DEEPENING OF GRÅDYB
PROJECT PROPOSAL
MAY 2022

Project name	Port Esbjerg – Deepening of Grådyb
Client	Port Esbjerg
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DRAWINGS

No.	Subject	Scale	Date
001	Grådyb depths (m DVR90) from multibeam survey	1:50,000	10 May 2022
002	Grådyb dredging volumes	1:50,000	29 June 2022

1 INTRODUCTION

Port Esbjerg has requested WSP to prepare a project proposal for deepening of the Grådyb fairway used by vessels to navigate from the North Sea into Esbjerg harbour. Grådyb runs from buoy 0 to Tauruskaj, a stretch of approx. 21.6 kilometres.
The fairway is marked in the chart section shown in figure 1.

Figure 1 – Grådyb fairway, Esbjerg harbour

As shown in the chart, the depth of the fairway extends approx. down to contour level -10.3 m MLWS, and the requested future minimum water depth is -12.5 m MLWS, see figure 2 (however excluding sections 1 and 2 for which the requested water depth is initially specified at -11.5 m MLWS – see appendix 002 for information on the division into sections.

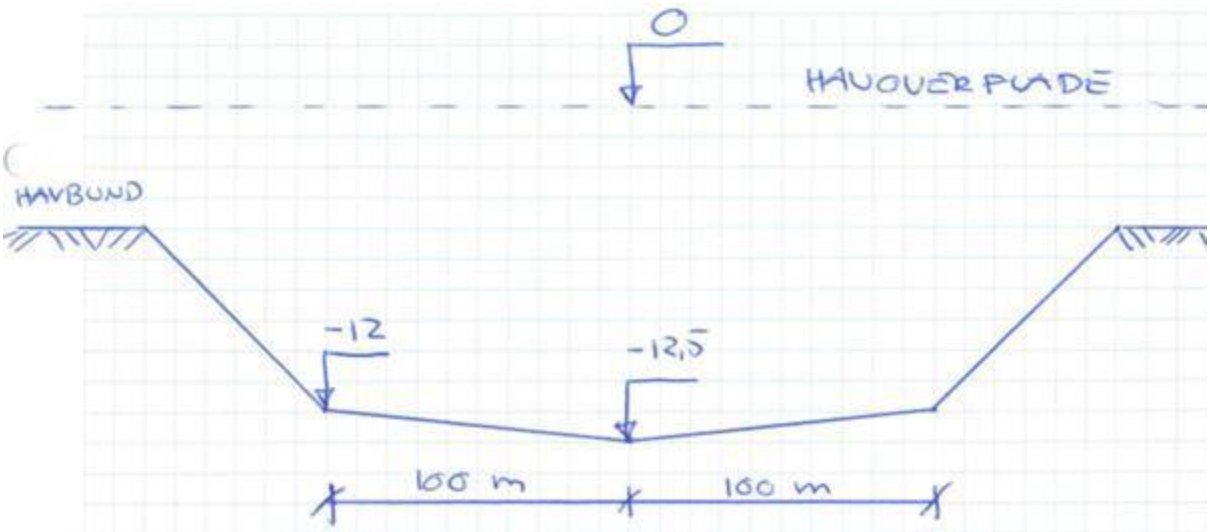

Figure 2 – Requested profile of the Grådyb fairway (contour lines according to MLWS), Port Esbjerg, 25 November 2021

In the chart and Port Esbjerg's dredging profile and map contour lines are specified in metres according to mean low water spring (MLWS). In the other documents, they are mainly specified in metres according to the Danish vertical reference system 1990 (DVR90). In Esbjerg harbour, the correlation between the contour systems is as follows: DVR90 = MLWS + (-0.82 m).

Figure 3 shows the dredging profile with contour lines according to DVR90.

