TECHNICAL REPORT

ABLE UK LTD

ENVIRONMENTAL ASSESSMENT OF DREDGING OPERATIONS, CHANGES IN HYDRODYNAMICS AND SEDIMENT TRANSPORT; TERRC FACILITY

REPORT NO. 2004-1387

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DET NORSKE VERITAS

TECHNICAL REPORT

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Summary:

Det Norske Veritas (DNV) has conducted a numerical modelling study to assess the impact on hydrodynamics and sediment transport due to dredging required in the development of the TERRC facility in the Tees Estuary. Generally the velocities and bottom shear stress are lowered within the bounds of Seaton Channel due to deepening of the proposed dredging areas. Outside the bounds of Seaton Channel changes in velocities and shear stress are low. The greatest changes are related to the deepening of Seaton Channel. For the most extensive dredging scenario the results indicate a decrease in average velocities of about 7 % on Seal Sands and around 18 % in the lower reaches of Seaton Channel, at some selected locations. The modelled results indicate minor changes in sediment transport and sedimentation rates. Some increase in sedimentation may be expected due to lower velocities and bottom shear stress within the bounds of Seaton channel and especially in the lower parts of the channel. Suspended sediment concentrations, sediment dispersion and sedimentation from the suggested dredging operations will be much larger compared to tidal driven transport and sedimentation. The model results indicate that the suspended sediment concentrations can exceed 1000 mg/l for the backhoe dredge, but are less for the hopper dredge. In all cases, the concentrations drop off quickly away from the dredge. Some of the released sediments for both the backhoe and the hopper dredge are transported into the shallow areas south of the Seaton Channel. The greatest impact are related to dredging Seaton Channel with a hopper dredge on spring tide which yields a deposition rate around 100 g/m^2 after only 2 days of dredging. Dredging around the clock for 12 weeks, as planned, can therefore introduce considerably amounts of sediment onto Seal Sands.

Impact on marine life has been evaluated due to changes in hydrodynamics and sedimentation regime as a result of the planned dredging operations at the TERRC facility. The level of contamination in the dredging areas and at Seals Sand has been mapped and compared with international sediment quality standards. Levels have been mapped for several metals (Ar, Cd, Cr, Cu, Hg, Ni, Pb and Zn), PCBs, PAHs and TBT in dredging area 1 to 4. On Seals Sands the levels of metals mentioned above have been mapped. The levels of contamination have been compared with international sediment quality standards.

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1 CONCLUSIVE SUMMARY

Det Norske Veritas (DNV) have conducted a numerical modelling study to assess the impact on hydrodynamics and sediment transport due to dredging required in the development of the TERRC facility in the Tees Estuary.

Generally the velocities and bottom shear stress are lowered within the bounds of Seaton Channel due to deepening of the proposed dredging areas. Outside the bounds of Seaton Channel changes in velocities and shear stress are low. The greatest changes are related to the deepening of Seaton Channel. For the most extensive dredging scenario the results indicate a decrease in average velocities of about 6 % on Seal Sands and around 18 % in the lower reaches of Seaton Channel, at some selected locations.

The modelled results indicate minor changes in sediment transport and sedimentation rates. Some increase in sedimentation may be expected due to lower velocities and bottom shear stress within the bounds of Seaton channel, especially in the lower parts of the channel.

Suspended sediment concentrations, sediment dispersion and sedimentation from the suggested dredging operations will be much larger compared to tidal driven transport and sedimentation. The model results indicate that the suspended sediment concentrations can exceed 1000 mg/l for the backhoe dredge, but are less for the hopper dredge. In all cases, the concentrations drop off quickly away from the dredge. Some of the released sediments for both the backhoe and the hopper dredge are transported into the shallow areas south of the Seaton Channel. The greatest impact are related to dredging Seaton Channel with a hopper dredge on spring tide which yields a deposition rate around 100 g/m^2 after only 2 days of dredging. Dredging around the clock for 12 weeks, as planned, can therefore introduce considerably amounts of sediment onto Seal Sands.

The levels of contamination have been compared with international sediment quality standards. Concentrations of contaminants are generally below recommended risk limits for effects on the ecosystem. The exceptions are for the following PAHs: benzo(a)pyrene, Acenaphthylene, Anthracene and Benzo(a)anthracene. These PAHs are found in concentrations that exceeds the Probable Effect Level (PEL) according to the Canadian Environmental Quality Guidelines.

2 INTRODUCTION

Able Ltd UK has engaged Det Norske Veritas (DNV) to conduct a numerical modelling study to assess the impact on hydrodynamics and sediment transport due to dredging required in the development of the TERRC facility in the Tees Estuary. The modelling effort consists of two components. The first relates to the impact on circulation and sedimentation due to changing the bathymetry of the Seaton Channel and associated dredged areas. The second relates to water column suspended sediment concentrations due to the dredging activity, which is done in co operation with Computational Hydraulics and Transport (CHT) and Applied Science Associates (ASA).

In addition DNV have, based on the modelling results, evaluated potential effects on marine life in the modelling area. DNV's work is a part of a larger Environmental Impact Assessment (EIA) carried out by another party. This report describes the modelling results and the potential impact on marine life in the area.

2.1 Assumptions and limitations

The following section discusses assumptions and limitations imposed upon this study which affect results and interpretations. As the study is based upon external data sources and no measurements or observations have been made on site it is influenced by assumptions and limitations from other studies, some of which may not be clear.

The scope of the study is to investigate the relative impact of the proposed development on hydrodynamic and sediment regimes, and thereby on marine life in the Tees estuary. In order to see the impacts clearly, masking elements like floods, storms, waves, dredging activities and vessel traffic have been omitted. The essential impact of each element of the proposed development is thus clear. However, the absolute values of water velocities, shear stress distribution, sediment concentrations and sediment erosion and deposition rates are not emphasized, as the Tees estuary sediment transportation processes are influenced by events like floods, wave action and propeller currents. Dredging operations are investigated to some degree to find the impact of dredging the TERRC dry dock and Seaton Channel, but the continuous dredging operation along the River Tees and the estuary is not included.

