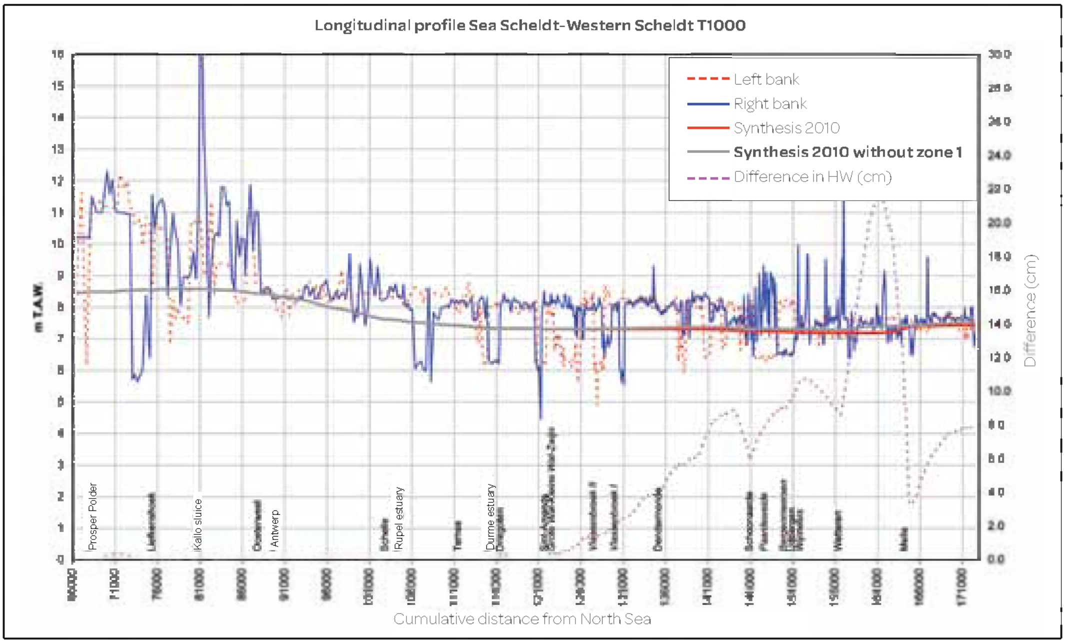

Figure 3.5. Longitudinal profile of the Sea Scheldt, maximum water levels during a storm with a recurrence interval of 1000 years

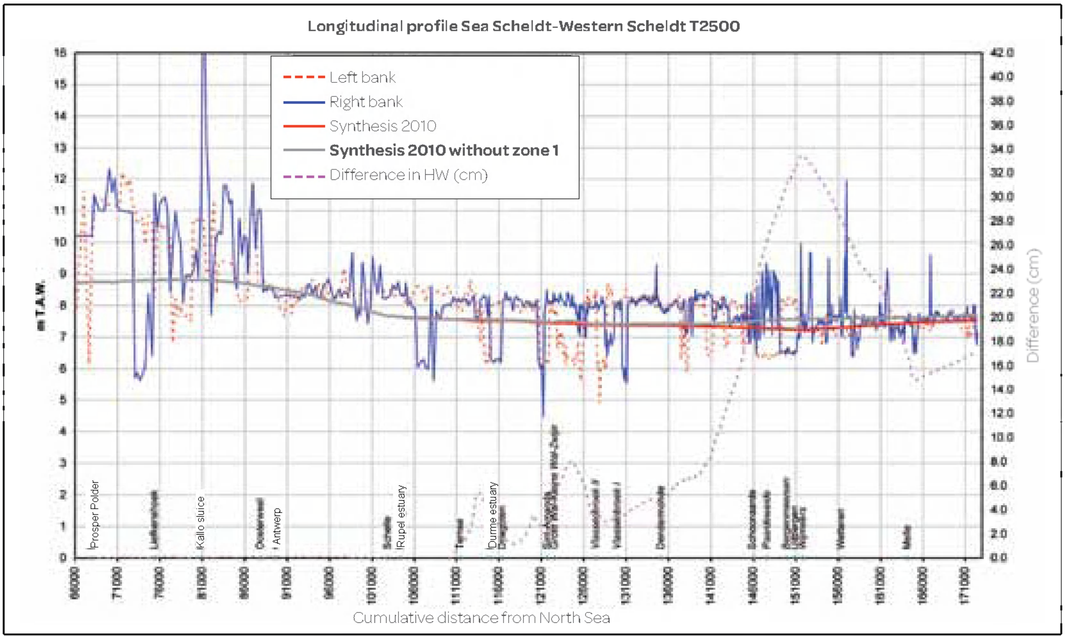

Figure 3.6. Longitudinal profile of the Sea Scheldt, maximum water levels during a storm with a recurrence interval of 2500 years

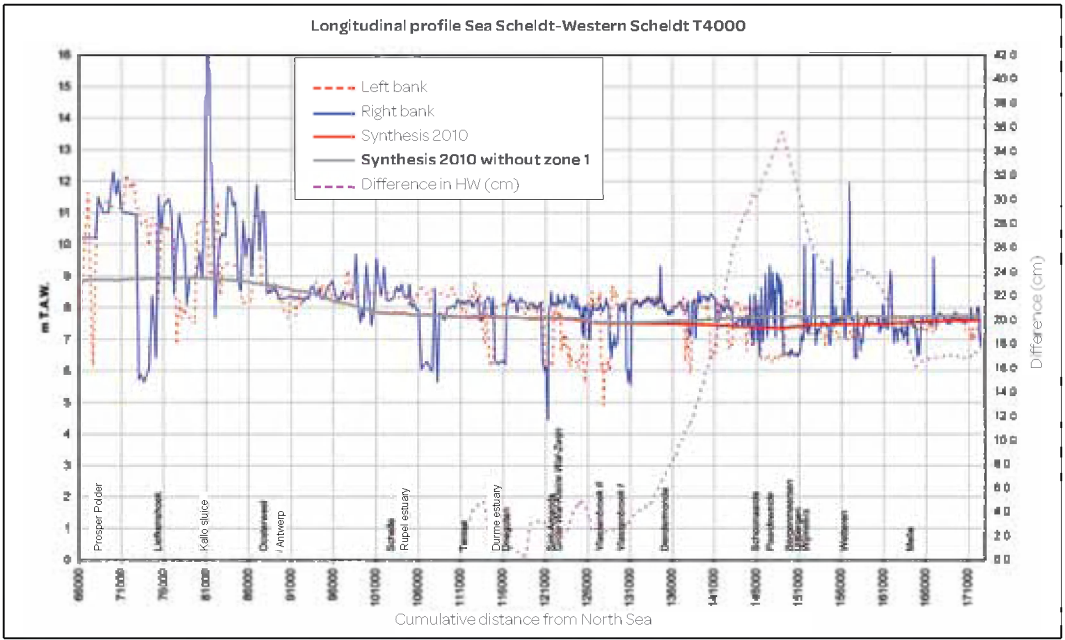

Figure 3.7. Longitudinal profile of the Sea Scheldt, maximum water levels during a storm with a recurrence interval of 4000 years

3.1.3 Contribution of the Kalkense Meersen Cluster to the nature objectives

The Sigma Plan approaches the Scheldt Valley in all its aspects. The aim is to restore as much of the river as possible in the most sustainable way possible. This will be achieved by restoring the contact between the river and the valley, creating wetlands and, where possible, once again increasing the intertidal zone and the opportunities for estuarine nature.

For the "natural quality" aspect, integrated European nature objectives (conservation objectives) were established for ecosystem functions, habitats and species. Thus, all legal requirements (the Habitats and Birds Directive and the Water Framework Directive) are satisfied without conflicting with each other. In general terms, these objectives encompass developing wetland types and estuarine nature within the Kalkense Meersen Cluster.

Estuarine nature: Bergenmeersen and Wijmeers 2

The Flemish Government has selected a number of areas that are favourably situated to once again be brought under the influence of the tidal pattern of the river. This is achieved by reducing the action of tides or by removing polders. By establishing the right preconditions in these areas for optimal ecological development, as dynamic a system as possible is sought, with nature itself as the main controlling factor. After all, tidal action is the driving force behind the development of an ecosystem with mud flats and marshes. A pattern of creeks will develop along which the water will flow in and out. In the lowest-lying zones, which flood daily, mud flats will be created. In the higher zones, which flood less often, marshes will develop in which unique vegetation will quickly spring up. This new landscape is known as "estuarine nature" (see also Chapter 4).

Bergenmeersen

The Bergenmeersen subsector has been organised as an FCA. Thanks to a sophisticated inlet and outlet system, the area is brought under the influence of a controlled reduced tide (CRT). The influence of the tidal dynamic creates mud flats and marshes. In particular, it is the imitation of the spring neap tide variation that makes a difference in mud flat and marsh habitats and leads to a diverse, functional ecosystem (see Chapter 4). The estuarine nature that will develop here will contribute towards the conservation objectives for the Scheldt estuary defined within the context of the European Habitats and Birds Directive.

At the new low-lying inlet and outlet structures, a main creek onset has been dug at mean low water level (MLW level). The connecting drainage channels ensure that the area can drain sufficiently, for example in the event of the design storms.

Based on further studies, certain zones were excavated to provide a sufficient open water area.

Wijmeers 2

Wijmeers 2 is being de-poldered, which will bring it under the influence of the Scheldt's tidal pattern. Here, too, estuarine nature will develop that will contribute towards the

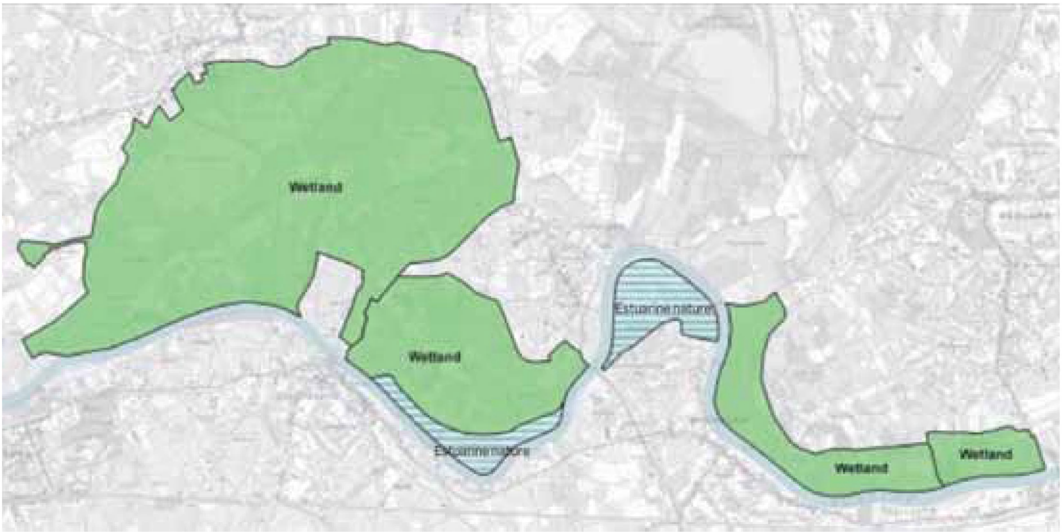

Figure 3.8. Nature objectives according to the Most Desirable Alternative for the Kalkense Meersen Cluster

European nature objectives for the Scheldt estuary.

Wetland: Kalkense Meersen, Wijmeers 1, Paardebroek and Paardeweide

The updated Sigma Plan aims to restore more space to the typical and water-rich river landscapes. The plan capitalises fully on ecological potentials by applying the most appropriate forms of management for the different types of wetland.

In the context of the Sigma Plan, "wetland" is a collective name for water-rich natural areas not influenced by the tide. Here, water levels follow a natural path, with higher levels in the winter than in the summer. Wetlands can form widely varying landscapes. For the Kalkense Meersen Cluster, this involves different types of grassland, open water, reed vegetation and wet woodland. The final type depends on the form of management applied.

By definition, wetlands are situated on lower-lying land in the valley. Some areas are naturally so low-lying that they are permanently wet (without artificial watering) and provide adequate opportunities for nature to develop. Surface water from the surrounding area is then drained to these zones via brooks and channels. Other zones were too heavily drained in the past to still be able to develop into ecologically valuable wetland. In these areas, weirs can be used to raise the groundwater level in relation to the surrounding area, where drainage remains guaranteed at all times.

Figure 3.9. Walkway in Bergenmeersen

Finally, the deep ponds of little natural value – mostly created by peat or soil excavations – can be filled in again, creating opportunities for marshes and hydrosere vegetation. By managing the areas in a natural way (grazing, mowing, zero management, etc.), rare plant and animal species will be attracted once again.

The rewetting is achieved by increasing the base level throughout the entire area as well as building weirs or digging channels and making the brooks shallower locally.

3.2 Reconciling divergent interests

Various points for attention were discussed during consultations with the project-based work group and the different thematic work groups. The following paragraphs describe how these points for attention were addressed when drawing up the land use plan for Bergenmeersen.

When drawing up the land use plan for Bergenmeersen, consideration was given to various concerns of the municipality of Wichelen (see also Chapter 2). Besides reorganising the existing FCA as an FCA-CRT by building a new inlet/outlet construction, the existing ring dyke was also brought up to Sigma height (+8 m TAW).

Figure 3.10. Land use plan for the Kalkense Meersen Cluster Sigma project

Figure 3.11. Detail of the land use plan for Bergenmeersen

Figure 3.12. Extract from the regional plan (a) and the "Kalkense Meersen Cluster" GRUP (b)

When designing the raised and broadened ring dyke, the current landwards-facing toe of the dyke was retained. The necessary raising and broadening were carried out along the river side of the FCA. In this way, the impact of this work on nearby homes in the district of Nederkouter could be limited: the distance between the ring dyke and the nearby homes has not changed.

The area was designed so that the higher parts of the flood area are on the edge of the built-up area of Nederkouter. In this way – as requested – sufficient distance was retained between the built-up area and those parts that regularly flood as a result of the reduced tidal action (see Section 2.6.1 and 2.6.2).

The ring dyke was made inaccessible to recreational users further to the request from the municipality of Wichelen. This prevented people from looking into and disturbing the homes in Nederkouter. However, walkers and cyclists can obviously use the existing overflow dyke to move along the Scheldt. A walkway was also constructed along which walkers can explore the area. The same walkway also allows visitors to admire the inlet sluices and the Scheldt water flowing in at high tide from close up.

3.3 Land use plan and spatial implementation plan

The land use plan for the Kalkense Meersen Cluster is the result of a great deal of research and consultation (see Figure 3.10).

Figure 3.13. "Kalkense Meersen Cluster" GRUP, finalised by the Flemish Government on 26 March 2010, shows the regional plan around the cluster.

The Bergenmeersen FCA-CRT is part of that land use plan. Figure 3.11 shows a detail of the flood area. The various dykes, the inlet/outlet construction and the source for the formation of streams are also shown.

As mentioned above, a regional spatial implementation plan (GRUP) was produced for the entire Kalkense Meersen Cluster. This GRUP changed the designated use of most of the plots to nature areas.
For Bergenmeersen, this meant that its designation as a rural area of ecological interest, rural area, nature area and residential area was changed to nature area.

To mitigate the effects for the agricultural sector, the GRUP provides for a phased conversion to nature area (see also Section 2.4.3). For Bergenmeersen, the conversion to nature area began on 1 January 2012. Figure 3.12 shows an extract from the graphic plan of the original regional plan and the new designations according to the GRUP.

3.4 References

- ***Ecosysteemvisie Cluster Kalkense Meersen (zone 1). Studie t.b.v. aanleg overstromings-gebieden en natuurgebieden i.h.k.v. het Sigmaplan.*** *(Ecosystem vision for the Kalkense Meersen Cluster (zone 1). Study for the development of flood areas and nature areas as part of the Sigma Plan.) G. Van Ryckegem et al. (2008), INBO.R.2010.3 / www.inbo.be/files/bibliotheek/83/246583.pd*

Figure 3.14. People walking on the walkway

4. NATURE

The sluices of the Bergenmeersen FCA-CRT were opened for the first time on 25 April 2013. At the time of writing, the natural development of the area was still in a primordial stage. Therefore the actual observed nature development in Bergenmeersen could not be described in this book (although some actual results are given in Chapter 8). Therefore, this chapter explains the expected nature development with relation to similar environments along the river Scheldt.

The nature target scenario was defined in the objective of the updated Sigma Plan. In this plan, just one coordinating objective was set out for Bergenmeersen: the development of 40 ha of estuarine nature. What this precisely implies is described below.

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4.1 Freshwater tidal area: a dynamic environment

Freshwater tidal mud flat and marsh areas are among the rarest habitats in Europe. Many estuaries have been cut off through the building of sluices and dams. Important area losses have occurred as a result of ever more intensive polder building. In the Scheldt estuary, however, remnants of these freshwater tidal mud flats and marshes still remain. Thanks to the Sigma Plan, the area is being extended through the creation of FCA-CRTs and managed re-alignment or managed dike retreat. The Bergenmeersen FCA-CRT will develop into such a rare and ecologically valuable freshwater tidal area.

Freshwater tidal areas differ sharply from the image the general public usually has of tidal areas. They are not the low grassy vegetation or vast treeless areas of the saltwater Zwin or the brackish Drowned Land of Saeftinghe. In the freshwater part of the Scheldt, the tidal areas tend to develop into extremely structured vegetation, leading ultimately to the development of tidal forest as the determining focal element.

This chapter describes the dynamic environment in freshwater tidal areas. A number of basic processes are outlined, such as nutrient exchange and the succession of plant communities and their inhabitants. Where possible, they are compared with existing

Figure 4.1. Freshwater tidal mud flats and marshes in the Scheldt estuary

areas along the Scheldt and developments in the Lippenbroek trial project. This shows, for example, that the management of the CRT sluice can determine to a large extent the morphological and ecological development in the area (see "Lippenbroek pilot project", p. 80).

4.2 Morphology of the terrain

4.2.1 Mud flats and tidal marshes

Mud flats develop in the lowest parts of the tidal area, which are flooded by the Scheldt at each high water. Few plants can withstand the stress of this flooding, so mud flats are generally barren. The higher-situated marshes only flood during spring tides and have plant growth according to the frequency of flooding. The elevation determines this frequency of flooding and consequently the habitat that is found there. For the development of a diverse mud flat and marsh ecosystem, it is therefore vital that the differentiation in flooding frequency is comparable to that of natural mud flat and marsh areas.

In the highest parts of the mud flats, some plants nevertheless manage to put down roots, such as common algae (*Vaucheria* sp.), water speedwell (*Veronica anagallis-aquatica* ssp. *anagallis-aquatica*), marsh-pepper knotweed (*Polygonum hydropiper*) and bog yellowcress (*Rorippa palustris*). As soon as these plants establish themselves there, the mud flat has evolved into a tidal marsh. The silt to which these plants attach themselves gradually increases in height, opening the way to further colonisation.

Thanks to their higher location, the marshes are no longer subject to daily flooding. Young marshes experience the highest flooding frequency. These young marshes gain in height because they always retain

Figure 4.2. Arial photo of the pattern of streams

sediment. This lowers the flooding frequency, and eventually, they only flood during spring tides.

Marshes are interwoven with channels along which the water flows in at high tide and flows out again when the tide ebbs. These channels create a distinct relief. When the water, loaded with sediment, leaves the channels at high tide, the heaviest sediments are deposited right next to the channel: the sand. This creates sandy bank walls. The lighter sediments, the silt, are only deposited further away in the lower-lying and wetter basins (or stream ridges). This therefore not only creates variations in flooding frequency, but also in soil composition.

4.2.2 Imitating the natural tidal dynamic

To introduce a tidal mud flat and marsh ecosystem into an FCA-CRT, a specific system of sluices is required that firstly enables the daily exchange of Scheldt water, and secondly, still ensures that the area can store sufficient water. On the one hand, the sluices must therefore dramatically reduce the inflow of water to ensure the function as an FCA (tide storage). On the other hand, they must guarantee an essential daily variation in water levels (the tide), maintaining a variation in level between spring and neap tides.

The sluices of an FCA-CRT consist of a system with high inlet sluices and low outlet

Figure 4.3. CRT sluice and stream source

sluices, which can also be adjusted by stop-logs. This system can reduce the tide while maintaining the spring/neap tide variation. However, the tide curve is no longer sinusoidal, but experiences a stagnant phase (see "Lippenbroek pilot project", p. 80).

Setting the right tidal dynamic is the decisive factor when developing tidal marshes. Hydrology is, after all, the main driving force behind physical, biological and chemical processes in tidal areas.

