AQUA-FACT


Aqua-Fact International Services Ltd.,
12 Kilkerrin Park, Tuam Road, Galway.
Tel: 091 756812, Fax: 091 756888
e-mail: info@aquafact.ie
Report Title: A visual and photographic survey of two juvenile lobster release grounds in the outer Waterford Harbour Estuary.

Job Number: JN325

Date of Issue: 15-2-00

Author: John Costelloe

REPORT APPROVAL SHEET

No: 1
Date: 14/2/2000
Nature of Amendment: [Signature]

No: [Blank]
Date: 18.2.00
Nature of Amendment: [Signature]

No: [Blank]
Date: 13.3.00
Nature of Amendment: [Signature]

No: [Blank]
Date: [Blank]
Nature of Amendment: [Signature]
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Introduction</td>
<td>1</td>
</tr>
<tr>
<td>2. Method</td>
<td>2</td>
</tr>
<tr>
<td>3. Results</td>
<td>2</td>
</tr>
</tbody>
</table>
1. **Introduction**

Waterford Harbour Authorities commissioned Aqua-Fact to survey and assess the status of the bottom communities at two locations in the outer Waterford estuary area. The two study areas are within the sites of ongoing experimentation where juvenile hatchery reared lobsters have been released from captivity into the wild. The survey areas were approximately 250m x 250m and located off Swines head in the south west of the estuary and off Hook Head in the south east of the estuary. The latitude and longitude of the centre of the surveyed boxes are (Box 1) 52°07’30”N, 07°02’40”W and (Box 2) 52°06’65”N, 06°55’50”W, respectively (Figure 1).

The survey was carried out on the 21st of January, 2000 subsequent to heavy rainfall over the previous two months and a dredge spoil dumping operation at a site in the mouth of the estuary (52°07’45”N, 06°58’80”W; 52°07’45”N, 06°58’10”W; 52°07’10”N, 06°58’80”W; 52°07’10”N, 06°58’10”W). The dumping at sea took place in two phases with the vast majority of deposited material being dumped in the initial phase in July/August, 1999. A second dumping operation was conducted in December, 1999.

The dive surveys were undertaken by experienced biologist and the bottom conditions documented with the assistance of underwater cameras. The photographic equipment used was a Nikonos V camera fitted with a 15mm lens and a dedicated Isotecnic flash system. The dives at both locations were in the order of a half hour duration and the diver generally stayed plus or minus 2-3m within the depth contours of the centre of the study box. The survey was carried pout on the 21st of January shortly after low water on a running tide.

3. Results.

(Box 1) 52° 07'30"N, 07°02'40"W. Mean depth 16m

Box 1 on the south West Side of Waterford estuary was surveyed first. This site experiences strong currents and from the evidence of freshwater flow and drogue studies it would appear that much of the ebbing tide leaves the estuary via the southwest side of
the bay. This is further evidenced by the volume of suspended material in the water body in this area. In marked contrast to the East site, the site on the West side of the bay was relatively denuded with sparse fauna present. The bottom consisted of rocky outcrops and loose boulders. The entire area was covered in a fine deposit (Photographs 1-12) which in some areas accumulated in troughs and spaces between the rocks (Photograph 3). Fish such as wrasse (Photograph 1), dogfish (Photograph 7), pollock and gobies were common in the area. Although the percentage cover of epifaunal animals on the rocks was low, a number of species were present such as the sea-cucumber Astia lefrevrei, (photograph 2), Devonshire cup coral, Caryophyllia smithii, (Photograph 2); sponges Myxilla incrustans, Cliona chelata, Mycale rotalis; tube worms Pomatoceros triquetor; Barnacles; Echinoderms, Echinus esculentus (Photographs 10 & 6), starfish Asterias rubens (Photograph 5, 6 & 12) and Henricia oculata, and dead-man’s fingers Alcyonium digitatum. A sparse cover of red algae was also apparent on the upper surface of a number of boulders (Photographs 4-10). A feature of the dive was the lack or paucity of crustacean species recorded.

The physical attributes of rocky bottoms generally can provide substrates on which many animals can attach to or shelter in. However, in areas where there is a high degree of siltation the bottom may have a radically different appearance to one in a
cleaner water environment. Fine sediments in the water column can result in poor light penetration resulting in a paucity of algae growth on the bottom. In addition the rain of fine material can have a serious smothering effect particularly on animals which are attached to the bottom (sessile animals) and live on suspended material in the water column (suspension feeders). The rain of fine material can both smother the animals and clog their filtration mechanisms. Where the input of fine material has been gradual the effect on mobile animals is less severe and gives these animal groups time to migrate from the effected areas. However, sessile animals are attached permanently to their substrate and in the event of severe sudden sediment deposition are vulnerable to smothering. A further feature of heavy sedimentation results from a combination of strong currents and sediment load. In this type of environment the bottom is physically abraded where the combination of strong currents and suspended load effectively results in a type of "sand blasting" of the bottom.

(Box 2) 52°06'65"N, 06°55'50"W, Mean depth 20m

In stark contrast to box 1, box 2 is indicative of a clean water strong current environment. The bottom had a dense covering of epifaunal animals which include such animals as the large suspension feeding Bryozoans, Pentapora foliacea (Photograph
13,14 & 16), Anthozoans, Alcyonium digitatum (Photograph 13, 15, 18, 20); Sponges, Cliona chelata (Photograph 18), Maryophyllia Smithii, Myxilla incrustan, Styostichon plumosum, Phorbas fictitius, Halicondria bowerbankia, Raispailia ramosa (Photograph 15) Halicondria panicea, Haltclona viscosa (Photograph 17), Pomatoceros triquetor, and Balanus species. In addition to the large epifaunal, there was a number of mobile species foraging over the area and these include the top shells (Calliostoma zizyphinum), Asterias rubens, Henricia oculata, Echinus esculentus, Dogfish, wrasse, pollock, blennies and gobies. The fauna in this area is rich and diverse and although we have described many of the macro species, there are many other species and smaller animals which were not photographed.

Between the ridges of rock there are occasional pockets of coarse sands (Photograph 22 & 23). In some instances the coarse sand has been mounded into long ridges and troughs as a result of the strong current activity.

In conclusion the bottom in this area consists of a rich and diverse fauna and is typical of high-energy sites in this type of environment. There was no evidence in either the water column or settled to the bottom of fine sediments.

Note: Figures and Appendices can be provided upon request.
Dredging of Duncannon Bar

Environmental impact of dredging and spoil dumping.

W.D. Eysink et al.

WL | delft hydraulics
Contents

List of Tables

List of Figures

1 Introduction ........................................................................................................... 1
   1.1 Description of the problem ........................................................................... 1
   1.2 Terms of Reference ......................................................................................... 1
   1.3 Results and conclusions ................................................................................. 2

2 Available data ...................................................................................................... 4
   2.1 Data from previous studies ............................................................................ 4
   2.2 Additional field measurements ...................................................................... 5
   2.3 Additional information ................................................................................... 5

3 Tidal flow modelling ............................................................................................. 6
   3.1 General ........................................................................................................... 6
   3.2 Available data ................................................................................................ 6
   3.3 Set-up of the flow model ................................................................................. 9
      3.3.1 Conventions and definitions .................................................................... 9
      3.3.2 Schematisation ......................................................................................... 9
      3.3.3 Grid generation ........................................................................................ 10
      3.3.4 Depth schematisation .............................................................................. 11
      3.3.5 Boundary conditions .............................................................................. 12
      3.3.6 Parameter settings .................................................................................... 13
   3.4 Calibration and verification ............................................................................. 13
      3.4.1 General approach ..................................................................................... 13
      3.4.2 Calibration results .................................................................................... 14
      3.4.3 Verification results ................................................................................... 16
      3.4.4 Conclusions of calibration/verification ..................................................... 17

4 Sand dispersion at the dump site ......................................................................... 19
   4.1 General .......................................................................................................... 19
4.2 Approach and input parameters .................................................. 19
4.3 Results ...................................................................................... 21

5 Effect of dredging on silt dispersion in Suir River estuary ............... 22
5.1 Approach ................................................................................. 22
5.2 Mathematical representation of physical processes ...................... 22
5.3 Field measurements ................................................................. 23
5.4 Calibration .............................................................................. 27
  5.4.1 General approach .............................................................. 27
  5.4.2 Parameter settings ............................................................ 27
  5.4.3 Results ............................................................................ 29
5.5 Validation ................................................................................. 30
5.6 Simulations on dredging and disposal .......................................... 30
  5.6.1 Input of sediment load due to dredging activities ................. 30
  5.6.2 Run scenarios, simulation periods and dredging-dump cycle ... 32
  5.6.3 Results of computations ................................................. 36
5.7 Conclusions ............................................................................. 37

6 Ecological impact of dredging and dumping ................................... 38
6.1 Description of the Environment ................................................... 38
6.2 Potential Ecosystem Impacts of Dredging and Dumping ............... 41
  6.2.1 Introduction ....................................................................... 41
  6.2.2 Ecological Functions of Silt ............................................ 42
  6.2.3 Potential Impacts of Increased SPM Concentration ............. 44
  6.2.4 Potential Impacts of Burial of Benthic Organisms ............... 45
  6.2.5 Potential Impacts of Removal of Benthic Organisms .......... 47
  6.2.6 Potential Impacts of Siltation on Tidal Flats ....................... 47
6.3 Estimated Impacts of Dredging and Dumping ............................. 48
  6.3.1 Estimated Impacts of Increased SPM Concentration .......... 48
  6.3.2 Estimated Impacts of Burial of Benthic Organisms ............ 49
  6.3.3 Estimated Impacts of Removal of Benthic Organisms ......... 50
  6.3.4 Estimated Impacts of Siltation on Tidal Flats .................... 50
6.4 Proposed monitoring plan for Suir River and Estuary .................. 51
  6.4.1 The Monitoring Cycle ...................................................... 51
  6.4.2 Information needs ........................................................... 52
6.4.3 Monitoring Strategy and Design ............................................. 53

6.5 Conclusion on Estimated Ecosystem Impacts .............................. 54

List of References
List of Tables

3.1 Applied water level data
3.2 Applied current data
3.3 Adjustment to amplitudes and phases at the open boundaries
3.4 Model performance at 5 ATT tidal stations

4.1 Probability that highest of sea and swell occur in the given height and direction class at 20 m depth line near Waterford, Waterlevel = MSL (after Eysink et al., 1996)
4.2 Probability that highest of sea and swell occur in the given height and period class at 20 m depth line near Waterford, Waterlevel = MSL (after Eysink et al., 1996)
4.3: Schematised wave climate for morphodynamic computations

5.1 Measurement locations for calibration and validation
5.2 Settling velocity from fitted Rouse concentration profiles
5.3 Parameter setting for calibration
5.4 Run programme
5.5 Simulation periods
5.6 Dredging and dumping cycle and loads

6.1 Fatal depth (cm) for incidental deposition with silt
6.2 Exposure time to anaerobic and sulphide rich conditions at 50% mortality
6.3 Maximum tolerance for continuous deposition of silt and fine sand in cm/month
6.4 Maximum additional SPM concentration at the monitoring stations
4 Sand dispersion at the dump site

4.1 General

The purpose of the sand dispersion study is to determine the long term spreading of the dump. For this purpose the dump has been schematised into a heap of sand on the sea bed. To study the spreading of the sand a morphological model has been made based on the DELFT3D model system. This model system includes the tidal flow model as discussed in Chapter 3. A 2-dimensional wave propagation model has been added to provide the wave conditions over the area. Based on the results of the flow and wave model the sediment transports and the bottom changes were determined using the morphological model DELFT3D-MOR. This is an integrated model system combining the effects of flow, waves, sediment transports and bottom changes. The model has been run for a simulation period of 10 years to compute the morpho-dynamic behaviour of the heap of sand.

In this chapter first the study approach and input parameters are described. Hereafter the results are presented and discussed.

4.2 Approach and input parameters

In an ideal situation, the simulations for the spreading of the sand heap should be carried out covering all possibilities of water levels, current velocities, wave heights and directions related to their possibilities of occurrence. This approach however would result in an unrealistic number of simulations to be carried out. Therefore, the hydraulic conditions are schematised into a few conditions which are representative for the total flow and wave climate.

For the tidal conditions a morphological tide has been selected based on a weighting procedure considering sediment transport rates related to the tidal range. This approach has proven to be reliable in similar projects carried out in the past. The selected tide has been shown in Figure 4.1 and covers 25 hours.

The wave climate is an important input parameter for the transport capacities in the study area. Due to the wave activity, sediment is stirred up after which it can be transported by the tidal flow. The wave climate has been derived from our previous study for Belview Quay (Eysink et al., 1996). The probability of occurrence of the wave conditions at the 20 m depth contour near Waterford are presented in Table 4.1 and 4.2. This wave climate is based on ships observation data in the period between 1949 and 1994 which were derived from the British Met Office.

According to the 1996 study, the wave climate has been schematised into three wave conditions (calm, moderate and rough). The schematisation was carried out in such a way that the representative wave conditions, together with their corresponding durations, give
more or less the same annual transport rates in the area of interest as the total wave climate. The representative wave conditions are shown in Table 4.3.

<table>
<thead>
<tr>
<th>Condition</th>
<th>$H_s$ (m)</th>
<th>$T_p$ (s)</th>
<th>duration (%)</th>
<th>duration (days/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 calm</td>
<td>0.0</td>
<td>-</td>
<td>50</td>
<td>182.5</td>
</tr>
<tr>
<td>2 moderate</td>
<td>1.5</td>
<td>6.6</td>
<td>40</td>
<td>146.0</td>
</tr>
<tr>
<td>3 rough</td>
<td>3.0</td>
<td>9.0</td>
<td>10</td>
<td>36.5</td>
</tr>
</tbody>
</table>

Table 4.3 Schematized wave climate for morphodynamic computations

For a more detailed description of the wave climate reference is made to Eysink et al., 1996.

For the morphological computations the wave pattern has been computed at the high waters of the morphological tide and at the low waters (see Figure 4.1). For the intermediate water levels the wave parameters are obtained by interpolation between the wave patterns at HW and LW. The wave pattern at LW for condition 3 ($H_s = 3.0$ m) are presented in Figures 4.2 (without the sand heap) and 4.3 (with the sand heap) for the open sea area at the dump site. These figures indicate that the influence of the sand heap on the wave pattern is only minor.

The total amount of dredged material is estimated at 335,000 - 425,000 m$^3$. Based on the dimensions of the dump site, the resulting sand heap at this location has a height of approximately 0.8 - 1.0 m. For the assessment of the dispersion of the sand the maximum value of 1.0 m has been selected to take the maximum disturbance into account in the model simulations. This means that the depth reduces from approximately 21 m to about 20 m.

Sieve curves of the bottom material were provided by the client. Analysis of these curves indicated that the bottom material at the dredging site is finer than the bottom material at the dump site. However, it can be expected that during dredging the percentage of fine material will reduce during the overflow of the hopper. Furthermore, part of the finer material will be washed out during dumping. Assuming that 50 % of the material less than 63 μm will be washed out, it can be concluded that the dump material at the bottom of the dump site will be comparable to the original material at the sea bed of the dump site. For this material the following sediment characteristics have been selected:

$D_{50}$  100 μm  
$D_{90}$  300 μm  
fall velocity 0.008 m/s

The sand transport rates in the area were computed using the Bijker formula which includes the transport contributions of both waves and currents. The transports were computed over the morphological tide in discrete steps of 15 minutes (which means a total of 100 steps) taking into account the variation of the wave field during the tide. Hereafter the average transport over the morphological tide was computed. Based on this average transport the bottom changes were determined.