It is therefore important to realise that the relative impacts presented here are of importance, but that siltation rates and subsequent needs for maintenance dredging should not be based upon the modelling results unless specified.

The theoretical basis for the hydrodynamic and sediment transportation models and the cohesive sediments in particular, are known to be simplifications of natural processes. This imposes some limitations on the accuracy and realism of the results obtained. Models for erosion, transportation and deposition of cohesive sediments like clay and silt are unstable, as are the natural processes the models represent. A small change in input parameters or geometry may have severe impacts on the results obtained. Any interpretations made should focus on the relative impact of the proposed developments rather than the absolute values of sediment erosion and accretion.

Further assumptions and limitations are discussed in relevant sections.

3 DREDGING SCENARIOS AND VOLUMES

Based on the bathymetry quantities for different dredging scenarios have been calculated.

3.1 Initial dredging

Figure 3-1 to Figure 3-6 illustrates the definition of each area in question. With regards to quay 10 and 11 there are missing depth data just outside the quays, so in the calculations the assumption that the depth just outside the quays is the same as the first point in the bathy data (transects) has been made.

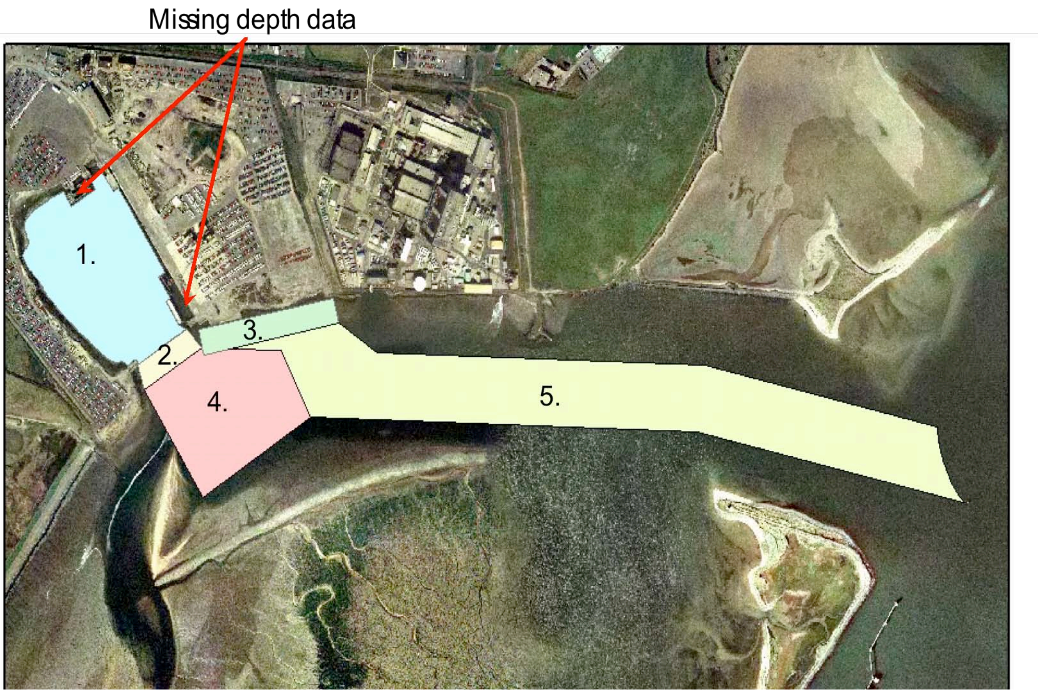


Figure 3-1 Overview of the dredging areas. 1) dry/wet dock, 2) Bund/cofferdam area, 3) Quays 10 and 11, 4) holding basin and 5) Seaton Channel

Detailed figures showing the bathymetry in each dredging area are presented below. The bathymetric charts are drawn up such that the areas which need to be dredged are made as visible as possible.