4.2.3 Sedimentation and erosion

Sedimentation is necessary to allow marshes to develop. The input of fresh sediment helps establish a typical marsh morphology (with among other things, stream ridges) and the typical marsh soil. These encourage the establishment of estuarine vegetation and benthic organisms. Hard polder clay does not contain the same organisms as a well-developed marsh soil. Furthermore, numerous biochemical processes occur in such marsh soil that are important to the functioning of the Scheldt ecosystem, such as the nitrogen or silicon cycle.

Overly fast sedimentation is not desirable. If alluvial deposits build up too quickly, this can create a poorly draining, semi-liquid, silt mass. In contrast to a developed mud flat teeming with benthos, liquid silt is unattractive to nature. Also because of the safety function in the FCA-CRT, excessive sedimentation must be avoided, as this leads to a loss of water-storing capacity, which in turn jeopardises protection against flooding. Because an FCA-CRT is entirely surrounded by dykes, it is less dynamic and there is more chance of sedimentation. On the other hand, the high inlet sluice only lets the top of the high-water wave in, which contains fewer suspended solids.

Besides sedimentation in and erosion of the polder area, the geomorphological development of channels is also anticipated. Despite the reduced tidal dynamic, a dense system of streams is expected to develop spontaneously (see "Lippenbroek pilot project", p. 80). As usual, an onset for the main channel was dug by the sluice construction in Bergenmeersen. This facilitates the inflow and outflow of water in the initial phase and will control, to some extent, the formation of channels away from archaeologically important sites.

In terms of sedimentation, FCA-CRTs differ fundamentally from natural marshes. In a natural marsh, a low elevation ensures a higher frequency of flooding, and thus greater silt deposits. This raises the height of the marsh, resulting in fewer alluvial deposits. This is known as negative feedback: the system will limit the alluvial deposits itself. In an FCA-CRT, the tide is not so much determined by the elevation, but by the sluices. The amount of water flowing through the sluices into the area does not change if an FCA-CRT is raised.

Monitoring of all sedimentation and erosion processes will show whether the area's tide storage changes significantly. Varying the inlet and outlet heights by adjusting stop-logs can help guide the process. This can be done depending on both the tide-storing capacity (safety) and the development of the natural dynamic in the area (natural quality).

Figure 4.4. Colonisation in the Lippenbroek

4.3 Vegetation

4.3.1 Initial succession

Before the work, Bergenmeersen was an agricultural landscape consisting mainly of intensively farmed grasslands. After the construction phase, some of these grasslands remained, in addition to a large area of bare, churned-up earth in the worksite zones.

The expected development of vegetation implies a dramatic shift towards hydrophyllic species . The first summer Bergenmeersen may retain the aspect of a (flooded) grassland. Eventually the grassland species and with a slight delay, also the more stress-resistant species such as stinging nettle (*Urtica dioica*) and hairy willowherb (*Epilobium hirsutum*) will be replaced by genuine wetland species. In line with the succession observed in the Lippenbroek, colonisation is expected by purple loosestrife (*Lythrum salicaria*), broadleaf cattail (*Typha latifolia*), speedwell (*Veronica* sp.), common reed (*Phragmites australis*) and willow (*Salix* sp.). In the more frequently flooded zones, the vegetation cover will make way for mud flat zones.

*1. Schematic depiction of the vegetation on a **saltwater marsh**. Only salt-tolerant plant species are found: mud colonisers (glasswort, common cordgrass), levee species (sea wormwood, seapurslane, seablite) and tidal soil species (sea lavender, sea aster, sea plantain, seaside arrowgrass).*

*2. Schematic depiction of the vegetation on a **brackish marsh**. We recognise the same mud colonisers as on the saltwater marsh: glasswort and common cordgrass. Bulrush and reeds grow on the tidal soils, with sea couch and spearscale on the levees. Once sufficient alluvial deposition has taken place, and in the absence of grazing, an extended reed land will emerge.*

*3. Schematic depiction of the vegetation on a **freshwater marsh**. Here, we find exclusively salt-averse plant species: mud colonisers are benthic algae and rushes, after which brushwood herbs appear on the levees, with reeds and other hardy marsh plants appearing on the tidal soil. Once sufficient alluvial deposition has taken place, a willow shrub and eventually willow wood will develop.*

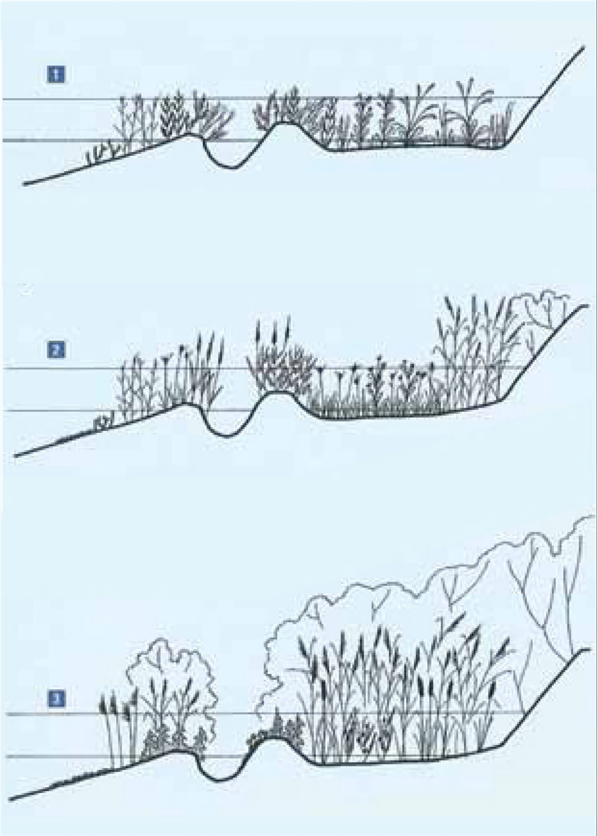

Figure 4.5. Schematic depiction of various marsh vegetations

4.3.2 Climax vegetation in a freshwater tidal marsh

The salt content in the saltwater and brackish part of the river is too high to allow trees to germinate. There, the marsh vegetation is treeless.

In the freshwater to slightly brackish part of the river, however, willows are able to germinate on the marshes, as they are highly resistant to widely varying water levels. Without management (mowing or grazing), freshwater tidal marshes therefore evolve into willow shrubs and woods. The willow tidal forest forms the climax vegetation on freshwater marshes. However, the willows on the boggy marsh soil rarely grow into tall trees: they are easily blown over in a storm, although they will continue to grow undisturbed. Freshwater marshes therefore look like mangroves: an impenetrable tangle of branches and channels.

Figure 4.6. The undergrowth of a tidal forest

The willow woods along the Scheldt naturally consist mainly of white willow (*Salix alba*) and crosses with crack willow (*Salix fragilis*). Along the Scheldt, the composition of willow wood is also subject to a heavy anthropogenic influence. The dome-shaped willow shrubs were often the product of the historical cultivation of willow twigs, used for wicker-making. These willows generally produce seeds with less germinative power than the species that form trees. On natural marshes, the dome-forming species, such as sharp-stipule willow (*Salix mollissima*) and basket willow (*Salix viminalis*), spread mainly through roots that wash up and sprout. This input is much less expected in an FCA-CRT with trash screens. Therefore it is expected that the willow shrub will tend to evolve towards a sprouting type of wood with the species specific to the area.

The undergrowth consists of marsh plants and brushwood herbs, such as rough bluegrass (*Poa trivialis*), common comfrey (*Symphytum officinale*), hedge false bindweed (*Calystegia sepium*), large bittercress (*Cardamine amara*), wild chervil (*Anthriscus sylvestris*), cleavers (*Galium aparine*), spider marsh marigold (*Caltha palustris* ssp. *araneosa*), angelica (*Angelica* sp.), touch-me-not (*Impatiens noli-tangere*), European water plantain (*Alisma plantago-aquatica*), European marshwort

(*Apium nodiflorum*), bitter dock (*Rumex obtusifolius*), cowparsnip (*Heracleum* sp.) and figwort (*Scrophularia* sp.). Specific mosses grow on the regularly flooded root base of the willows in the willow thickets and woods. These mosses prefer this dynamic, food-rich and muddy environment.

4.3.3 Spider marsh marigold: the tidal freshwater marsh specialist

The spider marsh marigold (*Caltha palustris* ssp. *araneosa*) is a subspecies of the "ordinary" marsh marigold. The ordinary marsh marigold (*Caltha palustris* ssp. *palustris*) is a fairly common species on well-developed wet grasslands. The spider marsh marigold, conversely, is one of our rarest species, bound to the freshwater marshes along the Scheldt and a number of other rivers.

Figure 4.7. The spider marsh marigold

What is remarkable about the spider marsh marigold is its adaptation to the action of the tides. It is, for example, much hardier than the ordinary marsh marigold. Germination is difficult due to the daily fluctuations in the tidal zone in that environment. The variety has therefore specialised on vegetative reproduction. Young leaves with their own roots develop on the buds and in the leaf axils of old leaves. The roots join together in a ball, making them look much like a spider. These "spiders" are released in the autumn, carried away by the tidal flow, and can develop into a new plant in another location. The spider marsh marigold therefore makes ingenious use of tidal movements to propagate itself.

4.3.4 Timing of operation as a determining factor

The initial situation and the time at which the sluice is opened for the first time are very important for the development of a complete vegetation succession. Experience in other areas (mainly de-poldering) shows that a long period between completion of the work and the onset of tidal flooding gives willows ample time to germinate. An extremely dense willow wood very quickly develops on the fallow ground. Once established, the willows continue to grow – even after the tide has been let in. As a result, herbaceous marsh vegetation has less chance to develop, and the complete succession pattern is shortened. The woody plants anchor the bottom with roots, thereby restricting the dynamism of the formation of streams. This is also a missed opportunity for joint use by benthos (animal life on, in or near the soil) and birds.

Work in Bergenmeersen was completed early in the spring of 2013. To allow natural succession to take place as much as possible and avoid rapid colonisation by willows, the sluice of the FCA-CRT was opened as quickly as possible, on 25 April 2013.

4.3.5 Forests in Bergenmeersen

The proportion of forest in the area is determined by controlling the inlet and outlet sluices, as these determine the ratio of mud flat to marsh. The project stipulates that the maximum flooding may be around 80% at spring tide. On the remaining 20% flooding is only expected during extreme weather conditions and can therefore be characterised as high marsh. The bare ground left after the work forms an ideal germination bed for willows. Willow woods are expected to appear quickly on this 20%. If further marshes are formed, this may extend to more than 50% of the area (in the long term even to around 75% or 30 ha of forest).

In a little afforested region as Flanders (with only around 10% forest cover), the development of several dozen hectares of forest is extremely welcome. For this same reason, the project development aims to preserve the total wooded area in the project cluster. In connection with the EIA (see Chapter 1), a forest audit was produced that monitors the wooded area for the Kalkense Meersen Cluster as a whole.

During the work, trees unavoidably had to be felled for dykes to be constructed, but also to allow nature to develop. Over the years, many (often small) plots of grassland were planted with poplars. These poplars will be felled to restore the former grassland biotopes. The deforested area will be fully restored within the project cluster. The 30 ha of willow tidal forest in Bergenmeersen represents the main positive contribution to the forest audit (alongside an alder carr in Wijmeers of approximately the same size).

Biodiversity increases with forest size. A rule of thumb is that a genuine forest environment only exists from a minimum size of 10 ha. Consolidating the many small areas of forest (on average less than 1 ha) into one larger forest of several dozen hectares therefore represents significant added value for the forest ecosystem. Moreover, the willow tidal forest thus created is also a seriously threatened type of forest and therefore highly valuable. This means that Bergenmeersen's importance also lies in the formation of forests. This may seem surprising as an image of a tidal area, but it is a normal evolution in a freshwater marsh.

4.3.6 Diatoms

Algae form the basis of the entire estuarine food chain. They capture the energy of the sun and use it to accumulate sugars through photosynthesis. The algae thus form a source of food for many small organisms

Figure 4.8. Diatom

in the water column (zooplankton) and the soil (zoobenthos), which are in turn eaten by higher trophic levels, such as crustaceans, fish or birds.

However, not all algae are equally suited as a source of food. Diatoms take precedence. These single-cell algae have a special skeleton that offers them extra protection. This skeleton is made from silicon. Dissolved silicon is therefore an essential food source for diatoms. Since diatoms are an important basis of the food pyramid, the available silicon plays an important role in the aquatic ecosystem (unlike terrestrial ecosystems).

4.4 The nutrient cycle

4.4.1 Eutrophication

One of the main problems that coastal zones and estuaries faced in recent decades is eutrophication, or over-fertilisation. Untreated waste water from agriculture, industry or households carries large amounts of the nutrients nitrogen and phosphorus into the Scheldt estuary via watercourses. However, silicon has not increased, which has led to a major change in the ratio between the nutrients silicon, nitrogen and phosphorus.

The changing ratio between the basic nutrients can lead to "silicon limitation". Diatoms grow until all the silicon has been used up. If there is then still a surplus of nitrogen and phosphorus, other unwanted algae can take it over. These so-called pest algae result in a massively negative phenomenon: among other things, foaming, anoxic water and toxic water masses. Because diatoms form the basis of the estuarine food chain, eutrophication and the associated silicon limitation can cause the collapse of the entire food chain.

4.4.2 Exchange processes in the tidal areas

The processes in an FCA-CRT and other tidal areas can have a major influence on the composition of the water. Bacteria in the mud convert nitrogen into nitrogen gas through the process of nitrification/denitrification (see "Lippenbroek pilot project", p. 80), which allows nitrogen to escape from the water. As a result, tidal areas play an important role in reducing the pollution load.

Conversely, almost no phosphate conversion takes place. Only a small fraction is absorbed by plants.

Oxygen-enrichment of the water occurs physically through the operation of the sluices, the sharp rise in the surface area of the water and the primary production of the plants in the FCA-CRT. Results from the Lippenbroek show that the amount of dissolved oxygen in the water increases enormously after it has spent time in the FCA-CRT.

A less well-known aspect is the release of dissolved silicon into the marshes, which is of great importance to the growth of diatoms (see Section 4.3.6).

4.4.3 Silicon cycle

In particular, common reeds (*Phragmites australis*) absorb dissolved silicon (DSi) (H_4SiO_4) through the roots. Once the silicon has been absorbed by the plant, it is fixed in highly silicon-rich structures:

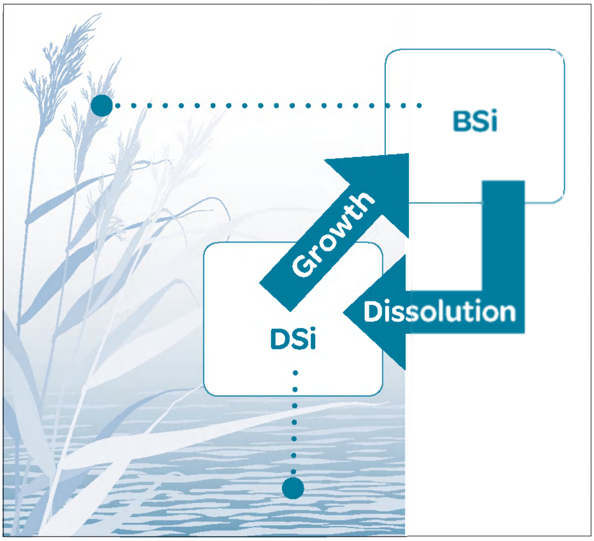

Figure 4.9. The silicon cycle

phytoliths (biogenic silica or BSi). The fixing of silicon can give a plant various competitive advantages compared with other species: greater resistance to plant diseases, damage from herbivores and metal toxicity, and greater strength. Reeds stack up silicon during their growth: higher concentrations of silicon are found in the longest-living plants, at the end of the growing season. Once a dead reed stem has fallen over (e.g. knocked over by wind or water), the silicon can dissolve into DSi and become a source of silicon.

Besides dead reed stems, there are other potential sources of BSi for marsh sediments. At high tide, a great deal of floating material such as sediment, dead and live phytoplankton and other plant material is carried in by the water. Some of this material settles onto the surface of the marsh. The BSi from the decaying organic material is also stored in the sediment.

The BSi in the sediment gradually dissolves into DSi in the interstitial water. This means the concentrations of dissolved Si in freshwater marsh interstitial water are much higher than the concentrations in flood water. During the frequent floods, the BSi that has dissolved into DSi can easily be exchanged with flood water. BSi also dissolves relatively quickly when it comes into contact with water with low dissolved silicon concentrations. Therefore, the Scheldt water that flows out of the CRT is enriched with silicon compared with the incoming water. Marshes form rich reservoirs of silicon within the estuarine ecosystem, which is important for the growth of diatoms and the support of the food pyramid.

In short, the Bergenmeersen FCA-CRT will play a role in the enrichment of dissolved silicon and oxygen, and in the reduction of the nitrogen load. It is expected that there will be at least a local positive impact on the ecosystem of the Scheldt.

4.5 Higher trophic levels

4.5.1 Fish

Importance of the Scheldt estuary to fish

Estuaries serve as nursery grounds for many young marine and freshwater fish and are a transit and spawning zone for migratory fish. In the Sea Scheldt, on the one hand, marine fish species flourish to upstream of Antwerp; some species even swim further to past Dendermonde. On the other hand, freshwater fish are sometimes seen downstream of Zandvliet. A great many of the species of fish known in Flanders can thus occur in the Sea Scheldt. In 2012, sampling revealed 41 species of fish in the Sea Scheldt. These figures are considerably high than in the past. The return of migratory fish in particular illustrates the benefit of the efforts made to reduce the pollution load in the river and increase oxygen levels.

The FCA-CRT as fish habitat

Within the estuary, the mud flat and marsh areas play an important role as an incubating and foraging area. Research into the fish communities in the Lippenbroek show that fish can also make use of an FCA-CRT. The area is less dynamic than the estuary and the diversity of habitats ensures that different species come into their own at different stages of life. Over the years, the number of species and individuals has increased in every type of habitat studied. A total of 20 species were observed.

The fish community in the Lippenbroek initially consisted mainly of pioneer species and introduced species such as the three spined stickleback (*Gasterosteus aculeatus*), the Prussian carp (*Carassius gibelio*) and the stone moroko (*Pseudorasbora parva*). Over the years the fish community evolved differently according to the habitat, with mainly European smelt (*Osmerus eperlanus*) in the stream, common roach (*Rutilus rutilus*) in the reservoir and three-spined stickleback in the permanent pools.

Species such as the Prussian carp, the stone moroko and the common roach complete their entire life cycle in the Lippenbroek. Migrating species such as the European flounder (*Platichthys flesus*), the European smelt and even the European seabass (*Dicentrarchus labrax*) use the Lippenbroek as a nursery area (see "Lippenbroek pilot project", p. 80). Predatory fish such as the European pikeperch (*Stizostedion lucioperca*) mainly forage in the reservoir.

It is expected that the creation of the Bergenmeersen FCA-CRT can contribute significantly to the fish community of the river ecosystem. This could be directly, through the creation of habitat in the flood area, and indirectly, by improving conditions in the river (see Section 4.4). Initial fish monitoring has produced highly encouraging results (see Chapter 8).

Eel in the FCA-CRT

The importance of the Lippenbroek as a foraging area for the European eel (*An-*

Figure 4.10. Common roach

Figure 4.11. Eel

guilla anguilla) was recently investigated. The question was whether the FCA-CRT is important as a foraging area for eel and if so, how the eel's diet in the FCA-CRT differs from that in the Scheldt.

Comparison of the stomach contents of eels from the Lippenbroek and the Scheldt revealed that the diversity of prey in the Lippenbroek is around four times greater than in the Scheldt. In the Lippenbroek, eels feed more on terrestrial prey such as earthworms, caterpillars and other insects, in addition to fish, fish eggs and other benthic organisms. The energy value of the prey taken in both cases was calculated using information from the literature. This showed that the value in the Lippenbroek was around twice as high as in the Scheldt.

Although a health index reveals approximately equal values, it was demonstrated statistically that eels caught in the Lippenbroek are significantly heavier for a given body length than the examples caught in the Scheldt. It has therefore been shown that FCA-CRTs are an important habitat for the eel and contribute towards the recovery of the eel population.

Figure 4.12. Twaite shad

The return of the twaite shad

Until the end of the nineteenth century, the Scheldt was an important spawning area for various species of migratory fish such as the twaite shad (*Alosa fallax*) and European smelt (*Osmerus eperlanus*). The populations of these species were large enough to allow commercial fishing. The Scheldt became so polluted during the twentieth century that an anoxic zone was created and parts of the river were de facto biologically dead. Considerable efforts have been made to improve the ecological quality of the Scheldt since the end of the twentieth century. In the first place, efforts to treat domestic waste water play an important role. The Sigma Plan is continuing to improve the ecological quality (habitat, nutrient cycle) and by increasing the area of estuarine habitat through the removal of polders or the creation of FCA-CRTs.