The bottom changes were computed by morphodynamic computations. This means that the interaction between the variation of the water depth due to sedimentation and erosion and
the hydraulic conditions has been taken into account. After computing the bottom changes in a certain period of time the hydraulic conditions were updated by new flow, wave and transport computations, and so on.

The sediment transports and bottom changes in the existing situation were computed as well. These bottom changes were subtracted from the bottom changes in the situation with the spoil dump assuming that the bottom changes in the existing situation can be dealt with as noise. Finally, this gives the resulting effect of the spoil dump on the morphological developments at the dump site.

4.3 Results

Firstly, the cumulative bottom changes due to the various conditions were computed in the first year after the dumping of the sand. The bottom changes after respectively conditions 1, conditions 1 and 2, and after all three conditions are shown in Figures 4.4, 4.5 and 4.6.

From these first computations it can be concluded that the contribution of the calm condition on the morphology can be neglected. During this condition no significant bottom changes occurred. The bottom changes due to the moderate and rough sea states indicate that the height of the sand heap tends to reduce. The sand from this heap is deposited in the direct vicinity of the dump site at the north-western and at the south-eastern side. Due to this process the height of the sand heap is reduced while it is spread out over a larger area.

As the calm conditions have a negligible influence on the sand dispersion, these conditions can be neglected in the long term prediction of the sand dispersion. Therefore, only the moderate and rough conditions are taken into account in the simulations from 1 year to 10 years. The resulting bottom changes are presented in Figures 4.7 to 4.11 showing the results after 2, 3, 4, 5 and 10 years. These results show a progressive dispersion of sand in time. However the process of dispersion reduces in time due to the reduced disturbance of the spoil dump. After 10 years the dispersion of sand is still limited to a distance of about 1.5 km from the centre of the spoil dump. The maximum erosion of the sand heap then is equal to -0.8 m while the maximum sedimentation appeared to be 0.35 m at the north-western site of the dump location.
5 Effect of dredging on silt dispersion in Suir River estuary

5.1 Approach

Predictions on the impact of dredging activities at Duncannon Bar on spreading of suspended sediment in the estuary of the Suir river requires a tool that adequately describes the physical processes in the area. These physical processes include:

(i) Hydrodynamics as governed by tidal forcing, river discharges and wave forcing and
(ii) Suspended sediment transport processes as determined by the hydrodynamics and the exchange fluxes with the bed (erosion and deposition).

In order to meet the objectives of the study the software package DELFT3D was used. DELFT3D has been developed by Delft Hydraulics and includes different modules on hydrodynamics, waves, sediment transport, morphology and water quality processes. Between the various modules there is an off-line coupling, which means that computed quantities by a specific module are stored on an intermediate file (communication file) and subsequently used by another module. In the case of suspended sediment transport modelling discharges, water levels and bed shear stresses of the FLOW module and bed shear stresses of the WAVE module are used by the suspended sediment module. Together with appropriate values for the input parameters of the sediment module predictions are made on suspended sediment transport. Because the two-dimensional, depth-averaged, version of DELFT3D is used, values for the dispersion coefficient have to be defined. This coefficient determines the magnitude of the dispersive transport, resulting from the depth-averaging in the model. The sum of dispersive and advective transport, the latter resulting from the flow velocities, gives the total transport of suspended sediment.

The horizontal transport of suspended sediment in the model is calibrated by comparing the suspended sediment concentration in a number of locations in the estuary and adjusting the model parameters, so that an optimum agreement between measurements and model results is achieved. The calibration procedure is described in detail in the next section.

5.2 Mathematical representation of physical processes

The horizontal transport of suspended sediment in a two-dimensional, depth-averaged, model is given by the advection-diffusion equation:

$$\frac{\partial \alpha}{\partial t} + \frac{\partial}{\partial x}(uc) + \frac{\partial}{\partial y}(vc) - \frac{\partial}{\partial x} \left( D_z \frac{\partial \alpha}{\partial x} \right) - \frac{\partial}{\partial y} \left( D_{ij} \frac{\partial \alpha}{\partial y} \right) = E - D$$

with:
c  suspended sediment concentration [mg/l],
\( u \)  depth-averaged velocity in x-direction [m/s],
\( v \)  depth-averaged velocity in y-direction [m/s],
\( t \)  time [s],
\( D_x \)  dispersion coefficient in x-direction [m²/s],
\( D_y \)  dispersion coefficient in y-direction [m²/s],

and where the erosion flux \( E \) is given by:

\[
E = M \left( \frac{\tau_b}{\tau_e} - 1 \right) \quad \text{for } \tau_b > \tau_e
\]
\[
E = 0 \quad \text{for } \tau_b \leq \tau_e
\]

with:

\( M \)  erosion parameter [kg/(m²·s)],
\( \tau_b \)  bed shear stress [Pa],
\( \tau_e \)  critical erosion shear stress [Pa].

and the sedimentation flux is given by:

\[
D = \omega_s c \left( 1 - \frac{\tau_b}{\tau_d} \right) \quad \text{for } \tau_b < \tau_d
\]
\[
D = 0 \quad \text{for } \tau_b \geq \tau_d
\]

with:

\( \omega_s \)  settling velocity [m/s],
\( \tau_d \)  critical deposition shear stress [Pa].

### 5.3 Field measurements

Field data for the calibration and validation of the suspended sediment model are taken from two different references:

- Measurements that were carried out as part of the hydraulic studies for Checkpoint upper and lower bar as carried out by Delft Hydraulics (Rijn, 1990a);
- Measurements that were carried out by HSL in 1999 specifically for this study.

It is noted that since the measurements of 1989 and 1990 the hydrodynamics in the upper estuary have changed due to the construction of Belview Quay and groynes in the vicinity of Checkpoint. This will introduce uncertainties in that area when comparing the measurements of 1989/1990 and the results of the simulations, because in the latter case the present geometry and bathymetry is taken into account. This holds for Station A on the River Suir and in particular for Station E near Checkpoint harbour. Because Station E is
located close to the present construction works (see Figure 3.1) the results of the measurements in this station have not been taken into account in the present study.

The selected locations for calibration and validation are listed in Table 5.1. The time frames of the measurements and the hydrodynamic conditions during these measurements have also been indicated in the table.

<table>
<thead>
<tr>
<th>Location name</th>
<th>Time frame</th>
<th>Tide</th>
<th>Tidal range 1)</th>
<th>Used for:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Station A</td>
<td>1989-12-29</td>
<td>Spring</td>
<td>3.4 m</td>
<td>calibration</td>
</tr>
<tr>
<td>Station B</td>
<td>1989-12-30</td>
<td>Spring</td>
<td>3.5 m</td>
<td>calibration</td>
</tr>
<tr>
<td>Station G</td>
<td>1990-01-01/02</td>
<td>Spring</td>
<td>3.3 m</td>
<td>calibration</td>
</tr>
<tr>
<td>Duncannon Bar (DB)</td>
<td>1999-06-12</td>
<td>Spring</td>
<td>3.5 m</td>
<td>calibration</td>
</tr>
<tr>
<td>Disposal Site (DS)</td>
<td>1999-06-11</td>
<td>Spring</td>
<td>3.1 m</td>
<td>calibration</td>
</tr>
<tr>
<td>Duncannon Bar (DB)</td>
<td>1999-06-22</td>
<td>Neap</td>
<td>2.4 m</td>
<td>validation</td>
</tr>
<tr>
<td>Disposal Site (DS)</td>
<td>1999-06-23</td>
<td>Neap</td>
<td>2.4 m</td>
<td>validation</td>
</tr>
</tbody>
</table>

1) from the model

Table 5.1 Measurement locations for calibration and validation

In most cases the measurements have been performed during a complete tidal cycle of 12.5 hours, apart from Station G where the measurements prolonged for only 10 hours. During the 1989/1990 survey measurements were done at five levels, i.e.: 0.15 m, 0.65 m, 1.65 m and 4.65 m from the bed and 1 m below the water surface. In 1999, samples were taken at three depths, i.e.: near the bed, at mid-depth and near the surface. From these measurements a depth-averaged concentration is computed for comparison with the model simulations. It is noted that for the 1989/1990 measurements the two positions at 0.15 m and 0.65 m from the bed contribute only for 10% to the depth-averaged concentration. The measurements during the spring tides are used for calibration of the model, whereas the measurements during the neap tides are used for validation.

Suspended sediment concentration

The 1989/1990 measurements in Stations A, B, E and G (see Figure 3.1) on suspended sediment concentration of the fraction smaller than 63 μm (denoted as mud) show a dynamic variation during the tide, with maximum concentrations at 0 to 2 hours after maximum ebb and flood currents and minimum concentrations at 0 to 2 hours following slack water. Concentrations vary between 50 and 500 mg/l in Stations A and B. In Station G the maximum concentration reaches values of more than 1000 mg/l, whereas in Station E concentrations are always less than 150 mg/l. Variations in concentration may be caused by local bed exchange processes (erosion and deposition) and advection. In the latter case a water body carrying sediment with a different sediment concentration results in a decrease or increase of the concentration when passing through the survey station. A first estimate of the settling velocity is obtained by assuming uniform conditions and thus neglecting advection. This settling velocity is then used as input for the model simulations. Because the model takes into account advective transport of the sediment, the settling velocity may
be modified during calibration in order to obtain an optimum agreement between measured and computed suspended sediment concentration.

First estimates of the settling velocity are obtained in two ways:
1. From the complete emptying of the concentration profile the settling velocity follows from:

\[ w_s = \frac{h}{T_{sed}} \]

with:

- \( h \quad \text{water depth [m]} \)
- \( T_{sed} \quad \text{sedimentation period [s]} \)

For Stations A, B and G the characteristic water depth is 10 m and the concentration decreases over a period of 1 to 3 hours. This results in a settling velocity of 1 to 3 mm/s.

2. During maximum ebb and maximum flood the concentration profiles can be approximated with Rouse profiles from which the settling velocity follows. This assumes steady state conditions with fully adapted concentration profiles. The time \( T_{\text{adapt}} \) required to obtain these profiles is given by:

\[ T_{\text{adapt}} = \frac{h^2}{e_z} \]

with the vertical mixing coefficient given by:

\[ e_z = \frac{1}{6} hu^* \]

where:

- \( u^* \quad \text{shear stress velocity [m/s]} \)

The shear stress velocity follows from the depth-averaged velocity and the roughness parameter:

\[ u_* = u \sqrt{g \frac{n}{H^{1/6}}} \]

With \( u_* = 0.02 \text{ m/s} \) and \( n = 0.026 \) the adaptation time becomes approximately 1 hour indicating that during flood and ebb there is sufficient time to arrive at fully adapted concentration profiles.

The Rouse concentration profiles are described by:
\[
\frac{c}{c_a} = \left( \frac{h - z}{z} \right)^{\frac{a}{h - a}}^{\text{ex}}
\]

with:

- \( c_a \) reference concentration at height \( a \) above the bed [mg/l],
- \( z \) height above the bed [m],
- \( \kappa \) von Karman constant (= 0.4).

Figures 5.1a and 5.1b present the measured and computed concentration profiles during ebb and flood for Stations A, B, E and G respectively. The reference concentration is the measured concentration at a height 0.15 m above the bed. The results indicate that the resulting settling velocities vary between 1 and 4 mm/s (or even 7 mm/s when in Station G the concentrations at 18:00 hrs are used), see Table 5.2. Values between brackets indicate that probably no steady state condition is reached with respect to the horizontal flow velocity or the vertical sediment concentration distribution, so that values for the settling velocity may be biased.

<table>
<thead>
<tr>
<th>Location</th>
<th>Maximum ebb</th>
<th>Maximum flood</th>
</tr>
</thead>
<tbody>
<tr>
<td>Station A</td>
<td>2.8</td>
<td>3.3</td>
</tr>
<tr>
<td>Station B</td>
<td>(1.1)</td>
<td>(0.8)</td>
</tr>
<tr>
<td>Station E</td>
<td>3.8</td>
<td>3.8</td>
</tr>
<tr>
<td>Station G</td>
<td>1.0</td>
<td>(4.0)</td>
</tr>
</tbody>
</table>

( ) no steady state reached

Table 5.2 Settling velocity from fitted Rouse concentration profiles

The settling velocities as derived above are significantly larger than those presented in report H1118 (Rijn, 1990a). The latter have been obtained from a device employed in the field (Field Pipette Withdrawal Tube) giving median settling velocities between 0.03 and 2 mm/s. It is well-known that there is discrepancy between settling velocities from this kind of tubes and those obtained by e.g. in-situ video camera systems (see e.g. van Leussen, 1994). The sampling of a water-sediment mixture probably destroys the fragile flocs that contribute most to the median settling velocity.

The 1999 measurements did not give any reason for a different approach.

**Bed composition**

In 1989 bed samples were taken in the area enclosed by Stations A, B and G. The grain size distributions of these samples show that the mud fraction (\\%<63 \mu m) can be more than 40%. Highest mud fractions were encountered along the sides of the estuary and lowest in the channel. The sand is mostly fine, i.e. between 63 and 200 \mu m. From these measurements it is concluded that there is availability of mud over the whole area between Stations A, B and G.
In 1999 additional information became available about the composition of the sea bed in front of the Suir estuary showing a more sandy bed.

5.4 Calibration

5.4.1 General approach

A calibrated suspended sediment transport model requires a calibrated model on hydrodynamics and proper values for the parameters that are needed for the formulations representing the sediment exchange fluxes with the bed. The flow model has been calibrated on tidal propagation, water levels and discharges as described in Chapter 3. The sediment transport model is then calibrated by adjusting the parameters that follow from the sediment properties and by imposing correct boundary conditions for the suspended sediment concentrations. The procedure to arrive at the proper parameter values is done by means of sensitivity runs with the model, taking into account the available data on sediment properties. Those parameters that can not be deduced from the available data are varied within a realistic range, as set by data from literature and consultant's experience. Following calibration the suspended sediment transport model is validated. In that case model predictions are compared with independent data that have not been used during calibration and representing conditions that are different from those for calibration. During validation the model parameters are not changed.

5.4.2 Parameter settings

The objective of the calibration of the model is to determine the parameters of the erosion and sedimentation fluxes and the longitudinal dispersion coefficients in such a way that the computed sediment concentrations and the measured values show similar variation. The following parameters are investigated to arrive at an optimum reproduction:

- Settling velocity \( w_s \);
- Critical shear stress for sedimentation \( \tau_s \);
- Erosion parameter \( M_e \);
- Critical shear stress for erosion \( \tau_e \);
- Longitudinal dispersion coefficients \( D_x \) and \( D_y \).

During calibration the longitudinal dispersion coefficients \( D_x \) and \( D_y \) are kept equal. At the sea and river boundaries concentrations of 10 mg/l are imposed. The exact values of these concentrations are not important as the suspended sediment transport in the estuary is mainly governed by the erosion and sedimentation processes. The calibration run assumes a mud bed all over the estuary, rivers and adjoining sea. In reality this is not true for the outer estuary and sea, but if no erosion takes place the presence of mud in the model in these areas will not affect the calibration results.