Figure 3-2 Detailed bathymetry for dredging of Seaton Channel

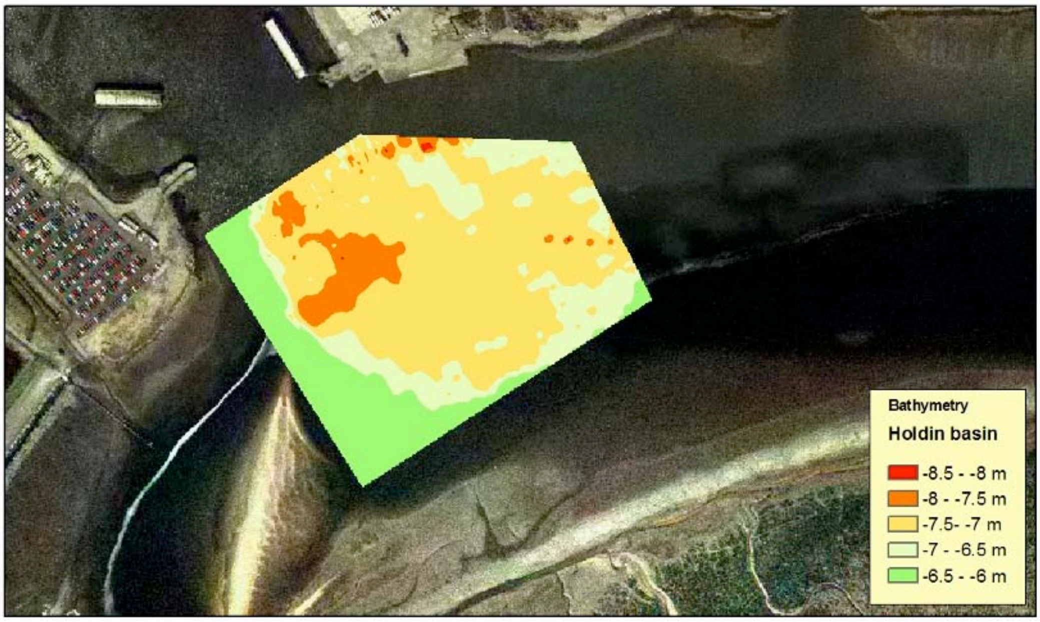


Figure 3-3 Detailed bathymetry for dredging of Holding Basin

Figure 3-4 Detailed bathymetry for dredging of Quay 10 and 11

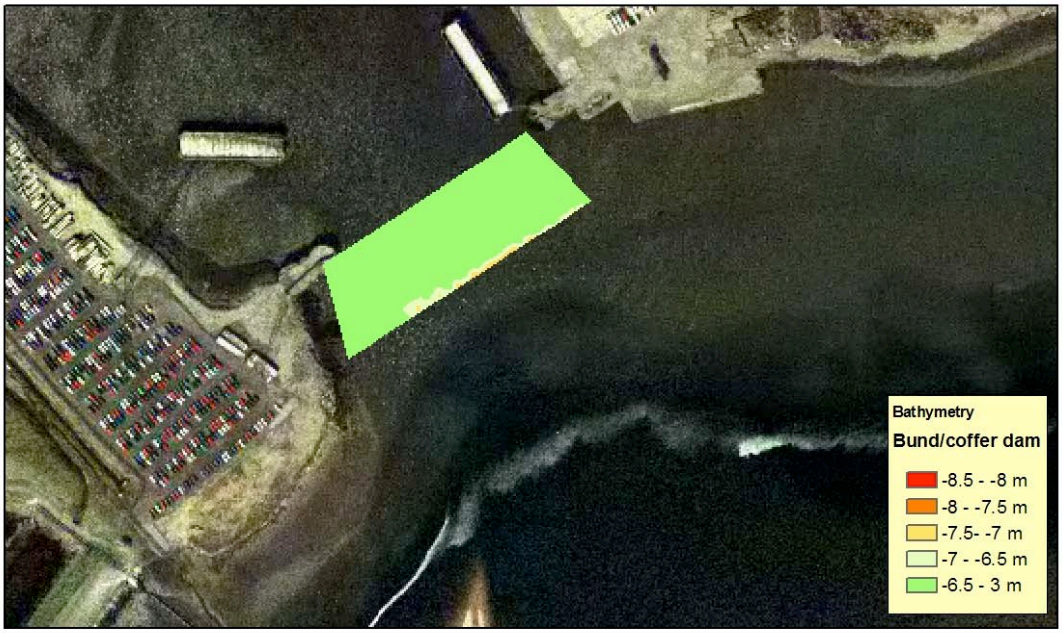


Figure 3-5 Detailed bathymetry for dredging of Bund/cofferdam area

Figure 3-6 Detailed bathymetry for dredging of Dry/wet dock

With regards to the dock itself there are some missing depth data under the ships and the construction in the south eastern and north eastern limit of the dock, which is illustrated in Figure 3-1. Based on the surface area of these two areas an assumption is made on the dredging volumes in these two areas, and these have to be added to the calculated volumes for the dock.

The area in the south eastern corner of the dock is approximately 2500 m^2. The depth in this area is assumed to be 3 m on average and is based on the depths in the bathymetric transect which border on this area.

The area in the north eastern corner of the dock is also approximately 2500 m^2. The depth in this area is assumed to be 4.5 m on average and is based on the depths in the bathymetric transect which border on this area.

The estimated volumes of these two areas have to be added to the volumes for the dry/wet dock.

Calculated dredging volumes for different scenarios are presented in Table 3-1. In addition dredging volumes for a proposed extension of quay 10 & 11 are calculated and presented in the table. The areas of dredging related to the proposed extension are shown in Figure 3-7 below.

Figure 3-7 Areas of dredging for the proposed extension of Quay 10 and 11

Table 3-1 Calculated volumes of dredged sediments.

Scenario	Reference area	2D area m^2	Dredging depth	Volume m^3
Seaton Channel	5	179 555.69	- 6.0 m LAT	276 797
Seaton Channel	5	189 565.76	- 6,5 m LAT	369 496
Seaton Channel	5	194 714.11	- 7.0 m LAT	465 568
Seaton Channel	5	196 570.24	- 7.5 m LAT	563 492
Seaton Channel	5	197 083.74	- 8.0 m LAT	661 934
Seaton Channel	5	197 404.28	- 8.5 m LAT	760 559
Holding basin	4	8 698.49	- 6.0 m LAT	15 157
Holding basin	4	12 655.33	- 6.5 m LAT	20 585
Holding basin	4	25 340.03	- 7.0 m LAT	28 710
Holding basin	4	59 683.65	- 7.5 m LAT	52 332
Holding basin	4	64 426.92	- 8.0 m LAT	83 793
Holding basin	4	64 483.00	- 8.5 m LAT	116 031
Holding basin	4	64483.00	- 9.0 m LAT	148 273
Holding basin	4	64483.00	- 9.5 m LAT	180 515
Quay 10 and 11 – 30 m off	3	8 600.18	- 5.0 m LAT	36 920
Quay 10 and 11 – 30 m off	3	8764.83	- 6.0 m LAT	45 608
Quay 10 and 11 – 40 m off	3	11 719.74	- 7.0 m LAT	68 575
Quay 10 and 11 – 40 m off	3	11 871.00	- 8.0 m LAT	80 415
Quay 10 and 11 – 40 m off	3	11 871.00	- 9.0 m LAT	92 286
Quay 10 and 11 – 40 m off	3	11 871.00	- 10.0 m LAT	104 157
Quay 10 and 11 – 40 m off	3	11 871.00	- 11.0 m LAT	116 028
Quay 10 and 11 – 40 m off	3	11 871.00	- 12.0 m LAT	127 899
Quay 10 and 11 – 40 m off	3	11 871.00	- 12.5 m LAT	133 835
Quay 10 and 11 – area A	3	2 696	- 12.5 m LAT	20 007
Quay 10 and 11 – area B	3	2 529	- 12.5 m LAT	37 286
Quay 10 and 11 – area C	3	5 559	- 12.5 m LAT	63 591
Bund/coffer dam area	2	5 975.13	- 6.0 m LAT	5 357
Bund/coffer dam area	2	6 321.10	- 6.5 m LAT	8 440
Bund/coffer dam area	2	6 584.91	- 7.0 m LAT	11 671
Bund/coffer dam area	2	6 630.00	- 7.5 m LAT	14 983
Bund/coffer dam area	2	6 630.00	- 8.0 m LAT	18 298
Bund/coffer dam area	2	6 630.00	- 8.5 m LAT	21 613
Bund/coffer dam area	2	6 630.00	- 9.0 m LAT	24 928
Bund/coffer dam area	2	6 630.00	- 9.5 m LAT	28 243
Dry/wet dock	1	68 271.40	- 6.0 m LAT	66 709 [1)]
Dry/wet dock	1	76 739.22	- 6.5 m LAT	106 916 [2)]
Dry/wet dock	1	76 922	- 6.65 m LAT [4)]	119 192 [3)]