As a result of these efforts, fish stocks are recovering. One species that has made a remarkable comeback in the Scheldt is the twaite shad (*Alosa fallax*). The twaite shad is a member of the herring family and can grow to a length of 60 cm. Because of the spots on its sides, it is also known as the spotted giant herring. Another local name is the May fish, because it is caught in the tidal zone of major rivers in the spring (May). The twaite shad is an anadromous fish: it lives in the sea, but spawns in the mouths of rivers. If the temperature rises above 11°C, the fish swim upstream. Where the tides are more pronounced, they lay their eggs in more low-dynamic zones with gravel and/or sand.

Until a few years ago, twaite shads were no longer found in the Scheldt. Now both adults and juveniles are being found, which points to successful reproduction. The lower limit of dissolved oxygen for twaite shads is 3 mg/l. The presence of twaite shads is therefore an indication of good water quality. If the water quality continues to improve, the twaite shad could herald the return of other species.

4.5.2 Birds

General

Freshwater tidal areas maintain particularly large and diverse bird populations. The Scheldt is of international importance for 21 species of waterfowl. Approximately 100 species of bird use the estuary to breed or when passing through. This is why almost all of the tidal area of the Sea Scheldt was designated as a Habitats and Birds Directive area.

The Scheldt between Ghent and Dendermonde is characterised by a narrow navigable channel and very little mud flat and marsh areas. The waves created by ships make it impossible for birds to look for food along the water line in peace. Waterfowl numbers are therefore also much lower. Where there are still mud flats and marshes of reasonable size, such as in the tidal arm by Ghent, the population of reed birds and waterfowl is more diverse and more extensive.

Figure 4.13. Bluethroat

The relationship of several bird groups to the developing environment is outlined below. Not all species and groups are covered. The focus is on bird groups that are likely to be encountered in Bergenmeersen.

Songbirds

Depending on the proportion of willow shrub, two groups of songbirds can be distinguished on the freshwater marshes. The first only breeds in relatively broad and fresh reed vegetation without thickets. Typical species are the sedge warbler (*Acrocephalus schoenobaenus*) and the common reed bunting (*Emberiza schoeniclus*).

A second group consisting of the Eurasian reed-warbler (*Acrocephalus scirpaceus*), the marsh warbler (*Acrocephalus palustris*) and the bluethroat (*Luscinia svecica*) not only breed in pure reeds, but in coarse reeds, brushwood and thickets. They also breed easily in relatively narrow, linear strips of reed vegetation.

Bergenmeersen will remain unmanaged, and over time a large part of the FCA-CRT will evolve into willow tidal forest. The settings of the sluice of the FCA-CRT will determine the evolution of the proportion of mud flat and marsh and thus also the breeding area of the second group of reed birds in particular.

Herons

The nature objectives of the updated Sigma Plan include a limited number of breeding pairs for colony-forming thicket- and tree-breeders, such as black-crowned night-herons (*Nycticorax nycticorax*), Eurasian spoonbills (*Platalea leucorodia*) and purple herons (*Ardea purpurea*). Creating opportunities for these species consists of providing

Figure 4.14. Purple heron

suitable breeding locations close to good foraging areas.

The purple heron is currently not a breeding bird in Flanders. It is relatively flexible in its choice of nesting location. Key preconditions are tranquil environment and a nesting place that is difficult for predators to reach. They nest in reeds or dense scrub (willow and alder thickets) as well as high in the trees. The foraging habitat of the purple heron consists mainly of marshy areas and ditches in grassland areas. The birds forage exclusively by day, actively walking along the banks. Their food consists of fish, mammals, amphibians and large water insects.

There is considerable potential for the purple heron in the Kalkense Meersen Cluster, thanks to the combination of suitable foraging habitats: wet grasslands, marshes, reed land, combined with the development of willow tidal forests of which Bergenmeersen can become the primary example. This combination makes the cluster one of the most promising zones for the purple heron along the Scheldt.

Bergenmeersen could become important as a breeding location for a number of other species of heron. A condition is that good spatial complementarity is established at cluster level between Bergenmeersen as a breeding area (breeding colony) and the rest of the Kalkense Meersen Cluster as a foraging area. At the same time, Bergenmeersen could become attractive as a foraging area to species such as the Eurasian spoonbill and genuine "marsh herons" such as the night heron.

Waterfowl

Large groups of ducks are mainly found in the freshwater part of the Sea Scheldt. For the common teal (*Anas crecca*), the area in the zone upstream from Dendermonde is very important. During the winter, up to 1,000 overwintering common teals are

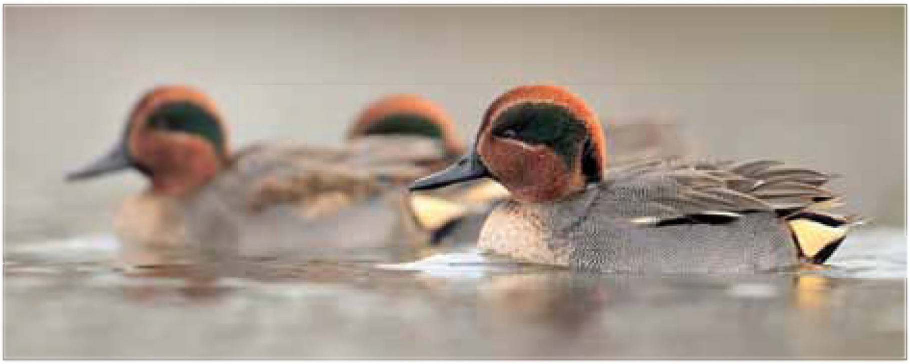

Figure 4.15. Common teals

counted. With up to 300 individuals, the Northern shoveler (*Anas clypeata*) is approaching the Ramsar norm here (1% of the population of north-western Europe). The larger mud flat and marsh areas, such as the tidal arm by Ghent, are home to up to 70 mute swans (*Cygnus olor*). The importance of the mud flats and marshes becomes even greater in times of frost, when other freshwater areas in the vicinity freeze over. The tidal areas along the Scheldt then form an area for rest and foraging that helps maintain populations in adjacent areas.

The different species of duck depend on mud flats and open water for their food. Common teals (*Anas crecca*), gadwalls (*Anas strepera*), common shelducks (*Tadorna tadorna*) and mallards (*Anas platyrhynchos*) filter mud, looking for seeds, earthworms (*Oligochaeta*) and other benthic organisms. Common shelducks are known to eat small crustaceans, snails and diatoms. Common pochards (*Aythya ferina*) and tufted ducks (*Aythya fuligula*) dive in the water for their food. The ducks look for food and shelter in the relatively open marshes when water levels are higher.

The action of the tide in Bergenmeersen is creating a dynamic system that will reach a state of equilibrium in a number of years or decades (see "Lippenbroek pilot project", p. 80). The initial situation will include a large proportion of mud flats and open water, which means mainly ducks and waders are expected at the onset. As the marshes evolve and become covered with reeds and willows, reed birds and thicket-breeders can colonise the area.

4.5.3 Mammals

General

The number of mammal species expected in Bergenmeersen is quite a bit smaller than the number of bird species. For several species adapted to the water, however, the area could provide a habitat in time.

Water shrew

The water shrew (*Neomys fodiens*) is found in water-rich biotopes with rich bank vegetation and structurally rich banks. In addition to the banks of streams and lakes that are not too steep, the flood zones of rivers, marshy areas and reedy borders also form the biotope of this species in Flanders. Wooded areas are also possible (temporary) habitats. The water shrew is a good swimmer and looks for its food – all manner of invertebrates and small fish – in the water. The shrew is a mobile species that is found in the Scheldt basin and could possibly colonise the flood area.

Figure 4.16. Water shrew

Beaver

The common otter (*Lutra lutra*) and Eurasian beaver (*Castor fiber*) are on the rise in Flanders, and are therefore significantly interesting. Bergenmeersen is not expected to become a suitable area for otters, but things may well be different for the beaver.

Figure 4.17. Beaver

The ecological amplitude of the beaver is considerable: the species can be found in flowing highland streams, lowland marshes, but also in tidal areas. In principle, the beaver needs adequate open water to build a lodge, channels to move about without leaving the water and sufficient food. Beavers are uniquely able to adapt circumstances to their advantage. They do this, for example, by building dams or digging small channels to extend their range. This is why they are also known as "ecosystem engineers". Beavers are strict vegetarians: thanks to special bacteria in their caecum, they can digest woody plants without any problem. They prefer soft varieties of wood, such as poplar, willow and birch, of which they eat the bark, twigs and leaves. They also eat a variety of water and marsh plants, including the roots.

Studies in Canada indicate that the density of beaver lodges is nowhere greater than in untouched estuaries or tidal forests. The area required by a family of beavers is thus relatively small in a freshwater tidal area. Therefore Bergenmeersen could be big enough to house a beaver family.

Beavers became extinct in Flanders in the nineteenth century, but are now gradually colonising Flanders again after being reintroduced in Wallonia. It is therefore not impossible that the beaver will soon also appear in Bergenmeersen.

4.6 Sluice settings as guiding factor

The setting of the sluices in an FCA-CRT is decisive for the development of the area. This is because the sluices determine the tide, and the tide is the determining factor in estuarine areas. In Bergenmeersen, the aim is to develop such an estuarine area and to give the natural succession as many opportunities as possible. Adaptive sluice management was chosen in order to anticipate on the developments in the area. This is described in Chapter 8, where the relationship with other requirements (such as safety) is also discussed.

The basic requirements for sluice management in favour of nature development can be summarised as follows:

1. Allow tidal flooding as soon as possible after the completion of the construction works. This prevents the land from becoming quickly and permanently wooded.
2. In an initial period (the **transformation phase**), a fairly high tidal dynamic should be created to begin the formation of channels and deposit a first layer of sediment. The former agricultural area is converted into an estuarine area as quickly as possible, with as large a proportion as possible of mud flats.
3. In the subsequent, possibly rather long period (the **succession phase**), the sluice management should be carefully controlled to allow mud flats to gradually evolve into marshes and the succession

to reed vegetation and willow tidal forest can take place.

4. Once the desired mud flat/marsh ratio has been achieved, the sluices can be given their permanent settings (**stable phase**). The global picture of the area is then more or less established; it now consists of up to 75% willow tidal forest. In the long term, however, the relief can be altered by sedimentation and erosion such that the flooding frequencies differ from the desired final picture. At that point, minor adjustments to the sluices may be required.

4.7 Conclusion

The concept of an FCA-CRT is a recent one. Bergenmeersen is the first full-scale FCA of this type in the world, after the Lippenbroek pilot area. Compared with de-poldering, the situation is highly controlled. After all, the sluice of the flood area and the sluice settings will determine the dynamics and succession of mud flats and marshes.

Current knowledge of the tidal areas in the freshwater part of the Scheldt, including the Lippenbroek, give us an idea of the future development of the Bergenmeersen area. The final picture is a willow tidal forest of approximately 30 ha and a mud flat area of approximately 10 ha, cut through by tidal channels. The whole guarantees exceptionally diverse fauna and flora, the expected elements of which are more or less known. However, surprises cannot be ruled out, given the size of the area and recent developments in the Scheldt basin. The influence of the new arrangement on the local river ecosystem will be subject to close monitoring.

Figure 4.18. Tidal forest

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PILOT PROJECT

THE LIPPENBROEK

The concept of the flood control area with controlled reduced tide (FCA-CRT) is being applied for the first time on a large scale in Bergenmeersen. But it was previously tested extensively in the Lippenbroek pilot project (Hamme). There, various universities and institutes, such as the University of Ghent, the Free University of Brussels, the Research Institute for Nature and Forest, Flanders Hydraulics Research and the Royal Netherlands Institute for Sea Research, headed by the University of Antwerp, are investigating the operation of the concept. The key question for the Lippenbroek: can sustainable ecological structures and functions develop in FCA-CRTs that are qualitatively and quantitatively similar to those of undyked mud flats and marshes?

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The Lippenbroek is a former polder area of 10 ha along the left bank of the Scheldt in Hamme. It was a typical Scheldt polder used for agriculture, with maize and potatoes as the principal crops and a small poplar plantation.

The Lippenbroek lies in the freshwater tidal area of the Scheldt, some 10 km upstream of Rupelmonde. In times of flood, this meant that the area received part of the pollution load of the city of Brussels and experienced high nutrient concentrations and a low oxygen saturation when the water flowed in. Because the intention was to measure the area's contribution to the recovery of the quality of the estuary's water, this was not seen as a problem. Water treatment in Brussels (and throughout Flanders) has since advanced considerably, and the quality of the Scheldt water has improved significantly.

In 2004, work began to convert the area into an FCA-CRT. This involved building the new ring dyke, lowering an overflow dyke on the side of the Scheldt and constructing a new inlet sluice to create the reduced tide. Drainage is through a separate sluice construction with a non-return valve.

A low elevation, +2.5 to 3 m TAW, is typical of such an area. By way of comparison: the undyked marshes before the Lipenbroek lie at +5.5 to 6 m TAW. The ingress of water into the flood area must ensure that the tide in the lower-lying polder approaches that of the river

Figure 4.19. Arial photo of the Lippenbroek

as closely as possible. The inlet sluices were therefore fitted with stop-logs. Experiments with "trial water ingress" helped find the most suitable sluice configuration.

The sluices were opened permanently in March 2006. An extensive monitoring programme was begun to see how the organisation of such a flood area leads to the development of mud flats and marshes.

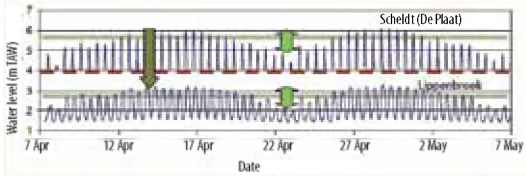
Tidal cycle

Modelling showed that, thanks to the system of high inlets and low outlets, it is possible to vary the frequency of flooding considerably. However, the inlet construction must be sufficiently high (+4.7 m TAW in the Lippenbroek). Only then is there sufficient difference in water ingress duration and volume to create the desired significant variation in water levels in the polder.

Measurements of the water level in the Lippenbroek and De Plaat reference marsh show that the sluice construction reduces the high water level by around 3 m, without affecting the variation between neap tide and spring tide. The slack tide is reduced to the level of the polder. As a result the Lippenbroek is not flooded daily, but experiences a wide range of flooding frequencies. These are mainly determined by the sluice configuration and no longer by elevation in relation to the level of the Scheldt. This provides opportunities for marshes to develop in low-lying areas.

Figure 4.20. Situation of the Lippenbroek

Figure 4.21. Tidal variation



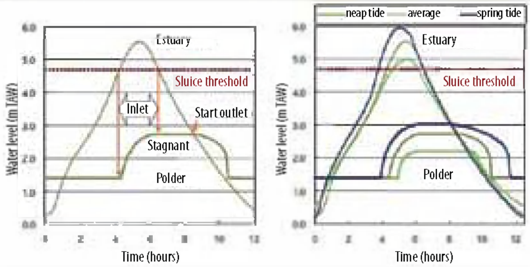


Figure 4.22. Tidal modelling

Detailed measurements of individual tidal cycles show, as already indicated by the modelling, that the shape of the tide is altered. The tidal curve is no longer sinusoidal. The tidal cycle in the FCA-CRT now has three phases: flood, stagnant and ebb. As soon as the level of the Scheldt exceeds the high ingress level, a powerful flood occurs. Following ingress, the stagnant phase begins. The ebb phase can only begin when the level of the Scheldt drops below the water level in the Lippenbroek. The stagnant phase, which lasts an average of 2 to 2 and a half hours, is a key artefact of an FCA-CRT. For a similar flooding frequency, such flood areas therefore experience an extended period of flooding. The possible ecological implications of this are being investigated in the Lippenbroek.

Sedimentation and erosion

Sedimentation is monitored closely due to its considerable importance for the ecosystem and safety. The results are clear: the Lippenbroek exhibits sedimentation speeds that are comparable with those of natural marshes. At the lowest points these are high, up to 10 cm a year. The higher parts hardly silt up at all, with just a few millimetres a year. As a result, the lower parts increase in height more quickly and the area levels off: we get a marsh plateau, cut through by large and small channels. Somewhat unexpectedly, these channels form quickly and easily in the Lippenbroek. The hard polder clay and the sluice constructions do not prevent the tide from cutting out numerous new channels. Obviously this process takes time,

Figure 4.23. Network of streams in the Lippenbroek

but after just six years, a clearly branched network of streams has begun to emerge. The existing polder ditch was also affected by the tide. This ditch became wider and deeper towards the mouth; it is silting up into a narrow channel at the back of the area.

Water quality

Water that leaves the Lippenbroek is clearly of better quality than water that flows into it. Passing through the sluices and spending time in the area ensure significant oxygen enrichment.

One important characteristic of natural tidal areas is that they remove nitrogen. The inflow and outflow of nitrogen in the Lippenbroek was therefore closely monitored during various tidal campaigns. With each tidal movement, the Lippenbroek removed approximately 10 kg of nitrogen from the Scheldt water. That is a lot, but the area of FCA-CRTs will never be large enough to reduce the current nitrogen load in the Scheldt to an acceptable level. Measures at the source are therefore required, such as water treatment plants and restrictions on the use of fertiliser. Tidal areas have the job of removing the remaining diffuse influx that evades the water treatment plants.

Phosphorus was not initially removed from the Lippenbroek, on the contrary. There was an outflow of phosphorus during the first few years, probably a legacy of years of fertilisation in the former arable land. In recent years, however, the trend has reversed and the Lippenbroek is now also absorbing phosphorus.

The export of silicon is a more subtle story. When there are no shortages in the estuary, the Lippenbroek absorbs dissolved silicon. If there are shortages, it is expected that dissolved silicon will be released: this is how natural marshes work. And initially, this was indeed what happened in the Lippenbroek: large amounts of dissolved silicon were released from the mud flats and marshes. But a large part of that silicon will probably be consumed in the Lippenbroek itself. The channels and tidal pools that are permanently under water are hot spots of biological activity. The released silicon strengthens the function of the Lippenbroek as a rich food area, but the export of dissolved silicon to the Scheldt has decreased.

Fauna and flora

For a habitat to recover successfully, complete fauna and flora development is needed to form a stable food chain. Vegetation, zoobenthos and fish have been monitored systematically since March 2006; the bird population has been monitored since autumn 2006. These observations are dealt with in Chapter 4.

What is remarkable for the Lippenbroek is the influence of the separate inflow and outflow of water on fish migration. Targeted basket weir catches show that the fish are not entering the polder in large numbers via the water inlet. Rather, a fairly limited passive migration was noted via this route. Nevertheless, the fish do find their way in and out of the flood area, via the outlet sluice. Perhaps the fish are attracted by the oxygen-rich lure flow that leaves the polder as the water flows out. This means the fish are migrating against the outflowing water, from the Scheldt to the polder. It is expected that outlet sluices will also be mainly responsible for fish migration in other areas.

Conclusion
The Lippenbroek shows that estuarine recovery in low-lying polders can be made to proceed very quickly by developing FCA-CRTs. Thanks to the creation of suitable tidal conditions, spontaneous rapid evolution follows towards a functional mud flat and marsh ecosystem. Oxygen enrichment and nutrient cycling were demonstrated in the Lippenbroek. The prolonged flooding period of an FCA-CRT does not seem to present an obstacle to colonisation by fauna and flora.

The effects of the Lippenbroek on the water quality of the Scheldt itself cannot be measured. This is because the pilot project is too small to have an influence. However, model calculations show that large FCA-CRTs such as Bergenmeersen nevertheless make a significant contribution to the Scheldt ecosystem. The updated Sigma Plan provides for the creation of hundreds of hectares of that type of flood area, thereby giving the Scheldt estuary a welcome boost.

Figure 4.24. The yellow iris grows profusely in the Lippenbroek.

5. PREPARATORY INVESTIGATION

A great deal of preparatory investigation preceded the organisational work at Bergenmeersen. This was necessary to gain an insight into soil quality and structure and the archaeological richness of the project area, since these elements influence the design and costs of the project.

This chapter describes the results of the environmental, geotechnical and geophysical soil survey and the archaeological survey. It also examines the model trials of the inlet and outlet sluices. It is through these sluices that the Scheldt water will flow into and out of the flood control area with controlled reduced tide (FCA-CRT).

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5.1 Environmental soil survey

To allow earth to be moved in accordance with Flemish legislation, a technical report was produced. During that environmental survey, the OVAM (the Public Waste Agency of Flanders) guidelines, in the form of codes of good practice, were followed. The accredited soil remediation expert Talboom NV was called on in this connection within the context of an ongoing framework agreement.

A drilling plan was drawn up, resulting in 52 mixed samples. These mixed samples were analysed on the standard package for earth-moving and 5 mixed samples for the water bed. Gradings were also taken of 24 soil samples, to allow an initial estimate of structural quality to be made. The fieldwork and analyses were carried out in mid-September 2010.