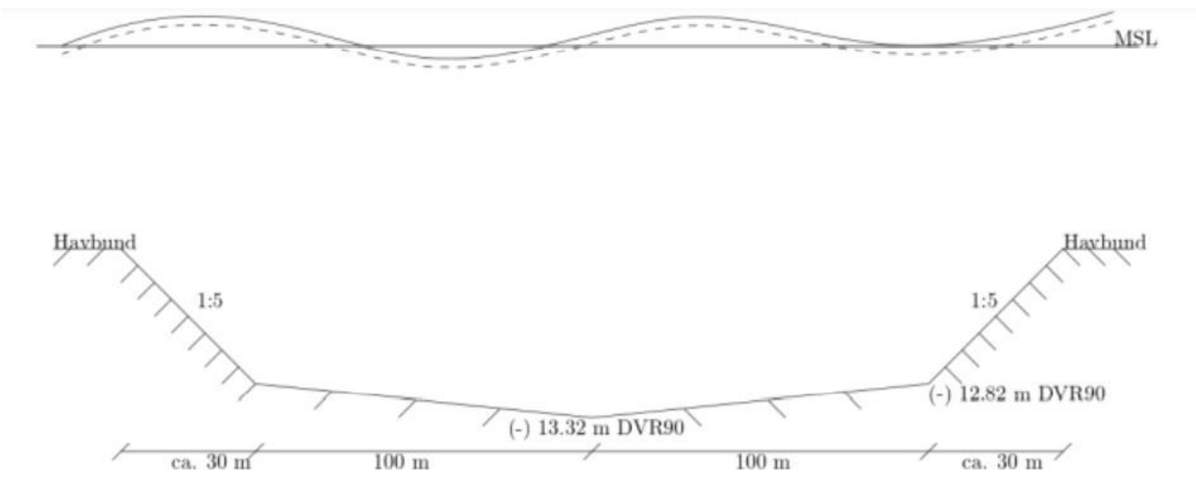

Figure 3 – Requested profile of the Grådyb fairway (contour lines according to DVR90). The mean sea level (MSL) shows the schematic position of the mean sea level, equal to contour line 0 m DVR90.

This project proposal describes how the project may essentially be implemented, including execution method, time schedule and estimated dredging volumes. The project proposal is conditional on all permits and licences (environmental impact assessment (EIA), permit for recovery, etc.) being obtained.

The project proposal is based on the following data:

- Grådyb dredging profile, *Port Esbjerg, 25 November 2021*
- Electronic sounding plans, XYZ files, *Port Esbjerg/Danish Coastal Authority, 7 March 2017*
- Chart 95, *Ministry of Energy, Utilities and Climate, October 2015*
- Plan of harbour and fairway (DWG), *Port Esbjerg*
- Cross section – deepening – Grådyb, buoys 0–10 (DWG and PDF), *Port Esbjerg, 1 December 2021*
- Excerpt from the 1993 EIA
- Materiality assessment of dredging at Esbjerg harbour, Deepening at Grådyb, *Niras, 27 January 2022*

Calculations of volumes are based on sounding data from 2017. Sounding/hydrographic survey data are subject to some uncertainty as the fairway will sand up and require regular maintenance dredging (such maintenance dredging being performed by the Danish Coastal Authority). However, as maintenance dredging is performed regularly, any uncertainty in that respect is considered to be of minor significance.

2 DREDGING VOLUMES

The dredging volume is calculated based on a multibeam survey performed on 7–8 March 2017. By adding a CAD profile with the requested fairway depths, this can be subtracted from the measurement. The difference between the two profiles equals the volume of sediment to be removed. The calculation was performed using ArcMap. Surface Volume was subsequently used for calculating the total volumes to be dredged.

Requested fairway depths:

Section 1: -11.5 m MLWS over the entire cross section

Section 2: -11.5 m MLWS over the entire cross section

Section 3: -12.0 m MLWS along the outer edge with a mid-depth of -12.5 m MLWS

Section 4: -12.0 m MLWS along the outer edge with a mid-depth of -12.5 m MLWS

Section 5: -12.0 m MLWS along the outer edge with a mid-depth of -12.5 m MLWS

In addition, there is a slope of 1:5 from the outer edge of the fairway to the surrounding seabed.

Figure 4 shows a map of the calculated dredging volumes. Maps of depths and dredging volumes are attached as drawings 001 and 002. The map only shows dredging volumes for the future requested depth of the individual sections.