1) An estimated volume of 12 500 m^3 is added for the two areas where depth data is missing
2) An estimated volume of 15 000 m^3 is added for the two areas where depth data is missing
3) An estimated volume of 15 750 m^3 is for the two areas where depth data is missing
4) Original dock floor level

3.2 Maintenance dredging

The hydrodynamic and sediment transport model are assumed to be driven by tidal processes. This assumption is valid when comparing the relative impacts from the different scenarios, but when absolute values of sedimentation are considered, other factors like floods, storms and dredging will have a great impact on the sediment transport and distribution. It is unrealistic to take all these factors into account in one model, and indeed they would create an unclear picture, and mask the relative impacts that are important in the EIA.

We have therefore based this estimate of probable dredging quantities during operation on historical dredging quantities, and used the model results to indicate areas of higher and lower sedimentation. This is justified by the hydrodynamic modelling results, which indicate minor changes to the hydrodynamic regime and sediment transport in the area for the different modelled scenarios. However, some more sedimentation might be expected due to lower velocities and shear stresses at the bottom, especially at the lower part of Seaton channel.

Table 3-2 Dimensions of "Chart 9"

Element	**Dimensions (m)**	**Area (m^2)**
Turning circle	D = 500 m	196,250
Channel N of turning circle	L x W = 450 x 230 m	103,500
Channel S of turning circle	L x W = 400 x 400 m	160,000
Philips inset dock	L x W = 800 x 270 m	216,000
Seaton Channel	L x W = 1500 x 120 m	180,000
Holding basin	L x W = 250 x 180 m	45,000
SUM		**900,750**

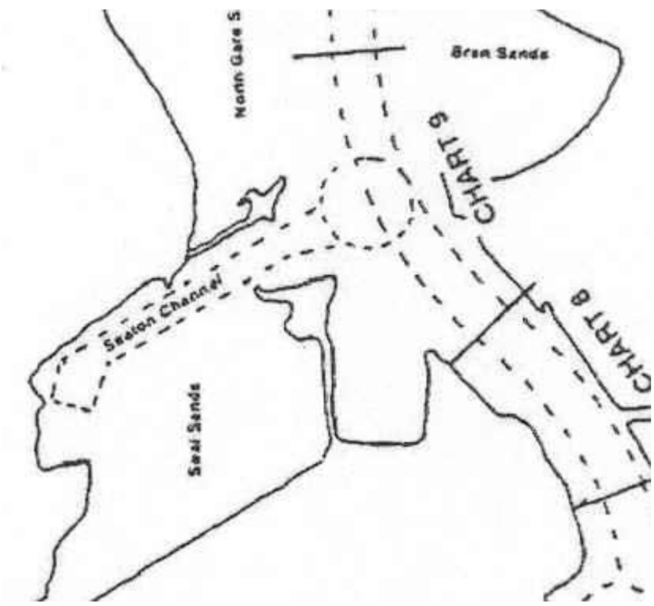


Figure 3-8 "Chart 9" in Tees Estuary dredging plan /2/

The average annual dredging volume for “Chart 9” from 1991 to 2001 is found to be 106,000 m^3 /2/. The estimated average annual deposition rate for Chart 9 can be calculated thus:

$$106{,}000\ m^3/year\ /\ 900{,}750\ m^2 = 0.12\ m/year$$

The average deposition rate for the area of Chart 9 can be expected to be in the region of 120 mm/year.

Higher siltation rates can be expected in areas where water velocities are lower, such as the inner reaches of Seaton Channel, the holding basin, and in the dry dock when this is open. Relative differences of siltation rates are estimated from the sediment transportation model. The following quantities are therefore estimated:

Table 3-3 Estimated annual maintenance dredging quantities from “chart 9” /2/

Element	Area (m^2)	Expected siltation rate (m)	Expected siltation vol
Seaton Channel	180,000	0.10 (80% of average)	18,000 m^3
Holding basin	45,000	0.12	5,400 m^3
Sum ex dry dock			**23,400 m^3**
Dry dock	83,600	0.15 (30% over average)	12,540 m^3
SUM			**35,940 m^3**

Based on chart 9 /2/ and when the dry dock is closed, an annual dredging volume of 23,000 m^3 is estimated for Seaton Channel and the holding basin. When the dry dock is open, this volume is anticipated to rise to an estimated 36,000 m^3.

Estimated volumes for different scenarios are presented in Table 3-4. These numbers are based on calculated dredging areas in this project and will differ somewhat from the numbers in Table 3-3 which are based on the dimensions in chart 9 /2/.