Because Bergenmeersen is an historical polder where controlled flooding has already been taking place for three decades, a certain increase compared with background values was to be expected. This is because the Scheldt sediment is still enriched by historical industrial (discharge) activities. The survey revealed that reuse of the soil within the same cadastral work zone was possible from an environmental perspective. As a result the transportation of soil and the hindrance that comes along with it were significantly reduced.

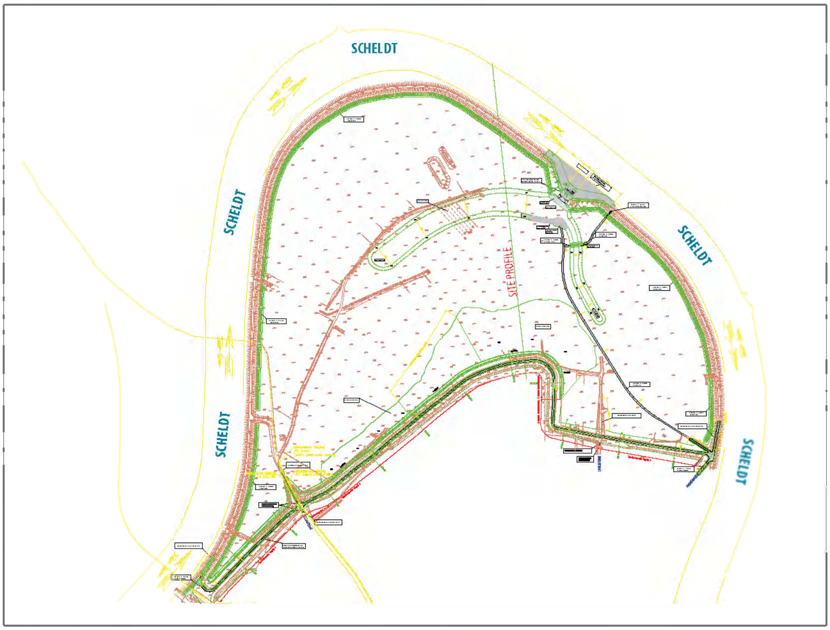

Figure 5.1. Results of the environmental soil survey

5.2 Geotechnical and geophysical survey

5.2.1 Geotechnical survey by the Geotechnical Department

In a preparatory phase, the Geotechnical Department was commissioned to carry out a thorough survey of the subsoil. The Department first reviewed the information that was already available in that area. Old maps (Ferraris (1771-1778), old topographical maps, etc.) were studied, focusing on things that might have disturbed the subsoil, such as wheels, dyke breaches, old channels and meanders. During this phase, the investigators also looked at which geotechnical tests were previously conducted in the area based on the Database of the Subsoil of Flanders (DOV).

A soil study programme was drawn up based on the available information. This study was split into fieldwork and lab work.

Eleven cone penetration tests (CPT) were performed in the zone of the ring dyke and at the site of the future structures in the existing dykes, on average every 50 m. In cone penetration tests, steel pipes are forced into the ground using hydraulic jacks. The resistance of the soil is measured every 2 cm, allowing an initial diagnosis of the subsoil to be made.

Based on the results of the cone penetration tests, it was decided at which locations bore holes would be useful. A total of 4 bore holes were drilled to a depth of between 15 and 30 m. During this process the soil was loosened; in total, 17 intact samples were taken, which were then tested in the laboratory. An extensive series of lab tests (diagnostic tests, determination of weight by volume and water content, compression tests and CU triaxial tests) allows the composition of the soil to be accurately determined, in addition to a number of specific properties such as slide resistance and compressibility.

Based on the soil survey, a layer structure was produced over the entire course (Figure 5.2). The subsoil was divided into layers and the calculation parameters that would enable the stability calculations to be made were determined. At the ring dyke, the subsoil consists of a series of weak layers 5 to 6 m thick, followed by clay and sand alternately. At a depth of 10 to 15 m is a stronger sandy subsoil layer.

5.2.2 Non-destructive geophysical test by G-Tec/IMDC

In addition to the geotechnical study by the Geotechnical Department, G-Tec/IMDC carried out a non-destructive geophysical test of the Scheldt dyke. This consisted of a geophysical diagnosis using electromagnetic measurements and diagnosis via resistance tomography.

Electromagnetic measurements are designed to plot the electrical conductivity of the body of the dyke and the subsoil. The primary electromagnetic field generated by

Figure 5.3. Equipment used for non-destructive geophysical tests

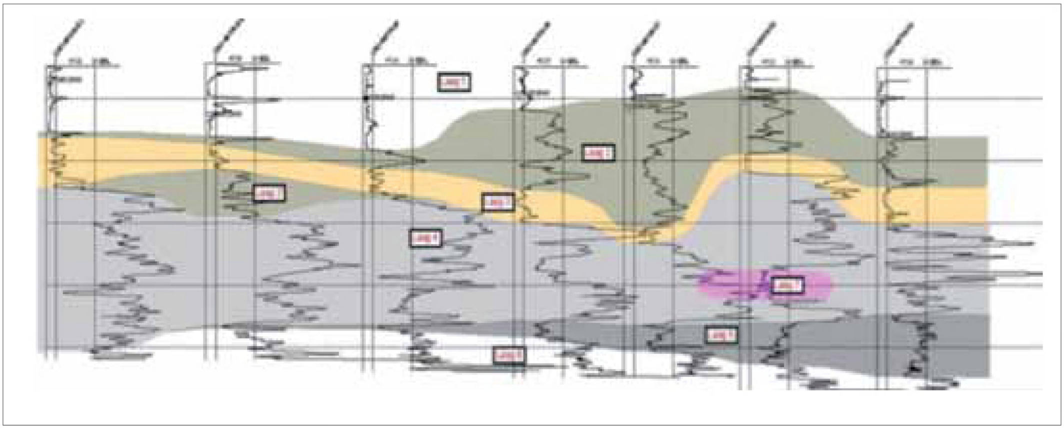

Figure 5.2. Layer structure of the ring dyke

the equipment will develop a secondary electromagnetic field in the vicinity. The phase displacement of the resulting field provides information about the apparent conductivity of the shallow soil. Variations in soil type, moisture content and electrically conducting objects will lead to variations in recorded apparent conductivity.

The use of resistance tomography is intended to provide an indication about the material from which the dyke is constructed or of which the subsoil consists. Here, the potential is measured between two electrodes under the influence of a current field created between two other electrodes. In practical terms, hundreds of combinations are measured with a set-up of several electrodes. Figure 5.4 shows an extract of the results.

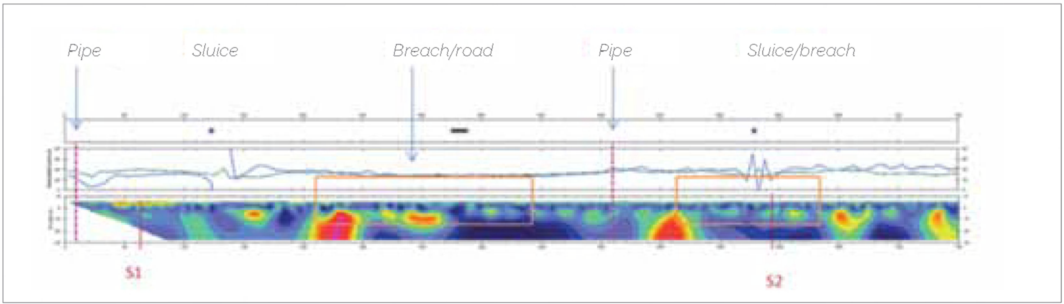

Figure 5.4. Results of the non-destructive geophysical test

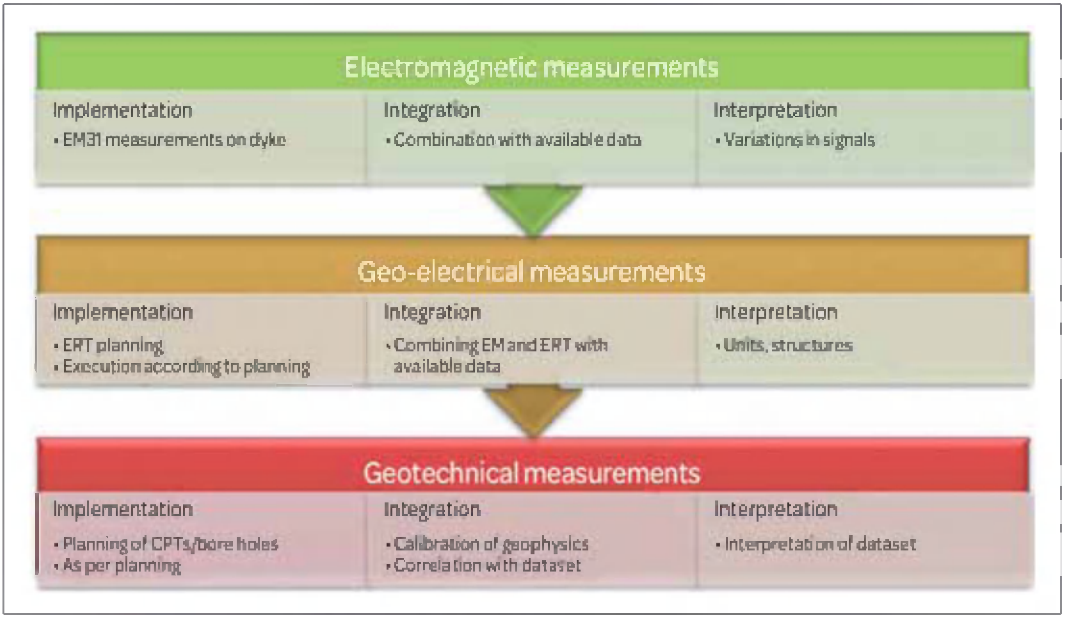

Figure 5.5. Step-by-step plan of the geotechnical and geophysical tests

5.2.3 Interaction of geophysical survey with classic geotechnical survey

Following a study by Flanders Hydraulics Research, a step-by-step plan was developed (Figure 5.5). In the future, other projects will therefore begin with the geophysical survey, consisting of electromagnetic and geoelectrical measurements. Once these have been evaluated, the geotechnical survey can be continued on a targeted basis.

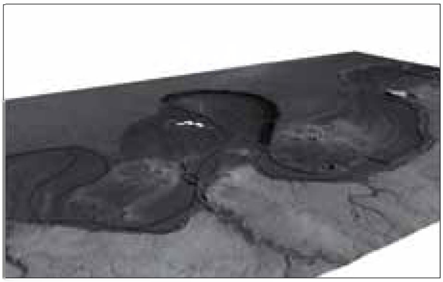

Figure 5.6. Remnants of an impressive river system in the subsoil of the Kalkense Meersen Cluster

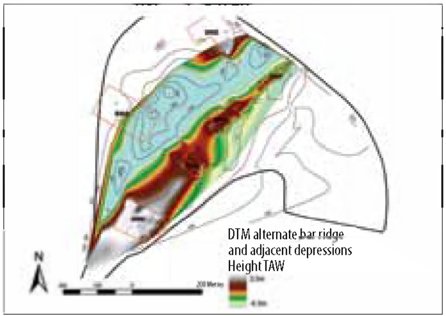

Figure 5.7. The channels flank a striking ridge.

5.3 Exceptional archaeological heritage

From early prehistory, the evolution of the landscape in Bergenmeersen was dominated by the behaviour of the Scheldt. Since the end of the last Ice Age, around 12,000 years ago, mankind always found its place in that changing landscape.

The archaeological survey in Bergenmeersen therefore firstly mapped the earlier landscape, through ground samples and historical maps. This allowed several zones to be identified that seemed very well suited to the presence of archaeological sites. Using ground samples and so-called geophysical prospecting, archaeologists went looking for possible sites.

The original construction plans were partially adapted, so that several archaeological sites were spared. Two other locations, where the threat of future erosion could not be avoided, were excavated in 2012. All this information, perhaps only the archaeological tip of the iceberg, shows an area rich in archaeological sites, from prehistory to the present day.

A dynamic landscape

The structure and evolution of the landscape in Bergenmeersen can only be understood from a broader regional perspective. After all, the subsoil of all the zones in the Kalkense Meersen Cluster contains the remnants of an impressive river system, the main river of which was 100 m wide and up to 9 m deep (Figure 5.6).

This channel is also present in Bergenmeersen; it is now full of peat and clay and is invisible on the surface. A small side channel still runs to the south-east of this channel. These channels therefore flank a striking ridge, which formed a "peninsula" throughout early prehistory (Figure 5.7).

The study of fossil pollen grains and radio carbon dating of the infill of these channels give a good picture of the changing environment and the speed at which the system silted up. Thus, from the end of the last Ice Age, we see the evolution towards a densely wooded landscape, first with birch and pine, and later towards a highly diverse deciduous forest, with oak, lime and hazel, among others. By around 6,000 years ago, however, the system of channels had completely silted up and the area became very boggy. Alder and later willow were the dominant tree species. From this period on, the Bergenmeersen "peninsula" gradually disappeared beneath peat and clay. The Scheldt river system evolved towards a pattern of smaller rivers that wound through the carr.

It was only around 3,000 years ago that, at the start of the Iron Age, a river of significance was again cut: the current Scheldt. Bergenmeersen's subsoil still shows numerous traces of this river's activity, in the form of small side channels and lobes of sandy flood deposits. All these relics of the earlier Scheldt are covered by a layer of clay, flood sediment mainly deposited in the Roman period to after the Middle Ages. Historical sources point to the fact that polders were only created at Bergenmeersen fairly late on, in the eighteenth or nineteenth century. Before this period, the sources only mention small summer dykes. Major floods of the area are therefore reported until into the seventeenth century. One last noteworthy change is the straightening of the Scheldt at the end of the nineteenth century, when the eastern meander bend was cut off (Figure 5.8). This brought a large number of important archaeological finds to light.

Archaeological sites

Even before the archaeological fieldwork, earlier finds in the Bergenmeersen zone showed that the area probably contains a great many archaeological sites. When the Scheldt was straightened at Paardeweide in 1892, for example, one of the largest collections of tools made from bone and antler was collected by a lawyer, A. Moons (Figure 5.9). A large number of these finds entered the collection of amateur archaeologist Georges Hasse through a public auction in 1922. In the mid-1930s, Hasse devoted two articles to "Wichelen préhistorique" on the basis of the finds.

Study has revealed the location of the finds to be no surprise. After all, the straightened section crosses the earlier loop of the Scheldt perfectly (Figure 5.8). In all

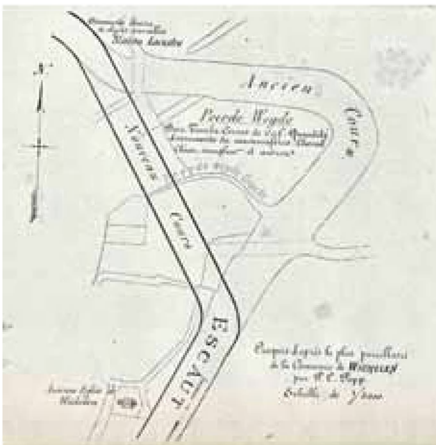

Figure 5.8. Map from 1905 drawn by A. Moens, with the locations of the straightened meander bend and the prehistoric finds

Figure 5.9. When the Scheldt was straightened at Paardeweide in 1892, one of the largest collections of tools made from bone and antler was collected.

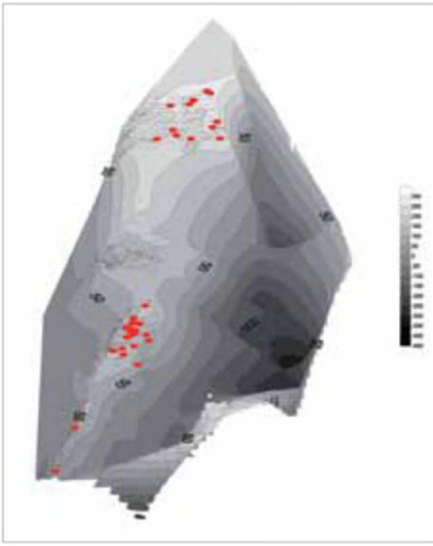

Figure 5.10. Digital height model of the central ridge in Bergenmeersen, indicating archaeological ground samples. The ground samples containing prehistoric finds are shown in red.

likelihood, the objects come from encampments of prehistoric hunter-gatherers on the banks of this channel. Radio carbon datings of several tools indicate that various periods of habitation are covered by the collection, ranging from around 5,300 to 3,800 years ago.

The 2009 bore-hole survey confirmed the area's appeal for prehistoric man. A relatively large number of finds (flint tools) were unearthed on the ridge between the two old Scheldt channels. These show that the location was visited regularly during the Stone Age. The excavations in 2012 also uncovered prehistoric finds. Some of the excavated finds (more flint tools) can be assigned to the start of the middle Stone Age (early Mesolithic, around 8,500 to 7,500 years ago).

Various finds and traces were unearthed from the Iron Age and Roman times, such as several channels, drains and post-holes. However, it is not clear what precisely these finds mean. The traces are probably situated on the edge of farming settlements from these periods.

Historical sources point to the fact that Wichelen was an important centre in the early Middle Ages, more specifically in the tenth century (Carolingian-Ottonian period). However, finds from this period remain rare.

During earlier dredging work in the Scheldt near Wichelen, several cloak pins from this period were found, among other things. During the excavations in 2012, finds from this period were limited to one or two shards. Perhaps the centre of early Middle Ages Wichelen lies outside the Bergenmeersen area, on higher and dryer ground.

One of the most remarkable finds in Bergenmeersen comes from the later Middle Ages. Based on historical sources, the presence of a medieval "castle" had long been suspected in the area (Figure 5.11). In one of these sources, a plot was indicated with the name "motte". That led people to suspect that this could be the site of a medieval castle. In 2009, geophysical measurements indicated that the subsoil of that plot could indeed contain a broad circular moat, which was confirmed by the excavation in 2012.

The moat, approximately 12 m wide and 2 m deep (Figures 5.12 and 5.13), surrounds a circular "island" approximately 40 m in diameter. Unfortunately, the central embankment of that island appeared to have been completely excavated, which meant no structures of the earlier edifice remained. One or two natural stone blocks and fragments of brick dumped on the inside of the moat recalled the presence of stone structures. Thanks to the other waste in the moat, mainly pottery, the site was able to be placed in the thirteenth to fourteenth century.

The remains of a bridge, a brick pillar and several wooden beams were found in the eastern part of the moat. This construction is probably more recent. Dating studies on the wooden beams will confirm this. Together with the location of the former church of Wichelen (in the current churchyard, just outside Bergenmeersen), the late medieval structure undoubtedly forms one

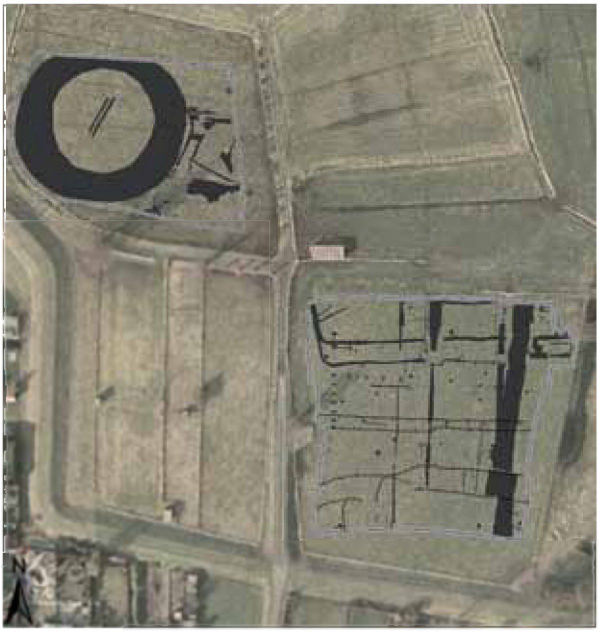

Figure 5.11. General excavation plan of Bergenmeersen. The moat from the castle site is in the north-west.

Figure 5.12. A section of the medieval moat

of the core elements of medieval Wichelen. The erection of this type of castle site, circular structures with a diameter of approximately 40 m, is typical of the thirteenth and fourteenth century.

Figure 5.13. A section of the medieval moat

However, most traces date from the post-medieval period, more specifically from the sixteenth and seventeenth centuries. Finds from this period can most likely be associated with the presence of the "Hof ter Zeype", which appears on historical maps from the eighteenth century (Figure 5.14).

Figure 5.14. The Hof ter Zeype appears on historical maps from the eighteenth century.

Historical sources already show a substantial farmstead at this location in the sixteenth and seventeenth century. The traces mainly concern a number of channels, drains and holes. The precise significance of these traces is yet to be explained.

