

# 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.

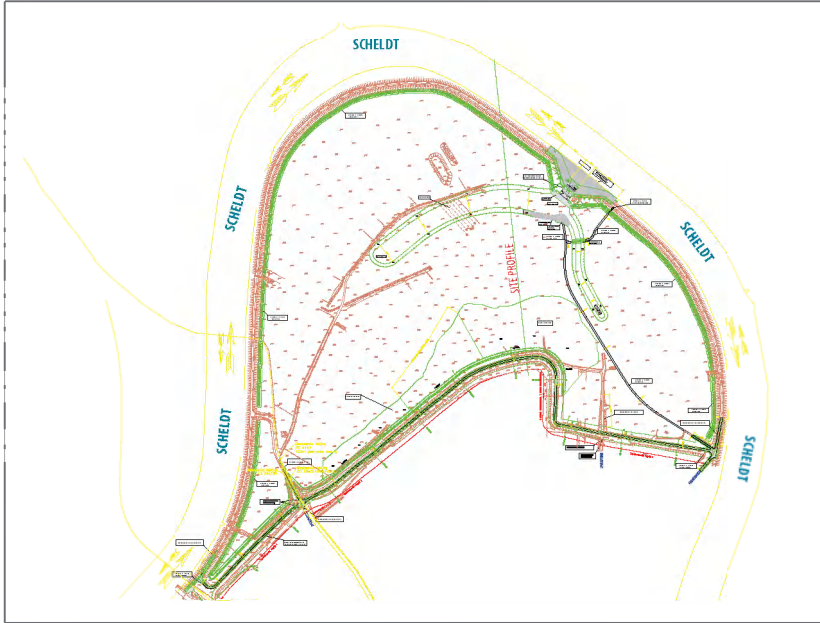


Figure 5.1. Results of the environmental soil survey

## 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

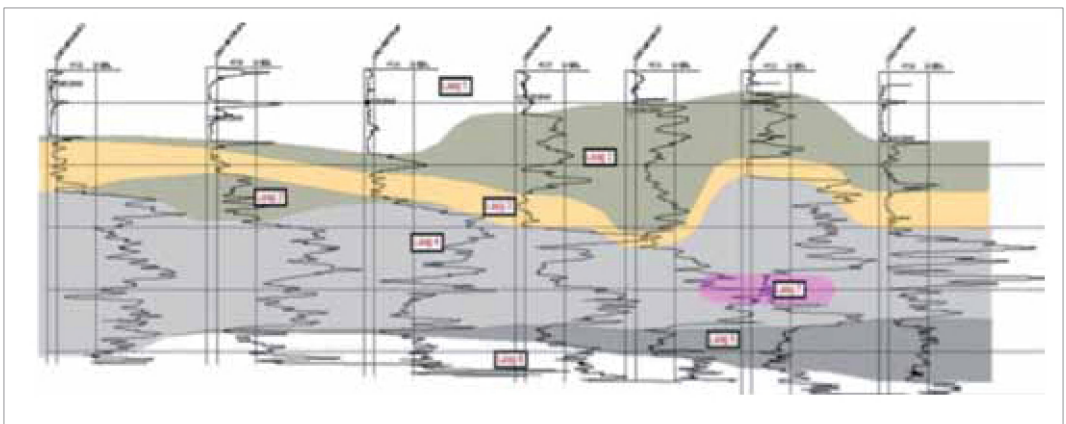


Figure 5.2. Layer structure of the ring dyke

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.