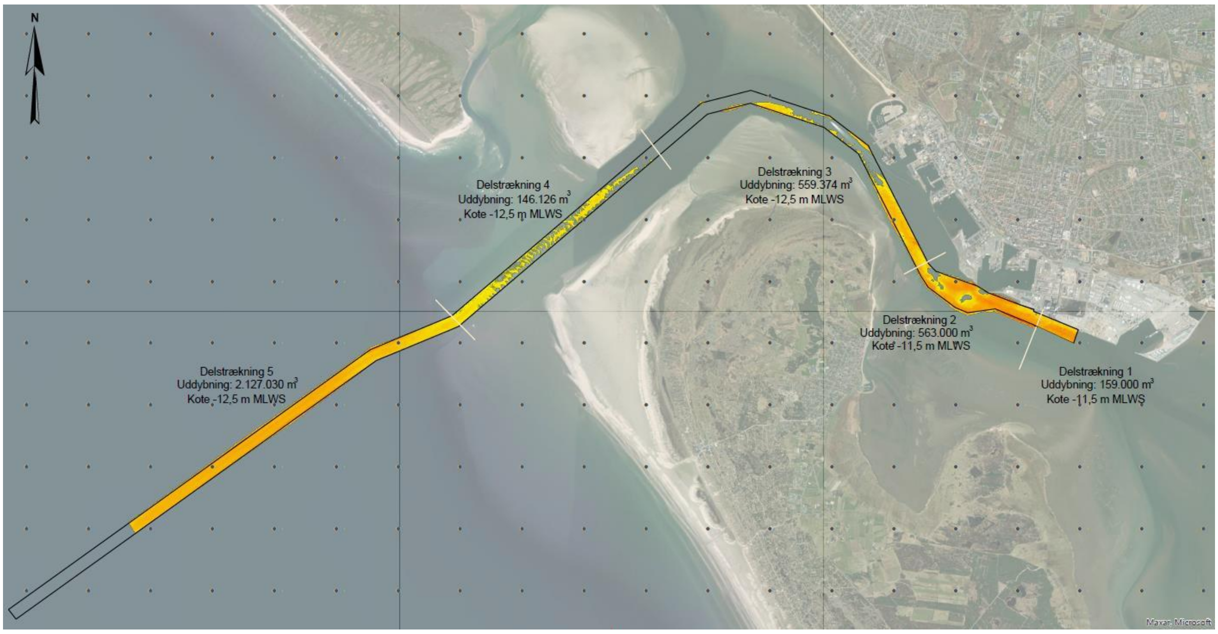

Figure 4 – Map of calculated dredging volumes in sections 1–5.

Figure 4.2 in the excerpt from the 1993 EIA shows four sections (sections 2–5), with bar charts illustrating the distribution by sediment type. Sediment is categorised as sand, fine sand w. 2–3.5% silt, fine sand w. 20% silt, clay w. layer of sand/silt, marine clay and peat/gyttja. The figure is reproduced below as figure 5.