Conclusion

Although the excavation results are still being processed, it can be concluded from all the information that the Bergenmeersen project area contains exceptional archaeological heritage. Numerous finds have been made from prehistory in particular, which suggests that the area was a choice spot for hunter-gatherers for thousands of years. From later periods, the presence of a late medieval "motte" is particularly noteworthy.

5.4 Model tests of the inlet and outlet sluice

The combined inlet and outlet sluice is a key element in the concept of the FCA-CRT. Flanders Hydraulics Research carried out a hydraulic revision of the desktop design of the combined inlet and outlet construction of Bergenmeersen. Waterways and Sea Canal outsourced the design of the construction itself to Tractebel Engineering in collaboration with IMDC NV. The hydraulic functioning of the construction was tested by means of a scale model study.

To test the combined inlet and outlet constructions of several FCA-CRTs with a single scale model, a very simplified 2DV scale model was designed. 2DV means that the model is built into a channel; only the flow in a two-dimensional vertical plane is studied. The scale model has a geometrical scale of 1:8. The model zone is 0.56 m wide, 1 m tall and 15 m long. The geometry of the constructions under test is formed by flat plates, secured to movable scissor lifts. With this arrangement, not only can constructions easily be changed, geometric adjustments can also easily be made. Figure 5.15 shows the possibilities for adjusting the scale model.

Figure 5.15. Possibilities for adjusting the scale model

The following recordings were made in the scale model:

- level upwards and downwards,
- rate of flow through the construction,
- near-bottom speed,
- length of fall,
- level of drainage shaft,
- visual recordings of flow pattern.

The difference in level over the construction is greater when water is being let in than during drainage, which means proportionally more energy has to be dissipated. The scale model study therefore limited itself to inflowing water.

When water is flowing in, the energy is dissipated via a hydraulic jump. For the durability of the construction, the supercritical flow after the falling stream must immediately be converted into a subcritical flow via a hydraulic jump. To make this hydraulic jump possible, a sufficiently high level is needed in the FCA-CRT. The minimum level at which the hydraulic jump occurs immediately after the drop is the "corresponding" level. The required corresponding level increases the higher the level of the Scheldt. Figure 5.16 illustrates the situation with a water level that is too low on the left and the situation with the corresponding level on the right.

Figure 5.16. The situation with a water level that is too low (left) and the corresponding level (right)

If the water level in the flood area is too low, the water flows into the area: the so-called supercritical flow. In the flood area, this is only converted into a subcritical flow via a hydraulic jump. Such a situation leads to unacceptable flow speeds above the gabions, and possibly to scouring at the point of the hydraulic jump downstream from the constructions. If the water level is equal to or higher than the corresponding level, the hydraulic jump occurs immediately after the drop (in the construction itself). Since the construction is made of concrete, that is not a problem.

It follows from comparing the corresponding level with the simulated levels in the area that the hydraulic jump will always occur immediately after the drop.

To adjust the incoming volumes depending on the tide, stop-logs are placed in the inlet shaft. After the stop-logs, the inflowing water in the inlet shaft can accelerate to supercritical speeds. The influence of stop-logs on the course of the falling stream, the occurrence of a hydraulic jump and near-bottom speeds were investigated. It followed from these investigations that the configurations with stop-logs are less critical than the configurations without stop-logs because of the lower rate of flow.

To dimension the soil protection consisting of gabions on the side of the flood area, the near-bottom speed above the gabions and the length of the hydraulic jump were measured.

To obtain a stable falling stream, the literature recommends aerating the space below the stream. To investigate the need for aeration, tests have been carried out with both aerated and non-aerated streams. Air is added where the falling stream comes into contact with the water surface. The air in the drainage shaft is also sucked in below the falling stream. This creates an underpressure in the drainage shaft if the falling stream is not aerated. This underpressure aspirates the falling stream and raises the level in the drainage shaft. No influence was noted of the (non-)aeration on the occurrence of a hydraulic jump and on the near-bottom speed above the soil protection. No unstable course or vibrations were noted with a non-aerated falling stream.

Eddies with an air core can occur at the point when the ceiling above the stilling pool is flooded. The combination of Scheldt levels and the levels of the FCA-CRT at which

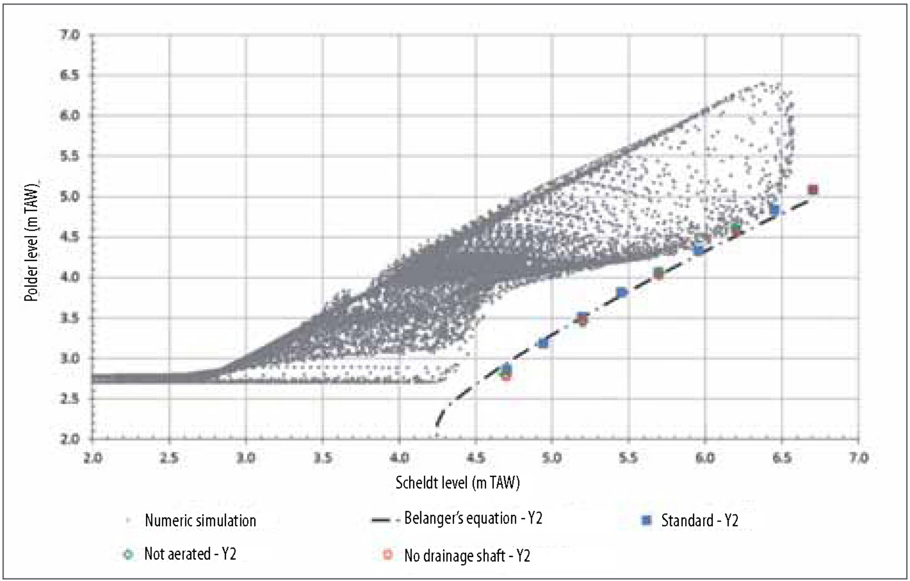

Figure 5.17. Results of standard configuration: polder level Y2 depending on the level of the Scheldt

eddies occur merits the necessary attention. It is inferred from the simulated levels that a flow pattern involving eddies with an air core occurs only exceptionally and so does not present a danger to the durability of the construction.

It could be concluded from the hydraulic revision that the design of the engineering firm for the combined inlet and outlet construction is hydraulically adequate. Important insights were gained. These are significant on the one hand for evaluating the construction when it is operational, and on the other for combined inlet and outlet constructions still being designed for other Sigma areas.

5.5 References

- ***Inlet sluices for flood control areas with controlled reduced tide in the Scheldt estuary: an overview.*** *T. De Mulder et al. (2013), IWLHS 2013: international workshop on hydraulic design of low-head-structures. p. 43-53 / www.vliz.be/imisdocs/publications/243672.pdf*
- ***Stilling basin optimization for a combined inlet-outlet sluice in the framework of the Sigmaplan.*** *J. Vercruysse et al. (2013), IWLHS 2013: international workshop on hydraulic design of low-head-structures. p. 55-66 / www.vliz.be/imisdocs/publications/88/243588.pdf*
- ***Paleolandschappelijk, archeologisch en cultuur-historisch onderzoek in het kader van het geactualiseerde Sigmaplan, sigma-cluster Kalkense Meersen, zone Bergenmeersen en Paardenweide***. *(Paleo-landscape, archaeological and cultural-historical study for the updated Sigma Plan, Sigma-Kalkense Meersen Cluster, Bergenmeersen and Paardenweide zone.) F. Bogemans et al. (2009), Intern rapport, Flanders Heritage Agency (Brussels)*
- ***Digitale Ondergrond Vlaanderen*** */ Database of the Subsoil of Flanders / www.dov.vlaanderen.be*
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6. TECHNICAL DESIGN

To convert Bergenmeersen from a flood control area (FCA) to a flood control area with controlled reduced tide (FCA-CRT), the existing dykes were modified and a new inlet and outlet construction was built. This chapter outlines the hydraulic and geotechnical design. This encompasses raising the existing ring dyke around the area, the new stability calculations and the modified dyke revetment along the water and land side. The inlet and outlet structure is also described. The hydraulic boundary conditions are extremely important to the design.

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6.1 Hydraulic boundary conditions

These hydraulic boundary conditions are important for the design: water levels, water velocities, wind waves and ship induced waves.

6.1.1 Water levels

For the updated Sigma Plan, the dyke (crest) heights are fixed. They were determined for the entire Sigma area on the basis of a study of social costs and benefits. It follows from the assumptions of the update study for the Sigma Plan that dykes along the Sea Scheldt and tributaries must be water-retaining to water levels equal to 0.5 m below the crest of the dyke. Non-water-retaining infrastructure such as overflow dykes and inlet and outlet constructions may not fail structurally at these water levels. In concrete terms, this means that the constructions are designed for a high water level of +7.5 m TAW for Bergenmeersen.

No unique return period was assigned to the water level to be retained (or the design water level). Because the updated Sigma Plan is being implemented on a phased basis, safety will gradually increase in the period 2010-2030 (or the probability of the design water level will decrease). The interplay of climate change, economic and ecological developments and additional measures will then maintain the risks of flooding at socially acceptable levels.

In addition to the maximum water level of +7.5 m TAW, the variation of the level is also

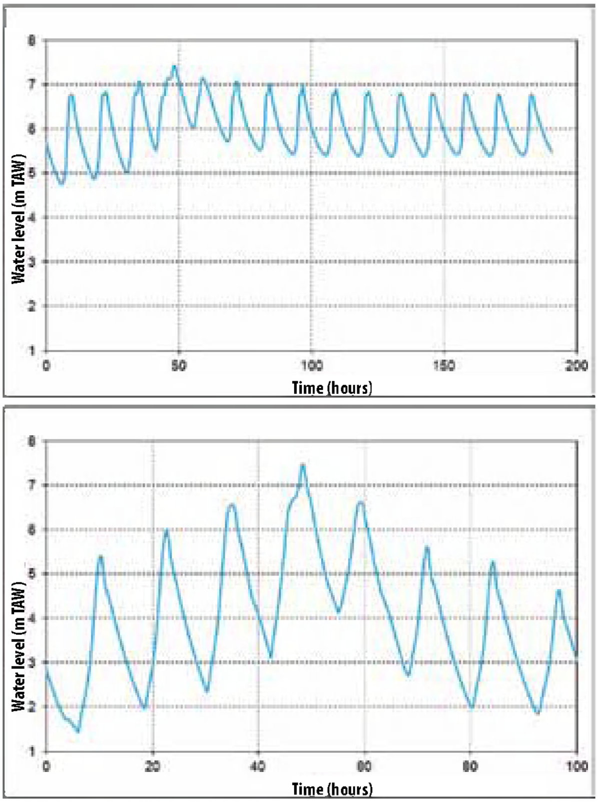


Figure 6.1. Two examples of level variations used for the design: small level variation (above) and large level variation (below)

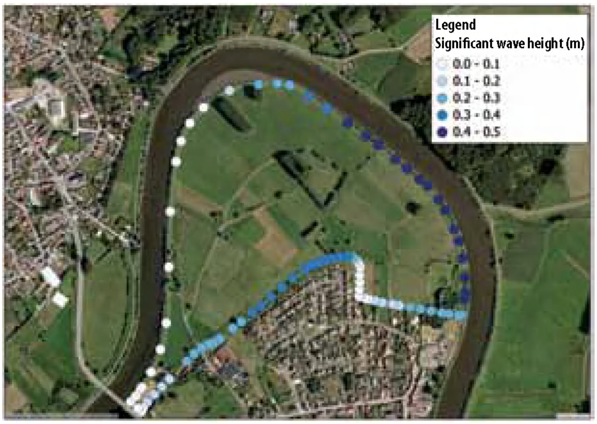


Figure 6.2. Wind wave load on the dykes of Bergenmeersen

extremely important. A rapid fall or rise in the water level, for example, leads to high flow speeds through the outlet structure. If the water level remains more or less constant for a long time, the load on a grass covering on the dyke increases. Allowance was therefore made for different variations in level. In total, 15 different hydrographs were taken into account in each case. These hydrographs were determined on the basis of a thorough statistical analysis of water levels in the Scheldt. Figure 6.1 shows two extremes. Both are characterised by the same maximum water level of +7.5 m TAW, but the variation of the levels differs significantly.

6.1.2 Water velocities and waves

In addition to the design water level, the load on the hydraulic structures is also caused by water velocities, ship induced waves and wind waves. The water velocities were determined on the basis of one-dimensional hydrodynamic simulations of the Scheldt; the ship waves were calculated using the DIPRO method. As with the water levels, no return period was assigned to the design ship waves and water velocities.

Wind waves, on the other hand, were estimated for various return periods. They were calculated using Wilson's empirical formula, given the wind direction, wind speed and fetch length, and then combined with the design water levels.

Figure 6.2 shows an example of the wind wave load on the flood area side of the overflow dyke and the ring dyke. The eastern dyke segments clearly experience a greater load than the western segments.

6.2 Dykes: calculation method and safety

6.2.1 General

Bergenmeersen is surrounded by dykes with a total length of 3.2 km, comprising 2 km of overflow dyke and 1.2 km of ring dyke. The crest of the overflow dyke is at +6.4 m TAW, the crest of the ring dyke at +8 m TAW. The slopes are relatively gentle, with a gradient of 12/4 on the Scheldt side and 16/4 on the land side.

The dykes are inspected for macrostability (sliding of the land or river slope), uplifting of the water-retaining layer (microstability) and seep erosion (piping and heave) beneath and along the dyke.

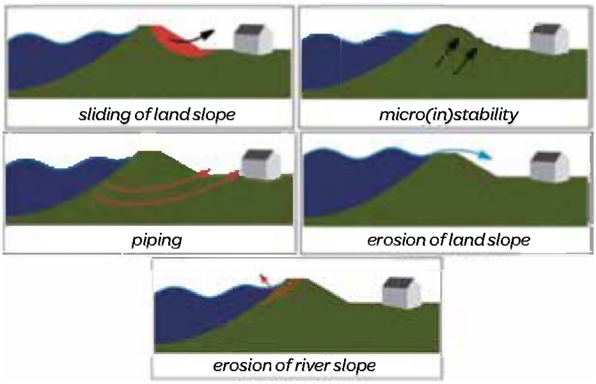


Figure 6.3. Failure mechanisms investigated

The land side of the overflow dyke is loaded by the high flow speeds of the overtopping water when the flood area is filling. The land side of the ring dykes can be loaded by overtopping water as a result of wind waves. A suitable revetment must prevent erosion of the land slope as a consequence of this phenomenon. Every effort was made to find an ecological solution.

The water side of the ring dyke is loaded by the impact of wind waves. Once again, a revetment that is suitable but preferably as natural as possible protects the dyke against possible erosion of the river slope.

Strictly speaking, settlement is not a failure mechanism. However, settlement calculations were carried out to be able to determine the initial settlement allowance of the dykes.

6.2.2 General stability

To check general stability, both stationary (with constant values for the water levels) and non-stationary calculations (with variable water levels) were carried out. The calculations were carried out with the Plaxis finite element package and in Geostudio.

An undrained calculation was also carried out in Plaxis. This allows the implementation period of the various construction phases to be taken into account. Stability in Plaxis was determined using the φ-c-reduction. Within this calculation, the tan φ and cohesion c of the ground are gradually reduced until (part of) the structure fails.

For the interim phases (such as the construction of the sand core), a minimum safety of 1.1 was required; for the final phase (construction of final dyke profile, possibly fully consolidated), a minimum safety of 1.3. This value was achieved for all dyke segments. Figures 6.4 and 6.5 show two typical results of this modelling.

6.2.3 Uplifting

To avoid uplifting, it was checked whether the upward water pressure below the impermeable layer on the land side is greater than the dead weight of the earth package. If that is the case, earth will be pushed up and a leak will appear on the land side. If that phenomenon occurred, further checks were performed to see whether the resulting flow through the dyke remains limited. No problems with uplifting were found for the dykes of Bergenmeersen.

6.2.4 Seep erosion

Two types of seep erosion play a role: piping and heave. Piping develops along the underside of the structure, more or less in a horizontal direction. This forms an erosion channel. Heave is vertical, and is associated with the disappearance of the effective grain pressures. The grains of sand are picked up and rinsed away by the water, as it were. The critical (outflowing) hydraulic gradient is limited to 0.5.

Piping is irrelevant for dykes on permeable and cohesionless subsoil. No piping can occur if material rinses out at the inner toe of a dyke. This is because the hole immediately caves in, since sand is cohesionless. For dykes on a subsoil that is cohesive and poorly permeable (clay and peat), piping will only occur if the earth can be lifted up outwards from the dyke.

If the dimensions satisfy one of the following criteria, there is no danger of piping:

- $\Delta g / \Delta w > 1$
- $L / 18 > \Delta H - 0.3 d$

No seep erosion problems were found for Bergenmeersen.

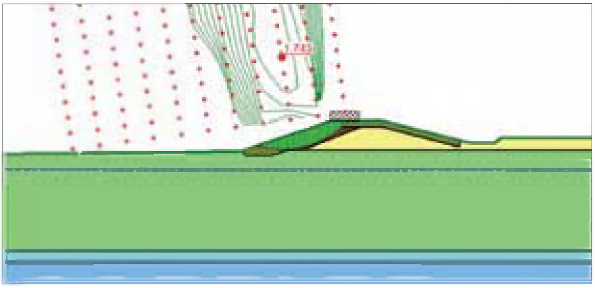


Figure 6.4. Example of sliding at the GEO-08/228-S7 test bore (outwards LW linear, Geostudio)

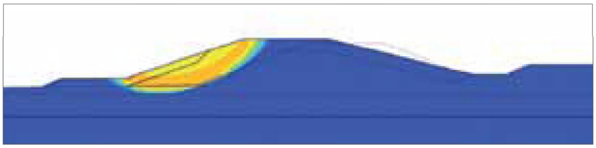


Figure 6.5. Example of sliding at the GEO-08/228-S7 test bore (consolidated LW Plaxis)

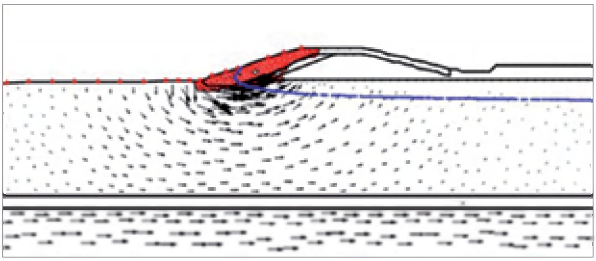


Figure 6.6. Flow at the GEO-08/228-S7 CPT. There is flow below the dyke, but the hydraulic gradient at the outflow does not exceed the critical value.

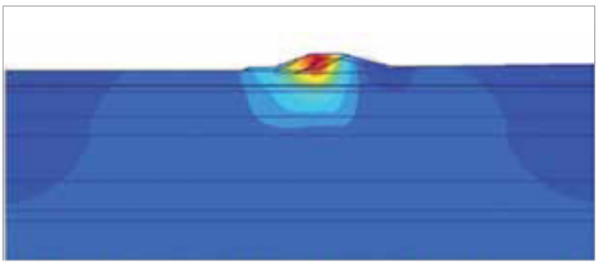


Figure 6.7. Vertical movements at CPT S5, consolidated condition (Plaxis, maximum 13 cm)

6.2.5 Settlement

Even after the dykes have been constructed, further settlement occurs. Settlement was checked using Plaxis and verified by manual calculations (according to Terzaghi). Based on the soil characteristics and layer structure, a choice was made beforehand of where the minimum and maximum settlement is expected (based on the CPT numbers).

The settlement was checked in drained and undrained conditions. For the undrained condition, a realistic estimate was made of the minimum implementation periods for the different phases. In this way, the expected consolidation of the materials was taken into account.

The settlement of the ring dyke is 3 to 13 cm. It was proposed that this dyke be constructed with a settlement allowance of 15 cm at the crest and that the settlement allowance be decreased to 0 cm towards the toe of the dyke.

6.2.6 Erosion of the land slope

The water that flows over the overflow dyke is moving at high speed and can cause erosion of the slope and the toe of the dyke on the side of the flood area. To avoid dyke instabilities, slope protection and soil protection at the toe are provided.

The supercritical flow over the slope changes to a subcritical flow downstream from the toe of the dyke. This occurs with a hydraulic jump. To position the hydraulic jump above the soil protection, an energy dissipater (stilling bassin) is installed at the foot of the overflow dyke. This takes the form of a lined channel that not only drains water, but also acts as a dissipater.

To dimension the energy dissipater channel, a software program was developed that calculates the water levels and water velocities from the crest of the overflow dyke, over the slope and into the channel, as far as the flood area. The calculations took account of the filling of the area behind. The result: a channel with a depth of 0.5 m, a bottom width of 2 m and 8/4 slope gradients is sufficient to fix the hydraulic jump.