Results of the hydrodynamic simulations are written to the communication file with a time step of 10 minutes. The computations with the sediment module are performed with a
integration time step of 10 minutes. An implicit, unconditionally stable, numerical scheme is used for the discretisation of the equations.

A number of combinations of the aforementioned parameters has been investigated. The best result is obtained with the parameter settings as indicated in Table 5.3.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Settling velocity</td>
<td>3</td>
</tr>
<tr>
<td>Critical shear stress for sedimentation</td>
<td>0.5</td>
</tr>
<tr>
<td>Erosion parameter</td>
<td>3.47 $10^{-5}$ kg/(m$^2$.s)</td>
</tr>
<tr>
<td>Critical shear stress for erosion:</td>
<td>0.5</td>
</tr>
<tr>
<td>Dispersion coefficient:</td>
<td>20</td>
</tr>
</tbody>
</table>

Table 5.3 Parameter setting after calibration

The selected settling velocity of 3 mm/s is in the range as estimated directly from the field measurements. Further, it should be realised that in the prototype the sedimentation flux is given by:

$$S_{\text{prototype}} = w_c c_b$$

whereas in the model the flux to the bed follows from:

$$S_{\text{model}} = w_s c_{avg}$$

Because $c_b$ is larger than $c_{avg}$ the settling velocity in the model should be increased in order to arrive at the correct sedimentation flux.

The critical shear stress for deposition is somewhat larger than normally found for homogeneous mud mixtures in laboratory flumes (0.1-0.2 Pa). A higher value seems reasonable considering the amount of silt in suspension.

The erosion parameter can vary various orders of magnitude and thus this parameter is used to arrive at the correct average concentration level. The value is varied within the range as found in literature (see e.g. Winterwerp, 1989): $10^3 - 10^5$ kg/(m$^2$.s).

A critical shear stress for erosion equal to 0.5 Pa is realistic for loosely deposited cohesive sediment. The consequence of $\tau_d$ being equal to $\tau_c$ is that with increasing bed shear stress following slack water a decreasing deposition rate is immediately followed by an increasing erosion rate. This appeared to be necessary to reproduce the strongly varying suspended sediment concentrations during the tidal cycle.

Also the rate of the dispersion coefficient has been varied within realistic limits during calibration. Ultimately the settings as presented in Table 5.3 are selected for the silt dispersion computations.
5.4.3 Results

Results of the calibration run are shown in Figure 5.2 for Station A, in Figure 5.3 for Station B and in Figure 5.4 for Station G. Station E has been eliminated from the analysis, because it is located very close to the present training works near Checkpoint; these training works were not present during the survey of 1989/1990. In Figure 5.5 and Figure 5.6 the model results at Duncannon Bar (DB) and at the Disposal Site (DS) respectively are compared with the measurements. The measured concentrations at five depths for the 1989/1990 survey and at three depths for the 1999 measurements have been converted to depth-averaged concentrations. For each cross-section the model results are presented in three or four locations (for example denoted as A4, A5, A6 and A7 for Station A) to check for concentration differences in lateral direction. The x- and y-coordinates of the outermost observation locations in the cross-sections are given below.

<table>
<thead>
<tr>
<th>Location</th>
<th>x</th>
<th>y</th>
<th>Location</th>
<th>x</th>
<th>y</th>
<th>Width [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>A4</td>
<td>265962</td>
<td>112592</td>
<td>A7</td>
<td>265844</td>
<td>112635</td>
<td>126</td>
</tr>
<tr>
<td>B3</td>
<td>267230</td>
<td>116174</td>
<td>B5</td>
<td>267139</td>
<td>116108</td>
<td>129</td>
</tr>
<tr>
<td>G3</td>
<td>269449</td>
<td>111467</td>
<td>G8</td>
<td>268932</td>
<td>111353</td>
<td>529</td>
</tr>
<tr>
<td>DB3</td>
<td>272540</td>
<td>105300</td>
<td>DB7</td>
<td>272686</td>
<td>105280</td>
<td>147</td>
</tr>
<tr>
<td>DS3</td>
<td>270153</td>
<td>97112</td>
<td>DS7</td>
<td>270415</td>
<td>97072</td>
<td>265</td>
</tr>
</tbody>
</table>

From the simulation results in these locations it is concluded that in the model the suspended sediment is rather homogeneously distributed in lateral direction. Thus, for comparison with field data the choice for a location in a specific cross-section does not significantly affect the reproduction quality of the model.

In Stations A and to a larger extent in Station B magnitude and variation of the suspended sediment concentration are reproduced by the model. However, a phase lag appears between measurements and model results with the model results shifted forward in time. The same applies to Station G. The high concentration of 300 mg/l is not reproduced by the model and may be caused by meteorological effects as it was quite stormy on the day of the measurements (Rijn, 1990a). At Duncannon Bar (DB) the peak concentration preceding low water slack is reproduced, although the concentration is two times larger in the model. The peak concentration is attributed to the outflow of water from the estuary loaded with sediment. Although, after the turning of the tide, during flood, the velocities are comparable with those during ebb, no increase in sediment concentration is found. This is due to the inflow of sea water which carries almost no sediment. At the Disposal Site no noticeable concentration is computed, which compares with the measurements. From these results it is concluded that the dynamic variation of the suspended sediment due to the tidal flow and the large scale distribution of the concentration field is fairly well reproduced by the model.

The phase lag of the suspended sediment concentration may be explained to some extent by the hydrodynamics in the model. The water level in Station A is approximately 1 hour later in the model as compared with the measurements, possibly resulting from the new groynes at Checkpoint.

Finally, model results are compared qualitatively with satellite images. Figure 5.7 shows the computed silt-concentration pattern during spring tide conditions. This pattern quantitatively agrees rather well with the spot image presented on Figure 5.8.
5.5 Validation

The model is validated against measurements at Duncannon Bar and at the Disposal Site during neap tide. Results are presented in Figure 5.9 and Figure 5.10 respectively. The maximum sediment concentration at Duncannon Bar has reduced in the model to 30% of its maximum value during spring tide. This still is approximately 100% larger than according to the neap tide measurements. At the Disposal Site no significant increase in concentration is found, which is in accordance with the measurements. In spite of these differences it is concluded that the effect of different hydrodynamic conditions (spring tide versus neap tide) on suspended sediment concentrations is described satisfactorily by the model.

5.6 Simulations on dredging and disposal

5.6.1 Input of sediment load due to dredging activities

General

The maintenance dredging involves two major dredging areas:

- Duncannon Bar, halfway the mouth of the estuary;
- Checkpoint Lower Bar, more upstream, near the river junction.

The disposal area is at sea just in front of the mouth of the estuary.

With regard to turbidity caused by the dredging activities factors of importance are:

- The composition of the bottom in the dredging area (dredged material);
- The dredging and disposal technique and working method used;
- The hydrodynamics (and water quality) in the dredging area.

The dredging and disposal actions and the hydrodynamic circumstances (flow, wave climate, water depth and scale) determine the source value of turbidity generated by the maintenance dredging. The dispersive processes in the near field water area will be predicted by numerical simulation.

The dredging is executed by the ‘Lesse’, a trailing suction hopper dredge (TSHD) with a hopper of 1538 m³. Loading of the ‘Lesse’ on the site takes on average 1 hour and 10 minutes, whereas overflow of the hopper already starts after 10 minutes. Overflow continues throughout the rest of the loading time. The fully laden draught of the dredge is approximately 5 m. Unloading at the disposal area takes place by opening the bottom valves and takes on average 5 to 7 minutes.
Analysis and evaluation of the material to be dredged

From the geotechnical information from the grab samples it can be concluded that the (top) layer to be dredged at Duncannon Bar largely consists of silt and fine sand ($D_{50}$ approx. 63 $\mu$m).

The geotechnical information from the Checkpoint Lower Bar area is more ambiguous. In "deeper" areas the fine sand content is predominant ($D_{50}$ > 63 $\mu$m: 80 - 90 %), whereas in the shallow areas the silt content prevails ($D_{50}$ < 63 $\mu$m: 50 - 65 %). No information was found about the organic matter content. No indication was found about the occurrence of coarse debris.

Turbidity generated by the dredging activity

The amount of dredged material would be a total of 525,000 in-situ m³. The sailing distance from Duncannon Bar to the disposal area is 8 km; from Checkpoint to the disposal area 20 km.

The turbidity production is analysed in an absolute sense. In an evaluation the turbidity generated by the dredge must be weighed against the turbidity which results from natural causes (e.g. storm surges) and the background turbidity (e.g. navigation) that occurs in the dredging area before, during and after the dredging activity.

Turbidity generation during the trailing suction hopper dredging process occurs during the following stages:

- The trailing involves the movement of the suction head(s) and suction pipe(s) through the water at a velocity in the order of 2 to 4 knots (1 - 2 m/s). This causes turbidity close to the bottom.
- With low keel clearance the return flow under and along the dredge is a possible source of turbidity.
- During the manoeuvring of the dredge, propeller wash will cause erosion and turbidity. During trailing significantly less erosion is caused by the propeller wash.
- Lean mixture discharge overboard (LMOB).
- Hopper overflow during the loading process.
- Dredged material degassing and gas release from the river bed (here probably not an issue).
- Leakage from the hopper bottom valves.
- Deblocing of the suction head(s) in the event of coarse material stuck in the suction system.

It should be noted that, apart from overflow and hopper leakage, the turbidity production is confined to the lower part of the water depth. This is an advantage.

From literature it can be concluded that the amount of dredged material brought into suspension by a medium size trailing suction hopper dredge is about 10 to 12 kg dry solids
per cubic meter removed sediment (or in this case 3.7 kg dry solids per second) using LM08 but no overflow. Overflow results in a considerable contribution of the additional turbidity which then becomes about ten times as much as without overflow and is estimated to be 37 kg dry solids per second. The overflow effluent not only contains more silt but it is also introduced high in the water column. A major part of the resuspended material settles in the direct vicinity of the dredge.

At a distance of about 50 m around a dredging TSHD the additional turbidity on top of the background turbidity, will be caused by an additional, resuspended silt concentration of about 250 to 300 mg/liter.

**Turbidity generated by disposal of the dredged material**

The spoil will be dumped by opening of the bottom valves/doors of the hopper of the dredge. When the contents of the hopper drops into the water and sinks to the bottom part of the dredged material gets into suspension by segregation of the perimetry and turbulent exchange. The amount of suspension depends on the type of dredged material, the granular composition and the consistency. The discharge will take only a few minutes. The impact of the spoil on the sea bed will result in erosion and resuspension of bed material and can even create craters of several meters. This becomes more severe if the discharge takes place on earlier discharges. Also density currents will occur up to several hundreds of metres. In relation with silt loss during loading and the geotechnical information it is estimated that the dumping process of the hopper can cause additional turbidity by a silt source of about 12 kg dry solids of silt per second during dumping. The plume will develop for a major part low in the water column. The averaged silt concentration is estimated to be 20 to 40 mg/liter at a radius of 50 m from the disposal site.

**5.6.2 Run scenarios, simulation periods and dredging-dump cycle**

**Scenarios**

The effect of dredging and disposal on the suspended silt concentration is studied for spring as well as neap tidal conditions, both, with and without waves. The parameter setting as obtained from the calibration and validation of the model has been applied.

Basically, a mud bed is present all over the model area. The silt mass per computational cell was set at $1 \times 10^{20}$ grams, which guarantees an unlimited supply of silt during the simulation period. In these cases with a mud bed, the discharged silt will form part of the existing bed after deposition. When it is subsequently resuspended, there will be no difference with the reference situation (i.e. without discharges) and thus the effect of dredging and disposal is reduced to the small part of the additional silt load that has not settled yet during the first slack tide.

In addition, simulations have been performed starting with a fixed bottom. In these cases the discharged silt due to dredging and dumping can be followed as a tracer throughout the estuary. Silt that is resuspended due to dredging and dumping will be transported by the tide and settle around slack water. After slack water, the silt is eroded again if the local velocity
becomes higher than the critical velocity for erosion and in this way the sediment gradually disperses in the estuary. This scenario describes the behaviour of a loosely deposited sediment on a fixed bed.

The scenarios with and without an initial mud bed can be considered as extreme cases of the actual situation where mud is not present everywhere.

The tidal difference at Duncannon Bar is 3.6 m during spring and 2.1 m during neap tide. For the simulations with waves a wave height of 1.5 m is prescribed at the sea boundary of the WAVE-module. The wave heights are computed for a mean water level. Wave heights decrease from 1.5 m at the entrance of the estuary (Hook Head) to 0.5 m at Duncannon Bar and 0.3 m at the Upper Bar (see Figure 5.11).

The model simulations performed to determine the impact of dredging and dumping are presented in Table 5.4 and labelled with their run numbers.

<table>
<thead>
<tr>
<th></th>
<th>With fixed bed</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No waves</td>
<td>With waves</td>
</tr>
<tr>
<td></td>
<td>No dredging</td>
<td>With dredging</td>
</tr>
<tr>
<td>Spring</td>
<td>-</td>
<td>Run 40</td>
</tr>
<tr>
<td>Neap</td>
<td>-</td>
<td>Run 41</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>With mud bed</td>
<td></td>
</tr>
<tr>
<td>Spring</td>
<td>Run 42a</td>
<td>Run 42b</td>
</tr>
<tr>
<td>Neap</td>
<td>Run 43a</td>
<td>Run 43b</td>
</tr>
</tbody>
</table>

Table 5.4  Run programme

Simulation periods

The simulation times are given in Table 5.5. They refer to arbitrary dates in 1999. Times for spring and neap tide are similar.

<table>
<thead>
<tr>
<th>Process</th>
<th>Start simulation period</th>
<th>End simulation period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrodynamics</td>
<td>1999-01-01 00:00</td>
<td>1999-01-05 04:00</td>
</tr>
<tr>
<td>Results to communication file</td>
<td>1999-01-04 03:00</td>
<td>1999-01-05 04:00</td>
</tr>
<tr>
<td>Silt transport</td>
<td>1999-01-04 03:00</td>
<td>1999-01-07 06:00</td>
</tr>
</tbody>
</table>

Table 5.5  Simulation periods

During the simulations on silt transport the same hydrodynamic results are used from the communication file for each period of 25 hours.

Dredging operation cycle

The cycle of operation during dredging and disposal is based in information supplied by the Client. It consists of:
1. Dredging at Duncannon Bar (1 hr and 30 min);
2. Sailing from Duncannon Bar to the Disposal Site (30 min);
3. Dumping at the Disposal Site (5 min);
4. Sailing from the Disposal Site to Duncannon Bar (30 min);
5. Dredging at Duncannon Bar;
6. Sailing from Duncannon Bar to the Disposal Site;
7. Dumping at the Disposal Site;
8. Sailing from the Disposal Site to the Upper/Lower Bar near Checkpoint (1 hr and 15 min);
9. Dredging at the Upper/Lower Bar (1 hour and 20 min);
10. Sailing from the Upper/Lower Bar to the Disposal Site (1 hr and 15 min);
11. Dumping at the Disposal Site;
12. Sailing from the Disposal Site to Duncannon Bar;
13. etc.

A complete cycle as described above takes a total time of 9 hrs and 5 min. For the simulations the times have been slightly adapted so that 3 dredging-disposal cycles fit in a cyclic simulation period of 25 hours. Table 5.6 gives in detail the times and loads as used during the simulations. It is further noted that during dredging and loading of the dredger the first 10 minutes are without overflow and thus the sediment input is reduced.

The dredging and dumping cycle is graphically depicted in Figure 5.12.

