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Realisation of the Ketelmeer Storage Depot

Abstract

Lake Ketelmeer, located at the end of the river IJssel, a branch of the River Rhine, covers an area of 3800 ha, of which 2800 ha is polluted. As treatment of the contaminated material is not economically feasible, it was decided to build a large storage depot in the middle of the lake, to be called "IJsselooig".

The storage depot will change the entire scenery of the eastern part of the Ketelmeer, creating a combination of recreational islands and non-cultivated nature reserves. The IJsselooig depot is meant primarily to store contaminated mud in a safe, cost-effective and environmentally acceptable way, which led to a protracted design process, part of which is described here. The complicated tendering process is also described.

All together the project will take some 20 years to be completed with various public authorities and private companies involved in this dfl 200 million project.

Introduction

History of pollution

Lake Ketelmeer is located at the end of the river IJssel, a branch of the River Rhine. At the mouth of the IJssel there has always been natural silt deposition and delta forming. People have also contributed to land forming by reclaiming large parts of the Zuiderzee. Thus Lake Ketelmeer was created between the polders Noord-oostpolder and Oostelijk Flevoland.

In the period between 1950 and 1980 large quantities of pollutants ended up in the river water, because industrial plants along the Rhine and IJssel discharged into the river, in Holland as well as in Germany, Switzerland and France (Figure 1).

The pollution settled in Lake Ketelmeer, where the current of the river loses its velocity, which causes a reduction of the transport capacity of the river sediments. Together with the adhered pollutants, the silt was deposited in thick layers.



Figure 1. Map of catchment area of the River Rhine, and inset the location of Ketelmeer storage depot.



Figure 2. Birds-eye view of the future situation of the depot and delta at the mouth of the IJssel.



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The lake covers an area of 3800 ha, of which 2800 ha is polluted. On average the polluted layer is 50 cm thick, varying from a few centimetres to over a metre. Overall a quantity of 15 million cubic metres of heavily polluted sediments has been deposited. Since the beginning of the 1990s the incoming sediment is much less polluted.

The accumulated pollution causes deviations in animals that live there. Also the pollution slowly seeps through to the groundwater and is spread by wind, current and turbulence caused by ships propellers. For all these reasons, in 1994 it was decided to clean the Ketelmeer. As treatment of the contaminated material is not economically feasible, it was decided to build a large storage depot in the middle of the lake, to be called “Ijsselooi”. The net depot volume will be 23 million m³, to be able to store contaminated mud from other sources as well.

Master plan for the Ketelmeer

The building of the storage depot will change the entire scenery of the eastern part of the Ketelmeer (Figure 2). At the east side of the 1 km diameter depot, a combination of recreational islands and non-cultivated nature reserves will be constructed. For this, use is made of the surplus of the dredged sand and the non-contaminated clay and peat.

The mouth of the river IJssel will also be newly designed. It will get the appearance of a river delta with marsh-

Figure 3. Construction of the storage depot Ijsselooi in Lake Ketelmeer. Situation at February 1998 (Aeroview bv)



APPENDIX I. GEOTECHNICAL SITUATION OF THE PROJECT AREA

In the Ketelmeer area and the adjacent polders, the separation level of the Pleistocene sand layers and the Holocene soft soils is generally found at NAP -7 to -7.5 m. The bottom level is NAP -4 m. The top layer of 0.3 to 1.0 m (with a mean value of 0.5 m) is classified as contaminated, and will be stored in the final depot. The intermediate layer of Holocene deposits consists of peat and silty clay (partly medium to strong humous). The natural consolidation rate of this material is limited, resulting in low shear strength values and a high water content (sometimes exceeding the liquid limit). Generally this layer is some 2.5 m thick. At distinct locations extreme thick layers appear, as a result of historical river branches and of former sand mining operations (Figure 4).

The reclamation of the Noordoostpolder and Oostelijk Flevoland, confining the Ketelmeer at either side, required extensive water management to be applied to the area. This is owing to the fact that the surface level of the polders surrounding the Ketelmeer is some 4 metres below NAP (Nieuw Amsterdams Peil, the Dutch water level reference). The phreatic level of the polders is kept at NAP -4 to NAP -6 m, by means of pumps. Being part of the same geohydrological system, the equivalent water level in the sand layer throughout the area is also below NAP. The clay layer with its low permeability reduces the flow of water from the Ketelmeer into the polders to manageable proportions.

Figure 5 shows the situation. During construction the isolating clay layer at the depot location is removed, highly influencing the phreatic levels and the groundwater flow into the polders. During depot filling the original situation gradually returns.

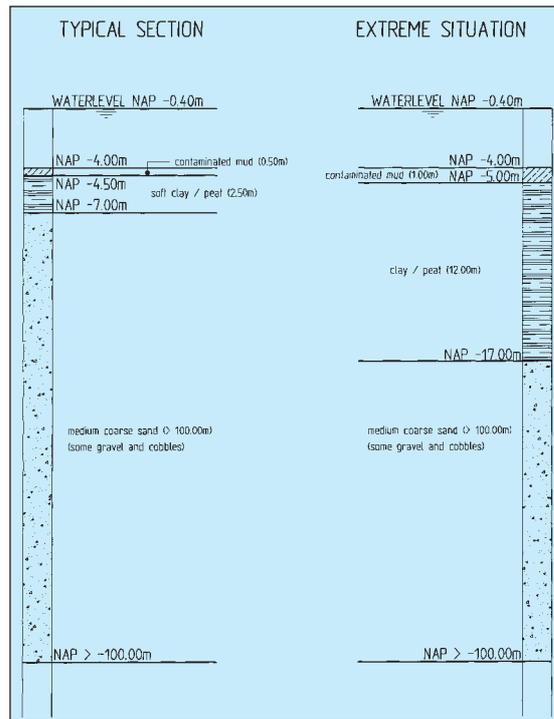
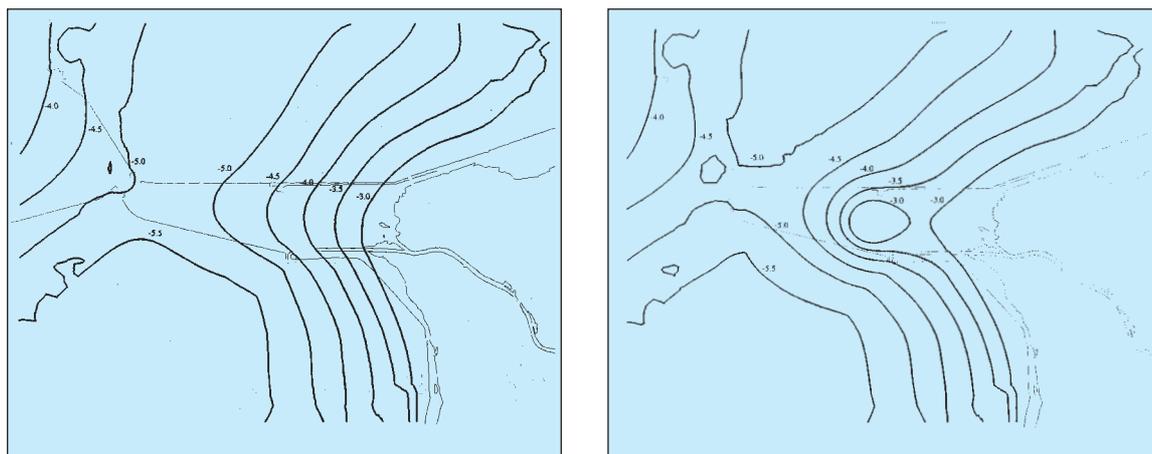