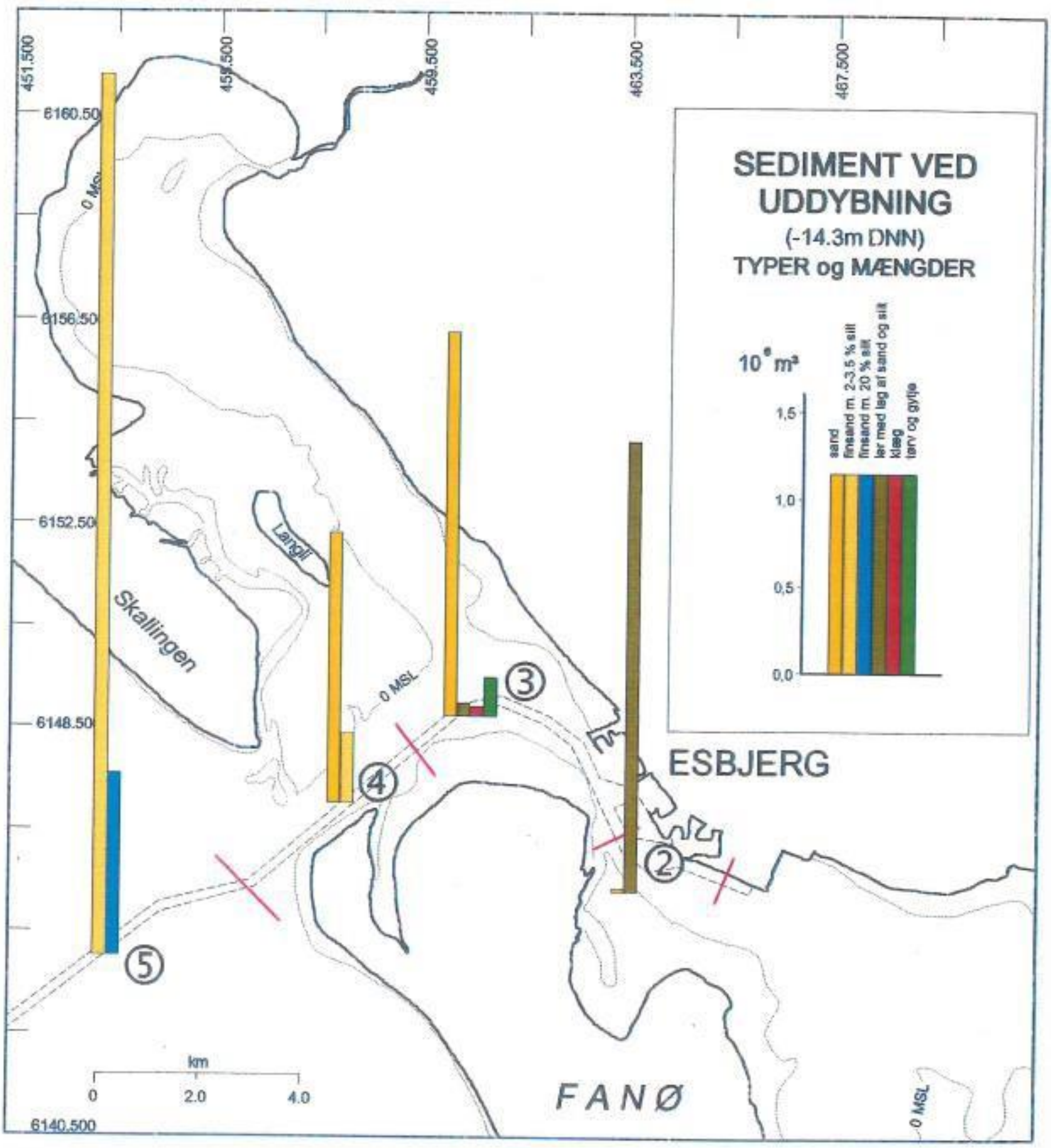

Figure 5 – Sediment types by section, excerpt from the 1993 EIA.

The distribution of sediment in the individual sections (2–5) is based on samples taken in the existing fairway prior to the 1993 EIA for the purpose of dredging down to -14.3 m (DNN). As indicated, sections 3, 4 and 5 consist in large part of friction materials (sand, fine sand and different silt content). Section 2 mainly has clay fractions.

As the fairway sands up and is regularly maintained by dredging, the chart is not considered have changed significantly since 1993 as the distribution applies from the bottom of the fairway and down.

In the calculation of dredging volumes, a percentage distribution of sediment has been calculated for each section, corresponding to the ratios shown in the bar charts (in section 4, for example, the ratio of sand to fine sand with silt is approx. 1:5).

Based on this, the distribution shown in table 1 has been estimated for the total volume of all five sections.

REMOVAL	PERCENTAGE OF TOTAL VOLUME	DREDGNING VOLUME	VOLUME
Sediment recovery: Pumping in at East Port, sand	17%	600,000 m^3	2,770,000 m^3
Sediment recovery: Pumping in at East Port, fine sand w. silt	61%	2,170,000 m^3	
Sediment recovery: Integration in other areas, other sediments (clay/silt)	22%	800,000 m^3	800,000 m^3
TOTAL			**3,570,000 m^3**

Table 1 – Estimated distribution of sediment

Sand and sand containing silt (i.e. the yellow and blue bars shown in figure 5) are to be pumped into the East Port, while the other types of sediment are to be recovered and used in one or more other projects. In practice, not all material will be pumped into the filling area as pumping is expected to generate a certain loss in many of the silt fractions. The total silt volume corresponds to 4–5% of the sediment to be pumped in, and the loss is therefore assessed to be insignificant.