Table 3-4 Estimated annual maintenance dredging for different scenarios, based on calculated areas of the dredging areas in this project

Element	Area (m^2)	Expected siltation rate (m)	Expected siltation vol
Dock & Holding basin	141 580	0.15 Dock and 0.12 Holding basin	19,303 m^3
Dock & Seaton channel	275 440	0.15 Dock and 0.1 S.Channel	31,399 m^3
Dock and Quays 10 and 11 50 m off	92 134	0.15 Dock and 0.12 Quays	13,369 m^3
Dock, S. channel and Quays 10 and 11 50 m off	290 477	0.15 Dock, 0.12 Quays and 0.1 S. Channel	33,203 m^3
S. channel & Quays 10 and 11 50 m off	213 380	0.12 Quays and 0.1 S.Channel	21,638 m^3
Quays 10 and 11 30 m off	8 781	0.12	1,053 m^3
Quays 10 and 11 40 m off	11 871	0.12	1,424 m^3
Quays 10 and 11 50 m off	15 037	0.12	1,804 m^3
Area A	2 826	0.12	339
Area B	2 660	0.12	319
Area C	5 803	0.12	697
Bund/cofferdam area	6 630	0.135	895 m^3

Based on this maintenance dredging of all the areas in Figure 3-1 (Dock, bund/cofferdam, Holding basin, Quays 10 and 11 50 m off and Seaton Channel), an annual dredging volume of 41,836 m^3 is estimated. An additional volume of 1355 m^3/year is estimated for the three areas marked A, B and C in Figure 3-7, and total annual dredging volume then yields 43,191 m^3. When the dry dock is closed, this volume is anticipated to decrease to an estimated 30,271 m^3 or 31,626 when area A, B and C are included.

4 METHODS AND MODELS

The aim of this study is to describe the general impact on the hydrodynamic properties and sediment transportation regime, with subsequent impact on marine life, stemming from the proposed developments at the TERRC site and Seaton Channel.

In order to capture these general impacts, the basic hydrodynamic and sediment processes are modelled. Impacts from unpredictable events like storms, waves and traffic complicate the picture and may "mask" the general impacts from the developments. These events are therefore omitted from the study.

Omitting wave, storm and traffic action will, however, have an impact on absolute figures for hydrodynamic and sediment processes. The sediment transportation in particular is influenced by wave action and storm events. It is found that predicted sediment concentrations and erosion/deposition rates differ from observed values and rates. It is therefore important to realise that the relative differences between the baseline and the various scenarios are of interest, as these best describe the impact of the proposed development.

4.1 Modelling the hydrodynamic regime and sediment transport

4.1.1 Software

River hydrodynamics are modelled with Surface Water modelling System (SMS) from EMS-I (Environmental Modelling Systems, Inc.). More specific the RMA-2 hydrodynamic model and the SED2D model are used in this project. The RMA2 and SED2D model have been developed since 1972-73 and they are well documented models.

4.1.1.1 Hydrodynamic modelling software – RMA2

The RMA2 model was developed by Norton, King and Orlob (1973), of water Resources Engineers. Further developments have been carried at the University of California and by the USA ERDC at the Waterways Experiment Station (WES) Coastal and Hydraulics Laboratory.

The RMA2 is a two-dimensional depth averaged finite element hydrodynamic numerical model /10/. It computes water surface elevations and horizontal velocity components for sub critical, free-surface two-dimensional flow fields.

RMA2 computes a finite element solution of the Reynolds form of the Navier-Stokes equations for turbulent flows. Friction is calculated with the Manning's or Chezy equation, and eddy viscosity coefficients are used to define turbulence characteristics. Both steady and unsteady (dynamic) problems can be analyzed.

The RMA2 has been applied to calculate water levels and flow distribution around islands, flow at bridges having one or more relief openings, in contracting and expanding reaches, into and out of off-channel hydropower plants, at river junctions, and into and out of pumping plant channels, circulation and transport in water bodies with wetlands, and general water levels and flow patterns in rivers, reservoirs an estuaries.

4.1.1.2 Sediment transport modelling software – SED2D

The SED2D was originally developed by Dr. Ranjan Ariathurai (STUDH model) and rewritten at USACE-WES to become SED2D-WES.

The SED2D is a generalized finite element computer model for vertically averaged sediment transport in open channels flow /11/. It is the sediment transport companion for the RMA2 hydrodynamic model, and is so based on the results from the RMA2. Both clay and sand may be analyzed, but the model considers a single effective grain size during each simulation. Generally the sediment is mobilized when energy forces exceed critical shear stress, and sediment is immobilized when opposite conditions exists.

When modelling erosion and deposition of non-cohesive sediments (sand) the model assumes a bed of finite thickness, a non-erodible surface under bed, one grain size for transport equations, separate grain size for bed roughness calculations (Ackers-White only), and that erosion and deposition occur simultaneously.

For modelling of cohesive sediments (silt, clay), up to ten layers can be defined and clay layers change with time and overburden. Three shear stress (τ) values can be defined which will determine the erosion and deposition pattern.

4.1.1.3 The SSFATE modelling system

SSFATE was developed by Applied Science Associates, Inc located in Narragansett, RI and the US Army Corps of Engineers Research Development Center located in Vicksburg, MS in response to a need for tools to assist dredging project managers confronted by requests for environmental windows. Details about SSFATE can be found in The DOER Technical Notes Collection (ERDC TN-DOER-E10). A summary of the modelling system is given below.

SSFATE is a versatile suspended sediment computer modelling system based on the concept of Lagrangian sediment particles. SSFATE contains many features. For example, ambient currents, which are required for operation of the basic computational model, can either be imported from a numerical hydrodynamic model or drawn graphically using interpolation of limited field data. Model output consists of concentration contours in both horizontal and vertical planes, time-series plots of suspended sediment concentrations, and the spatial distribution of sediment deposited on the sea floor. In addition, particle movement can be animated over Geographic Information System (GIS) layers depicting sensitive environmental areas.

SSFATE employs a shell-based approach consisting of a colour graphics based, menu-driven user interface, GIS, environmental data management tools, gridding software, and interfaces to supply input and display output data from the model. SSFATE runs on a personal computer and makes extensive use of the mouse (point/click) and pull down menus. Data input/output is interactive and mainly graphics based. The system allows a full set of tools to allow the user to import data from standard databases, a wide variety of GIS's, and other specialized plotting/analysis programs. At the heart of the system is a computational model that predicts the transport, dispersion, and settling of suspended dredged material released to the water column as a result of dredging operations. An integral component of the modelling system is the specification of the sediment source strength and vertical distribution.