Figure 4. Soil description.

Figure 5. Groundwater level in the Ketelmeer area. Left, the original situation, right the temporary situation during construction.



land as is so characteristic for the genesis of large parts of Holland. To prevent obstruction in the outflow of the river water when the delta is made, a deep southern main channel will be dredged. North of this channel

mud flats and sand shoals will be made, where vegetation will be allowed to develop naturally. The deepening of the fairway will be extended throughout the Ketelmeer, allowing larger ships into the region (Figure 3).

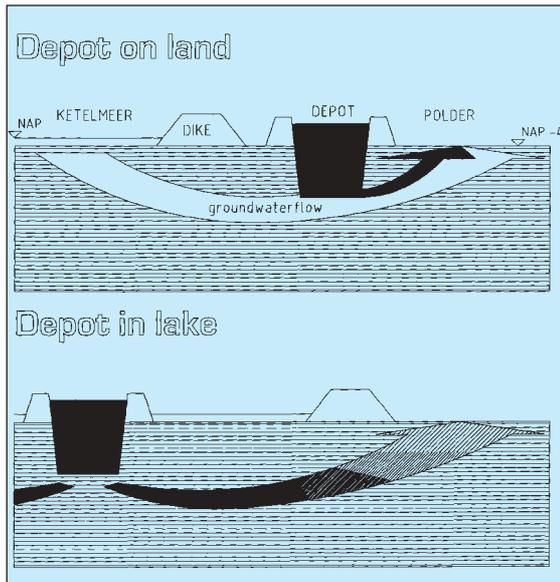


Figure 6. Spreading of contaminated seepage flow.

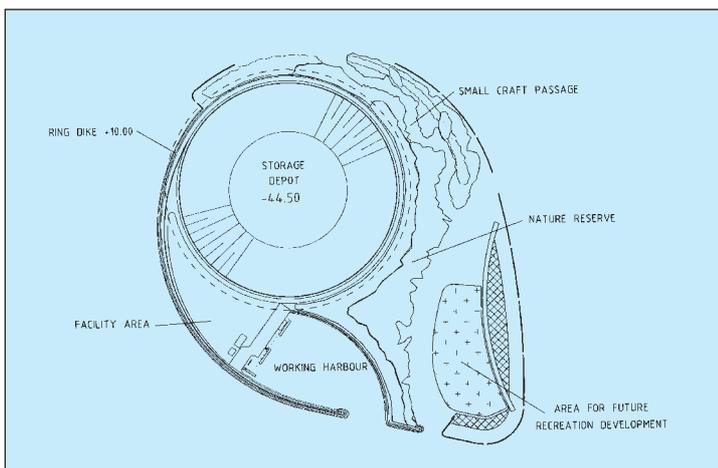


Figure 7. General lay-out of "IJsselooog" (future situation).

DESIGN PHASE

The IJsselooog depot is meant primarily to store contaminated mud in a safe, cost-effective and environmentally acceptable way. This led to a protracted design process, part of which will be described in this section.

Depot location

The size of the anticipated construction, combined with its the contents of heavily polluted sediment, made it necessary to look carefully for the best location. Indeed, this has been a much reviewed topic, not only among the engineers of the federal government, but in an open discussion with the local authorities, environmentalists, pressure groups and the public.

Principally, two options have been studied: A land-based storage or an island-like depot somewhere in the lake. The isolation problem of the pollutants was the

main topic from a technical point of view, mainly because of the geotechnical situation of the project area (described in Appendix I). The reduced groundwater level of the subsoil, caused by the drainage of the polders, is of great influence to the isolation topic. For the public, especially inhabitants and farmers in the immediate vicinity of the Ketelmeer, the fitting of the depot into the land was their main concern.

The two options were (Figure 6):

- 1) Land-based storage. Situated close to inhabited areas, the seepage from the storage depot will reach these areas in some decades, causing a relatively high degree of pollution in a small area (some hundred hectares).
- 2) Lake depot. The distance between depot and cultivated land is large. The pressure gradient (see Appendix I) enhances the seepage from the depot into the groundwater. The flow into the polders causes spreading over a large area (thousands of hectares). However, the degree of pollution is very low, and it will take millennia to spread this far.

The first option was considered better manageable. However, the resistance of the public and local authorities to a close-by land-based storage depot were such that significant delay of the project was expected. Keeping in mind that a delay of one year of the overall sanitation of the Ketelmeer would cause an additional spreading of pollutants far worse than the advance of the land-based option, the choice for a depot in the middle of the Ketelmeer was made.