The co-ordinates of the dredging and dump locations are:

<table>
<thead>
<tr>
<th>Location</th>
<th>x</th>
<th>y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duncannon Bar</td>
<td>272586</td>
<td>104004</td>
</tr>
<tr>
<td>Upper/Lower Bar</td>
<td>267142</td>
<td>113757</td>
</tr>
<tr>
<td>Disposal Site</td>
<td>270300</td>
<td>97098</td>
</tr>
<tr>
<td>Cycle</td>
<td>Dr./dump</td>
<td>Act. no.</td>
</tr>
<tr>
<td>-------</td>
<td>----------</td>
<td>---------</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>Dredging DB-filling</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>Dredging DB-overflow</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>Sailing DB-DL</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>Dumping DS</td>
</tr>
<tr>
<td>1</td>
<td>5</td>
<td>Sailing DS-DB</td>
</tr>
<tr>
<td>1</td>
<td>6</td>
<td>Dredging DB-filling</td>
</tr>
<tr>
<td>1</td>
<td>7</td>
<td>Dredging DB-overflow</td>
</tr>
<tr>
<td>1</td>
<td>8</td>
<td>Sailing DB-DL</td>
</tr>
<tr>
<td>1</td>
<td>9</td>
<td>Dumping DS</td>
</tr>
<tr>
<td>1</td>
<td>10</td>
<td>Sailing DS-LB</td>
</tr>
<tr>
<td>1</td>
<td>11</td>
<td>Dredging LB-filling</td>
</tr>
<tr>
<td>1</td>
<td>12</td>
<td>Dredging LB-overflow</td>
</tr>
<tr>
<td>1</td>
<td>13</td>
<td>Sailing LB-DL</td>
</tr>
<tr>
<td>1</td>
<td>14</td>
<td>Dumping DS</td>
</tr>
<tr>
<td>1</td>
<td>15</td>
<td>Sailing DS-DB</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>Dredging DB-filling</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>Dredging DB-overflow</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>Sailing DB-DL</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>Dumping DS</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>Sailing DS-DB</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>Dredging DB-filling</td>
</tr>
<tr>
<td>2</td>
<td>7</td>
<td>Dredging DB-overflow</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
<td>Sailing DS-DB</td>
</tr>
<tr>
<td>2</td>
<td>9</td>
<td>Dumping DS</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>Sailing DS-LB</td>
</tr>
<tr>
<td>2</td>
<td>11</td>
<td>Dredging LB-filling</td>
</tr>
<tr>
<td>2</td>
<td>12</td>
<td>Dredging LB-overflow</td>
</tr>
<tr>
<td>2</td>
<td>13</td>
<td>Sailing LB-DL</td>
</tr>
<tr>
<td>2</td>
<td>14</td>
<td>Dumping DS</td>
</tr>
<tr>
<td>2</td>
<td>15</td>
<td>Sailing DS-DB</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>Dredging DB-filling</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>Dredging DB-overflow</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>Sailing DB-DL</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>Dumping DS</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>Sailing DS-DB</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>Dredging DB-filling</td>
</tr>
<tr>
<td>3</td>
<td>7</td>
<td>Dredging DB-overflow</td>
</tr>
<tr>
<td>3</td>
<td>8</td>
<td>Sailing DB-DL</td>
</tr>
<tr>
<td>3</td>
<td>9</td>
<td>Dumping DS</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td>Sailing DS-LB</td>
</tr>
<tr>
<td>3</td>
<td>11</td>
<td>Dredging LB-filling</td>
</tr>
<tr>
<td>3</td>
<td>12</td>
<td>Dredging LB-overflow</td>
</tr>
<tr>
<td>3</td>
<td>13</td>
<td>Sailing LB-DL</td>
</tr>
<tr>
<td>3</td>
<td>14</td>
<td>Dumping DS</td>
</tr>
<tr>
<td>3</td>
<td>15</td>
<td>Sailing DS-DB</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>Dredging DB-filling</td>
</tr>
</tbody>
</table>

Start of cycle time: 1-6-99 5:00  
DB: Duncanon Bar  
LB: Lower Bar  
DS: Disposal Site

Table 5.6  Dredging and dumping cycle and loads
5.6.3 Results of computations

The results of the computations with the different scenarios are presented as follows:

- Time histories of silt concentration at 16 monitoring stations, the two dredging locations and the disposal site.
- Contour plots of silt concentration distributions in the estuary and at sea at various time intervals.

For the simulations with a mud bed the differences in silt concentrations in the water between the case with silt discharges due to dredging and the reference situation without silt discharges are presented (for locations see Fig. 6.1 in Section 6.1).

Spring tide-fixed bed-no waves (Figs. 5.13-5.30)

The additional depth-averaged sediment concentration generated during dumping at the location of the Disposal Site is less than 6 mg/l due to the large water depth. At the dredging locations the additional concentrations generated during dredging are much higher: up to 120 mg/l at Checkpoint Lower Bar and 90 mg/l at Duncannon Bar. Results of the computations for this scenario indicate that the rise in suspended sediment concentrations in the monitoring stations in the model due to dredging and dumping rapidly reduces to less than 20 mg/l and is even not noticeable at a larger distance of the additional silt sources.

Contour plots for this situation are presented in Figures 5.18 - 5.30 at intervals of 1 hour for a complete tidal cycle showing the spreading of the suspended sediment. No effects are observed south of Dunmore East.

Neap tide-fixed bed-no waves (Figs. 5.31-5.36)

During neap tide the suspended sediment concentrations due to dredging and dumping in the monitoring stations are comparable with or less than those during spring tide. For comparison the contour plot of 1999-01-06 at 22:00 hour is shown on Figure 5.36.

Spring tide-mud bed-no waves (Figs. 5.37-5.44)

The computational results in the monitoring stations indicate that the effect of dredging and dumping with the mud bed is less than for the same case with a fixed bed. In the former case the discharged silt becomes part of the existing bed after deposition and during erosion there is no difference between the reference situation and the situation with dredging and dumping. In both cases the increase of suspended sediment concentrations due to dredging in the monitoring stations is 20 mg/l or less. The contour plots at three time intervals show that the dredging and dumping activities result in a more local effect if a mud bed is present.
Neap tide-mud bed-no waves (Figs. 5.45-5.49)

During neap tide the effect of dredging and dumping is very local and almost negligible in most of the estuary. Largest differences (up to 20 mg/l) occur in the upstream part of the estuary near the confluence of the River Suir and the River Barrow.

Spring tide-mud bed-with waves (Figs. 5.50-5.57)

In case waves are present differences in sediment concentration due to dredging slightly increase in the monitoring points along the banks in the outer estuary. Sediment is kept in suspension in areas with high waves and is transported to locations with low wave heights. However, the increase in suspended sediment concentrations due to dredging in these monitoring stations still is well below 20 mg/l. In the monitoring stations in the upper part of the estuary the results for the cases with and without waves are the same.

Neap tide-mud bed-with waves (Figs.5.58-5.62)

For neap tide conditions with waves the increase in suspended sediment concentration due to dredging activities is comparable with or less than for spring tide conditions.

5.7 Conclusions

1. The effect of dredging and disposal of sediment results in an increase of the suspended sediment concentration of approximately 100 mg/l in the vicinity (i.e. one grid cell) of the dredging location and less than 10 mg/l near the disposal site.
2. At the locations of the monitoring stations near areas of ecological importance the increase of suspended sediment concentration is 20 mg/l or less.
3. The results of the simulations are not very much affected by the assumption whether a fixed bed or a mud bed is present at the start of the simulations.
4. Differences in suspended sediment concentrations due to dredging and dumping are slightly higher during spring tide conditions.
5. The effect of dredging and dumping is not sensitive to waves; similar results were found under conditions without and with waves of moderate height. It is assumed that dredging will be stopped during rough sea conditions.
6 Ecological impact of dredging and dumping

6.1 Description of the Environment

The Duncannon and Cheekpoint Bars are located in the River Suir, in the Southeast of Ireland, at approximately 52°12’N, 6°56’W.

Activities

The River Suir contains a number of environmental and economically important activities that can potentially be affected by the dredging and dumping operation. The type and locations of these activities are summarised below:

- Herring spawning grounds at locations 1a and 1b at open sea.
- Lobster release areas at locations 5a and 5b near the coasts of Falskirt Rock and Hook Head at open sea.
- Oyster production area at location 9 along Woodstown Strand just inside the estuary behind Creadan Head.
- Mussel beds along the estuary from Passage East up to Snowhill Point (locations 10, 11, 17, 19).
- Fish weirs (white fish, cuttle, salmon and eel) at various locations along the lower estuary (locations 12, 13, 15, 16, 18, 20, 21).
Suspension Sediment

Estuaries are naturally turbid systems. Due to the river discharge of suspended particulate matter (SPM) and the salinity gradient, high SPM concentrations do occur.

Commissioned by the Waterford Port Company, Hydrographic Surveys Limited carried out a study of selected environmental parameters, including suspended sediment concentrations. Suspended sediment was measured at two locations, Dredge Disposal Site and Duncannon Bar, during spring as well as neap tides. Suspended sediment concentrations were measured at three depths, at the surface, at the middle and at the bottom of the overlying water column.

At the Disposal Site turbidity, measured as suspended solids, was low. Surface, middle and bottom depth concentrations were approximately 5 mg/l at neap tide. A peak in concentration at the surface (19 and 14 mg/l), found slightly after high water in the neap tide situation, was not reflected at the deeper measurements. The spring tide situation shows some higher concentrations (9, 14 and 19 mg/l) at the middle and bottom depths compared to the neap tide situation.

At Duncannon Bar turbidity was also low at neap tide. Surface, middle and bottom depth concentrations were ranging between 5 and 9 mg/l, with a maximum of 14 mg/l around low water in the evening of 22 June 1999. At spring tide, concentrations of over 100 mg/l were measured near the bottom and in the middle of the water column. A maximum
concentration of 28 mg/l was found at the water surface. Notable is that a passing ship visibly was disturbing sediment, resulting in a significant increase in suspended sediment concentrations. Figure 6.2 presents the results of the measurements of suspended solids at Duncannon Bar in a spring tide situation.

Figure 6.2. Suspended solids concentration at Duncannon Bar in a spring tide situation

In summary, suspended particulate matter concentrations at the Disposal Site are low (5 mg/l). At Duncannon Bar a turbidity maximum occurs, SPM concentrations can reach high levels (>100 mg/l). Highly turbid water may also occur due to ships.

Figure 6.3. Current speed and Suspended Solids concentration at Duncannon Bar at spring tide near the bottom

Figure 6.3 shows the relationship between the current velocity and the suspended solids concentration near the bottom. The gradual decrease and subsequent increase in current velocity around low water correlates very well with the suspended solids concentration near the bottom. Note that the high SS concentrations just before 11:00 and 14:00 h are outliers, caused by the passing of a ship. The correlation between current velocity and suspended solids around high water is not very good.
Bottom Sediment

Commissioned by the Waterford Port Company, Hydrographic Surveys Limited carried out a study of selected environmental parameters, including bottom sediment composition. The bottom sediment was sampled at the Disposal Site, Duncannon Bar, Woodstown Strand, Carters Patch and two offshore sites.

Sediment samples always show a large variance, due to the heterogeneity of sediments. Special emphasis in this analysis is put on the sediment silt content.

The Disposal Site is characterised by a fine brown silty sand, sometimes mixed with (broken) shell and small gravel. The weight percentage of fine silt particles is low, ranging between 0.28% and 13.10%, with a mean of 3.0% silt particles (< 63 μm).

The northern samples of Duncannon Bar are characterised by a fine grey-brown sandy mud with pockets of dark grey organic material. The percentage of fine silt particles is definitely high, ranging between 18.5% and 49.0%, with a mean of 32.2% silt (< 63 μm). The southern samples of Duncannon Bar are characterised by a fine brown silty sand. The percentage of silt is low, ranging between 2.1% and 5.8%, with a mean of 3.7% silt (< 63 μm).

Woodstown Strand is characterised by a fine to medium brown silty sand with a thin layer of silt. The percentage of silt ranges between 0.9% and 18.1% with a mean of 5.8% (< 63 μm).

Carters Patch is characterised by a fine grey-brown sandy mud and fine brown sand. The percentage of silt ranges between 1.4% and 26.4% with a mean of 10.9% silt (<62μm).

The offshore areas are characterised by rock. One grab sample also contained some finer material.

In summary, the Suir estuary shows a wide diversity of grain sizes, ranging from large rocks, gravel and pebbles, primarily in the offshore zone, via silty sand and sandy mud in less exposed areas, to high silt percentages in the sedimentation area of Duncannon Bar.

6.2 Potential Ecosystem Impacts of Dredging and Dumping

6.2.1 Introduction

Generally speaking, short-term, small-scale dredging and dredge spoil disposal projects have less ecological impacts than long-term, large-scale projects (Allen & Hardy, 1980). The most direct, physical effects of the dredging and dumping activities are an increase in the Suspended Particulate Matter (SPM) concentration and a covering of the bottom sediment with disposed material. The increase in SPM can directly and indirectly affect several ecological processes in the water column and in the sediment.
SPM can be classified according to the grain sizes. The larger and heavy fractions will settle easily, while the finer fractions will resuspend and stay in suspension longer. The effects of an increased SPM concentration differ between fractions. The fine fraction of silt and their silt-related processes are very important to the ecological functioning of estuaries. Any change in silt concentrations and silt characteristics may have a potential impact on the ecosystem. In this chapter the ecological functions of silt are briefly addressed, and subsequently, potential ecosystem impacts of the dredging and dumping activities are discussed.

A brief overview of potential effects of suspended material is given in Section 6.2.3. The suspended material may also settle to the bottom. A direct effect may be the burial of benthic species. This is described in Section 6.2.4. Another direct effect is the 'Removal of Benthic Species' at the dredge site (Section 6.2.5). Finally, an indirect effect of the sedimentation of the material may be a change of the sediment composition. This is described in Section 6.2.6.

6.2.2 Ecological Functions of Silt

Silt often is mentioned as an important substance in estuaries. It is clear that silt plays a significant role in chemical, physical and biological processes. Notable aspects of silt related processes are the formation of salt marshes and sedimentation on tidal flats.

To understand the potential ecological effects of the dredging and dumping, this section will provide a synopsis of the ecological functions of silt.

Definitions

In this study silt is defined as follows:

- Silt: that fraction of the sediment that is smaller than 63μm, with or without adsorbed organic (C, P, N) or inorganic material and that is in a floating or (not-consolidated) sedimented condition. Silt is in a dynamic state: dependent of time, place and physical-chemical-biological surroundings, the quantity of adsorbed organic or inorganic material, shape and size of the resulting complex and the position in the water column, bottom or organism will vary.

Partly overlapping definitions that are often used besides or instead of silt are:

- Particular detritus: All not-living particular organic material, such as pseudofaeces, feecal products, excretion products, dead algae, dead bacteria and other dead organisms.
- Seston: the particulate material that consists of inorganic sediment smaller than 63μm, particulate detritus and living cells of algae and bacteria
- Macofloccs or marine snow: fragile flocs of sediment, organic material, algae and bacteria sizing in between several hundreds μm’s to more than a mm.
• Fluid mud: a suspension of silt with a concentration of more than 10 grams per litre. It has a non-Newtonian behaviour and can be transported under certain circumstances with a current velocity of more than a few metres per minute.