4.1.2 Hydrodynamic model setup, calibration and verification

The numerical hydrodynamic model of the Tees estuary is based upon measured bathymetry, observed tidal variations and documented river flows.

The upstream boundary of the model was taken as the Tees barrage, where good flow records exist and the tidal influence is negligible. The long distance upstream of the study area ensures that the model is numerically stable in the area if interest, and that the upstream tidal storage is described adequately.

The downstream boundary was chosen to be an arbitrary arc in the ocean approximately 3-5 km from the mouth of the estuary. This ensures that tidal effects are well established in the study area.

Predictions close to the model boundaries must be evaluated carefully, as the boundary conditions will affect results, especially regarding sediment concentration and deposition.

See Figure 4-1 for details of area included in the model.

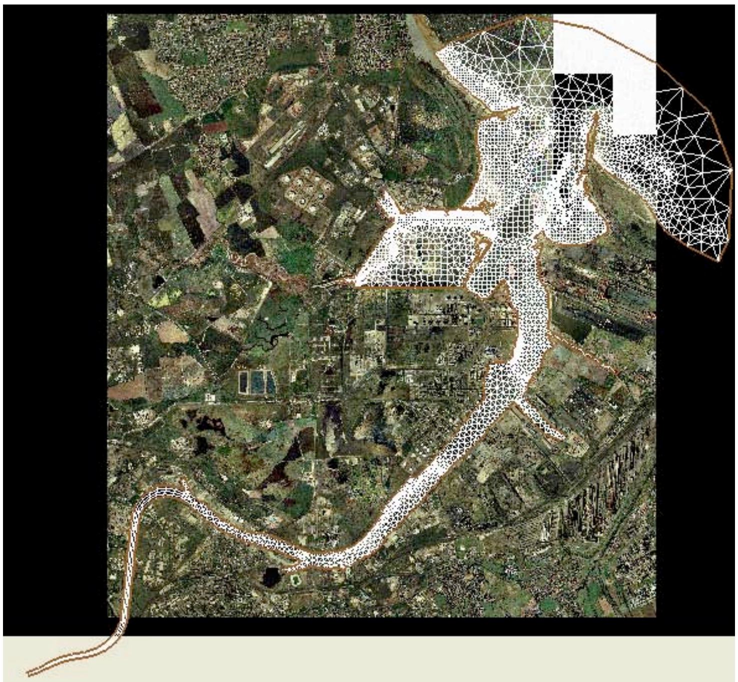


Figure 4-1 Area included in numerical model

4.1.2.1 Base data

Updated bathymetric data showing levels in the dredged parts of the Tees River, the Tees estuary and Seaton Channel were obtained from PD Teesport /6/. These data were sounded throughout summer 2004. In addition, bathymetry of Seal Sands, other sand/mudflats and tidal areas were obtained from the Environment Agency /7/. Further data were sourced from local authorities. Charts were digitized to describe the bathymetry of the area immediately outside the estuary mouth /8/.

River flow data were obtained from Zeneca /3/. This describes the flow at Tees Barrage on 6th and 14th of June 1995, after the commission of the barrage. River flow data for Greatham Creek do not exist according to the EA. The flow in the Tees estuary is, however, found to be heavily influenced by tidal movements, and the river flow has little impact on flow velocities. For instance, the normal flow in the river Tees is in the order of 6 m^3/s. With a relatively high river flow of 25 m^3/s and a spring tidal cycle, the maximum velocities on rising and ebbing tides are very similar, see Figure 4-2 below.

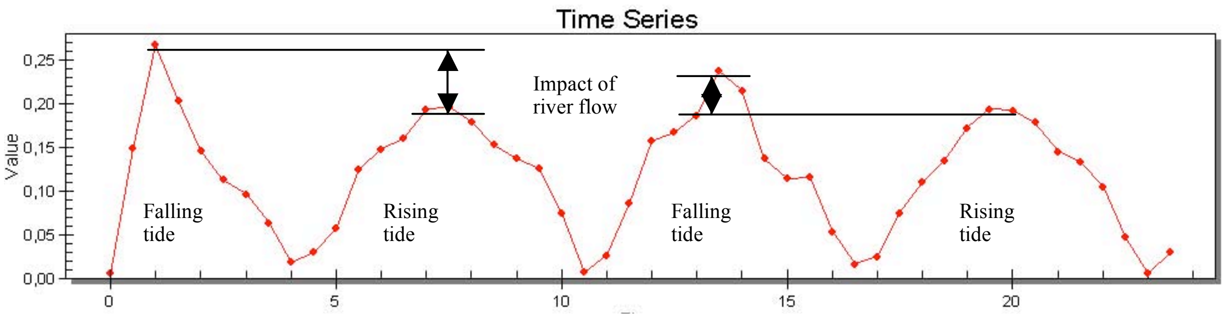


Figure 4-2 Water velocities (m/s) at Teesport with river flow 25 m^3/s, spring cycle

Observed tidal data from Teesport are found in /3/ for the 6th and 14th of June 1995, the same dates that river flow measurements at Tees barrage are found. This is used as downstream boundary conditions.

4.1.2.2 Calibration

The model was run with a spring and a neap cycle, with a constant inflow at the Tees Barrage and with varying bed roughness. Water surface elevations, water depths and velocity magnitude and directions were calculated at 17,000 points in the estuary for each 1/2 –hour time step throughout 24 hours.

The results were compared with observed water elevations and flow characteristics, and a representative global roughness factor was chosen.

River flow and tidal data for 6th and 14th of June 1995 were used for calibration.