Landscape fitting

The building of the storage depot in the middle of Lake Ketelmeer gave way to opportunities to boost the development of recreation and semi-natural non-cultivated areas. This fitted into the plans of local and regional authorities. Building the depot would yield a considerable surplus of (clean) medium sand and fertile clay and peat. The creation of a combined nature reserve and recreational areas adjacent to the eastern side of the depot fitted into the master plan for the Ketelmeer. Future developments may include a bungalow-ground, small craft mooring facilities in a delta-like area, and the rise of popular spots for family-outings (Figure 7).

The marshlands in between, planned to remain non-cultivated and develop naturally, require a surface height around water level, to be reached shortly after completion of the depot construction. Because of this, the excavation, transport and deposition of soft Holocene material had to be done mechanically. Pumping the clay would yield a clay-water mixture that would take decades of dewatering and consolidation.

Isolation measures

As mentioned earlier, the isolation of the contaminated

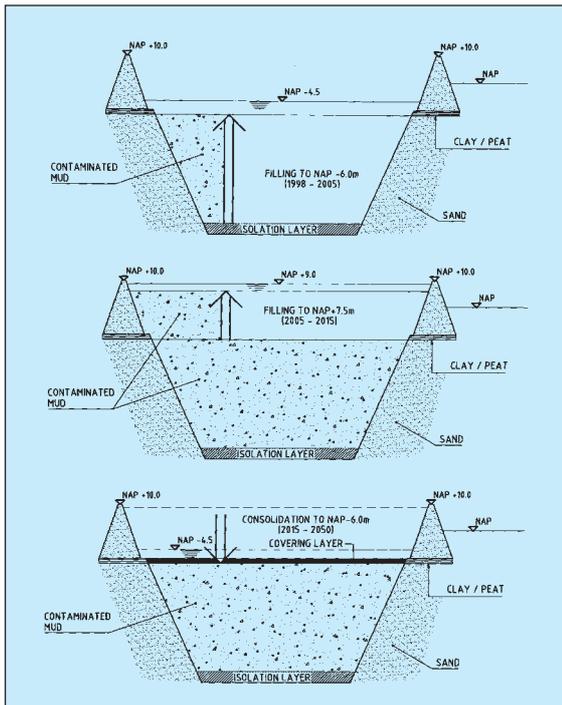


Figure 8. Depot water level management in relation to the filling schedule.

mud stored in the depot off of the surface and groundwater has been a major topic in the design stage. The question was: How can the seepage out of the depot be minimised, at acceptable costs? A combination of measures have been adapted for this purpose – some easily recognisable, others hidden.

Storage depot

Increasing the layer thickness of contaminated sediment leads to a higher degree of consolidation, thereby reducing the permeability of the material itself (Figure 8). A depot depth of NAP –45 m is adopted, limited by the depth at which regular dredging equipment is able to trim the slopes and bottom. The height of the surrounding dike has been restricted to NAP +10 m. Furthermore, given a certain spoil volume, a round depot minimises the contact surface.

Filling the depot with a total volume of 23 million m³, will give a mud top level of NAP +7.5 m. Calculations indicate a top level of NAP –6.5 m after 50 years of consolidation. To reduce the seepage (caused by the outward pressure gradient) the depot water level will be lowered to NAP –4.5, as soon as the mud level has sunk sufficiently. A cover layer of clean soil will be applied.

The local authorities, responsible for granting the applicable permissions, considered these measures of the preliminary design not enough. Both the diffusive and advective way of contaminants dispersion were not properly covered. The following additional measures were incorporated.

During the first 5 to 10 years of filling of the depot, the inside water level will be reduced to NAP –4.5. This way, the pressure difference with the groundwater will be neutralised, eliminating the advective way of transport almost completely.

The feasibility of applying an impermeable synthetic lining to the sides of the depot was investigated. The unreasonably high costs, together with the lack of experience to such works (at 45 m waterdepth), caused this to be dropped. However, acting in a comparable way, is the application of a clean layer of Holocene material on the bottom of the depot (soft clay with 5 to 10 % organics). Whatever construction method is chosen, the clay will be diluted to a low-density clay/water mixture. It is anticipated that a layer of 4 m with a density of 1200 kg/m³ will result from the dumping operation, to be consolidating to a layer of 1 m at 1800 kg/m³.

At the stage that the depot level arises above the Ketelmeer level, again a pressure gradient from the depot occurs. However, now the underwater layer of mud has been consolidating some 5 to 10 years, reducing its permeability to very low values, giving the material isolational characteristics itself.

On the contrary, the recently dumped mud in the upper layer has relatively low density, and easily leaks out. To prevent the outflow as a result of the pressure gradient, a combination of three measures have been taken:

- 1) Leaving at least 1.5 m of impermeable Holocene material under the base of the surrounding ring dike;
- 2) Construction of a seepage screen in the ring dike, from NAP +1 m to NAP –6 m (level of Holocene);
- 3) Covering of the inner ring dike slope with clay or asphalt, from NAP +1 to NAP +10 m.

Other measures

Before the construction of the storage depot could commence, the contaminated top layer of the site has to be removed, and temporarily stored. Because of the relatively short design life (two years), the requirements to isolation measures were less severe. Two square depots, formed by straightforward sheet pile walls, are used for this purpose. The only remarkable structural feature is the protection against drifting ice.

To prevent contaminated material from the remainder of the Ketelmeer spoiling the just cleaned project area, a sheet pile wall is constructed around the whole site. A floating construction (like a silt screen) was regarded as not feasible for effectively shielding the area off.