• Highly Concentrated Benthic Suspension (HCBS): a suspension of silt with a concentration of several to 10 grams per litre and with a Newtonian behaviour that can be transported with a velocity that is similar to that of non-disturbed water.

Ecological Functions

Silt affects ecological functions, i.e. processes and interactions within and between abiotic and biotic components of the ecosystem that yield a certain product or service. An ecological product is a measurable quantity such as the biomass of mussels or the surface area of salt marshes. An ecological service is a measurable quality such as the buffer against coastal erosion or possibilities for recreation.

Silt affects ecological functions by influencing:

1. Morphology
2. Habitats and substrate
3. Food
4. Water quality

Morphology

Morphological processes that are affected by silt are: floating, transportation, flocculation, sedimentation, consolidation and erosion; the presence and transport as diluted fluid mud and HCBS; the blowing of silt to coastal dunes; the accumulation of silt on flats; the capture, fixation and release - bio(de)stabilisation - by biota such as filterfeeders (Mussels, Cockles, Ensis, Spisula), seagrass beds, salt marsh vegetation, cyanobacterial mats and diatom mats.

Habitats and Substrate

Processes related to silt that affect the substrate and habitats for biota are: the presence of gradients in sediment composition that is favourable to certain benthic species; the presence of flocs as substrate for bacteria.

Food

Processes that are affected in relation to food are: the physical-chemical adsorption of organic material and inorganic nutrients; the exchange of adsorbed organic material with dissolved organic material; the sticking of living cells of algae and bacteria; the consumption by detritus eaters, the filtering by suspension feeders, the bacterial decay and subsequent promotion of mineralisation in sediment and water column and the release of nutrients for primary production.
Water Quality

Processes related to the quality of the water are: the extinction of light in the water column, the influence on water purification by suspension feeders, the accelerated sedimentation of dying phytoplankton blooms by sticking and flocculation.

6.2.3 Potential Impacts of Increased SPM Concentration

An increased Suspended Particulate Matter (SPM) concentration is especially harmful to ecological processes in the water column, but it may, directly or indirectly, also affect ecological processes that take place in the intertidal areas.

Primary production (PP) is defined by the growth of phytoplankton and phytothethos. The primary production of phytoplankton in an estuary is relatively low because of the natural turbidity. Additional turbidity may lead to a decrease in primary production by phytoplankton. When the primary production decreases, less food is available to primary consumers, such as zooplankton and zoobenthos.

The primary production by phytothethos is less sensitive to turbidity, because these species live on intertidal flats. A burial by sediment, however, may affect the PP of phytothethos.

Larvae and eggs of fish and shrimp, that are most abundant in shallow areas, are sensitive to increased suspended particulate matter concentrations, more sensitive than adults. An increased SPM may affect the respiration of larvae and the gas-exchange of eggs. SPM concentrations over 100 mg/l may lead to an increased mortality. An increased SPM concentration may also hinder the functioning of the gills of fish. In general pelagic species are more sensitive than bottom fish.

Herring spawning areas are sensitive to increased suspended matter concentrations. Herring preferably spawns on gravel and pebbles, but also on shell and seaweed. The eggs settle to the bottom and stick to these structures. A relative high current velocity (> 1 m/s) prevents siltation and supplies oxygen.

Birds and fish that hunt by using their eye-sight can also be sensitive for an increase in turbidity.

As a result of the increased suspended solids concentrations, the food uptake by filter feeders can be negatively affected in two ways. First, the high concentrations of particles can clog the food uptake system and second the food quality (organic to inorganic ratio) may decrease. The extra energy it takes to filter the suspended particulate matter (SPM) out of the water can result in a decrease in the growth rate. The increased turbidity may also lead to a decreased concentration of phytoplankton, what in combination with a hindered food uptake can increase the effect on filter feeders.

The decreased food uptake may lead to a reduced growth of filter feeders. The filtering speed of filter feeders shows an optimum curve with SPM concentrations. Research to the
filtering capacity of the Blue Mussel (*Mytilus edulis*) has shown that an average Mussel of 3 centimetres of length will cease filtering at a suspended solids concentration of 250 mg/l. When the SPM concentration is 225 mg/l, the filtering capacity has decreased to about 30% of the maximum filtering speed which is reached at a concentration of 125 mg/l (Widdows et al., 1979).

### 6.2.4 Potential Impacts of Burial of Benthic Organisms

An increased sedimentation near the dumping site can lead to burial of benthic species by a layer of (mostly anaerobic) sediment. The sensitivity of benthos for burial is dependent on the ability to grow or move upwards.

The potential effects of burial can be subdivided into effects of an incidental, but large, deposition and effects of a continuous, but small, deposition.

**Incidental deposition**

The potential impact of dredged material disposal on organisms living on or near the bottom can have strong negative impacts if the settling occurs in an area containing sensitive organisms. Areas of concern include coral reefs, seagrass beds, and fish spawning areas. Non-mobile species, such as the Blue Mussel (*Mytilus edulis*), anemones and oysters are also very sensitive to an incidental deposition, resulting in burial of the organism. Other species are more capable of surviving an incidental deposition, either by moving or growing upwards to the sediment surface.

For benthic organisms a ‘fatal depth’ can be defined, which denotes at what depth of incidental burial the organism will not survive. This fatal depth is species dependent, but also differs with the type of sediment. Essink (1993) provides a literature overview of fatal depths for different organisms and two sediment types, silt and fine sand. In general benthic species are more sensitive to burial by silt than by sand. Furthermore, species of a sandy bottom are more sensitive to burial by silt than species of a silty bottom. Larger species are generally more capable of moving upwards than smaller species. However, the adult *Mya arenaria* is exceptionally large and is not able to move at all.

The fatal depth for incidental deposition of silt for a number of benthic species, selected from Essink (1993), is presented in Table 6.1.

**Table 6.1.** Fatal depth (cm) for incidental deposition with silt (Essink, 1993 to: Bijkerk, 1988).
### Scientific name | Name | Fatal depth (cm)
--- | --- | ---
*Mytilus edulis* | Blue Mussel | 1
*Petricola pholadiformis* | Sandgaper | 3
*Mya arenaria* | Cockle | 7
*Cerastoderma edulis* | Mudsnaill | 11
*Hydrobia ulvae* | Balthic Tellin | 18
*Macoma balthica* | Balthic Tellin | 38
*Ensis ensis* | | 43
*Nephys hombergii* | | 60

Besides the physical effect of burial, chemical effects of the anaerobic sediment, often together with high sulphide concentrations, play a role. A decreased dissolved oxygen level can amplify the effects of an increased sedimentation. The cleaning of the siphons at an increased sedimentation flux will cost more energy, while at the same time the oxygen levels are lower. The tolerance levels for low oxygen levels and high sulphide levels differ between species. A species such as the Brown Shrimp is a lot more sensitive to anaerobic conditions than species that are used to similar situations.

The exposure time to anaerobic conditions (< 0.2 mg O₂/l) and for high sulphide concentrations (7 mg/l) at a 50% mortality level is presented in Table 6.2.

### Table 6.2 Exposure time to anaerobic and sulphide rich conditions at 50% mortality (Essink, 1993; Theede, 1973).

| Scientific name | Name | Exposure time oxygen (hours) | Exposure time sulphide (hours) |
--- | --- | --- | ---
*Mytilus edulis* | Blue Mussel | 800 | 600 |
*Serobicularia plana* | | 600 | 500 |
*Mya arenaria* | Sandgaper | 500 | 400 |
*Nereis diversicolor* | Ragworm | 150 | 100 |
*Cerastoderma edule* | Cockle | 100 | 100 |
* Asterias rubens* | Common Starfish | 90 | 70 |
*Carcinus maenas* | Beach Crab | 40 | 30 |
*Amphipura filiformis* | Brittle Star | 25 | 30 |
*Cragon crangon* | Brown Shrimp | 2 | 2 |

Effects of burial on soft bottom benthic species are temporary. Dependent on the original community structure, recovery may take a couple of years to a decade. Opportunistic species will quickly recolonise the affected site, but long-living bivalve species or some sea urchins do not reproduce each year. In general, soft bottom benthic communities show partial recovery in one year and full recovery in 18 to 24 months. In some cases it will take many years to recover the original species diversity (Allen & Hardy, 1980).
Continuous deposition

A continuous deposition of material to the bottom can have negative effects when the sedimentation rate is higher than the velocity at which the organisms can move or grow upwards. The sensitivity to a long-term continuous deposition again is species dependent and also dependent on the type of sediment. A continuous deposition of silt is in general worse than a deposition of sand. Table 6.3 presents the maximum tolerance for different benthic species for a continuous deposition of silt and fine sand in cm/month.

Table 6.3. Maximum tolerance for continuous deposition of silt and fine sand in cm/month (Essink, 1993; Bijkerk, 1988).

<table>
<thead>
<tr>
<th>Scientific name</th>
<th>Name</th>
<th>Deposition of silt (cm/month)</th>
<th>Deposition of fine sand (cm/month)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Mya arenaria</em></td>
<td>Sandgaper</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td><em>Cerastoderma edule</em></td>
<td>Cockle</td>
<td></td>
<td>17</td>
</tr>
<tr>
<td><em>Macoma balthica</em></td>
<td>Baltic Tellin</td>
<td>15</td>
<td>&gt;17</td>
</tr>
<tr>
<td><em>Arenicola marina</em></td>
<td>Lugworm</td>
<td>11</td>
<td>&gt;17</td>
</tr>
<tr>
<td><em>Nephys hombergii</em></td>
<td>Crab</td>
<td>&gt;35</td>
<td>&gt;17</td>
</tr>
<tr>
<td><em>Carcinus maenas</em></td>
<td></td>
<td>31</td>
<td></td>
</tr>
</tbody>
</table>

6.2.5 Potential Impacts of Removal of Benthic Organisms

At the location of the dredging activities, about 75% of the benthic species are removed from the site. Recolonisation of a new channel is often rapid and original biomass is sometimes reached in 2 weeks to 4 months. However, recolonisation is usually by opportunistic species, original species diversity is seldom achieved within the same period (Allen & Hardy, 1980).

A thorough analysis on the effects of dredging in the Lower Columbia River, Washington did not reveal any significant effect on the standing crops of benthic invertebrates. Apparently, benthic invertebrates in the dredged area were able to recoloniise quite rapidly after dredging (McCabe et al., 1998).

6.2.6 Potential Impacts of Siltation on Tidal Flats

The substrate composition is important for the benthic communities on intertidal areas. Substrate composition is measured as silt content, median grainsize and organic matter content. The composition is influenced by hydrodynamics and the presence of benthos on the flat which can influence the stabilisation, bioturbation and erodability of the substrate.

As a result of the dredging and dumping a certain amount of suspended material may eventually accumulate on the tidal flats of the estuary. This can result in an increased bottom silt content (siltation). In general, highest densities of benthic species are found in net sedimentation areas, where the deposition of organic material and nutrient concentrations are relatively high. An increase in bottom silt content does not directly have
to result in higher densities of benthic species. This is dependent on the suitability of high silt contents for different species. The siltation could result in a change of habitat distribution. Very high bottom silt contents can lead to a decreased suitability for specific species.

### 6.3 Estimated Impacts of Dredging and Dumping

#### 6.3.1 Estimated Impacts of Increased SPM Concentration

**Lobster Release and Herring Spawning Areas**

The dumping of dredged material at the Disposal Site will result in a local increase of the Suspended Particulate Matter (SPM) concentration. The increase, however, is very limited in magnitude and size. The fine silt particles will mix and settle relatively fast in the deep water. The additional concentration peak in a radius of 50m from the disposal site is estimated to be 20 to 40 mg/l.

The increased suspended sediment concentrations will hardly reach the locations of the lobster releases or the herring spawning areas. In the model runs a maximum additional SPM concentration of 0.5 mg/l was found at the lobster release areas and 0.25 mg/l at the herring spawning sites. These additional concentrations will not affect the functioning of the lobster release areas or the herring spawning grounds.

Spawning takes place in November-December. A mitigating measure therefore is not to dump the sediment during these months, but considering the low additional SPM concentrations, this is not necessary.

**Oyster Production Area and Mussel Beds**

The dredging operation of Duncannon Bar will result in an increase of Suspended Particulate Matter concentration (SPM). The increase in SPM concentration has a local and temporary peak of 250 to 300 mg/l at a distance of 50 m around a dredging suction hopper. The plume of suspended matter will be transported with the tidal flow in the Suir estuary. During slack water at the turn of the tide, most of the fine particles will settle to the bottom. Natural SPM concentrations that occur at the Duncannon Bar location, near the oyster production area and mussel beds, reach some tens to 100 mg/l.

The additional effect on the nearby activities, the oyster production area and the mussel beds, is limited. An additional peak increase of 10 mg/l was computed by the water quality model at location (11) (see Fig. 6.1) mussel bed. The other mussel beds, locations (10), (17) and (19), show an additional SPM concentration of 6 mg/l. The oyster production area (9) shows an additional increase of only 3 mg/l.
Concluding, the additional effect of the dredging on turbidity is negligible. Effects of the dredging operation on the oyster grounds and mussel beds in the Suir estuary are also negligible.

**Fish Weirs**

As a result of the dredging operation at the Checkpoint Lower Bar, near the fish weirs, a local and temporary increase of suspended particulate matter concentration of 250 to 300 mg/l can occur at a distance of 50 m around a suction hopper dredge. The natural turbidity in the Checkpoint area is relatively high. Measurements taken in monitoring stations nearby show suspended matter concentrations of over 200 mg/l.

The additional increase in SPM at the locations of the fish weirs is computed with the water quality model. The fish weirs closest to the Checkpoint lower bar show a temporary increase of 20 mg/l for fish weirs (12) and (13) (see Fig. 6.1). These are typical peak events that take place over a two hour period. All other fish weirs have a peak of maximum 5 mg/l in the worst case situation.

The additional turbidity at the fish weirs is limited to peak events and negligible relative to natural background concentrations. The impact on the functioning of the fish weirs is negligible.

**6.3.2 Estimated Impacts of Burial of Benthic Organisms**

As discussed in the previous section, the potential effects of burial can be subdivided into effects of an incidental deposition and effects of a continuous deposition.

**Incidental Deposition**

At the Disposal Site a large amount of dredged material will be dumped. It is to be expected that all benthic species that are present at this site will be covered by a thick layer of sediment and will be buried. Considering the type of sediment (primarily silty sand) and the depth of this location (20m), bivalves species, polychaetes (worms) and brittle stars may be found at this location. Of the species mentioned in the previous section, these may include the Sandgaper (*Mya arenaria*).

The sensitive herring spawning grounds will not be affected by an additional sedimentation due to the disposal of dredged material.

After the dumping, the disposal site will be quickly recolonised by benthic species. At first, opportunistic species such as worms and crabs will search for the dead remains of the original inhabitants, and after a while larvae of bivalve species can settle. After one year, the original biomass may be recovered, but the original species diversity may not be found for a period of a couple of years.

Short-term dissolved oxygen depletion due to the dumping are seldom a problem. At the dump site, reduced oxygen levels are usually found near the bottom at the point of
dumping, but are of a short duration. Adverse impacts are most likely to occur in poorly-mixed waters receiving highly organic dredged material, but that is not the case here.