3 EXECUTION METHOD AND TIME

The sand fraction is to be pumped into Stage 5 of the East Port expansion. Locations are shown in figure 6. According to Port Esbjerg, based on the EIA for the establishment of Stage 5, the project requires an expected 3.3 million m^3 of backfill.

Clay fractions are assumed to be recoverable for use in one or more projects, including for example:

1. **Land area in the Måde district**
   The material will be used as backfill material to be pumped in. This will cause the materials to soften, likely rendering subsequent cement stabilisation of the area necessary before the area can be used as harbour areas. According to Port Esbjerg, Måde has an area of approx. 31,000 m^2 that may accommodate approx. 6 metres of backfill. The Måde area also includes other areas of a total of approx. 343,000 m^2 that may accommodate filling up to a height of approx. 3 metres. This results in a total capacity of approx. 1.2 million m^3.

   If the distance between the exact area of recovery and territorial sea is too far for pumping purposes, significant additional time will be required for loading the material onto trucks or dumpers for transportation to and dumping in the area.

2. **East Port, Stage 5**
   The material will be used as backfill to be pumped in. This will cause the materials to soften, likely rendering subsequent cement stabilisation of the area necessary before the area can be used as harbour areas.

3. **Contemplated energy island in the North Sea**
   The material will be used as backfill to be excavated by grab dredging. This will generate significantly more marine traffic compared with the other recovery options. It will also imply a significant increase in the number of days lost due to inclement weather.

However, this project proposal does not detail the suitability of the materials or the process in terms of removal and refilling.

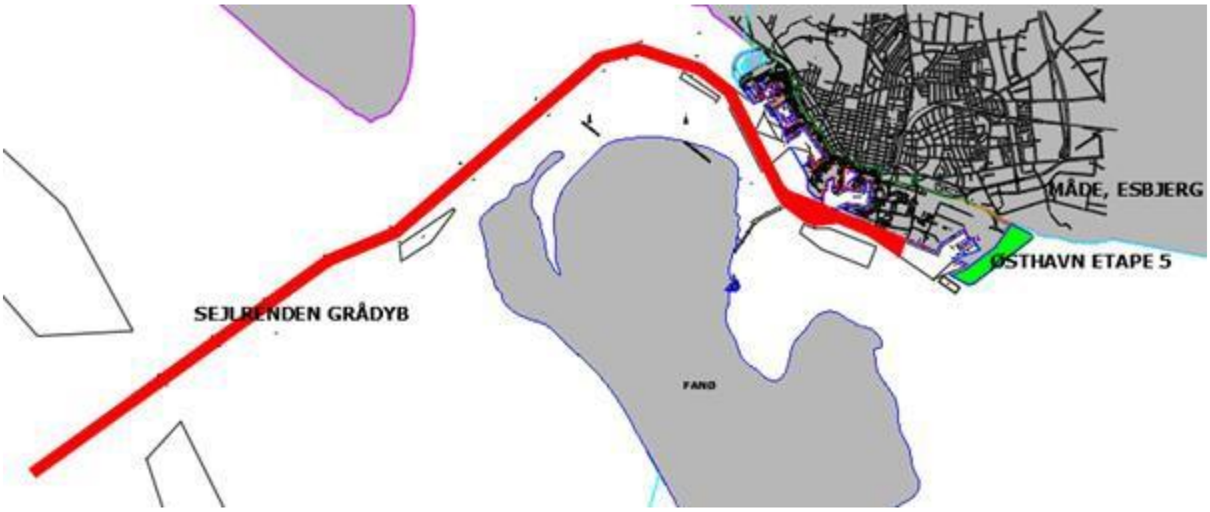

Figure 6 – Location of fairway, Stage 5 of the East Port and the Måde district

The 2022 materiality assessment concluded that the deepening may be executed using a hopper dredger of a type such as Rohde Nielsen's 'Balder R' (2022). This vessel has a theoretical capacity of up to 6,000 m^3/hour with a total loss rate of approx. 5% (Gray, J. S., 2006).

Generally, its hopper capacity (approx. 6,000 m^3) is not fully utilised. As each load is assessed at approx. 4,000 m^3, the expected duration of a round trip is approx. 5–6 hours, facilitating approx. four loads every 24 hours (approx. 16,000 m^3 in total).