Geotechnical design calculations

Probabilistic design philosophy

The ring dike surrounding the storage depot will be built using the excavated sand of the depot. Underneath

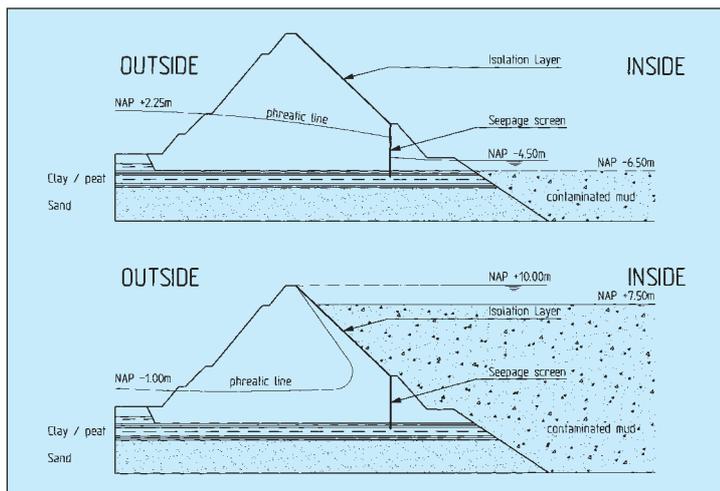


Figure 9. Groundwater flow through Ring dike in 2 design load conditions.

this dike a 1.5 to 10 m layer of soft Holocene material is present. Extensive analysis of groundwater flow, stability and settlement have been made. For this, the latest Dutch standards of semi-probabilistic design philosophy regarding soft soil engineering have been adopted (*CUR Report #162, 1992*).

The main failure mechanism of the depot is "dike collapse". The three subsequent project stages called "construction", "filling" and "consolidation", were appointed failure rates of 10⁻¹, 10⁻³, and 5*10⁻⁴ respectively.

Failure of part(s) of the construction can finally result in an almost complete dike collapse, and therefore have been analysed systematically. This way the appropriate safety classes for the various project stages have been determined: Class I for the construction stage, Class II for filling and consolidation.

Various soil investigation programmes have been executed in and around the project area, not only to determine the top layer of contaminated material precisely, but also to sample the intermediate soft soil layer extensively. A statistical analysis yielded probability distributions of layer thickness and strength parameters. According to the standards, the mean and characteristic (95%) values are subject to correction factors depending on the safety class, before they can be used in geotechnical design calculations.

Design calculations

As a result of a water pressure gradient a groundwater flow through the sandbody of the dike can occur. The direction can be inward or outward of the depot. Figure 9 shows the design load situations. Most critical happened to be the micro-stability of the Holocene toe (next to either side of the base of the dike). The permeability of the isolation layer, to be applied to the inner slope, resulted from the calculations.

The low permeability of the claylike material results in an increase of the pore pressure when a topload is applied. To prevent mud waves or horizontal displacement of the clay to occur, the load needs to be limited. In time, the process of consolidation cares for reduction of this water pressure and increase of the shear strength. A consolidation period of some months is generally sufficient, and the next layer can be placed on top. With the aid of a finite element programme the construction stages and the shape of the dike can be optimised (minimising the execution time but fulfilling the required factor of safety).

At distinct locations under the ring dike extreme thick layers of Holocene appear, as a result of historical river branches and of former sand mining operations. In and directly around these areas, the consolidation process has to be speeded up by means of vertical band drains, in fact increasing the permeability of the soil and thus enabling the decrease of the pore pressure. The drains had to be installed when reaching a construction level of NAP +1 m.

By applying electronic pore pressure indicators in the clay, the stability of the subsoil could be monitored throughout the construction stages.

The primary and secondary settlement of the Holocene layer is estimated as well, using appropriate tools. However, especially peat consolidation is very complex process, strongly dependent upon local soil properties. Measurement of the settlement throughout the construction period would give additional information.

TENDER PHASE

The complexity of the works and the strict regulations of the local authorities (mainly regarding the sanitation works, but affecting the whole project), combined with the tight time schedule for execution, gave way to a series of special requirements to tenderers. The contractors appreciate this system of tendering differently than the commissioner.

The main advantage for both parties is the need for early stud of the ins and outs of the project. The main disadvantage is the impossible position of the tendering contractor: Confirmation to all clauses is compulsory, even if it is considered technically impossible. Some examples will be given below.

- Planning of the works. The time to complete the works was limited, considering the size of the project. Therefore, it was required to show in a detailed planning how the progress of the various activities would be. The huge number of additional time or sequence restrictions to various parts of the works, gave way to a very complex works programme. Worse, complying to all the requirements at the same moment was not possible.

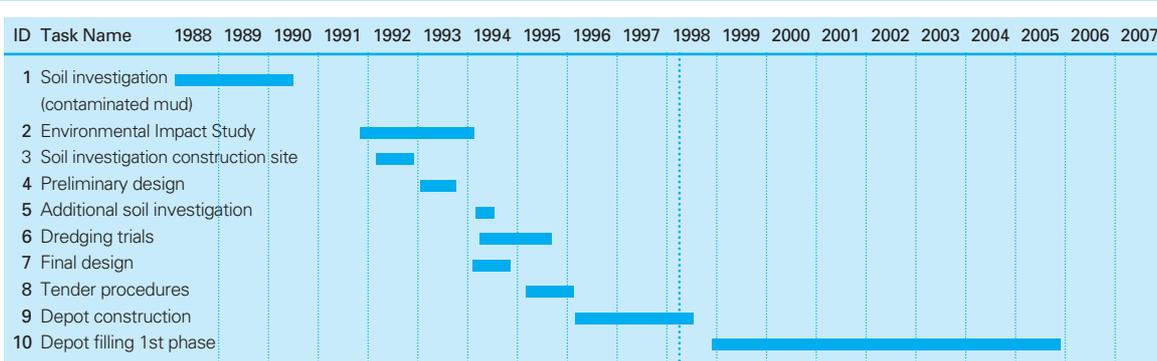


Figure 10. Bar chart showing the activities related to the storage depot realisation.

APPENDIX II. STORAGE DEPOT “IJSSELOOG”.

All together the project will take some 20 years to be completed. At the end of 1998 the filling of the depot with contaminated mud will commence (Figure 10). Various public authorities and private companies are involved in this dfl 200 million project (Figure 11).