Table 4-1 River inflow at the Tees Barrage for calibration period /3/

Date	Daily mean (m^3/s)	3-day mean (m^3/s)	Highest (m^3/s)	Lowest (m^3/s)
1995-06-03	5.31	5.80	6.47	4.10
1995-06-04	7.71	6.10	10.00	5.06
1995-06-05	6.75	6.59	7.97	5.58
1995-06-06	5.98	6.81	6.93	5.22
1995-06-07	6.49	6.41	8.99	4.55
1995-06-08	6.80	6.42	7.98	6.12
1995-06-09	5.46	6.25	6.11	4.91
1995-06-10	4.69	5.65	5.35	3.86
1995-06-11	4.29	4.81	4.95	4.85
1995-06-12	4.59	4.52	5.10	4.30
1995-06-13	5.03	4.64	6.00	4.25
1995-06-14	4.60	4.74	5.65	3.95
1995-06-15	4.82	4.82	5.62	3.70
MEAN	**5.58**	**5.66**	**6.70**	**4.65**

A flow of 6.0 m^3/s is adopted as an adequate "normal" flow for the period.

The neap tidal cycle of 6th of June 1995 and the spring tidal cycle of 14th June 1995 are shown in Figure 4-2 above.

In Table 4-2 and Table 4-3 below, the average difference between predicted and observed water surface elevations at Teesport are listed, together with maximum differences, minimum differences (largest negative difference) and the standard deviation of the differences. The roughness factor as Manning's n is varied from 0.025 (smooth, mud) to 0.085 (coarse pebbles, rocks). Neap and spring cycles are investigated.

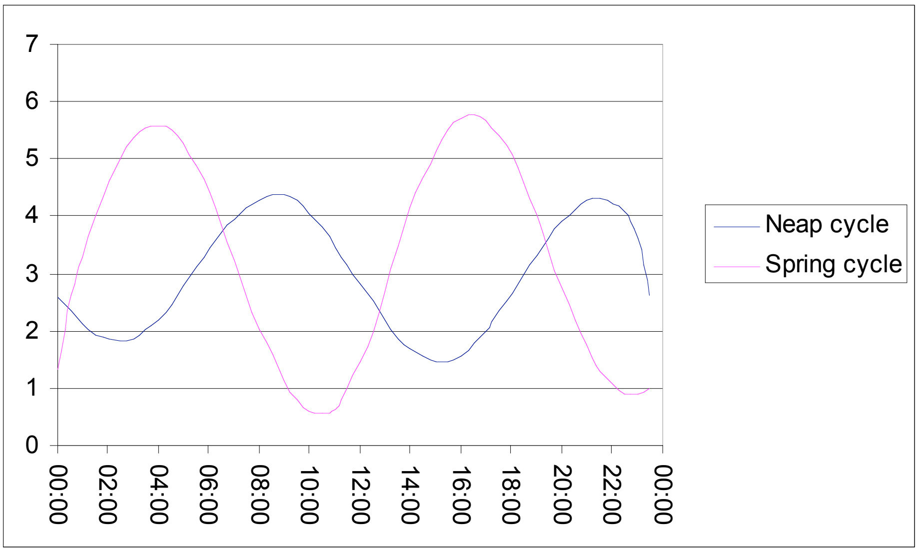


Figure 4-3 Spring and neap cycles for calibration /3/

Table 4-2 Comparison calculated and observed WSE to LAT, neap cycle

Manning's n	0.025	0.045	0.065	0.085
Average difference	0.002	0.002	0.003	0.003
Maximum positive difference	0.133	0.128	0.122	0.113
Maximum negative difference	-0.071	-0.080	-0.091	-0.104
Standard deviation	0.028	0.028	0.030	0.033

Table 4-3 Comparison calculated and observed WSE to LAT, spring cycle

Manning's n	0.025	0.045	0.065	0.085
Average difference	Not available	-0.004	-0.005	-0.008
Maximum positive difference	Not available	0.066	0.098	0.147
Maximum negative difference	Not available	-0.044	-0.062	-0.092
Standard deviation of differences	Not available	0.028	0.041	0.060

In general, the model predicts water surface elevations within 2-8 mm of observed values, with a spread of 3-6 cm, and maximum differences in the region of 15 cm. This is within acceptable limits when taking into account the complexity of the estuary and the possible errors in measurements. It is seen from the calibration exercise that a global roughness value of 0.03 produces predicted water levels close to observed levels, with a spread of about 3 cm.

Local roughness values are assigned based on references /4/ and /5/ for materials in specific areas. This will ensure local conditions are modelled more accurately. See Section 4.1.2.4 Model below for details.

4.1.2.3 Verification

The model has been reviewed by external numerical modelling personnel. The Environment Agency has been invited to comment on the model. The model and subsequent results have been verified internally in DNV following standard project verification procedures.

4.1.2.4 Model

The model has been adjusted in line with the results from the calibration exercise, by specifying unique material roughness factors for each material in the model. Material zones are displayed in Figure 4-4 below.

Figure 4-4. Material zones defined in the Tees estuary numerical model

The apparent roughness coefficient is estimated taking into account the material roughness, degree of bed irregularities, variations in channel cross section, effect of obstructions and vegetation, and channel meandering factor /9/, as described by the equation below:

$$n = (n_{mat} + n_{bed} + n_{x\sec} + n_{obs} + n_{veg}) * m_{mnd}$$ **(Equation 1)**

Where:

			low	high
n_{mat}	=	material roughness factor	0.010	0.070
n_{bed}	=	relative effect of bed irregularity	0.000	0.020
n_{xsec}	=	relative effect of variations of channel x-section	0.000	0.015
n_{obs}	=	relative effect of obstructions	0.000	0.060
n_{veg}	=	relative effect of vegetation	0.000	0.050
m_{mnd}	=	meandering degree factor	1.000	1.300

Factors are found in /4/, /5/ and /9/. Material descriptions are found in /1/, /2/, /3/, /7/ and /8/.