The time covers suction of materials, transit time, pumping, occasional crew rotation/bunkering, etc. (excluding time lost due to inclement weather and production stoppage).

Clay fractions are to be excavated. The use of a backhoe dredger or, alternatively, a bucket dredger is assumed. The materials are to be dredged and loaded onto a barge. The production rate is assessed at approx. 5,000–7,000 m^3/24 hrs (excluding time lost due to inclement weather and production stoppage). It is assumed that a portion of the top layer of the softened clay may be removed by suction.

As per section 2 above, approx. 2.8 million m^3 is expected to be removed by suction and approx. 0.8 million m^3 is expected to be dredged. In line with the above considerations and an assumption of 24/7 dredging operations, the execution time (example is based on one vessel for suction/pumping and one vessel for dredging) is estimated as set out below.

The execution time in large part depends on the location of the recovery project. The execution times set out below are estimated based on an assumption of pumping-in at Stage 5 of the East Port project.

Materials for suction/pumping:	**Approx. 175 days**	(excluding time lost due to inclement weather and production stoppage)
Materials for dredging:	**Approx. 135 days**	(excluding time lost due to inclement weather and production stoppage)

Preferably, the execution time should be limited to approx. 6–9 months. Thus, the execution method considered should either involve larger machinery or multiple vessels for simultaneous dredging. The example below is based on multiple vessels.

REMOVAL	2 VESSELS OF 16,000 M^3 CAPACITY/24 HRS EACH	3 VESSELS OF 16,000 M^3 CAPACITY/24 HRS EACH
Sand fraction: Suction and pumping into Stage 5 of East Port	Approx. 90 days *	Approx. 45 days *

* excluding time lost due to inclement weather and production stoppage

METHOD OF REMOVAL	2 VESSELS OF 5,000–7,000 M^3 CAPACITY/24 HRS EACH	3 VESSELS OF 5,000–7,000 M^3 CAPACITY/24 HRS EACH
Clay fraction: Dredging and pumping into Stage 5 of East Port	Approx. 70 days *	Approx. 35 days *

* excluding time lost due to inclement weather and production stoppage and possibly interruption for water drainage in connection with pumping on land area.

A proposal for the sand fraction (suction) could, for example, be intensive use of two or three dredgers for sand suction and sand pumping to allow this part of the project to be completed as quickly as possible, as the bulk of the sand is located outside the harbour, at the outermost part of Grådyb. This would reduce the execution time for this part of the project to two or three months. This solution would necessitate the installation of additional pump tubes to be used by the vessels at the Stage 5 pumping site.

Also, the use of multiple vessels will allow for clay materials to be dredged in the harbour area concurrently with the dredging of sand materials. An appropriate execution period of approx. 6–8 months could be envisaged if two vessels are used during certain periods, to be reduced to one vessel during part of the period in case of good progress.

Table 2. Example of time schedule for execution involving multiple vessels, limited to the summer half

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Vessel 1 Suction and pumping												
Vessel 2 Suction and pumping												
Vessel 3 Suction and pumping												
Vessel 1 Dredging and pumping												
Vessel 2 Dredging and pumping												

If the dredging time for sand materials to be pumped in is to be optimised to approx. two months, a third vessel could be introduced for that purpose. The execution time for dredging of clay materials is estimated at approx. 5–6 months. Two vessels may be used initially. However, as the areas are gradually filled, water drainage is assessed to restrict the rate of production, which is assessed to eventually result in a need for only a single vessel.

Uncertainty should be factored in with respect to time lost due to inclement weather. The works in the outermost part of the fairway outside the harbour are assessed to be more sensitive to weather conditions, assuming that materials will be transported on barges.
Estimates of time lost due to inclement weather for the two activities:

Suction/pumping of sand: Inclement weather allowance 1–5% (including production stoppage/machine failure, etc.)

Dredging/pumping of clay: Inclement weather allowance 10–15% (including production stoppage/machine failure, etc.)

As regards time optimisation through the use of larger equipment, it should be borne in mind that the draught of large dredgers may be very deep at full capacity load. For example, IHC Dredging's Beagle 12, with a hopper capacity of 12,000 m^3, has a draught of 9 metres, which may make it difficult to reach the Stage 5 pumping site. Shipping companies should perform their own individual assessment of which vessels would be suitable for the project.