Some key figures of the final design are as follows:

- The depot and adjacent reclaimed parts will cover 250 ha upon completion, of which 140 ha for the depot itself.
- Removal and controlled temporary storage of 1.9 million m³ of contaminated mud, with a situ layer varying from 30 to 100 cm.
- To prevent recontamination of the cleaned surface area, 9 km of sheet pile wall is driven around the project location
- Mechanical excavation of 3.5 million m³ Holocene material (soft clay and peat), using this to create the non-cultivated nature reserve adjacent to the depot.
- Dredging 14 million m³ of medium coarse sand to create the actual depot space. Dredging depth varies from NAP -7 m to NAP -44.5 m.
- Part of the sand has to be used to build a ring dike

- around the depot, with NAP +10 m crest height and a diameter of almost 1000 m at crest level.
- The remainder of the excavated sand will be used for the additional reclamation and for supply of the regional market.
- Various isolation measures have been incorporated, to prevent the pollutants to disperse out of the storage depot in time.
- A working harbour and related facilities are built at the southern side of the depot.

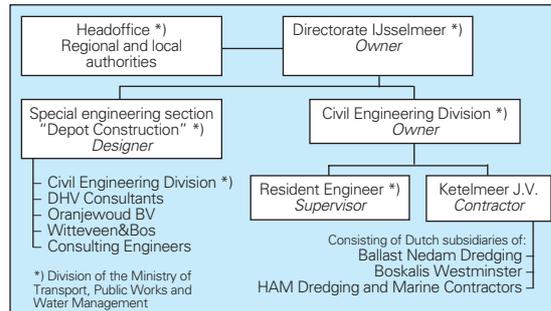


Figure 11. The main parties involved in commissioning the design and execution of the works.

- A detailed and legally binding method statement had to be prepared as part of the offering bid. This way, the tendering contractors have to figure out their working method very carefully as part of the estimate. Possible bottlenecks and risks can be identified at an early stage. However, the contractor’s interpretation of the soil characteristics happened to be fairly different from the designer’s, which made it desirable or sometimes necessary to apply different working methods than prescribed. Often this was not permitted.
- Excavating the Holocene material, consisting of soft clay and peat, required a tolerance of +/- 15 cm (vertically) at a water depth of -5 to -9 m. For the ring dike cunet this requirement was important: For isolation purposes a minimum layer thickness is required, but the need for a short consolidation time

- during dike construction restricts this thickness. The backhoe dredgers used have a bucket size of 5 to 13 m³. These units were bigger than anticipated during design, but considered necessary to achieve high production rates at low costs. The actual tolerance is a combination of various factors: measuring accuracy, relaxation of remaining peat, operators tolerance, production level and spill allowance. All together, even with the most sophisticated position indication systems possible, a combined tolerance of +/- 40 cm proved to be realistic (Figure 12).
- Strict regulations concerning maximum noise levels were prescribed by the local authorities. However, all tendering contractors reminded the authority of the impossibility of this requirement. The closing date was postponed one month, during which a

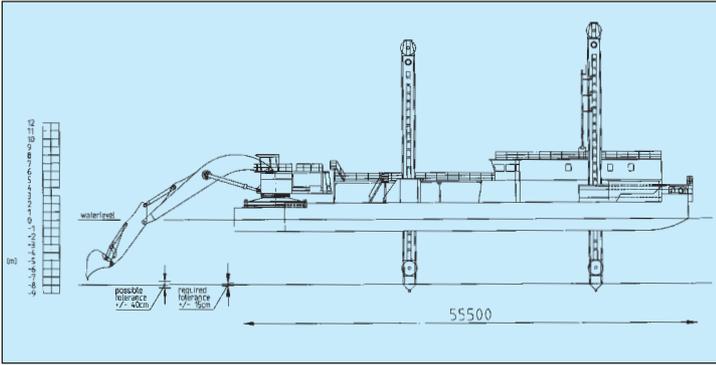
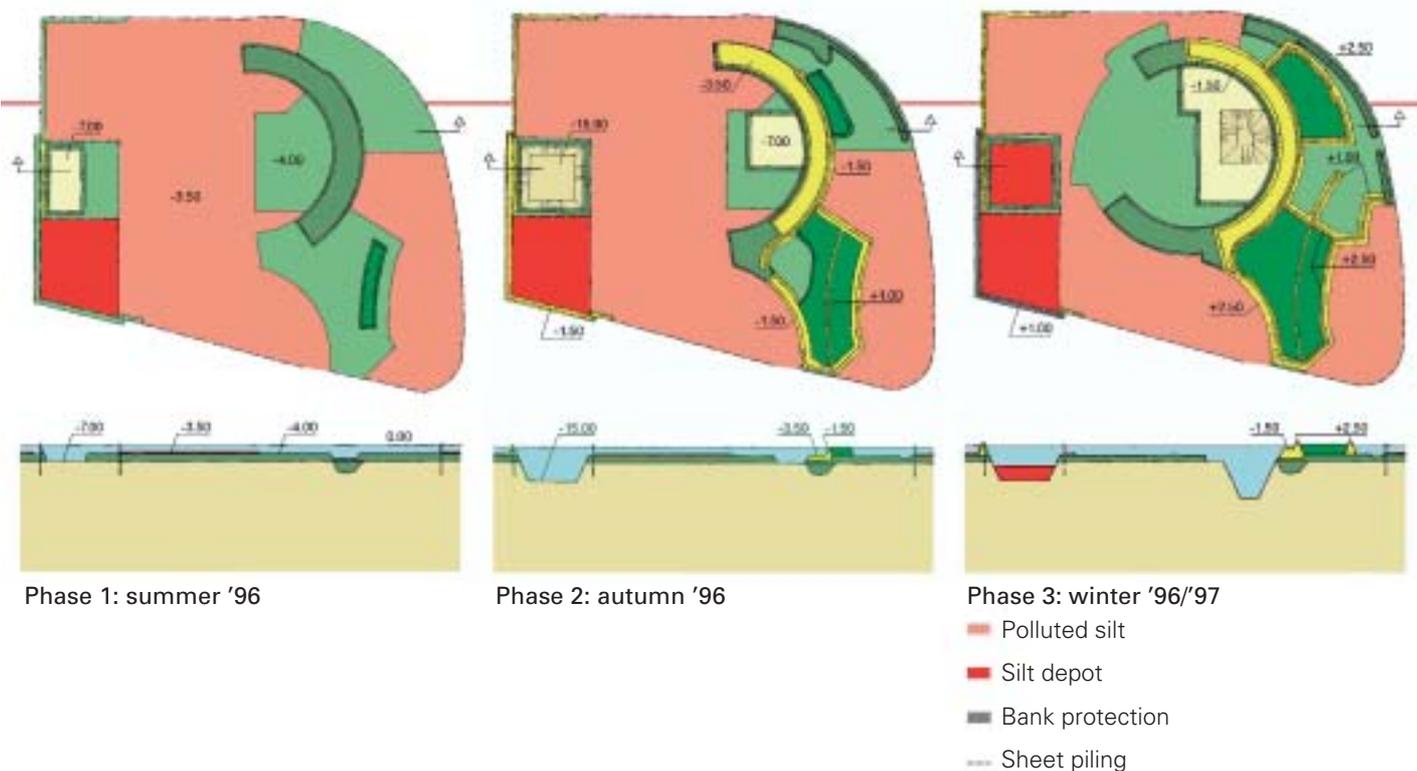


Figure 12. Tolerances for the backhoe dredger.