Continuous Deposition

The computations for the continuous resuspension and subsequent sedimentation of disposed sand at the Disposal Site show a very limited area in which sedimentation of sand takes place. Roughly twice the surface area of the Disposal Site shows an additional sedimentation of sand. The net sedimentation rate has a maximum of about 1 cm/month. This rate is sufficiently low for soft bottom benthic species to survive. The additional sedimentation does not reach the locations of the lobster releases and the herring spawning grounds.

6.3.3 Estimated Impacts of Removal of Benthic Organisms

At the Duncannon Bar and Checkpoint Lower Bar it is to be expected that about 75% of the benthic species are removed. Recolonisation is often rapid and the original biomass is sometimes reached within 2 weeks to 4 months. However, recolonisation usually occurs by opportunistic species. Considering the soft sediments and the natural dynamics of the Suir estuary, it is not expected that there are any very old organisms. The original situation in the dredged channels may be recovered in three years after settling of new bivalve larvae, if maintenance dredging is suspended.

6.3.4 Estimated Impacts of Siltation on Tidal Flats

The increase in concentration of fine matter is very limited compared to the natural background concentrations. A noticeable additional siltation of net sedimentation areas on tidal flats due to dredging is not anticipated.
6.4 Proposed monitoring plan for Suir River and Estuary

6.4.1 The Monitoring Cycle

![Monitoring Cycle Diagram]

Figure 6.4 The monitoring cycle (after UN/ECE, 1996)

Environmental monitoring can be considered as a series of successive steps which are related to each other in a cyclical fashion. The cycle starts with the identification of priorities in environmental management and definition of information needs, and ends with an information product which can be used by relevant environmental policy makers. A series of 7 steps can be defined which encompass all aspects of environmental monitoring:

1. Environmental Management
2. Information needs
3. Monitoring strategy and design
4. Data Collection
5. Data handling and analysis
6. Conversion of data to information needs
7. Reporting and information dissemination

1. Environmental Management: Identification of Issues
The need for information should be based on the core elements in environmental management, including identified priority issues.
2. Information needs
The most critical and difficult step in developing a successful monitoring programme is the clear definition and specification of information needs and monitoring objectives. Information needs are often based on priority issues, environmental pressures, and consideration of possible management measures. Information needs for monitoring are not stationary, but can and will evolve over time due to developments in environmental management, attaining of targets or changing policies.

3. Monitoring strategy and design
After the specification of information needs, a monitoring strategy and design is required to ensure that the monitoring programme operates to produce the desired information. The strategy and design must 'translate' the information needs into an operational monitoring programme. Design includes the details regarding the selection of variables, selection of sites and sampling frequency and methods.

4. Data collection
Data is collected based on the monitoring strategy and the details specified in the monitoring design.

5. Data handling and analysis
The data collected should be validated and archived in a way that they are accessible for current and future use.

6. Conversion of data to needed information
It is the actual goal of the monitoring programme to convert the collected data into information that will meet the specified information needs. This conversion involves integrated data analysis and interpretation. Applications such as Geographic Information Systems (GIS) and other computer programmes are often efficient ways of producing desired information.

7. Reporting and information dissemination
The reporting of information is the final step in the cycle and links the gathering of information with the information users. To distribute information, reports should be prepared and distributed on regular basis, with a level of detail depending on the use of the information. The evaluation of the obtained information may lead to new or redefined information needs, thus starting a new sequence (cycle) of activities. In this way the monitoring process will be improved.

6.4.2 Information needs
The dredging and dumping of sand that contains silt (<63μm) and clay (<2μm) can potentially cause an additional turbidity in the water column and subsequently an additional sedimentation.

It should be noted that an estuary is by itself a relatively turbid environment. Suspended material from the river is transported to the sea. In the estuary where the salinity increases, a turbidity maximum will occur, partly caused by flocculation. The goal of the monitoring
therefore will be to assess the distribution and sedimentation of silt / mud in relation to the natural seasonal dynamics. The question to be answered is whether or not the dredging and dumping will cause a significant additional turbidity and sedimentation.

6.4.3 Monitoring Strategy and Design

The aim of this monitoring plan is to gain maximum insight into the natural functioning of the estuarine system with a minimum of effort and costs.

Most important is to quantify the suspended matter (SPM) concentrations in the river for natural conditions. The SPM concentrations will show a gradient along the axis of the river caused by gradients in salinity and current velocities. This gradient will also show a temporal distribution caused by tidal movements and may show seasonal changes caused by changes in river run-off. Furthermore, the effect of storms and heavy rainfall on turbidity cannot be discarded.

Remote sensing images from the SPOT satellite provide an insight into the seasonal dynamics of the Suir River turbidity. Apparently, in autumn and winter, the plume of suspended matter reaches out further into the sea than in summer. Overall, the shape of the turbid plume is remarkably constant over the year. These pictures can also be used to quantify the concentration of SPM, but that requires excellent pictures, constant atmospheric conditions and constant image operations.

Turbidity Measurements

To get an understanding of the turbidity under natural conditions, turbidity measurements can be carried out over a 12-15 kilometres transect through the river. It is recommended to measure the salinity and turbidity profiles along the river from Belview Quay to Dunmore East during neap and spring tide. Preferably, this should be done around HW and around LW to show the effect of the tidal excursion on the position of the salt wedge and turbidity maximum. The profiles can be determined by measuring e.g. every kilometre just below the water surface, at mid-depth and say 1 m above the bottom. The measuring intervals can be optimised later on when more information is available.

The monitoring programme should consist of a regular site investigations campaign covering a neap and a spring tide in the dry/calm season with low river flow and one in the wet/rough season with high river flow. This could be complemented by one or two incidental site investigations per year after a (severe) storm.

With respect to the dredging operation, measurements are recommended:

1. Prior to dredging, preferably within one week before dredging;
2. and after dredging, preferably not within a week after the dredging has stopped.

Turbidity can be measured with a turbidity meter. An alternative and simple method to measure the suspended matter concentration is to collect a large amount of water in a jerry can (25 litres). Leave the sediment to settle for at least 24 hours and siphon off most of the
water. Than filter the sediment (a filter that is used to make coffee is a good choice), and rinse out the sediment with fresh water. After weighing, the SPM concentration in the sample is known. This method is not very useful when sediment concentrations are low, such as at the open sea.

Another possible technique is to make aerial photographs of the turbidity and take a couple of measurements of SPM concentration simultaneously. These measurements can then be used to calibrate the photographs with respect to the spatial distribution of SPM. This is not a simple and straightforward technique, but requires sophisticated modelling.

Note: In aid of the calibration of the computational modelling, several measurements of SPM concentrations over depth will be carried out on the dredging and dumping locations.

**Sediment Composition**

The increased SPM concentrations and subsequent settling of fine silt particles can potentially result in an increase of silt content on the intertidal flats near the oyster grounds or near the fish weirs. It is recommended to measure the sediment composition with regard to the sand/silt ratio in two transects in the River Suir.

The first transect is located perpendicular to the shoreline in between the fish weirs on Woodstown Strand. Three sampling locations on this transect are recommended. The sediment can be collected using a grab sampler at high water. The percentage of silt in the sample can be obtained by sieving.

The second sampling location is subtidal, near the fish weirs opposite from Seedes Bank (near Buttermilk Point), between Parkswood Point and Barron Quay. Three grab samples are recommended.

Before the grab samples are taken it is worthwhile to take a measurement of the local turbidity, or SPM concentration as well.
It is recommended to take photographs with date indication of the intertidal fish weirs and oyster grounds to establish the base-line situation and to monitor potential siltation in the area.

**6.5 Conclusion on Estimated Ecosystem Impacts**

The increase in suspended particulate matter concentrations, as a result of the dredging and dumping activities are restricted to a local and temporal effects. The additional increase at various monitoring stations were (ecological) activities take place were computed for different model conditions. Table 6.4 gives an overview of maximum additional SPM concentrations for the monitoring locations. It can be concluded that the additional increase in turbidity will have a negligible effect on the ecological functioning of the Suir.
<table>
<thead>
<tr>
<th>Monitoring station</th>
<th>Additional SPM concentration (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1a) Herring spawning</td>
<td>0.25</td>
</tr>
<tr>
<td>(1b) Herring spawning</td>
<td>0.25</td>
</tr>
<tr>
<td>(5a) Lobster release</td>
<td>0.5</td>
</tr>
<tr>
<td>(5b) Lobster release</td>
<td>0.5</td>
</tr>
<tr>
<td>(9) Oyster production</td>
<td>3</td>
</tr>
<tr>
<td>(10) Mussel bed</td>
<td>6</td>
</tr>
<tr>
<td>(11) Mussel bed</td>
<td>10</td>
</tr>
<tr>
<td>(12) Fish weir</td>
<td>20</td>
</tr>
<tr>
<td>(13) Fish weir</td>
<td>20</td>
</tr>
<tr>
<td>(15) Fish weir</td>
<td>5</td>
</tr>
<tr>
<td>(16) Fish weir</td>
<td>5</td>
</tr>
<tr>
<td>(17) Mussel bed</td>
<td>6</td>
</tr>
<tr>
<td>(18) Fish weir</td>
<td>5</td>
</tr>
<tr>
<td>(19) Mussel bed</td>
<td>6</td>
</tr>
<tr>
<td>(20) Fish weir</td>
<td>5</td>
</tr>
<tr>
<td>(21) Fish weir</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 6.4. Maximum additional SPM concentration at the monitoring stations

The dumping of dredged material will lead to burial of the local soft bottom community at the Disposal Site. This effect will be temporary and a relatively fast recovery of biomass is expected, although the original species diversity may not be found for a period of a couple of years. Effects of burial through continuous resuspension and subsequent sedimentation around the disposal site is negligible.

At the dredging locations about 75% of the benthic species will be removed. The original situation may be recovered in three years, after settling of new bivalve larvae if maintenance dredging is suspended.

Effects of additional siltation of the tidal flats is also negligible.
List of References


Leusden, W. van, 1994. Estuarine macroflocks and their role in fine-grained sediment transport, Thesis, University of Utrecht, Faculty of earth science, 7th February, 1994 (thesis 90-393-0410-6)


Note: Appendices available upon request
Prepared for:

Port of Waterford Company
New Ross Port Company

Dredging of Suir and Barrow Rivers

Environmental impact of annual spoil dumping at sea off Hook Head

Report on investigations
March 2001
Prepared for:
Port of Waterford Company
New Ross Port Company

Dredging of Suir and Barrow Rivers

Environmental impact of annual spoil dumping at sea off Hook Head

W.D. Eysink, R.F. de Graaff and K.J. Bos

Report on investigations
CLIENT: Port of Waterford Company and New Ross Port Company

TITLE: Dredging of Suir and Barrow Rivers
Environmental impact of annual spoil dumping at sea off Hook Head

ABSTRACT:

The Port of Waterford Company intends to maintain the nautical depth of the access channel to the Port of Waterford at a required level of OD - 6 m or more in the future. This requires annual maintenance dredging at Duncannon and Cheekpoint Bars in this fairway. The permit for the first dredging and dumping was granted by the Minister for the Marine and Natural Resources under specified conditions. One of the conditions was to perform a mathematical model study on the environmental impact of the dredging and dumping activities which was carried out at an earlier stage.

Similarly, New Ross Port Company (NRPC) wishes to maintain minimum nautical depths of OD - 0.3 m in Barrow River. This material also will be disposed of at sea by the NRPC.

This report considers the impact of disposal of dredged material from both the Suir and Barrow Rivers and Waterford Estuary at the disposal site off Hook Head. It considers the impact of a number of consecutive annual dumpings of dredged spoil over a 15 year period.

REFERENCES: Proposal by fax MCI05691/H3822/WE dated 27th November, 2000
Commission of work by fax dated 22nd December, 2000

<table>
<thead>
<tr>
<th>VER.</th>
<th>ORIGINATOR</th>
<th>DATE</th>
<th>REMARKS</th>
<th>REVIEW</th>
<th>APPROVED BY</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>W.D. Eysink et al.</td>
<td>January 2001</td>
<td>Preliminary</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>W.D. Eysink et al.</td>
<td>March 2001</td>
<td>Final</td>
<td>G. Toms</td>
<td>W.M.K. Tilmans</td>
</tr>
</tbody>
</table>

PROJECT IDENTIFICATION: H 3822

KEYWORDS: Environmental Impact, Sediment transport

CONTENTS: TEXT PAGES 14 TABLES 7 FIGURES 16 APPENDICES 0

STATUS: ☒ PRELIMINARY ☐ DRAFT ☒ FINAL
Contents

List of tables
List of figures

1 Introduction ................................................................................................................. 1

1.1 Description of the problem .................................................................................... 1

1.2 Terms of Reference ............................................................................................... 1

1.3 Results and conclusions ......................................................................................... 2

2 Sand dispersion at the dump site ............................................................................ 4

2.1 General .................................................................................................................. 4

2.2 Approach and input parameters ............................................................................ 4

2.3 Results .................................................................................................................. 6

3 Ecological impact of dumping ................................................................................. 9

3.1 Description of the environment ............................................................................. 9

3.2 Potential ecosystem impacts of dumping ............................................................... 10

3.2.1 Introduction ...................................................................................................... 10

3.2.2 Potential impacts of burial of benthic organisms ............................................... 11

3.3 Estimated impacts of dumping ............................................................................ 13

3.4 Conclusion on estimated ecosystem impacts ......................................................... 14

List of References
Tables
Figures
List of tables

2.1 Probability that highest of sea and swell occur in the given height and direction class at 20 m depth line near Waterford, Water level = MSL (after Eysink et al., 1996)
2.2 Probability that highest of sea and swell occur in the given height and period class at 20 m depth line near Waterford, Water level = MSL (after Eysink et al., 1996)
2.3 Schematised wave climate for morphodynamic computations
3.1 Fatal depth (cm) for incidental deposition with silt
3.2 Exposure time to anaerobic and sulphide rich conditions at 50 % mortality
3.3 Maximum tolerance for continuous deposition of silt and fine sand in cm/month
3.4 Computed maximum additional SPM concentration at the monitoring stations
List of figures

1.1 Situation of dredging and dump sites

2.1 Selected morphological tide
2.2 Wave pattern without the spoil dump, \( H_s = 3.0 \) m, low tide
2.3 Wave pattern with the spoil dump, \( H_s = 3.0 \) m, low tide
2.4 Dispersion of spoil heap after 0.5 year (condition 1)
2.5 Dispersion of spoil heap after 0.9 year (conditions 1 and 2)
2.6 Dispersion of spoil heap after 1.0 year (conditions 1, 2 and 3; before 2\textsuperscript{nd} spoil dumping)
2.7 Dispersion of spoil heap after 2 years (before 3\textsuperscript{rd} spoil dumping)
2.8 Dispersion of spoil heap after 4 years (before 5\textsuperscript{th} spoil dumping)
2.9 Dispersion of spoil heap after 6 years
2.10 Dispersion of spoil heap after 9 years
2.11 Dispersion of spoil heap after 12 years
2.12 Dispersion of spoil heap after 15 years
2.13 Cross section of erosion and sedimentation at the dump site; period 1-5 years
2.14 Cross section of erosion and sedimentation at the dump site; period 5-15 years

3.1 Activities in the Waterford Estuary (in text)
1 Introduction

1.1 Description of the problem

The Port of Waterford Company (PoWC) intends to maintain the nautical depth of the access channel to the Port of Waterford at a required level of OD - 6 m (or more in the future). This requires annual maintenance dredging at Duncannon and Checkpoint Bars in this fairway (Fig. 1.1). The permit for the first dredging and dumping was granted by the Minister for the Marine and Natural Resources under specified conditions. One of the conditions was to perform a mathematical model study on the environmental impact of the dredging and dumping activities which was carried out at an earlier stage (Eysink et al., 2000). Similarly, New Ross Port Company (NRPC) wishes to maintain minimum nautical depths of OD - 0.3 m in Barrow River. This material also will be disposed of at sea by the NRPC.