The maximum water speed over the overflow dyke is reached between the start of the overflow and the maximum level in the flood area. The maximum water velocity for Bergenmeersen is 6.3 m/s. In that case, the most suitable slope protection on the dyke is open stone asphalt (OSA). The open structure prevents water overpressures from the dyke acting on the revetment. To prevent erosion, the channel also has to be lined with OSA.

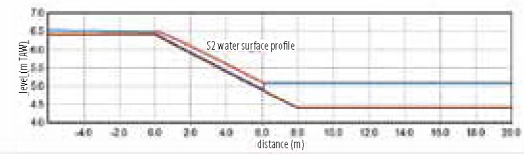


Figure 6.8. Calculation of the hydraulic gradient line over the overflow dyke

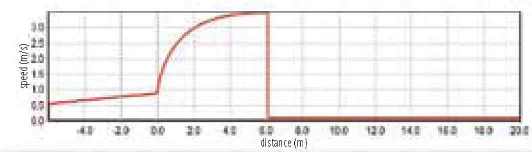


Figure 6.9. Speeds of the flowing water over the overflow dyke

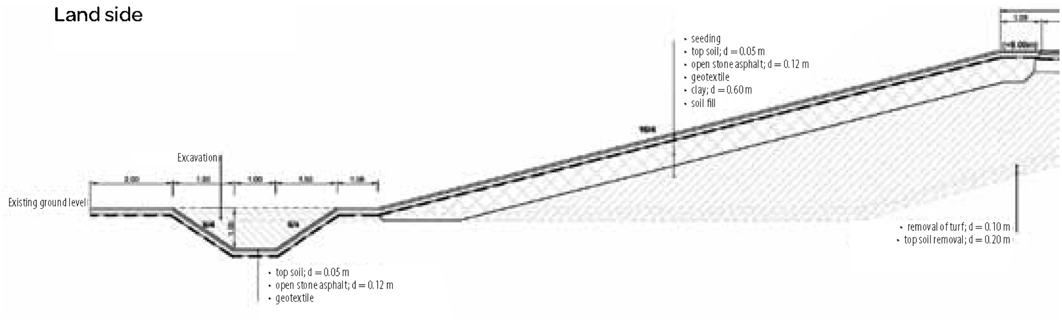


Figure 6.10. General structure of the covering of the overflow dyke

This lining is continued in the direction of the polder over a distance of 2 m.

The land side of the ring dyke can also be loaded by the flow of the water. The ring dyke is higher than the overflow dyke and therefore cannot flood directly. However, wind waves can overtop the dyke in highly exceptional situations. The wave overtopping flow rate was calculated. A good grass covering appeared to suffice to prevent erosion through overtopping.

6.2.7 Erosion of the water side of the ring dyke

In principle, this is the failure mechanism of erosion of the river slope. For the slope of the ring dyke on the side of the flood area, the most important load is caused by wind waves. These wind waves were calculated with Wilson's empirical formula. The final wave height can rise to 0.32 m for a return period of 100 years and 0.39 m for a return period of 4,000 years.

It was first investigated whether grass with a good layer of clay beneath it is sufficient as a revetment for the dyke. For grass, the duration of the load is very important, as well as the wave height. The lower section of the dyke in particular experiences long-term loading from wind waves. Figure 6.11 illustrates this for one of the calculated hydrographs.

A grass revetment by itself did not appear sufficient for the lower sections of the dyke. A combination of rip rap and grass was therefore sought as revetment. Calculations show that adequate strength is obtained if the bottom 1.5 m of the dyke is covered with rip rap (layer thickness 45 cm with standard sorting from 5 to 40 kg) and the top 3 m with good erosion-resistant grass.

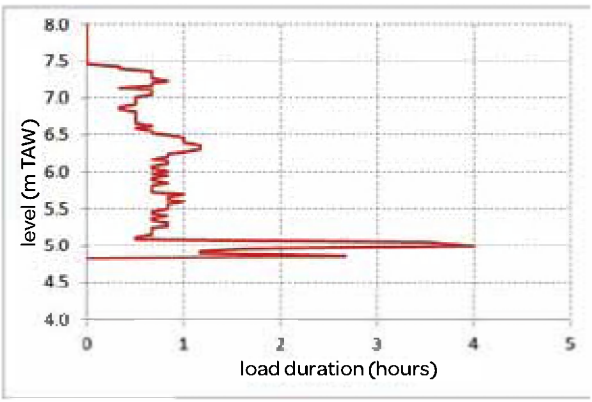


Figure 6.11. The total load duration of wind waves at different levels on the slope of the ring dyke

6.3 Inlet and outlet sluice

6.3.1 General

A structure was chosen in which the inlet openings are situated above the outlet openings. The advantages of this configuration have already been discussed above. Six inlet openings were installed, each with a width of 3 m and a height of 2.2 m. The desired sill level for each opening can be further adjusted with stop-logs. Three openings are required for outlet flow. These are also 3 m wide, but only 1.1 m tall.

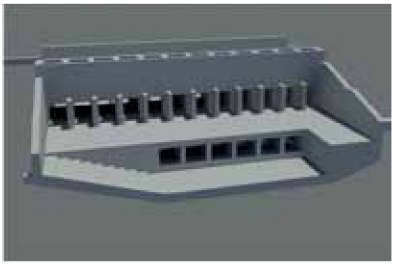


Figure 6.12. The Scheldt side of the inlet and outlet structure. The 3 drainage shafts are visible at the bottom (each shaft consists of 2 sections), and the 6 inlet shafts at the top (also each consisting of 2 sections).

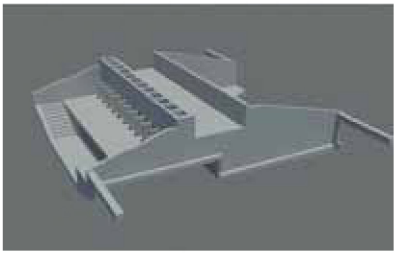


Figure 6.13. Side view of the inlet and outlet structure

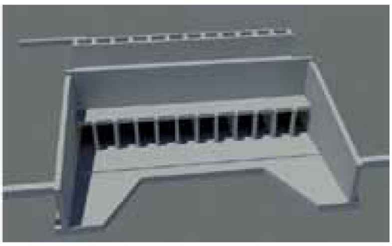


Figure 6.14. The polder side of the inlet and outlet structure. A number of these shafts are inlet shafts only. The central shafts are used as both inlet and outlet shafts.

6.3.2 Dimensioning

The dimensioning of the drainage structure is based on European standards and directives. The following loads act on the construction:

- Dead weight of the structure and its components.
- Earth pressures.
- Water level of the Scheldt: the water pressure on the construction is calculated according to the design level (7.5 m TAW). To be certain that the situation with the worst impact is taken into account, various scenarios were studied. There are four types of load: water pressure on the even openings, on the odd openings, water pressure on the Scheldt side and on the side of the flood area. All load combinations were combined with each other.
- Water pressure during heave: the worst scenario for heave was studied. This occurs just before the flood area is filled. The Scheldt is then as high as the overflow dyke, the flood area is dry and the non-return valves are closed. The water pressures were investigated according to the design level.
- Traffic loads on the crest of the dyke: the traffic load on the dyke road was determined according to standard ENV 1991-3 (2002). Although just one theoretical lane is required on the Bergenmeersen roadway, it was decided to study two theoretical lanes. That scenario can occur if appurtenances are installed or maintenance work is carried out with two vehicles standing alongside each other on top of the construction. Two scenarios were considered that are the mirror image of each other. In each of the scenarios, the lanes are loaded with a UDL

(uniformly distributed load) and a convoy. The convoy was positioned at different places in the lane to obtain the most negative loads. UDL 1 was also applied to the side walls of the construction to be able to withstand any loads alongside the construction.
- Overloads: the wire-floors and accessible zones were calculated with an overload of 300 kg/m^2.

The various load conditions were merged into combinations. Three major situations were examined. The first situation encompasses the earth pressure and the overload on the roadway. These combinations took account of the different positions of the convoys. The second situation encompasses earth and water pressures. These combinations took account of the various water level scenarios. The third situation encompasses earth and water pressures combined with the uniformly distributed overload on the dyke road.

The foundation characteristics are based on the study of the dyke bodies. The construction was calculated on an elastic bed. Characteristics for earth that is reloaded were assumed.

The environmental class and ambient class were set at XC4 and EE3 respectively.

The construction (concrete structure and steel girders) was calculated with the SCIA Engineer finite element package. The results of the computational model were used to calculate the reinforcement. This calculation was carried out on the basis of EN 1992-1-1 (2005) and separately for each element in the construction. The maximum capacity for the elements was determined with a standard net. Where overruns were found, additional reinforcement or a modified net was determined.

When checking heave, settlement and contact stresses, settlement of between 1 and 10 mm was still found in the worst scenario for heave. The relative settlement was finally limited to 5 mm, which is within the acceptable limits.

6.4 Modifications to the design

6.4.1 Feedback from public consultation

The original design was submitted to various services within the Flemish Government. The public was also given the opportunity to view the plans. The purpose: to create support for the plans and adapt them where necessary.

As indicated by the service that will be responsible for management and maintenance, further modifications to improve the safety and accessibility of the structure were applied. Thus an extra entrance was added, as well as a staircase. It was also ensured that the trash screens can easily be removed. An anti-theft system prevents the screens from being removed.

The residential area in question and the action committee set up there were concerned about the effect of litter. This could flow into the area through the sluice when this is operating daily. The trash screen was therefore narrowed further (from a gap of 10 cm to 5 cm), but without making the construction impassable to fish.

6.4.2 Optimization for fish migration

Due to Benelux and European directives, any sluice has to be maximally adapted for fish migration. This was achieved in Bergenmeersen by the optimization of the stilling basin.

At low tide fish can actively swim upstream into the CRT or passively out of the CRT, as long as the outlet gates are open (cf. Lippenbroek). As the length of the culvert is considerable, there is the risk of stranding by the end of the low-tide. By extending the stilling basin into the CRT area, the water body inside de sluice is made continuous with the CRT creek and provides a permanent and safe passage way. Juveniles and larvae, on the other hand, are expected to enter the CFA passively trough the inlet sluices, possibly dropping onto the floor slab. The addition of a stilling basin breaks their fall and again provides a connecting water body to the CRT creek.

Preliminary data in Chapter 8 already demonstrate that fish migration for larvae and adults is indeed possible through the Bergenmeersen CRT sluices, suggesting migration through both inlet and outlet culverts.

6.4.3 Sedimentation pond

Special interest goes to the amount of sediment entering the system each tide and partially remaining entrapped within a CRT-area. Intensive monitoring at the Lippenbroek shows that the suspended solid concentrations (SSC) entering the Lippenbroek are related to the amount of sediment in the Scheldt, but clearly smaller in absolute quantities. Following two different kinds of monitoring techniques, yearly sedimentation heights ranging between 2 and 3 cm are found.

Although excessive sedimentation will have adverse effects, it should be stressed that in order to obtain a well-functioning freshwater intertidal habitat, settlement of sediment is a necessity. A high inlet sill together with the implantation of the sluices somewhat more landward (Figure 7.4) create a self-maintaining sediment pond on the river side, limiting the sediment load entering Bergenmeersen. In addition, it is believed that yearly sedimentation heights will diminish after years of functioning (e.g. due to consolidation and subsidence). Moreover, when the amount of sedimentation becomes too high in terms of safety, appropriate action will be taken.

6.5 References

- ***Flood control areas as an opportunity to restore estuarine habitat.*** *T. Cox et al. (2006), Ecological Engineering: the journal of ecotechnology – 28 (1), p. 55-63*
- ***Stilling Basin Optimization for a Combined Inlet-Outlet Sluice in the Framework of the Sigmaplan.*** *J. Vercruysse et al. (2013) in IWLHS 2013: international workshop on hydraulic design of low-head-structures ISBN 978-3-939230-04-5 / www.vliz.be/imisdocs/publications/88/243588.pdf*
- ***Inlet Sluices for Flood Control Areas with Controlled Reduced Tide in the Scheldt Estuary: an Overview.*** *T. De Mulder et al. (2013) in IWLHS 2013: international workshop on hydraulic design of low-head-structures ISBN 978-3-939230-04-5 / www.vliz.be/imisdocs/publications/243672.pdf*

7. WORK

After the preparatory investigation and the design, the implementation of the project was on the schedule. Before the first spade touched the soil, a specification was drawn up and the necessary permits and licences obtained. Work began on 14 March 2012: the earthworks, the building of the combined inlet and outlet sluice, the construction of the walkway and the digging of the dissipation channel. During the work, close attention was paid to the impact on farmers and local residents.

Authors: Michaël De Beukelaer-Dossche (Waterways and Sea Canal) and Stany Vanremoortele (Herbosch-Kiere NV)

7.1 Preparing the work

7.1.1 Drawing up the specification

To carry out the project, a specification was drawn up, consisting of four sub-contracts. These were to be viewed as separate assignments described in accordance with two Flemish standard specifications, SB230 and SB250. Because a complete design had already been produced, and because there is considerable experience of that type of work in Flanders, it was decided to put the work out to public tender. This means the contractor is chosen on the basis of one criterion: price. Obviously minimum requirements were imposed that the contractor had to satisfy in order to be selected. The four sub-contracts were divided as follows:

- **Sub-contract 1 groundworks:** the work to reuse local earth to raise the ring dyke. The earth was obtained in such a way that the archaeologically rich zone in the centre of the area was not touched. Earth was also brought in and a local depression near the residential area had to be filled in and raised.
- **Sub-contract 2 inlet and outlet sluice:** the demolition of the existing drainage sluice and the building of a new combined inlet and outlet sluice. The work encompasses all aspects to complete the work, from installing the construction pit, the foundations, reinforcement, shutterwork and concreting to completing the construction with non-return valves, gates, stop-logs, etc.
- **Sub-contract 3 digging overflow channels and lining with open stone asphalt (OSA):** to protect the existing overflow dykes from landward erosion in heavier storms, dissipation channels were constructed at the heel of the dyke (land side). These channels were also lined with erosion-resistant materials, namely open stone asphalt. This allows a grass mat to take root (through the open structure). This improves the appearance, the natural value and the strength of the dyke.

- **Sub-contract 4 building a walkway:** to guarantee public support, the educational function and recreational use, a comfortable walking path is being built through the nature area, with views of the unique inlet and outlet sluice. The path is made from FSC (Forest Stewardship Council) wood.

To allow as much competition as possible, the contract was published throughout Europe for 52 days. Finally, seven offers were received from contractors, three of which were chosen for assessment. Of these bids, the submission of Herbosch-Kiere NV offered the best value.

7.1.2 Permission to start work

The following were required so that work could actually start:

- **An urban development permit:** the Flemish Government issued this permit, thereby granting permission to carry out the work described in the plans. The permit refers to the project EIA (environmental impact assessment) and other advice, such as that regarding the archaeological survey. The permit was obtained on 4 February 2011.
- **Authorisation to begin work on the sites:** because not all the sites in the area were owned or managed by Waterways and Sea Canal, use had to be made of the Flemish Parliament Act on Flood Defences. This provides for authorisation to carry out work – for infrastructure of public interest and to protect the population – on third-party land. The authorisation was signed by the competent minister. Authorisation was obtained on 4 November 2011.

Work finally began on 14 March 2012, after a start-up meeting had been held for local residents and stakeholders. This took place in the presence of the contractor, the engineering firm, the Purchasing Committee carrying out the expropriations and the Flemish Land Company (VLM), which supports farmers during expropriations, and the client. During and after the presentations, those present could put questions to the representatives. A leaflet was also handed out in the area. Dozens more questions and comments were answered by telephone and e-mail.

7.2 Carrying out the work

7.2.1 Earthworks

Protection against flooding is the primary objective of the updated Sigma Plan. Work therefore began with the ring dyke. This ring dyke had to be raised and widened. The removal of plant growth was the first step. Access roads to the area were closed and a site hut erected next to the area.

The contractor chose not to provide any additional protection against flooding during the work on top of the relatively low overflow dykes. A pilot level was therefore set at +6 m TAW with Flanders Hydraulics Research and Waterways and Sea Canal (approximately 40 cm below the crest of the overflow dyke). The predictive model used could then warn three days in advance when the waterlevel reached more than +6 m TAW. The site management was then automatically notified by text message.

Figure 7.1. Earthworks: start of excavating the channel source

Figure 7.2. Earthworks: raising and widening the ring dyke

Figure 7.3. Earthworks: end of excavating the channel source

The dyke was constructed according to a number of steps:

- stripping the turf from the dyke,
- removing the covering layer in heavy soil,
- reprofiling and compacting the raised core of the dyke,
- applying heavy soil,
- applying dyke strengthening to the toe of the dyke with quarry stone (to counter washout),
- applying sub-foundations and foundations for the towpath,
- creating a semi-metalled towpath (mixture of rubble and soil),
- seeding the towpath and the sides of the dyke with an ecological grass mixture.

To carry out the earthworks and site profiling correctly, the cranes and bulldozers were given a 3D map. This was linked to the GPS in the equipment.

In addition to this work, in sub-contract 1 the depression by the residential area also had to be filled in. The contractor chose to do this using the material from the channel source to be excavated around the archaeological island. This choice had to do with the high groundwater level and the lower quality of the material from a soil-mechanics point of view (a heterogeneous mixture of peat and heavy soil). Extra operations to reuse the material expertly as a covering material on the primary flood defence were thus avoided. In net terms, the following materials were used:

- supply of core material,
- supply of heavy soil,
- reuse of heavy soil from the excavation,
- quarry stone,
- grass seed.

The contractor used these machines at the same time:

- Hitachi 350 crane,
- Liebherr 925 Long Reach crane (finishing),
- Caterpillar D6 bulldozer,
- Volvo D25 dumpers,
- 40 tonne trucks,
- steamroller,
- etc.

The dyke was constructed in phases, but with a significant overlap between the various phases. Because machines were continuously used, time was saved and efficiency increased.

7.2.2 Combined inlet and outlet sluice

At the same time as modifying the existing dyke, work began to demolish the existing sluice in order to avoid the stormy season between October and February. If the work started in the spring, by October no further inconvenience would be caused by the operation of the existing FCA. The FCA currently has the chance of becoming operational from 1 to 2 fills a year. This approach also benefited the manager Waterways and Sea Canal and the Agency for Nature and Forest (ANB), as it allowed a finished safety and nature area to be implemented more quickly.

A sheet pile wall was first built as a construction pit for the work. Based on the calculations of the contractor the piles were driven in. Once the river side of the construction pit was ready, however, it emerged while demolishing the sluice that an older sluice was present in the dyke, partly beneath, partly alongside the existing sluice. This made demolition much more difficult.

In addition, the condition of the ground in the layers between +0 m and -5 m TAW did not appear to correspond fully with the analysis of the cone penetration tests. For example, the expected continuous layers of clay were not continuous, which meant it was not possible to seal the construction pit. This resulted in a construction pit where a "breakdown" occurred along the bottom on the river side. As a result, the pit could not be pumped dry and the sheet pile wall became distorted. Both the municipality and the Agency for Nature and Forest were notified of these problems.

The best solution was subsequently sought in consultation with the contractor and the design office. These solutions were considered:

1. **Modify the existing construction pit (deeper pile frame reinforcement):** this option did not appear viable due to the extra cost. Thus, the existing sheet piles were inadequate, with the result that longer and heavier sheet piles were needed. In addition to the cost, this solution also meant a major delay, because the sheet piles could only be delivered after approximately three months.
2. **Move the sluice further up on the overflow dyke:** this option would reduce the demolition work on the existing sluices. However, a real risk would remain of similar problems for breakdown, despite a marginally better stratification. To be certain of this, extra cone penetration tests were required. The cost and time of additional sheet piles also had to be factored in for this solution.

3. **Build the new sluice on the land side and then free up a link to the Scheldt afterwards by locally moving the overflow dyke:** this solution required only a limited construction pit, which was more beneficial. It also enhanced planning and time management by a fair amount.

Finally the third option was chosen. Once work had begun to build the new sluice, the municipal authorities rightly asked whether that did not imply a change to the work as provided for in the urban development permit. Because the structure had been moved by around 30 m, an additional urban development permit was applied for. This was quickly obtained thanks to the involvement of the municipality, local residents and the ANB in the project.

In the end, therefore, no construction pit was needed to build the sluice itself. This improved the safety and accessibility of the sluice.

The following materials were needed to build the sluice:

- 600 m^3 of concrete,
- 67,800 kg of reinforcing steel,
- 79,000 kg of steel sheet piles,
- 6 non-return valves,
- 12 HDPE gates with rubber seals,
- 24 gratings,
- aluminium stop-logs.

The following machines were used to build the sluice:

- Sumitomo cable crane,
- trucks and concrete mixers for the supply of materials.