3 dB relaxation was awarded. Normally, changing regulations like this requires at least half a year.

- A system of significant penalties and bonuses for late or early completion of (part of) the works was adopted. Such a system is widely used, adding pressure to the contractor to finish the job. There are certain benefits to the system, but during the execution of the works it interferes with discussions in case of unforeseen situations.
- The contractor had to possess the ISO-9002 certificate, and design a project-dedicated QA manual. Especially because of the complexity of the project, this seems appropriate, although – incorrectly – it is often regarded as an increase in paperwork only.

Figure 13. Execution of the works; a chronological sketch.



In each case, for all parties involved (contractor, supervisor, design engineer, commissioner) this meant adapting their nature of working, quite drastically sometimes.

DEPOT CONSTRUCTION

The various dredging, transportation, reclamation and other works, all related and mostly executed simultaneously, made a comprehensive and detailed planning of the activities indispensable. Although last-minute on-the-job alterations were sometimes necessary, the long-term planning acted as the main guideline for the sequence of the works.

In Figure 13 the planning of the works is schematically visualised, showing the development of the project in time. Not shown in this picture is the extensive fleet of equipment, working close to each other, with floating pipelines and anchoring wires spreaded all around. Besides this, surveying the progress of the works has to be done very frequently, to be able to hand over part of the works, subsequently enabling the next scheduled phase being started immediately. In the following, a selection of the activities is described. The inter-relationship as shown in the sketches is neglected here.

Dredging contaminated mud, temporary storage

For the dredging of contaminated mud, special equip-

ment is developed by the contractors during the last decade. Key requirements in this type of work are:

- very high accuracy (x,y,z) of the excavation tool
- low spill and turbidity caused during dredging
- little dilution of the situ mud density

Out of this, several tools have been developed, quite distinct in shape and excavating principal (Figure 14). With prototype-like dredgers many trials have been executed over the past years, in conjunction with the appropriate authorities and independent consultants. An extensive description of one series of testing is given in the literature (Arts et al. 1995). For everyone involved, these tests gave insight to the state-of-the-art of high-precision sanitation dredging, to desirable improvements, as well as to large-scale mud storage behaviour.

For the parameters involved a probability distribution has been deducted. In this way, it was calculated that a cleaning efficiency of 90% would yield an economically acceptable balance between the cleanliness level and the costs of sanitation involved. The costs increase dramatically at higher levels, both for site investigation (to determine contamination layer more precisely) and volume to be dredged and stored.

Three dredgers have been deployed to dredge the contaminated sediment. Each dredger has its advantages and disadvantages, but all did their job satisfactorily. A high degree of automation of the dredging equipment, experienced dredge masters, and close monitoring of the works (echo-sounding and dredge process



Figure 14. The auger and attached turbidity screen of the HAM 291, one of the dredgers which was specially developed for this type of sanitation dredging.

analysis) proved to be essential to fulfill the objectives mentioned above.

Holocene removal and storage

After removal of the contaminated top layer, the non-contaminated Holocene material had to be dredged separately. The need of removing all material from the area of the future depot is clear. Furthermore, a cut of