This report considers the impact of disposal of dredged material from both the Suir and Barrow Rivers and Waterford Estuary at the disposal site off Hook Head. It considers the impact of a number of consecutive annual dumpings of dredged spoil over a 15 year period.

1.2 Terms of Reference

WL | Delft Hydraulics undertook to carry out a study covering the following items in order to further characterise the environmental impact of disposal of dredged spoil:

- The behaviour of the sand dumped at the bottom of the sea at the prescribed dump site will be studied with the sand transport module of our program package DELFT2DMOR with the same model and procedures as applied in the previous study (Eysink, W.D. et al., 2000). This part of the study will provide the long-term behavior of the sand from 5 consecutive annual spoil dumpings of 300,000 m$^3$ following the initial spoil dumping which was studied in a previous report (Eysink, W.D. et al., 2000).

Dispersion of silt released into the water due to dredging in the Waterford Estuary and dumping off Hook Head are short-term effects which will only occur during the maintenance dredging operations. The impacts of the temporary additional silt sources due to the dredging and dumping operations have been dealt with in the previous study (Eysink, W.D. et al., 2000).

The required field data for the additional study were already available from the previous studies. The study has been performed by the following team:

- W.D. Eysink: Project manager and quality control of sediment dispersion studies. Editor of final report
- R.F. de Graaff and K.J. Bos: Sand dispersion study
- M.J. Baptist: Quality control of ecological aspects
- G. Toms: Overall quality control
1.3 Results and conclusions

The additional investigations on the impact of regular dumping of spoil at the approved disposal site at sea have provided with the following results and conclusions:

Behaviour of sand dumped at sea

The behaviour of the sand dumped at the dump site at sea was computed with the sand transport module of DELFT2D.MOR and the validated tidal flow model. Computations were made for an artificial sand heap with an initial height of 1 m on the sea bed at the dump site (representing 425,000 m$^3$ of spoil) under calm, moderate and rough sea conditions. Bottom changes were computed for 0.5 year (calm sea only), 0.9 year (calm and moderate sea) and 1 year (calm, moderate and rough sea).

After a year the bed level at the dump site was raised again by 0.7 m representing the spoil dumping of the next annual maintenance dredging (300,000 m$^3$ of sandy spoil) after which the sand dispersion in the following year was computed. This was repeated for a total of six annual spoil dumpings. The subsequent sand dispersion was computed over a period of ten more years.

The simulations indicate that no sand transport will occur at the dump site under calm sea conditions and only little transport under moderate sea conditions. Most of the erosion/sedimentation at the dump site will occur during rough sea conditions.

Computations of the sedimentation/erosion at the dump site over periods of 1 to 15 years show a continuous but slow spreading of the sand heap towards the East and the Northwest in the first 5 years. The spreading towards the East was limited to about 300 m and practically seems to stop after 5 years (see Figures 2.13 and 2.14) whereas the spreading towards the Northwest continued. In the next 10 years the dispersion at the northwestern side gradually extended further but more to the North towards the entrance of the estuary. In this period the sand also started to disperse along the 20 m depth contour line towards the Southeast. After 15 years the dispersion of sand will still be limited to a distance of about 2 km from the spoil dump towards the Northnorthwest and almost 3 km towards the Southeast (Figure 2.12). The total erosion at the centre of the sand heap amounts to 1.0 m at the time of the last dumping, i.e. 5 years after the initial dumping. At the end of the period of 15 years the total erosion at the centre of the disposal site will increase to 2.9 m. The maximum sedimentation appeared to be about 1.6 m at the toe on the northwestern site of the dump location.

The sedimentation rate close to the disposal site will increase in the first 6 years and will then gradually reduce again after the last spoil dumping. The maximum annual sedimentation rate at a distance of 200 m amounts to 20 cm/year and reduces to 11 cm/year at a distance of 400 m. Beyond a distance of 600 m it becomes very low (less than 7 cm/year).
Ecological impact

The ecological study dealt with the possible impacts of burial by sedimentation on different places of ecological interest at sea. This resulted in the following conclusions:

The dumping of dredged material will lead to burial of the local bottom community at the Disposal Site. This effect will be temporary and a relatively fast recovery of biomass is expected after each dumping, although the original species diversity may not be found for a period of a couple of years after termination of the spoil dumpings.

The effects of burial through continuous resuspension and subsequent sedimentation around the disposal site, also in this situation with more than one spoil dumping, is generally believed to be negligible. Some effect may be expected very close to the disposal site after several spoil dumpings.

Due to the general sedimentation pattern indicated by the models (see Figures 2.6 - 2.12), the herring spawning grounds (areas 1a and 1b; see Figure 3.1) at sea and the lobster release areas (areas 5a and 5b) will not be affected at all by the redistribution of the dumped sand.
2 Sand dispersion at the dump site

2.1 General

The purpose of the sand dispersion study is to determine the long term spreading of the dumped sand from the dump location at sea. For this purpose the initial dump has been schematised as a heap of sand on the sea bed. To study the spreading of the sand a morphological model has been made based on the DELFT3D model system. This model system includes the tidal flow model as discussed in Chapter 3 of our previous report (Eysink et al., 2000). A horizontal 2-dimensional wave propagation model has been added to provide the wave conditions over the area. Based on the results of the flow and wave models the sediment transports and the bottom changes were determined using the morphological model DELFT3D-MOR. This is an integrated model system combining the effects of flow, waves, sediment transports and bottom changes. In the previous study the model has been run for a simulation period of 10 years to compute the morpho-dynamic behaviour of the heap of sand of one spoil dumping of 425,000 m$^3$. In the present study a period of 15 years is simulated with 5 more spoil dumpings of 300,000 m$^3$ at an annual interval after the initial dumping to determine the total ecological impact in case the dump site is used for a longer period.

In this chapter first the study approach and input parameters are described. Thereafter the results are presented and discussed.

2.2 Approach and input parameters

In an ideal situation, the simulations for the spreading of the sand heap should be carried out covering all water levels, current velocities, wave heights and directions related to their possibilities of occurrence. This approach however would result in an unrealistic number of simulations to be carried out. Therefore, the hydraulic conditions are schematised into a few conditions which are representative for the total flow and wave climate as done in the previous study.

For the tidal conditions a morphological tide has been selected based on a weighting procedure considering sediment transport rates related to the tidal range. This approach has proven to be reliable in similar projects carried out in the past. The selected tide runs from 17:00h on 19th June to 18:00h on 20th June 1999 (Figure 2.1) and covers two tidal cycles in a period of 25 hours.

The wave climate is an important input parameter for the transport capacities in the study area. Due to the wave activity, sediment is stirred up after which it can be transported by the tidal flow. The wave climate has been derived from our previous study for Belview Quay (Eysink et al., 1996). The probability of occurrence of the wave conditions at the 20 m depth contour off the coast at Dunmore East at the mouth of the Suir River are presented in
Table 2.1 and 2.2. This wave climate is based on ships observation data in the period between 1949 and 1994 which were provided by the British Met Office.

According to the 1996 study, the wave climate has been schematised into three wave conditions (calm, moderate and rough). The schematisation was carried out in such a way that the representative wave conditions, together with their corresponding durations, give more or less the same annual sediment transport rates in the area of interest as the total wave climate. The representative wave conditions are shown in Table 2.3.

Table 2.3: Schematised wave climate for morphodynamic computations

<table>
<thead>
<tr>
<th>Condition</th>
<th>$H_s$ (m)</th>
<th>$T_p$ (s)</th>
<th>duration (%)</th>
<th>duration (days/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 calm</td>
<td>0.0</td>
<td>-</td>
<td>50</td>
<td>182.5</td>
</tr>
<tr>
<td>2 moderate</td>
<td>1.5</td>
<td>6.6</td>
<td>40</td>
<td>146.0</td>
</tr>
<tr>
<td>3 rough</td>
<td>3.0</td>
<td>9.0</td>
<td>10</td>
<td>36.5</td>
</tr>
</tbody>
</table>

For a more detailed description of the wave climate reference is made to Eysink et al., 1996.

For the morphological computations the wave pattern has been computed at the high waters of the morphological tide and at the low waters. For the intermediate water levels the wave parameters are obtained by interpolation between the wave patterns at HW and LW. The wave pattern at LW for condition 3 ($H_s = 3.0$ m) is presented in Figures 2.2 (without the sand heap) and 2.3 (with the sand heap) for the open sea area at the dump site. These figures indicate that the influence of the sand heap on the regional wave pattern is negligible. The major effect is that the orbital velocity at the sea bed will increase with decreasing water depth over the heap.

The amount of dredged material in the initial dump was estimated at 335,000 - 425,000 m$^3$ partly consisting of silt. Based on the dimensions of the dump site, the resulting sand heap at this location will have a height of approximately 0.8 - 1.0 m ignoring the part of the fine spoil which will be washed out during dumping. For the assessment of the dispersion of sand the maximum value of 1.0 m has been applied to take the maximum dispersion into account in the model simulations. This means that the depth initially reduces from approximately 21 m to about 20 m. The annual volume of the following dumpings are estimated at 300,000 m$^3$ which will cause an incremental raise of the bottom at the dump site of 0.7 m after each dumping.

Sieve curves of the bottom material were provided before by the client. Analysis of these curves indicated that the bottom material at the dredging site is finer than the bottom material at the dump site. However, it can be expected that while dredging the percentage of fine material will reduce during the overflow of the hopper. Furthermore, part of the finer material will be washed out during dumping. Assuming that 50% of the material less than 63 μm will be washed out, it can be concluded that the dumped material at the seabed of the dump site will be comparable to the original bed material at the dump site. For this material the following sediment characteristics have been selected which are applied for all dumpings (Eysink, W.D. et al., 2000):
$D_{90} = 100 \mu m$

$D_{90} = 300 \mu m$

fall velocity $0.008 m/s$

The sand transport rates in the area were computed using the Bijker formula which includes the transport contributions of both waves and currents. The transports were computed over the morphological tide in discrete steps of 15 minutes (which means a total of 100 steps) taking into account the variation of the wave field during the tide. Hereafter the average transport over the morphological tide was computed. Based on this average transport the bottom changes were determined.

The bottom changes were computed by morphodynamic computations. This means that the interaction between the variation of the water depth due to sedimentation and erosion and the hydraulic conditions has been taken into account. After computing the bottom changes in a certain period of time the hydraulic conditions were updated by new flow, wave and transport computations, and so on.

The sediment transports and bottom changes in the existing situation were computed as well. These bottom changes were subtracted from the bottom changes in the situation with the spoil dump assuming that the bottom changes in the existing situation can be considered as natural changes. The difference gives the impact of the spoil dump on the morphological developments at the dump site.

2.3 Results

Firstly, the cumulative bottom changes due to the various conditions were computed in the first year after the initial dumping of sand. The bottom changes after condition 1 (calm), conditions 1 and 2 (calm and moderate waves), and after all three representative conditions are shown in Figures 2.4, 2.5 and 2.6 respectively.

From these first computations it can be concluded that the impacts of the calm condition on the morphology can be neglected. During this condition no significant bottom changes occurred. The bottom changes due to the moderate and rough sea states indicate that the height of the sand heap tends to reduce. The sand from this heap is deposited in the direct vicinity of the dump site at the north-western and at the south-eastern side. Due to this process the height of the sand heap is reduced while it is spread out over a larger area.

As the calm conditions have a negligible influence on the sand dispersion, these conditions can be neglected in the long term prediction of the sand dispersion. Therefore, only the moderate and rough sea conditions are taken into account in the simulations from 1 year to 15 years. The resulting bottom changes are presented in Figures 2.7 to 2.12 showing the results after 2, 4, 6, 9, 12 and 15 years respectively. The results initially show, as in the previous study, a general tendency of sand dispersion from the disposal area towards the East and particularly towards the Northwest. However, after 5 years the dispersion towards the Northwest is somewhat stronger than in the situation with one dumping whereas also dispersion of sand towards the Southeast starts to develop (Figure 2.9). This is caused by the higher spoil heap due to the repetitive spoil dumpings. This dispersion process
continues in the next 10 years; at the Northwest side the sand dispersion gradually turns North towards the estuary mouth and at the Southeast side it further extends along the 20 m depth contour line (Figs. 2.10 - 2.12).

To get a better impression of the developments of the erosion and sedimentation at the disposal site in time, the computed bed development along a cross section running through the sedimentation area at the northwestern side, the disposal area and the sedimentation area at the eastern side is plotted in Figures 2.13 and 2.14. The first figure shows the computed annual development in the period with spoil dumping (increasing bed level in the disposal area), whereas the second figure shows the computed developments during the next ten years after the last spoil dumping.

Note that in Figure 2.13 some irregularities (saw teeth) appear in the bed development at the locations around the toe and the edge of the sand heap where the bed shows a sudden change in bed slope. This is caused by the numerical process of the computations and can be neglected in interpretations of the bed developments. These irregularities in the bed have been smoothed before starting the computations for the period of ten years after implementation of the last spoil dumping (see Figure 2.14).

The results in Figure 2.13 show a progressive erosion of sand in time with the increasing height of the spoil heap. This is caused by the increasing flow velocity and orbital velocity at the bed of the spoil heap with the increasing depth reduction. From these data the minimum annual erosion in the centre of the spoil heap can be approximately derived as a fitted function of the height of the bed level above the original bed at the start of the year:

\[ E = 0.071 \Delta h^{1.32} \]

where:

- \( E \) = annual erosion depth (m)
- \( \Delta h \) = initial height of bed level in centre of the disposal area above the original bed (m)

This relation indicates that in case of continuous annual dumping the erosion becomes equal to the annual dumping height of 0.7 m if the bed level is raised by 5.7 m above the original bed level. This means that, according to the computations, in that case the bed level at the disposal site would always remain below about OD - 15 m.

Figure 2.13 shows a decreasing sedimentation at the east side of the disposal site which remains limited to a distance of about 300 m from that site in the first 5 years. At the northwestern side the sedimentation continues progressively during the first 6 years after the first spoil dumping. In the first two years most of the sand remains within a distance of 400 m from the disposal site. This distance gradually increases to 600 m in the next three years and to about 2 km 15 years after the first spoil dumping. The sedimentation rate close to the disposal site increases in the first 6 years and then gradually reduces again after the last spoil dumping. The maximum annual sedimentation rate at a distance of 200 m amounts to 20 cm and reduces to 11 cm at a distance of 400 m. Beyond a distance of 600 m it becomes very low (less than 7 cm/year).
In ten years after implementation of the last spoil dumping, the sedimentation rate close to the spoil heap reduces in time due to the reducing height of the spoil heap which means less disturbance on the local flow conditions (see Figure 2.14). The total erosion at the centre of the sand heap (total dump height 4.5 m) is equal to 1.0 m five years after the first dumping and has increased to 2.9 m at the end of the total period of 15 years. The maximum sedimentation after 15 years appeared to be approximately 1.6 m at the toe of the dump heap on the northwestern side.
3  Ecological impact of dumping

3.1  Description of the environment

The Duncannon and Checkpoint Bars are located in the River Suir, in the Southeast of Ireland, at approximately 52°12'N, 6°56'W.