A permanent team of concrete pourers (6 people), a pile-driving team (3 people) and a team of steel fixers (4 people) worked on the construction of the sluice.

7.2.3 Constructing the dissipation channel

To prevent erosion, a dissipation channel was dug. The channel was lined with open stone asphalt and a layer of topsoil, which was then sown. This means the energy of flooding water is broken up in a dissipation channel. In the winter following construction the flood area became operational, as a result of which the topsoil was washed away and the open stone asphalt was slightly damaged.

Investigations revealed, however, that the damage was in fact to the overflow dyke (built in the 1980s) and not to the newly constructed layer. To apply the open stone asphalt to the same thickness, a steel frame was used that is equal to the profile of the channel.

7.2.4 A recreational walkway

As described above, a wooden walkway was constructed through the area. The walkway was built in various phases. Firstly, foundation piles were driven in every 32 m to establish the route. Next, 2 rows of foundation piles 3 m apart were driven in every 2 m. Then the substructure was installed, and following checks by the contractor it was decided to install two additional supporting beams underneath the wooden floor to limit sagging.

To reduce production costs, the contractor opted for prefabricated walkway modules in Kallo. The modules measured 3 x 3 m and could easily be installed in situ. After the walkway had been assembled, the planks appeared to sag more than expected on the basis of the calculations. To prevent the planks from breaking at a later point in time, the contractor ultimately installed a second layer of planks. The extra supporting beams and the additional layer of planks were unscheduled work and to be charged in addition to the tender amount.

The following materials were used to build the walkway:

- wooden piles with a diameter of 22 cm and length of 4 m (walkway) and 6 m (bridge over channel source),
- beam-supporting structure,
- 2 layers of grooved planks 2 cm thick.

These machines were used to build the walkway:

- crane,
- trucks for the supply of materials.

These teams worked on building the walkway:

- fixed team for assembly (2 people),
- pile-driving team for the wooden piles (3 people).

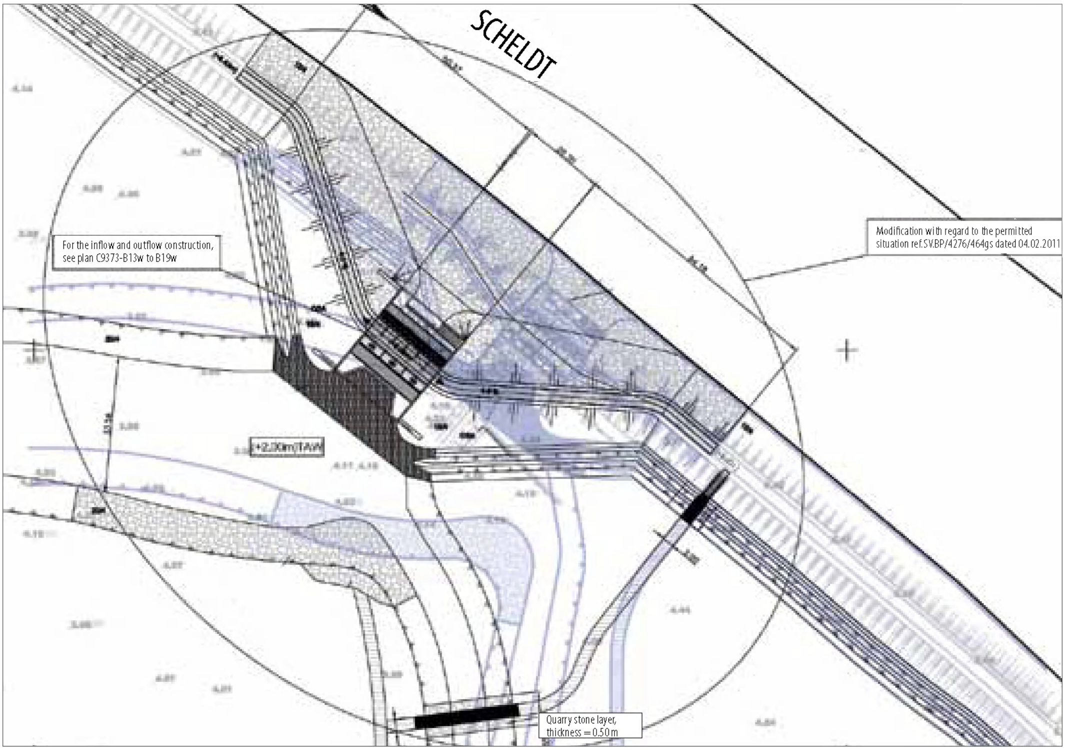


Figure 7.4. The altered location of the sluice

Photo report of the progress of the construction of the sluice

Figure 7.5. Formwork and reinforcement of the walls

Figure 7.6. Floor slab and sheet piles against seepage

Figure 7.7. Concreting the walls

Figure 7.8. Formwork and reinforcement of the intermediate plate of the inlet and outlet

Figure 7.9. Formwork and reinforcement of the superstructure

Figure 7.10. Installation of the framework infrastructure

Figure 7.11. Finished sluice

7.3 Public support

While the alteration work was being carried out, use was made of the flanking agricultural policy. For example, arrangements were made with farmers who wanted to continue using their agricultural plots in the work zone. In consultation with the contractor, plots were selected where that was possible. These were plots that were not affected by the actual construction work. The advantage was that the area was maintained even during the work at no extra cost, while the farmers were able to benefit from one or two extra mowings.

To guarantee safety, arrangements are in place regarding transports by the contractor and those of the farmers. These arrangements were formalised in revocable agreements between Waterways and Sea Canal and the farmers.

Local residents also received due attention. During periods of sunny weather ground particles could fly upwards, creating a dust nuisance for local residents in their adjoining gardens. To limit this dust nuisance, the contractor imposed strict speed limits on drivers. During rainy weather on the other hand, the ground became muddy as a result of the earth carried by trucks around the site all the way on to the public roads. So regular cleaning was carried out by a specialist company in consultation with the municipality.

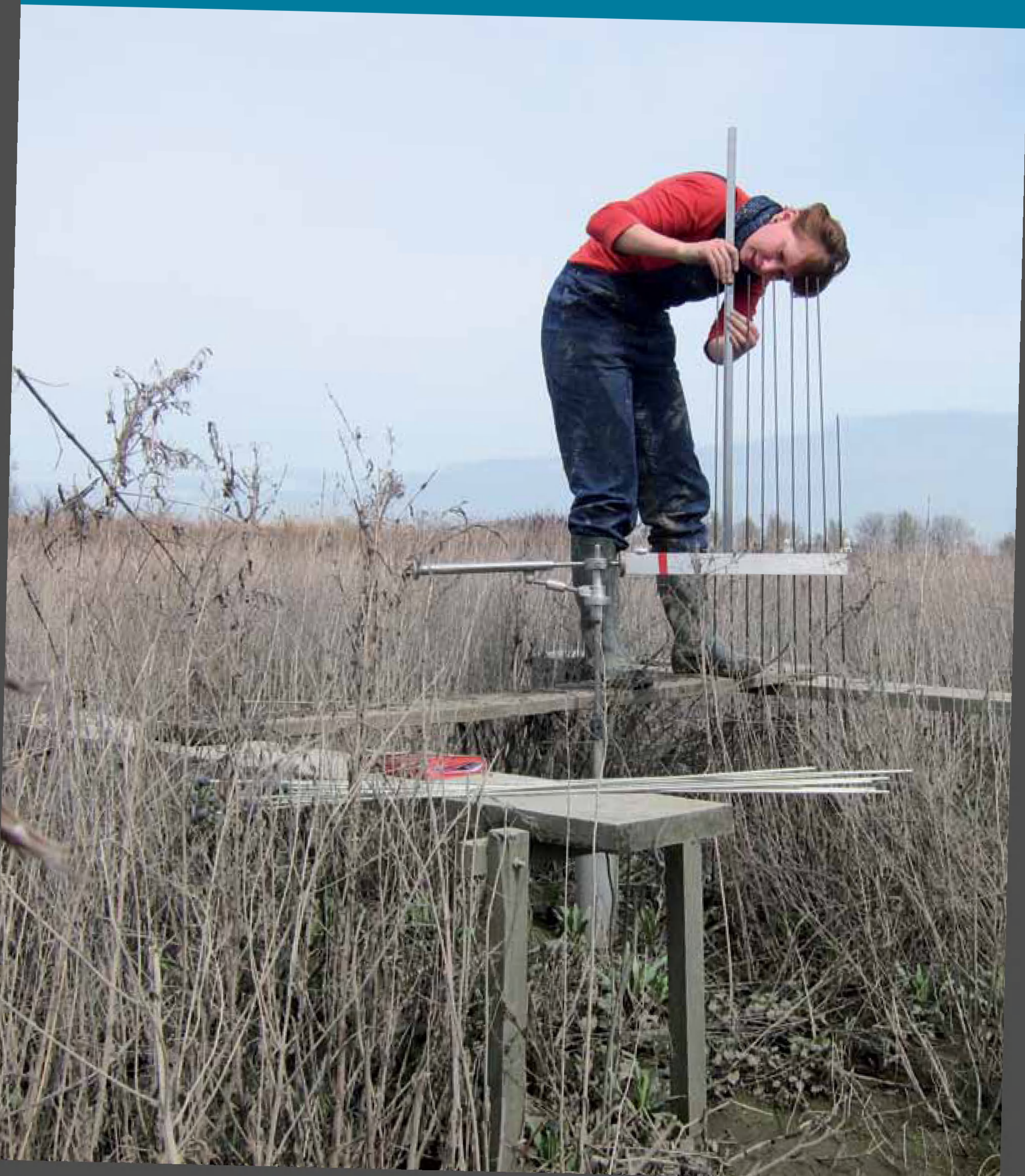
Figure 7.12. Construction of dissipation channel with open stone asphalt

Figure 7.13. Start of the walkway

7.4 References

- ***Standard Specification 260*** / *www.vlaanderen.be/nl/publicaties/detail/standaardbestek-260-voor-kunstwerken-en-waterbouw*
- ***Standard Specification 250*** / *www.wegenenverkeer.be/standaard-bestek-250*
- ***Herbosch-Kiere NV*** / *www.herbosch-kiere.be*
- ***Tractebel Engineering*** / *www.tractebel-engineering-gdfsuez.com*

Figure 7.14. A completed FCA-CRT



8. MONITORING

As a flood control area with controlled reduced tide (FCA-CRT), Bergenmeersen is expected to make a significant contribution to natural quality in the Scheldt estuary. Via a sophisticated sluice construction with combined inlets and outlets above each other, a reduced tide is introduced into the polder, while retaining the spring/neap tide variation. The purpose: a functional mud flat and marsh ecosystem. A monitoring programme was developed to examine whether these nature objectives are actually being achieved and to make adjustments where necessary.

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8.1 MONEOS: a coordinating monitoring programme

A coordinating monitoring programme, MONEOS, was drawn up for the Scheldt estuary. This programme describes three types of monitoring: system monitoring, research monitoring and project monitoring.

- **System monitoring** is a long-running programme that monitors all the basic parameters for the smooth operation of the Scheldt ecosystem. This includes, among other things, standard measurements of the water quality in the Scheldt. System monitoring also covers water levels and the safety-related functioning of the FCAs in the Scheldt basin, such as Bergenmeersen.

- **Research monitoring** encompasses the detailed monitoring of pilot projects to gain greater insight. The Lippenbroek is one such research monitoring project, in which knowledge is gathered for the development of other FCA-CRTs, of which Bergenmeersen is one.

- **Project monitoring.** During the first three years after the area starts up, a project monitoring programme examines the extent to which the area is meeting the set expectations and whether it is evolving in the right direction. Keeping a finger on the pulse allows possible problems to be detected earlier. This makes adaptive management and adjustment possible. Project monitoring is the best tool for this. The MONEOS report describes project monitoring as monitoring that is carried out – in addition to regular system monitoring – to measure certain parameters with an increased frequency, limited in time and space. After a period of three years, an evaluation is carried out. If everything is progressing as desired, project monitoring can be run down and the area included in the regular system monitoring.

8.2 Most suitable tide

Accurately setting the most suitable tide is vitally important to the successful development of an FCA-CRT. After all, for estuarine nature, that tide is the driving force behind ecological development. The volume of water (and suspended material) exchanged, the flooding frequency, duration and height, will be decisive for the development of the area. The success of the Bergenmeersen project therefore depends entirely on setting the right tide. Initial monitoring activities focus entirely on setting the tide, during which the desired final picture and the prevailing preconditions are taken into consideration. As an extra framework condition for Bergenmeersen, special attention is being paid to the sandfly issue.

First, an improved digital height model (DHM) needs to be created. Based on that DHM, the water heights and flooded areas can be estimated for different inflow volumes. The inflow and outflow volumes for average, neap and spring tides on the Upper Sea Scheldt were calculated by Flanders Hydraulics Research when determining the sluice dimensions.

The sluice configuration that followed from the modelling study forms the starting point for further refining the heights of the stop-logs. Specifically, experience from the Lippenbroek shows that minor discrepancies between model and reality, for example in the DHM, can produce differences in flooded area. The inflowing water volume can be adjusted by raising or lowering

Figure 8.1. SET measurement

stop-logs, and therefore also the flooded area. Particular attention is paid here to the differences in flooded area between spring and neap tide. These differences determine the frequency of flooding and are decisive for the development of a diverse ecosystem.

As well as setting the right tide, it is vital that sedimentation is steered in the right direction. More water means more sediment flowing in. The most suitable tide will be a compromise between a tide that is sufficient for nature development and a tide that limits sedimentation as much as possible. Specifically for Bergenmeersen, mud flat zones near the residential area must also be avoided to combat sandflies. The sluice configuration of an FCA-CRT is therefore not static. It forms part of the management with which the various objectives of the area will be aligned with each other over the coming years.

Producing a good digital height model
A good, up-to-date digital height model (DHM) is needed. In the land study, the morphology (also depth) of the channel system is also surveyed. This is necessary to accurately monitor silting-up in the channels during the start-up phase. The land surveys are carried out using an RTK (real-time kinematic) GPS to obtain an accurate picture of the topography. Such an RTK-GPS determines its position through ten satellites plus correction factors continually sent through by a reference station. This allows the position to be determined accurately to within a few centimetres.

Multiple level measurements are needed to monitor the tide during the start-up phase, but also to manage the sluices at a later stage according to the development of the area. In Bergenmeersen, the water level will be recorded every 10 minutes at 5 locations during the start-up phase. One gauge will be located near the sluice complex. The others will be spread over the site. This allows the duration, height and frequency of flooding to be determined in large parts of the area, which in turn enables slow-draining parts and parts with a high flood duration to be properly mapped out. This is extremely important for monitoring sandflies, for example.

SET measuring set-ups (surface elevation table) are recommended for monitoring sedimentation. Five SET set-ups are installed. A SET set-up allows changes in the bottom level as a result of sedimentation or erosion to be accurately measured (to within 1 mm). The set-up is useful during the start-up phase, but especially to continue to track sedimentation closely in the years that follow. A SET set-up consists of a fixed pole in the ground. To this is attached a level movable arm. Using ten or so vertical rods, the distance from the bottom of the marsh to this arm is measured. The distance measurement is repeated with the arm in 4 different directions. The SET measurement is repeated every 2 months. This allows the slightest change in bottom level around the SET pole to be accurately recorded. To avoid changes in the relief at the SET through walking on it, 2 benches are used. By carrying out measurements from on these benches it is possible to avoid disturbing the soil.

8.3 Starting up the flood area

Before the sluices are opened when the flood area starts, the threshold levels in these sluices must be selected. Determining the correct threshold level requires attention. The tide must be set as favourably as possible to be able to achieve the objective of the FCA-CRT as much as possible: a functional intertidal area that contributes to the operation of the Scheldt ecosystem. The area must also be managed sustainably and must not cause any nuisances for local residents (sandflies). Finally, the safety function as an FCA must never be jeopardised. All of which imposes clear preconditions for the (reduced) tide.

With the new DHM and the information from the preparatory study and the model output (based on previous and new sluice calculations), an estimate can be made of the flooded areas for different tidal levels in the Upper Sea Scheldt. Based on this, an initial stop-log configuration is chosen. Stop-logs are inserted to the desired level and the sluices are opened for a few tides. The tide is monitored and evaluated at various places in the polder. Does the tide meet the requirements? Where is adjustment needed? Is there any significant sedimentation? With the knowledge from measurements taken with this first stop-log configuration, a new configuration is drawn up. This is repeated several times in an iterative process to reach the most suitable configuration.

As soon as a potentially suitable configuration has been obtained, the newly set tide will be monitored closely for a few spring/neap tide cycles. Considerable attention will also be paid to sedimentation and erosion processes. Based on detailed measurements, a forecast will be made for the morphological evolution of the area. Detailed surveys of the thalweg of creeks, of a number of fixed ditches and SET measurements are designed to help map out sedimentation and erosion. A number of targeted thirteen-hour measurements are also carried out, paying particular attention to the inflow and outflow of floating material to then draw up water and sediment balances. If necessary, the sluice configuration is further adjusted on the basis of these insights.

After the start-up phase there are two possibilities: either a fixed tide is chosen that is maintained without being changed, or a tide is chosen that is adapted over time.

8.3.1 Unchanged sluice configuration

As soon as a favourable tide is found during the start-up phase, the tide is set and maintained. That is the option that was applied in the Lippenbroek. There, the stop-log configuration remained unchanged from the start of the flood area. However, choosing unchanged sluice parameters does not mean that changes to the sluices are never required. Through the action of the tide, the morphology of the area will change. This has an influence on the tide. Minor changes to the sluices may therefore be required to maintain the same flooding frequencies despite a changing morphology.

8.3.2 Adaptive management

In a new FCA-CRT it may be desirable to allow more tidal influence at the onset. As a result, morphodynamic processes such as sedimentation and erosion can play a bigger role. Thus, the area may evolve more quickly towards the desired mud flat and marsh area. Creeks may be formed more quickly, depressions may be filled in more quickly, and compact polder clay may be covered more quickly with a layer of typical marsh sediment rich in benthic life. After such an initial period of strong tidal action, as a consequence of which the area has undergone a first series of rapid morphological changes, the tide can be modified. After all, maintaining a tidal travel that is too large can lead to excessive silting-up of the area in the long term. The tide must then be further reduced to a typical controlled reduced tide.

Because of the sandfly problem in Bergenmeersen, water-saturated mud must be avoided near the ring dyke. It is therefore better to avoid an overly strong tidal action in the initial phase. However, increased water levels during average or spring tides do not lead in and of themselves to more mud flat zones near the ring dyke. It is therefore worth considering setting the tide a little stronger at the start, to promote faster creek development. After all, if the drainage of certain parts of the flood area is not running smoothly enough at the start because of the lack of a well-developed, branched system of creeks, this could encourage the proliferation of sandflies.

8.4 Project monitoring in the initial phase

On the one hand, starting up the FCA-CRT requires detailed monitoring of the tide, to be able to choose the desired stop-log configuration. On the other hand, monitoring of sedimentation and erosion, vegetation, nutrient exchange, development of benthic life and fish is recommended. After all, the flood area has multiple nature objectives. Among other things, specific habitats with associated species are sought. Ecological functions are also linked to the area, such as nutrient cycling (see Chapter 4).

Below you will find an overview of all monitoring efforts.

Sedimentation and erosion
Four times a year, the soil level is monitored by means of five SET set-ups. Twice a year the development of creeks is monitored, as well as a few ditches, with Total Station and/or RTK-GPS.

Vegetation
Three times a year, permanent squares are measured by the five SET set-ups. In addition, a vegetation map covering the whole area is produced each year.

Benthos
Twice a year the benthos is sampled in at least five locations (certainly the five SET locations). Benthos sampling is useful for monitoring the quality of the intertidal area as a suitable habitat.

Thirteen-hour campaigns
To monitor the area's functionality in terms of water quality, there are four thirteen-hour campaigns each year. During such a campaign, the water quality is sampled every hour for a complete tidal cycle. The following parameters are determined: floating materials, chlorophyll a, biochemical oxygen demand, nitrogen (ammonium, nitrate, nitrite, Kjeldahl nitrogen), phosphorus (phosphate and total phosphorus) and silicon (dissolved and biogenic). Oxygen, pH, conductivity, temperature and turbidity are continually monitored during the campaigns. These parameters will also be continually monitored for a few days before and after each campaign.

Based on the thirteen-hour campaigns, mass balances will be produced for the various substances. This allows the area's contribution to general water quality in the Scheldt to be estimated. This is intended to show whether the objectives set within the framework of European nature objectives are being achieved.