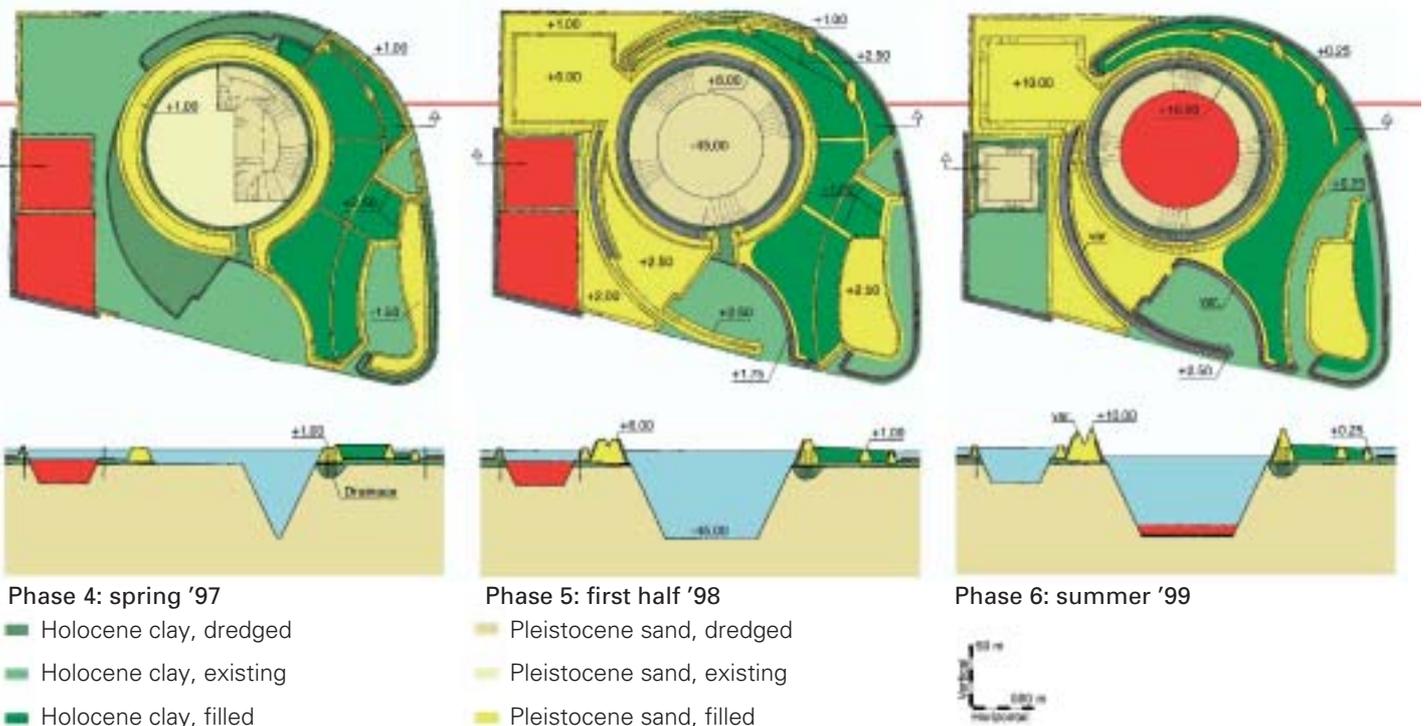




Figure 15. Backhoe dredgers *Manu Pekka* and *Kuokka Pekka* excavating Holocene material. With their buckets of 13 and 8 m³, and sophisticated bucket position indication system, they were very suitable for high production excavation (Rob de Wind bv).

0.5 to 3 m is dredged at the location of the surrounding ring dike, to reduce its construction time. In the contract it is prescribed that a mechanical excavation tool had to be used, in order to retain as much structure of the soil as possible. The use of backhoe dredgers was chosen because of their production level, availability and moveability (Figure 15).

Figure 16. Unloading Holocene material from barges into the future nature reserve area. Five conveyor belts and 25 barges were in use at a certain moment, together handling some 1500 m³/hour (Rob de Wind bv).

For the transportation of the soil to the unloading platform, barges and pushboats were used (Figure 16). Most of the dredged material, rich of organic material, had to be used for the creation of non-cultivated nature



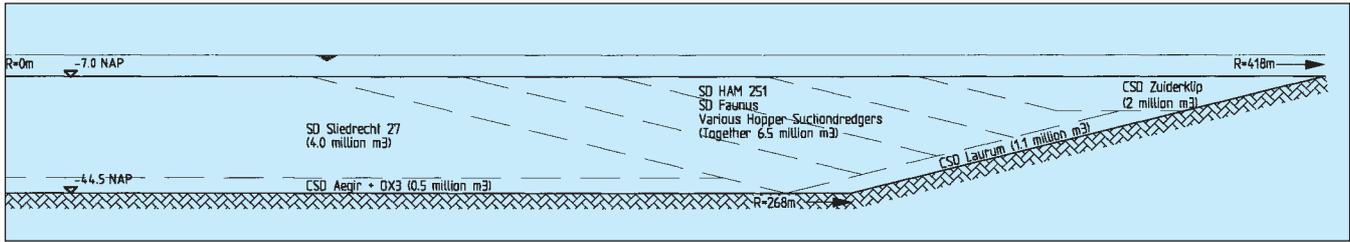


Figure 17. Deployment of sand dredging equipment. A large variety was used to fulfill the requirements of the contract at the most economical way (drawing to scale).

reserves at the east side of the depot. Part of the volume had to be stored temporarily for later re-use as an isolation layer at the bottom of the depot.

Originally, it was required to use the soft material directly for construction of the mud areas. However, the nature of the material, especially the high water content and therefore small consistency, makes it unsuitable for raising above water level. Only after construction of surrounding sand bunds, the Holocene material could be stored in the required fashion.

Dredging, transportation and deposition of sand

The choice of the dredging equipment has been subject to mainly three distinct considerations:

- 1) Sand dredging can only start after removal of the layers on top, i.e. the contaminated mud and the Holocene material.
- 2) To minimise the risk of a slope stability failure, a maximum layer thickness to be excavated was prescribed. In the area less than 15 m from the design slope, this layer may not exceed 1.5 m. The next 85 m, the maximum layer was 6 m. In the remaining area there was no restriction.
- 3) The sand had to be used in a variety of ways, i.e. building the surrounding Ring dike and secondary dams, a stockpile for future reselling, bund construction, or distribution to the local construction market.

This gave way to a large variety of dredging equipment (type and size) being used. Figure 17 shows the deployment of the dredgers as shown in Table I (see also Figure 18).



Figure 18. The suction dredger Faunus loading a self-propelled barge. Built in 1972, the Faunus has a remarkable track record in deep suction dredging in the IJsselmeer area, producing up to 2500 m³/hr.

The tolerances for excavating the depot were as follows:

- Side slope, from -7 to -16 m: +/- 60 cm (L slope angle)
- Side slope, from -16 to -44.5 m: +/- 2.0 m (L slope angle)
- Bottom, +/- 1.0 m tolerance (vertical).

Because of the huge dimensions of the depot, this stands for a volume of +/- 850,000 m³.

In Figure 19 (A), the cutter suction dredger Laurum and the required tolerance are drawn at the same scale, and also (B) a typical realised cross-sectional profile is shown.

The barges used for sand transport throughout the construction site were unloaded by means of clamshell

Table I. Variety of dredging equipment (type and size) utilised.