Activities

The River Suir contains a number of environmental and economically important activities that can potentially be affected by the dredging and dumping operation (See Figure 3.1).

Figure 3.1. Activities in the Waterford estuary.
The type and locations of these activities are summarised below:

- Herring spawning grounds at locations 1a and 1b at open sea,
- Lobster release areas at locations 5a and 5b near the coasts of Falskirt Rock and Hook Head at open sea,
- Oyster production area at location 9 along Woodstown Strand just inside the estuary behind Creadan Head,
- Mussel beds along the estuary from Passage East up to Snowhill Point (locations 10, 11, 17, 19) and at Barrow Bridge,
- Fish weirs (white fish, cuttle, salmon and eel) at various locations along the lower estuary (locations 12, 13, 15, 16, 18, 20, 21). Mussel Bed at Barrow Bridge to be inserted.

For this study only the Herring spawning grounds at locations 1a and 1b and the Lobster release areas at locations 5a and 5b near the coasts of Falskirt Rock and Hook Head at open sea are relevant. Those areas are located in the vicinity of the disposal area and ultimately might be affected by the dispersion of sand from that area.

### 3.2 Potential ecosystem impacts of dumping

#### 3.2.1 Introduction

Generally speaking, short-term, small-scale dredging and dredge spoil disposal projects have less ecological impacts than long-term, large-scale projects (Allen & Hardy, 1980). The most direct, physical effects of the dredging and dumping activities are an increase in the Suspended Particulate Matter (SPM) concentration and a covering of the bottom sediment with disposed material. The increase in SPM can directly and indirectly affect several ecological processes in the water column and in the sediment.

SPM can be classified according to the grain sizes. The larger and heavy fractions will settle easily, while the finer fractions will resuspend and stay in suspension longer. The effects of an increased SPM concentration differ between fractions. The fine fraction of silt and their silt-related processes are very important to the ecological functioning of estuaries. Any change in silt concentrations and silt characteristics may have a potential impact on the ecosystem. In this chapter the ecological functions of silt are briefly addressed, and subsequently, potential ecosystem impacts of the dredging and dumping activities are discussed.

An overview of potential effects of suspended material, the 'Removal of Benthic Species' at the dredge site and the indirect effect of a change of the sediment composition is described in the previous study (Eysink et al., 2000). These effects will not change due to the repetitive spoil disposal at the dump site. The major difference with the previously situation could be the more continuous and increased sand dispersion around the dump site. That aspect is discussed in the next Sections.
3.2.2 Potential impacts of burial of benthic organisms

An increased sedimentation near the dumping site can lead to burial of benthic species by a layer of (mostly anaerobic) sediment. The sensitivity of benthos for burial is dependent on the ability to grow or move upwards.

The potential effects of burial can be subdivided into effects of an incidental, but large, deposition and effects of a continuous, but small, deposition.

Incidental deposition

The potential impact of dredged material disposal on organisms living on or near the bottom can have strong negative impacts if the settling occurs in an area containing sensitive organisms. Areas of concern include coral reefs, seagrass beds, and fish spawning areas. Non-mobile species, such as the Blue Mussel (Mytilus edulis), anemones and oysters are also very sensitive to an incidental deposition, resulting in burial of the organism. Other species are more capable of surviving an incidental deposition, either by moving or growing upwards to the sediment surface.

For benthic organisms a ‘fatal depth’ can be defined, which denotes at what depth of incidental burial the organism will not survive. This fatal depth is species dependent, but also differs with the type of sediment. Essink (1993) provides a literature overview of fatal depths for different organisms and two sediment types, silt and fine sand. In general benthic species are more sensitive to burial by silt than by sand. Furthermore, species of a sandy bottom are more sensitive to burial by silt than species of a silty bottom. Larger species are generally more capable of moving upwards than smaller species. However, the adult Mya arenaria is exceptionally large and is not able to move at all.

The fatal depth for incidental deposition of silt for a number of benthic species, selected from Essink (1993), is presented in Table 3.1.

Table 3.1. Fatal depth (cm) for incidental deposition with silt (Essink, 1993 to: Bijkerk, 1988).

<table>
<thead>
<tr>
<th>Scientific name</th>
<th>Name</th>
<th>Fatal depth (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Mytilus edulis</em></td>
<td>Blue Mussel</td>
<td>1</td>
</tr>
<tr>
<td><em>Pecten pholadiformis</em></td>
<td>Sandgaper</td>
<td>3</td>
</tr>
<tr>
<td><em>Mya arenaria</em></td>
<td>Cockle</td>
<td>7</td>
</tr>
<tr>
<td><em>Cerastoderma edulis</em></td>
<td>Mudsnaile</td>
<td>11</td>
</tr>
<tr>
<td><em>Hydrobia ulvae</em></td>
<td>Balthic Tellin</td>
<td>18</td>
</tr>
<tr>
<td><em>Macoma balthica</em></td>
<td></td>
<td>38</td>
</tr>
<tr>
<td><em>Ensis ensis</em></td>
<td></td>
<td>43</td>
</tr>
<tr>
<td><em>Nephys hombergii</em></td>
<td></td>
<td>60</td>
</tr>
</tbody>
</table>

Besides the physical effect of burial, chemical effects of the anaerobic sediment, often together with high sulphide concentrations, play a role. A decreased dissolved oxygen level can amplify the effects of an increased sedimentation. The cleaning of the siphons at an increased sedimentation flux will cost more energy, while at the same time the oxygen levels are lower. The tolerance levels for low oxygen levels and high sulphide levels differ.
between species. A species such as the Brown Shrimp is a lot more sensitive to anaerobic conditions than species that are used to similar situations.

The exposure time to anaerobic conditions (< 0.2 mg O₂/l) and for high sulphide concentrations (7 mg/l) at a 50% mortality level is presented in Table 3.2.

Table 3.2 Exposure time to anaerobic and sulphide rich conditions at 50% mortality (Essink, 1993; Theede, 1973).

<table>
<thead>
<tr>
<th>Scientific name</th>
<th>Name</th>
<th>Exposure time oxygen (hours)</th>
<th>Exposure time sulphide (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mytilus edulis</td>
<td>Blue Mussel</td>
<td>800</td>
<td>600</td>
</tr>
<tr>
<td>Scrobicularia plana</td>
<td>Sandgaper</td>
<td>600</td>
<td>500</td>
</tr>
<tr>
<td>Mya arenaria</td>
<td></td>
<td>500</td>
<td>400</td>
</tr>
<tr>
<td>Nereis diversicolor</td>
<td>Ragworm</td>
<td>150</td>
<td>100</td>
</tr>
<tr>
<td>Cerastoderma edule</td>
<td>Cockle</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Asterias rubens</td>
<td>Common Starfish</td>
<td>90</td>
<td>70</td>
</tr>
<tr>
<td>Carcinus maenas</td>
<td>Beach Crab</td>
<td>40</td>
<td>30</td>
</tr>
<tr>
<td>Amphiura filiformis</td>
<td>a Brittle Star</td>
<td>25</td>
<td>30</td>
</tr>
<tr>
<td>Crangon crangon</td>
<td>Brown Shrimp</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

Effects of burial on soft bottom benthic species are temporary. Dependent on the original community structure, recovery may take a couple of years to a decade. Opportunistic species will quickly recolonise the affected site, but long-living bivalve species or some sea urchins do not reproduce each year. In general, soft bottom benthic communities show partial recovery in one year and full recovery in 18 to 24 months. In some cases it will take many years to recover the original species diversity (Allen & Hardy, 1980).

Continuous deposition

A continuous deposition of material to the bottom can have negative effects when the sedimentation rate is higher than the velocity at which the organisms can move or grow upwards. The sensitivity to a long-term continuous deposition again is species dependent and also dependent on the type of sediment. A continuous deposition of silt is in general worse than a deposition of sand. Table 3.3 presents the maximum tolerance for different benthic species for a continuous deposition of silt and fine sand in cm/month.

Table 3.3. Maximum tolerance for continuous deposition of silt and fine sand in cm/month (Essink, 1993; Bijkerk, 1988).

<table>
<thead>
<tr>
<th>Scientific name</th>
<th>Name</th>
<th>Deposition of silt (cm/month)</th>
<th>Deposition of fine sand (cm/month)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mya arenaria</td>
<td>Sandgaper</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Cerastoderma edule</td>
<td>Cockle</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>Macoma balthica</td>
<td>Baltic Tellin</td>
<td>15</td>
<td>17</td>
</tr>
<tr>
<td>Arenicola marina</td>
<td>Lugworm</td>
<td>11</td>
<td>17</td>
</tr>
<tr>
<td>Nephys hombergii</td>
<td></td>
<td>&gt;35</td>
<td>17</td>
</tr>
<tr>
<td>Carcinus maenas</td>
<td>Crab</td>
<td>31</td>
<td></td>
</tr>
</tbody>
</table>
3.3 Estimated impacts of dumping

The main effect of dumping is the impact on benthic organisms due to burial. As discussed in the previous section, the potential effects of burial can be subdivided into effects of an incidental deposition and effects of a continuous deposition.

Incidental deposition

At the Disposal Site a large amount of dredged material will be dumped. It is to be expected that all benthic species that are present at this site will be covered by a thick layer of sediment and will be buried. Considering the type of sediment (primarily silty sand) and the depth of this location (20 m), bivalves species, polychaetes (worms) and brittle stars may be found at this location. Of the species mentioned in the previous section, these may include the Sandgaper (Mysa arenaria).

The modelling has indicated that sensitive herring spawning grounds will not be affected by an additional sedimentation due to the disposal of dredged material.

After the dumping, the disposal site will be quickly recolonised by benthic species. At first, opportunistic species such as worms and crabs will search for the dead remains of the original inhabitants, and after a while larvae of bivalve species can settle. After one year, the original biomass may be recovered, but the original species diversity may not be found. This process will be repeated after each dumping. Full recovery of the original species diversity will take at least for a period of two years after the last dumping.

Short-term dissolved oxygen depletion due to the dumping is seldom a problem. At the dump site, reduced oxygen levels are usually found near the bottom at the point of dumping, but are of a short duration. Adverse impacts are most likely to occur in poorly-mixed waters receiving highly organic dredged material, but that is not the case here.

Continuous deposition

The computations for the continuous resuspension and subsequent sedimentation of disposed sand at the Disposal Site show a limited area in which noticeable sedimentation of sand takes place. Roughly twice the surface area of the Disposal Site shows a significant additional sedimentation of sand. The net sedimentation rate in this area generally has a maximum of about 1 cm/month. This rate is sufficiently low for soft bottom benthic species to survive. Only in a narrow zone along the disposal site the sedimentation rates are high. At a distance beyond 600 m from the disposal site the sedimentation rate is always less than 5 cm per year.

Due to the general development of the sedimentation pattern indicated by the modelling (see Figures 2.6 - 2.12) the herring spawning grounds (areas 1a and 1b) at sea and the lobster release areas (areas 5a and 5b) will not be affected at all. The model results indicate that the area affected by sedimentation due to spoil dumping generally will remain at a distance of about 1 km from the lobster release areas and more more from the herring spawning grounds.
3.4 Conclusion on estimated ecosystem impacts

At the dredging locations about 75% of the benthic species will have been removed during the first dredging campaign. The original situation will not be restored under the conditions with annual maintenance dredging.

The increase in suspended particulate matter concentrations, as a result of the dredging and dumping activities are restricted to local and temporal effects. In the previous study (Eysink et al., 2000) the additional increase at various monitoring stations where (ecological) activities take place, were computed for different conditions. Table 3.4 gives an overview of computed maximum additional SPM concentrations for the monitoring locations. It was concluded that the additional increase in turbidity will have a negligible effect on the ecological functioning of the Suir. This holds for each annual dredging campaign at Checkpoint and Duncannon Bars.

<table>
<thead>
<tr>
<th>Monitoring station</th>
<th>Additional SPM concentration (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1a) Herring spawning</td>
<td>0.25</td>
</tr>
<tr>
<td>(1b) Herring spawning</td>
<td>0.25</td>
</tr>
<tr>
<td>(5a) Lobster release</td>
<td>0.5</td>
</tr>
<tr>
<td>(5b) Lobster release</td>
<td>0.5</td>
</tr>
<tr>
<td>(9) Oyster production</td>
<td>3</td>
</tr>
<tr>
<td>(10) Mussel bed</td>
<td>6</td>
</tr>
<tr>
<td>(11) Mussel bed</td>
<td>10</td>
</tr>
<tr>
<td>(12) Fish weir</td>
<td>20</td>
</tr>
<tr>
<td>(13) Fish weir</td>
<td>20</td>
</tr>
<tr>
<td>(15) Fish weir</td>
<td>5</td>
</tr>
<tr>
<td>(16) Fish weir</td>
<td>5</td>
</tr>
<tr>
<td>(17) Mussel bed</td>
<td>6</td>
</tr>
<tr>
<td>(18) Fish weir</td>
<td>5</td>
</tr>
<tr>
<td>(19) Mussel bed</td>
<td>6</td>
</tr>
<tr>
<td>(20) Fish weir</td>
<td>5</td>
</tr>
<tr>
<td>(21) Fish weir</td>
<td>5</td>
</tr>
</tbody>
</table>

Effects of additional siltation on the tidal flats during dredging are also temporary and negligible.

The dumping of dredged material will lead to burial of the local bottom community at the Disposal Site. This effect will be temporary and a relatively fast recovery of biomass is expected, although the original species diversity may not be found for a period of about two years. Hence, between two consecutive dumpings with an interval of (less than) one year no full recovery will occur. Full recovery only can occur after the dump site is abandoned. Even then the species diversity may differ from the original one due to a change of bed composition.
Effects of burial through continuous resuspension and subsequent sedimentation of sand around the disposal site is generally expected to be negligible. Only close to the disposal site high sedimentation rates may cause damage due to burial after several dumpings.

Due to the general sedimentation pattern of the sand eroded from the disposal site as predicted by the models (see Figure 2.12), the herring spawning grounds (areas 1a and 1b) at sea and the lobster release areas (areas 5a and 5b) will not be affected at all.
List of References


E.2 General Information

Attachment E.2(i): Characteristics of the dumping site

Details of permits granted for this disposal site are outlined in Section A.7

Current Permit is included in Attachment A.7

Details of tonnages disposed since 2006 are included in Attachment D.1

The characteristics of dump site are included in the various reports included in Attachment E.1.

The above information is not included here to avoid repetition.

Attachment E.2(i): Coordinates and Location Chart of Dumping Site

The current licensed dumpsite coordinates are as follows:

<table>
<thead>
<tr>
<th>Disposal Site</th>
<th>WGS84 Coordinates</th>
<th>Irish Transverse Mercator (ITM)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Latitude</td>
<td>Longitude</td>
</tr>
<tr>
<td></td>
<td>52° 07.45' N</td>
<td>06° 58.80' W</td>
</tr>
<tr>
<td></td>
<td>52° 07.10' N</td>
<td>06° 58.80' W</td>
</tr>
<tr>
<td></td>
<td>52° 07.10' N</td>
<td>06° 58.10' W</td>
</tr>
<tr>
<td></td>
<td>52° 07.45' N</td>
<td>06° 58.10' W</td>
</tr>
</tbody>
</table>

A chart outlining its position is included as Figure 1 in Attachment D.2(ii).