Table 8.1. Results of fish monitoring in Bergenmeersen (May 2013)

	21/05/2013 Electrical	22/05/2013 Shoot trap	22/05/2013 Net trap
Common roach	0	7	0
Stone moroko	2	12	2
Flounder (larvae)	165	1	0
Three-spined stickleback	79	130	13
Prussian carp	0	2	1
European chub	1	0	0
Common rudd	0	1	0
European smelt (larvae)	3	0	0
Ten-spined stickleback	84	10	1
Species	6	7	4
Number of individuals	331	163	17
Chinese crab	1	3	14

Fish monitoring

During the project monitoring phase, the extent to which the area is being used by fish will be monitored. This monitoring is carried out by the Research Institute for Nature and Forest (INBO).

In April 2009 the baseline assessment was carried out. Fish were caught in the central channel in Bergenmeersen, one of the few water-retaining channels. At the time, only two species were caught: three-spined stickleback and ten-spined stickleback.

In May 2013, approximately one month after the area became operational, fish were caught electrically in the creek. Two traps were also placed for a period of 24 hours. A total of 9 species were caught. The presence of flounder larvae (on average 2.3 cm) indicates that this species is using the area as nursery habitat (incubator function). Several European smelt larvae were also caught. Table 8.1 shows the results (number of individuals per species). Clearly the pioneer species Prussian carp, stone moroko and common roach have very quickly found their way to the new area. The presence of European chub is remarkable. This species was caught only once in the last 10 years in the Sea Scheldt.

Figure 8.2. Young flounder

Bird monitoring
The agricultural area that Bergenmeersen was until recently was home to only a limited number of summer bird species. An inventory in 2008 recorded several territories of reed birds (Eurasian reed warbler, bluethroat and common reed bunting) and meadow and farmland birds (northern lapwing and grey partridge).

From the start of the work in April 2012, and certainly in the spring of 2013, the work zone attracted many waders (such as common redshanks, spotted redshanks, common greenshanks, common snipes and little ringed plovers) and a few waterfowl (such as northern pintails). In the first few weeks after the FCA-CRT became operational, the area also became very attractive to (transitory) waders and waterfowl. In addition to the species mentioned above, there were also black-tailed godwits, whimbrels, pied avocets, ruffs, red knots, common ringed plovers, wood sandpipers, northern shovellers, garganeys, black terns and little gulls.

The first inventory of summer birds in Bergenmeersen (23 May 2013) recorded breeding attempts by northern lapwings and little ringed plovers. The first regional breeding attempt by common redshanks was also recorded, the first "new" summer bird after the CRT had been operational for just one month.

Changes in the (summer) bird community will be monitored by the Agency for Nature and Forest over the coming years.

Flow rates through the sluices
By measuring flow rates and sediment at the inlet and outlet sluices, water and sediment balances can be drawn up and the amount of sediment that remains in the area estimated. The remaining quantities of sediment can be converted into sedimentation heights using sediment densities measured in situ and then compared with SET measurements.

Monitoring for sandflies
Because the area is close to habitation, a suitable programme for monitoring sandflies is advisable. No traps will be used. On the one hand, there is no evidence of the need to catch sandflies. On the other hand, the use of traps for monitoring draws too much attention to a problem that may not even exist. The suitable habitat is therefore monitored, linked to monitoring of sandfly larvae. This allows the potential of the area for sandflies to be estimated. Measures against sandflies, such as the raised ridge against the ring dyke, and measures for tide and drainage can also be evaluated. This allows better planning and more efficient management of future FCA-CRTs. If there are problems in Bergenmeersen, the measurements will help adapt management better.

8.5 References

- ***MONEOS. Geïntegreerde monitoring van het Schelde-estuarium.*** *(Integrated monitoring of the Scheldt estuary.) P. Meire et al. (2008), ECOBE Report 08-R-113. University of Antwerp / www.vliz.be/imisdocs/publications/136078.pdf*

9. GENERAL EVALUATION

The creation of the Bergenmeersen flood control area with controlled reduced tide (FCA-CRT) was a major operation. To learn lessons from the project with a view to future large-scale projects, the path followed was thoroughly evaluated. Despite various unforeseen circumstances, the high level of involvement of the local community and even one or two conflicts of interest, the partners involved succeeded in cooperating flexibly and efficiently. In this way the Bergenmeersen project developed into a socially valuable project, without tampering with the vision defined at the outset.

Author: Michaël De Beukelaer-Dossche (Waterways and Sea Canal)

9.1 Concept: adjusting the land use plan

When it was announced that the Bergenmeersen area would be selected as part of the updated Sigma Plan, it was clear that large-scale social involvement would play a part. For example, local residents ran campaigns during the initial presentation of the plan to the municipal council. Later on, an organised action committee made itself heard, with press articles and campaigns during information sessions. From the design phase, a resolute decision was therefore taken to adapt the area as much as possible to the wishes of the local residents, obviously within the chosen type interpretation.

This finally led to a much-altered land use plan to satisfy the concerns of local residents. This was possible due to the developed project and process structure and the close cooperation between, among others, the engineering firm Tractebel Engineering, the Agency for Nature and Forest (ANB) and the client, Waterways and Sea Canal.

All subsequent steps were therefore completed without much resistance. The extensive consultation in the project and process structure ensured that few unexpected aspects emerged during public participation sessions. The expected aspects were absorbed by preparation, study and reasoning from the preliminary phase.

9.2 Studies as the basis for the design

During the preliminary study, the preconditions for developing the area were defined. In this regard it was possible to make flexible use of a number of framework contracts and cooperation agreements with the various firms of experts. This provided the opportunity to promptly react to certain needs that emerged while the plans were being developed, without having to work through new contracts in each case as per government legislation. This made for faster working, and kept the additional administrative burden to a minimum.

Trouble-free cooperation with the advisory bodies, such as the Flanders Heritage Agency and the ANB, made it possible to adapt the plan on the basis of the results of the preliminary study.

All these preliminary studies were then used by Tractebel Engineering as the basis for developing a design. The only thing that could not be completed in time was the model tests. This was compensated for by a theoretical calculation based on empirical formulae. As a result, the design was ready in time. A few points for attention came to light:

- The siting of the structure must be better prepared on the basis of soil surveys. Specifically this involves a survey of the impermeable layers. After the experience in Bergenmeersen, the land-inwards location is to be chosen as default for FCA-CRTs too when developing Sigma projects. This offers the possibility of letting in less sediment and reducing construction costs.
- The wooden structure must be designed to be more solid and more use must be made of the expertise of e.g. the ANB. Greater exchange of experience during the design phase seems advisable.
- Retrieving old plans (and archiving them) and better knowledge of the land could predict additional costs, allowing the design to be adapted accordingly.

9.3 Flexibility during implementation

During implementation, solutions were in each case sought constructively with the contractor, Herbosch-Kiere NV, and the engineering firm Tractebel Engineering. The parties displayed a certain flexibility. This made certain modifications possible, which resulted in a better-quality project:

- The reuse of local earth (excavated channel source to protect the archaeological heritage in the centre of the area) was limited to raising the depression in the area. As a result, technically better-quality material was delivered to cover the dyke, in addition to recovery of the material present on the existing dykes.
- The position of the sluice was moved further inland. This provides significant benefits for the implementation and operation of the area.
- The walkway was strengthened and moved slightly to have a better view of the operation of the combined inlet and outlet.

During implementation this flexibility, together with provision of large amounts of equipment by the contractor, proved decisive in achieving a trouble-free implementation. The various sub-contracts were implemented simultaneously. As a result, it was possible for the area to become operational two years earlier than planned.

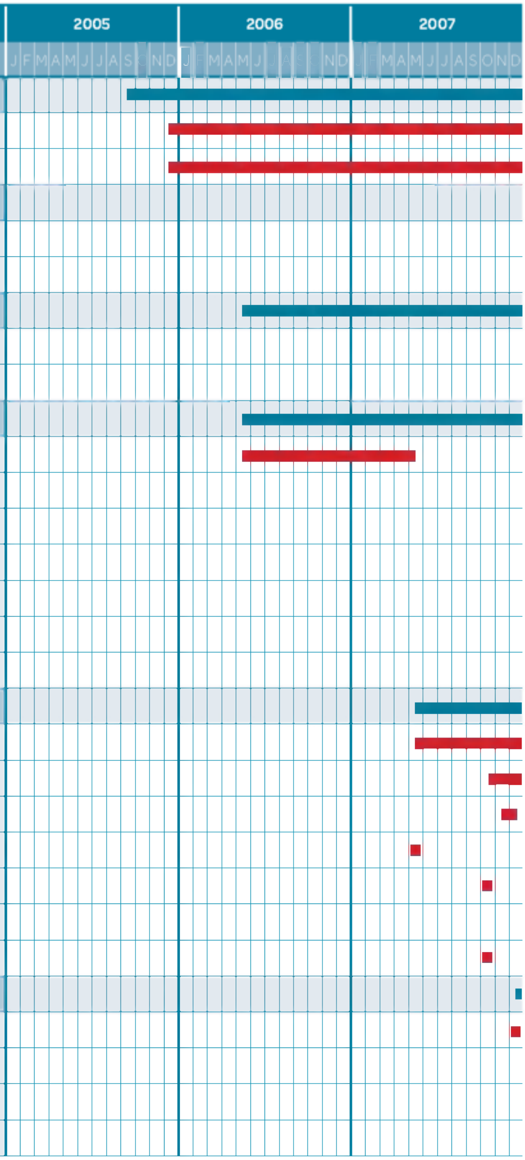
9.4 Full operation

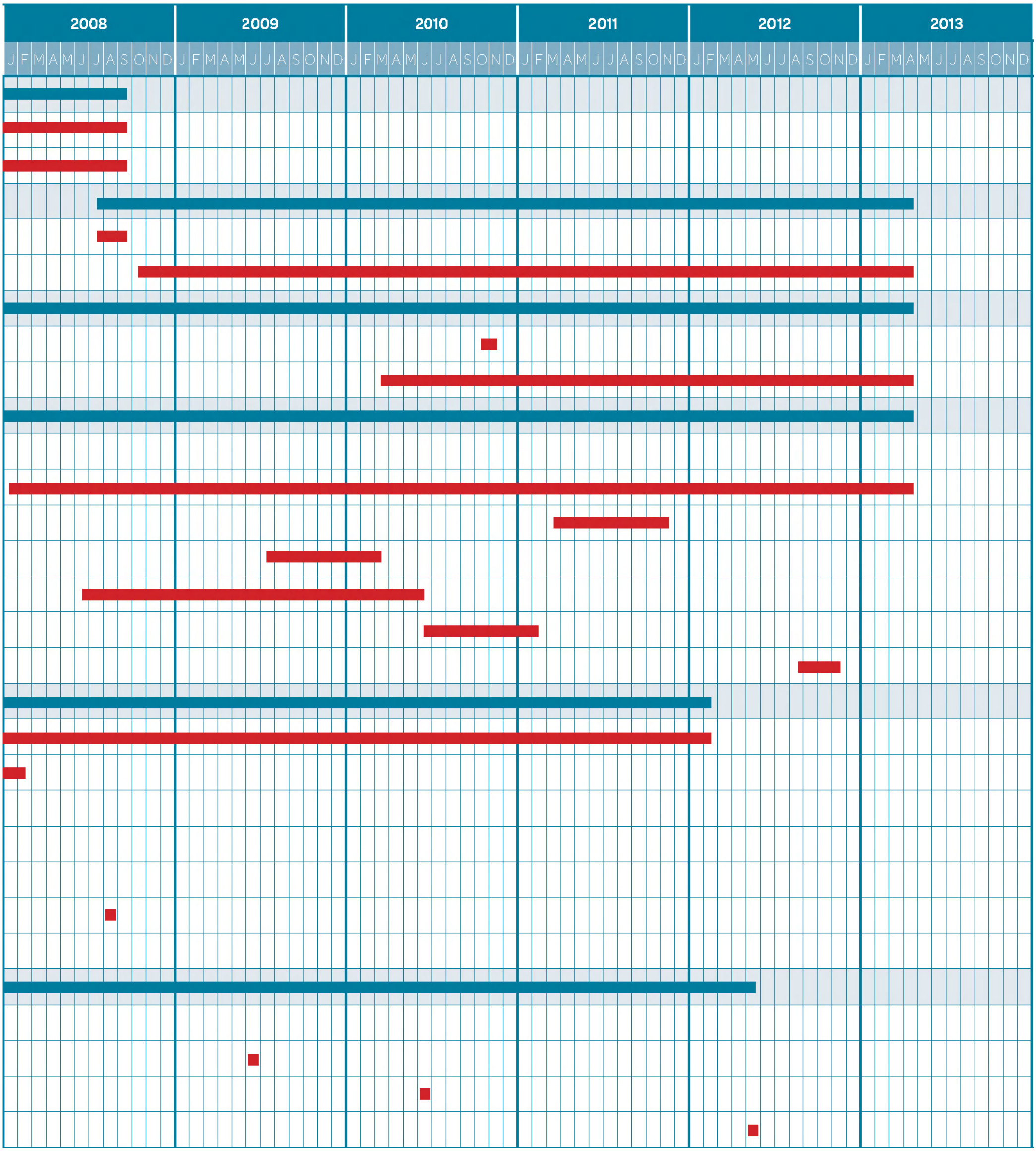
What really counts are obviously the results of the intensive cooperation, studies and implementation work. From the moment of coming into operation on 25 April 2013, the result appeared excellent. Within just a few days the first video clips from birdwatchers were appearing on YouTube, showing the remarkable increase in foraging birds. The walkway is already being heavily used by visitors and locals. In short, from now on the river and its nature will have room to show themselves off to their best, in complete safety.

9.5 Info sheet

Coordinating plan	Updated Sigma Plan - decided by the Flemish Government on 22 July 2005
Project title	Bergenmeersen
Function of the area	FCA-CRT
Expected climax vegetation	70% willow tidal forest, 30% mud flats and open water
Water-storing volume of area	1,500,000 m^3
Surface area of area	41.37 ha
Length of ring dyke	1,155 m
Length of overflow dyke	1,970 m
Average polder level	3.75 m TAW
Total estimate for 2005	EUR 3,550,000
Cost of study work	EUR 112,192
Cost of work	EUR 1,887,552
Cost of extra work and price adjustments	EUR 200,130.76
Cost of land acquisition and flanking agricultural policy	EUR 967,117
Total cost of project	EUR 3,584,846 (EUR 2,957,460.41 2005 price level)
	= 100.98% of the estimate in 2005 = 83.31% based on 2005 price level
Engineering firm	Tractebel Engineering
Contractor	Herbosch-Kiere NV
Number of specific government contracts	3
Number of framework contracts used	5
Estimated start and end date	1 July 2009 - 1 July 2015
Preparation period	2.5 years
Duration of procedures	3.5 years
Duration of implementation	1 year
Operational	25 April 2013

Task Name	Duration	Start	Finish
Specification 16EI0531 Land use	**775d**	**Sep 20, 2005**	**Sep 8, 2008**
Publication of specification 0531	56d	Sep 20, 2005	Dec 6, 2005
Study 0531	719d	Dec 7, 2005	Sep 8, 2008
Specification 16EI0830 Design	**1235d**	**Jul 9, 2008**	**Apr 2, 2013**
Publication of specification 0830	40d	Jul 9, 2008	Sep 2, 2008
Study 0830	1160d	Oct 22, 2008	Apr 2, 2013
Specification 16EI1041 Works	**1806d**	**May 15, 2006**	**Apr 15, 2013**
Publication of specification 1041	41.4d	Oct 6, 2010	Nov 16, 2010
Works 10/41	283d	Mar 15, 2012	Apr 15, 2013
Procedures	**1806d**	**May 15, 2006**	**Apr 15, 2013**
AIA	259d	May 15, 2006	May 10, 2007
Expropriations	1364d	Jan 23, 2008	Apr 15, 2013
Flemish Parliament Act on Flood Defences	164d	Mar 22, 2011	Nov 4, 2011
GRUP	201d	Jun 19, 2009	Mar 26, 2010
EIA project	531d	Jun 1, 2008	Jun 11, 2010
SBV	161d	Jun 25, 2010	Feb 4, 2011
SBV 2	80d	Aug 1, 2012	Nov 20, 2012
Work groups	**1247d**	**May 10, 2007**	**Feb 17, 2012**
Project-based WG	1247d	May 10, 2007	Feb 17, 2012
SubWG Nature	102d	Oct 9, 2007	Feb 27, 2008
SubWG Agriculture	11d	Nov 29, 2007	Dec 13, 2007
SubWG Agriculture	1d	May 10, 2007	May 10, 2007
SubWG Recreation	1d	Oct 16, 2007	Oct 16, 2007
SubWG Recreation	1d	Apr 15, 2008	Apr 15, 2008
SubWG Water	1d	Oct 10, 2007	Oct 10, 2007
Info sessions	**1160d**	**Dec 13, 2007**	**May 23, 2012**
Info land use plan	1d	Dec 13, 2007	Dec 13, 2007
Info GRUP	1d	Jun 19, 2009	Jun 19, 2009
Info SBV	1d	Jun 17, 2010	Jun 17, 2010
Info Works	1d	May 23, 2012	May 23, 2012

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10. GLOSSARY

- **Agricultural impact assessment (AIA):** by surveying farmers and horticulturalists, the Flemish Land Company (VLM) investigates the possible effect on individual businesses if land is taken out of use and what the possible flanking measures are.
- **Birds Directive:** European Directive (1979) on the conservation of bird stocks on the European territory of the Member States of the European Union. This Directive relates to the protection, management, regulation and exploitation of these species. Europe requires its Member States to designate special protection zones for certain species that are listed in Annex I of the Directive. These zones are known as Birds Directive Areas, or SPA-B for short (special protection areas within the framework of the Birds Directive).
- **Database of the Subsoil of Flanders (DOV):** lists and interprets data on the subsoil and also makes these available. All data belong to one of four sub-types, namely geology, geotechnology, groundwater and pedology. The purpose of DOV is to improve the accessibility and quality of these data. Besides the Internet Viewer at http://dov.vlaanderen.be there is also an intranet viewer on which the various partners can conduct extensive consultations.
- **Environmental impact assessment (EIA):** includes plotting the environmental consequences of a decision, before that decision is taken. The study results are published in the environmental impact assessment (EIA). An EIA is produced for activities and projects that could have a major impact on the environment.
- **Flanders Hydraulics Research (WL):** a centre of expertise that carries out scientific research into the effects of moving water. It investigates the influence of human activity and nature on water systems and the consequences of this for shipping and water-based infrastructure. The Flemish Government supports the research, but private institutions and international organisations also make use of this specialised knowledge.
- **Flemish Land Company (VLM):** as an external privatised agency, forms part of the Environment, Nature and Energy policy area of the Flemish Government. Countryside and Fertilizer Policy, Fertilizer Bank and Project Implementation are the core departments of the VLM.
- **Flood control area (FCA):** a flood area in which a river is given extra room to flood within defined contours. Because a quantity of water flows into the flood area, there is also less pressure on the dykes. This therefore reduces the chance of a dyke bursting. An FCA only floods during a storm tide. This combination of a spring tide and an extreme north-westerly storm occurs around once or twice a year. If the water level is high, the water flows over the overflow dyke and into the flood area.
- **Flood control area with controlled reduced tide (FCA-CRT):** in some flood areas safety is combined with nature. In these areas the daily tides are allowed into the flood area in tempered form. This creates unique tidal nature (mud flats and marshes). We also refer to an FCA with reduced tide or CRT.
- **Habitats Directive:** European Directive (1992) on the conservation of natural habitats and wild flora and fauna on the European territory of the Member States of the European Union. Member States are required to designate special protection zones for

certain habitats and species of Community interest, which are listed in Annexes I and II of the Directive. These zones are known as Habitats Directive Areas, or SPA-H for short (special protection areas within the framework of the Habitats Directive).

- **Natura 2000:** European network of protected nature areas on the territory of the Member States of the European Union. This network forms the cornerstone of the EU's policy for conserving and restoring biodiversity.
- **Recurrence interval (Tx):** the average time that lapses between two natural phenomena of similar intensity. The phrase "recurrence interval" is therefore used to designate the intensity of e.g. a storm or flood: the more extreme the storm or flood, the greater the recurrence interval and the smaller the frequency with which it occurs. Thus, a storm with a recurrence interval of 500 years is a storm that is so intense that on average it only occurs once every 500 years.
- **Regional spatial implementation plan (GRUP):** a plan in which the government defines the use of the land in a particular area. Based on the urban planning regulations from that GRUP, permits can be issued for the construction or modernisation of infrastructure.
- **Scheldt Estuarine Nature Development Plan (NDP):** the NDP must specify in specific terms where and why what measures must be taken in or along the Scheldt estuary in the medium term (to 2010) to be able to achieve the 2030 target for natural quality.
- **Tweede Algemene Waterpassing (TAW, Second General Levelling):** the reference height against which height measurements in Belgium are expressed. A TAW height of 0 m is equal to the average sea level at low tide in Ostend.