Name	Dredger type	Max depth [m]	Pump power [kW]	Mean production [m³/wk]	Pipe diameter [mm]
Haarlem	cutter suction	-16	3500	70,000	700
Zuiderklip	cutter suction	-18	3150	80,000	700
HAM 251	deep suction	-40	1270	115,000	600
Sliedrecht 27	deep suction	-55	5450	315,000	800/900
Aegir+OX3	cutter suction	-45	1750	70,000	700
Faunus	deep suction	-50	700	100,000	(barge loading)
Laurum	cutter suction	-45	800	37,500	350
Various	suction hopper				(600-800 m³)

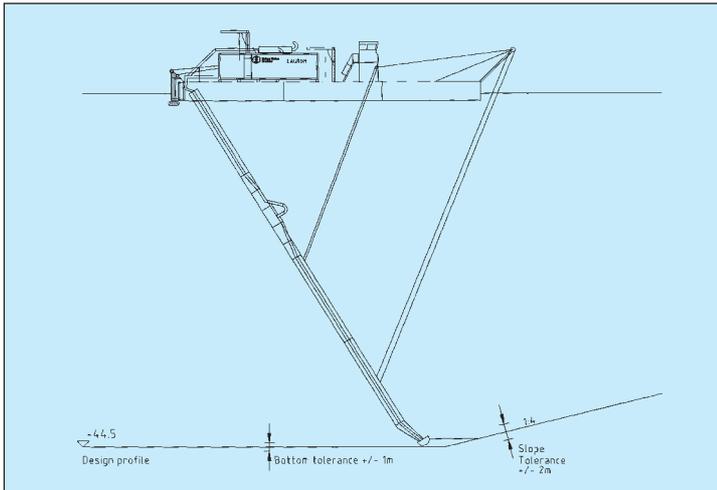
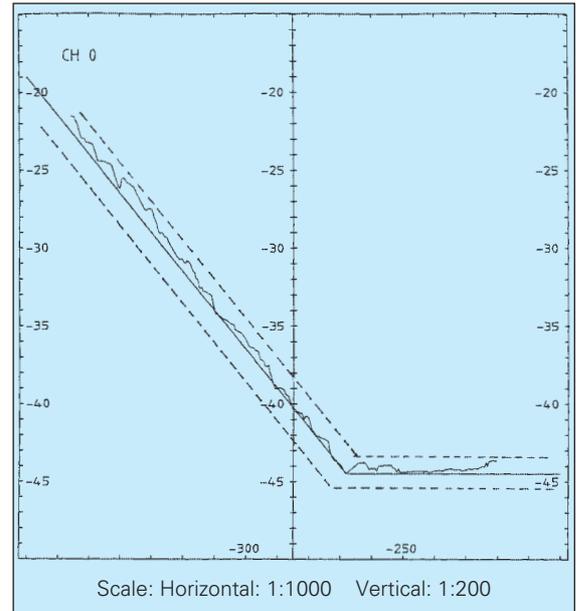


Figure 19. A) The slope and bottom of the depot had to be trimmed within the required tolerances. For this job the demountable CSD Laurum was employed (left). B) A typical realised cross-sectional profile is shown at right.



cranes, putting the sand into the feeder of a conveyor belt. This way the relatively small bunds for Holocene storage were constructed.

The use of a pipeline system (floating, sinker pipe or land-based) for transportation of the sand (with a maximum of a few kilometres) is to be preferred in terms of production capacity and production costs. Indeed, this method is used for the majority of the works. The final deposition of the sand has been done using two principles:

- 1) Underwater deposition by means of a floating spraying pontoon. In Figure 20 the *HAM 1208* is shown, which is equipped with a fully-automated control system: The six constant tension hydraulic winches move the pontoon, making use of a DGPS positioning system coupled to an online production measurement. This way, small layers can be put in place precisely, at a high production capacity (see Kranendonk and Vlak 1992).
- 2) A conventional reclamation site. The sand/water mixture is pumped behind prepared bund walls. Bulldozers are used to ensure an even distribution and good compaction of the sand. The surplus of process water is being let off at the far end of the reclamation area. The required fill profile and the generated production rate determine the number of pipes added per hour.

Ring dike construction

The geotechnical structure of the Ketelmeer area is described in Appendix I. Throughout the projected site an intermediate layer of Holocene material (peat and soft clay) is present.

Completely removing the Holocene layer at the ring dike location was not acceptable. It plays a role in shielding the contaminants off of the mainstream of

the groundwater (ending up in the polders). Thus, a layer of generally 2, but up to 10 m of compressible and low-strength material has been left in place. The ring dike is built on top of this, using the excavated sand of the storage depot. Consequently, the construction of the sand body is subject to stability and consolidation phenomena. The tender prescribed the building stages in quite a detailed way. Later, during the actual construction, it was proven that further optimisation of the construction schedule was possible.

An even distribution of the sand with limited layer thickness was required, because of the limited shear strength of the soft layer. The *HAM 1208* was used for the underwater part of the dike construction. The layers above mean water level were built by means of a conventional reclamation site, pumping the sand/water mixture between bund walls. Bulldozers are used to ensure an even distribution and good compaction of the sand.

In Figure 21 the results of a CPT (cone penetration test) from the NAP +1 m level is shown. The soil layers can be identified quite easily. Remarkable is the cone resistance of the sand layers. The sand placed by means of the spraying pontoon reaches values from 1 to 5 MPa (increasing upwards). In the conventional reclamation fill (from NAP -0.5 to +1.0 m) the values sometimes exceed 10 MPa.

Other activities

A substantial amount of bank protection works are part of the project, some for temporary use, some for long-lasting protection of the construction. Use is made of woven mats covered with a layer of stones. A working harbour will be installed outside the ring



Figure 20. Spraying pontoon HAM 1208, capable of building thin-layered underwater sand bunds at a production up to 4000 m³/hr (Rob de Wind bv).

dike. Quays and facilities will be constructed. Hopper barges will moor here during the major clean-up of the Ketelmeer, to unload the contaminated material into the storage depot by means of a pump/pipeline system.

Conclusion

The Ketelmeer clean-up and depot filling are planned to commence at the end of 1998. The tender procedure for the first sanitation contract of the Ketelmeer (eastern side) is currently in preparation.

At other sites in the northern part of The Netherlands (mainly small scale projects) the sanitation works are ready to start as well.

At this moment, other parts of the Ketelmeer master plan, like the IJsselmonding delta development and the Ketelmeer fairway deepening, are in a design stage.

References

“Construeren met grond” (Soft soil engineering). *CUR Report #162*. 1992.

Arts, Thomas et al.

“High accuracy sanitation dredging trials”. *Terra et Aqua*, nr 61. December 1995.

Kranendonk, J. and Vlak, J.

“Construction of a pilot project island in IJ-meer”. *Terra et Aqua*, nr 63. June 1996.

Figure 21. Results of a Cone Penetration Test from the NAP +1.