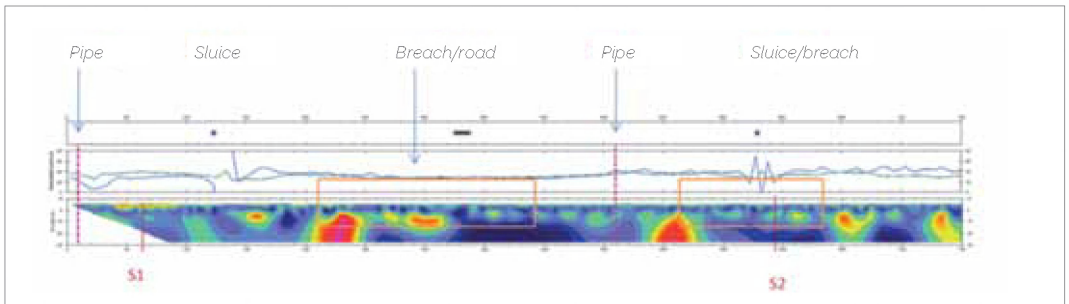


Figure 5.4. Results of the non-destructive geophysical test

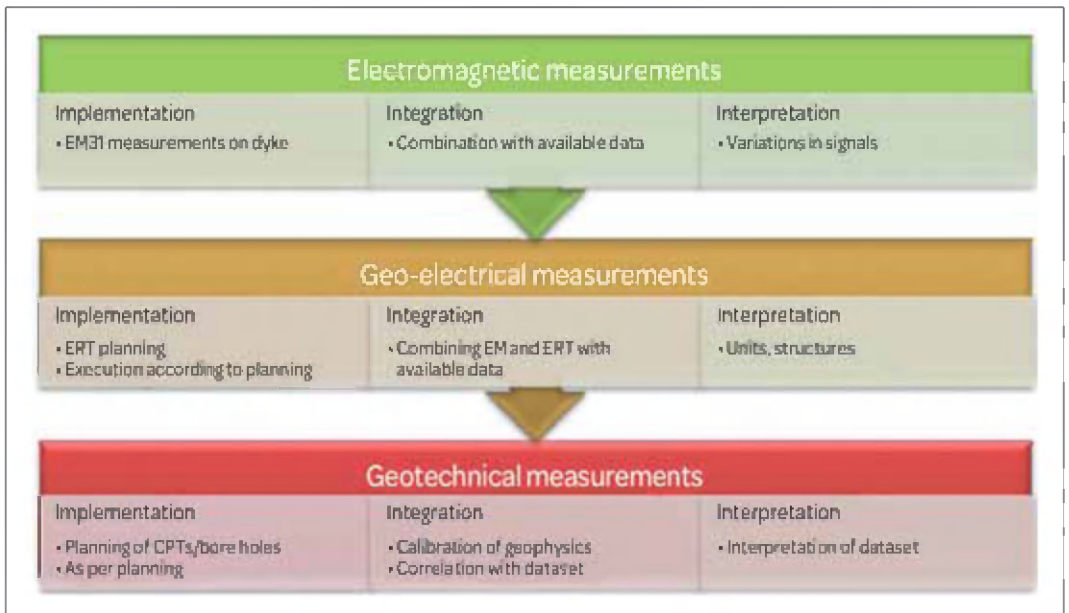


Figure 5.5. Step-by-step plan of the geotechnical and geophysical tests

### 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 geo-electrical measurements. Once these have been evaluated, the geotechnical survey can be continued on a targeted basis.

## 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



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

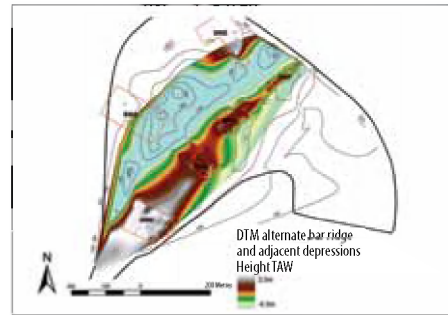


Figure 5.7. The channels flank a striking ridge.

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.

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).

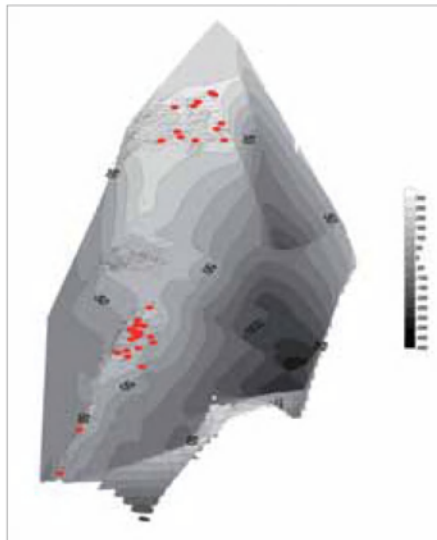


Figure 5.10. Digital height model of the central ridge in Bergenmeersen, indicating archaeological ground samples. The ground samples containing prehistoric finds are shown in red.

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).

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



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

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

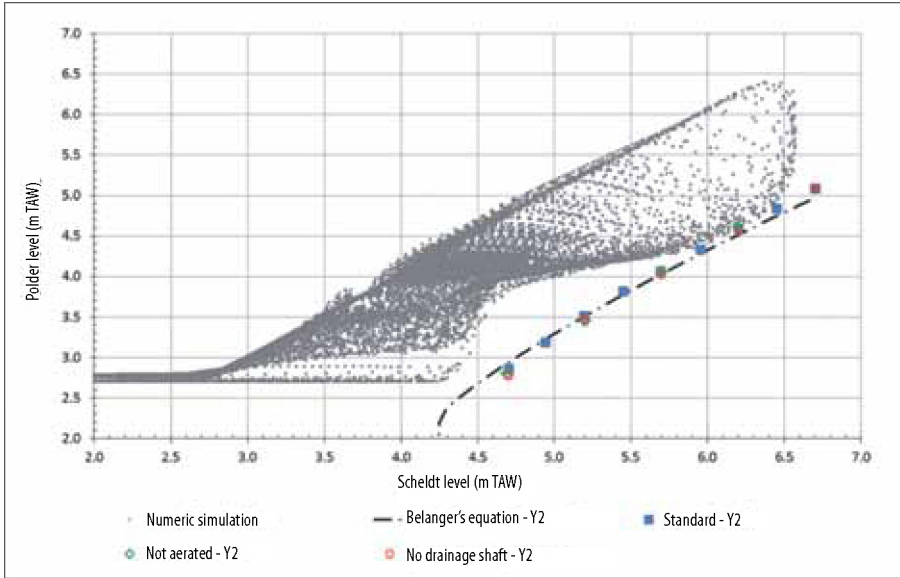


Figure 5.17. Results of standard configuration: polder level Y2 depending on the level of the Scheldt

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.

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