Table 4-4. Calculation of theoretical roughness factors for materials

Material	Material	n_{mat}	n_{bed}	n_{xsec}	n_{obs}	n_{veg}	m_{mnd}	n
Main channel and Sea	Sand/var.	0.020	0.000	0.005	0.010	0.000	1.050	0.035
Seaton Sands	Sand	0.020	0.000	0.000	0.005	0.000	1.000	0.025
Seal Sands	Sand/mud	0.020	0.005	0.000	0.005	0.005	1.000	0.035
Tees intertid. mudflats	Sand/mud	0.020	0.005	0.000	0.005	0.000	1.100	0.035
Bran Sands	Sand	0.023	0.010	0.010	0.010	0.000	1.100	0.060
Bran Sands Skerries	Rocks	0.050	0.020	0.000	0.050	0.010	1.200	0.155
Coatham Sands	Sand	0.020	0.000	0.000	0.005	0.000	1.000	0.025
Bran Sands Islands	Rocks	0.050	0.020	0.000	0.050	0.020	1.200	0.205
North Gare Sands	Sand	0.023	0.010	0.010	0.010	0.000	1.100	0.060
Seaton Channel	Sand/mud	0.023	0.000	0.005	0.010	0.000	1.000	0.035

The model geometry has not been adjusted for inclusion of jetties, pillars and local features, as this would have decreased model stability and predictability. Instead, anticipated flow resistance has been accounted for by calculating the apparent roughness coefficient as found in the table above. The model calibration exercise validated this approach.

In addition, the underlying bathymetry data is of such a quality that many local features, breakwaters, erosion barriers, skerries and such within the model are accurately described. Features such as the training wall between Seal Sands and Seaton Channel are thus included.

The RMA2 hydrodynamic modelling software includes the option of modelling wetting and drying of tidal areas using the concept of marsh porosity /10/. This involves assigning a fraction volume to elements depending on the degree of wetting. Semi-dry elements are allowed to convey a volume between zero and full dependent on the level of the water surface between the highest (dry) and the lowest (wet) node.

This concept ensures a numerically stable model. The alternative of turning elements completely off and on from iteration to iteration does not reflect reality, and produces an unstable model where flow boundaries and conveyance changes drastically throughout calculation iterations. The result is a divergent model.

The tidal boundary at the seaward end was chosen to be a synthetic 14 day tidal cycle, generated using Simple Harmonic Analysis using constituents for Teesport. The upstream boundary inflow at Tees Barrage was taken as 6 m^3/s, which is a representative normal flow as described in Section 4.1.2.2 above. The Tees estuary is found to be highly influenced by tidal activities as discussed previously, and the magnitude of inflow from the river Tees and Greatham Creek is found to be of little importance. For ease of modelling the inflow from Greatham Creek is therefore omitted.

The hydrodynamic model was run with ½-hour time steps. The tidal cycle goes from neap to spring tides as can be seen in Figure 4-5, and is representative for the full normal tidal activity in the estuary. The subsequent sedimentation rates from this representative 14-day period can be extrapolated to calculate annual sedimentation rates.

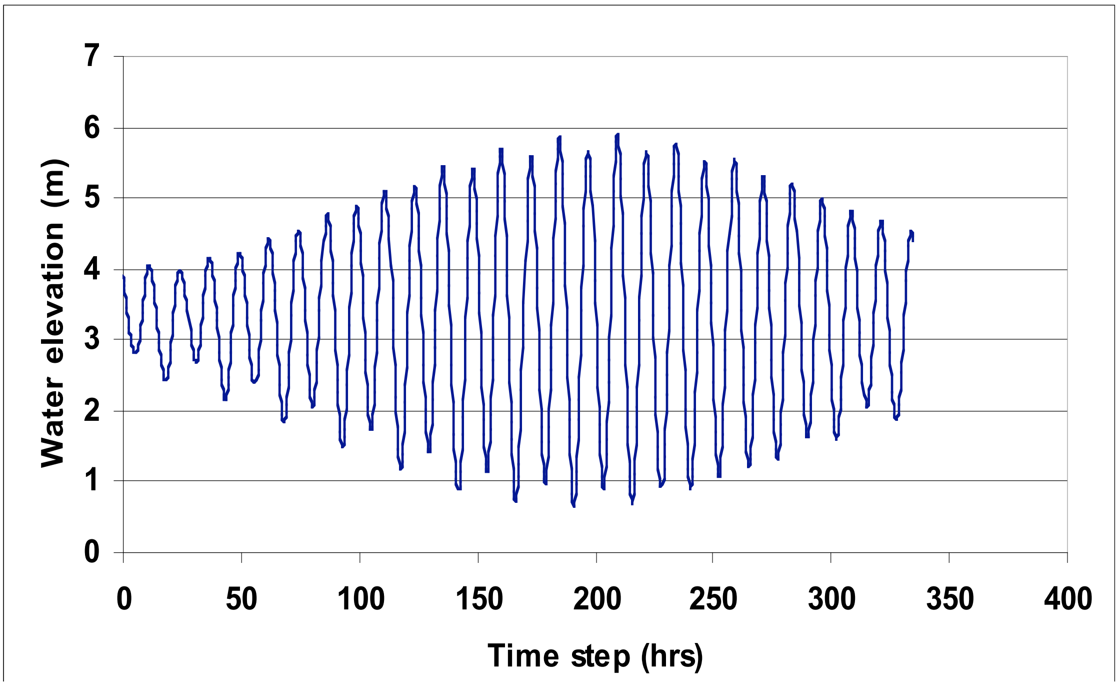


Figure 4-5 Spring and neap cycles for a period of 14 days used in the model runs.

4.1.3 Sediment transport, model setup, calibration and verification

The SED2D sediment transport model is based on the hydrodynamic input computed by RMA2.

The model was run with one representative non-cohesive (fine sand) fraction and one cohesive (silt/clay) setup. In both cases (sand and clay/silt) calculated values of sediment concentration and areas of deposition and erosion where compared to measured data (suspended material) from the area, and data and description on the grain size distribution of the sediment. A number of model runs were performed with varying input parameters in order to get the results fit, as good as possible, the measured field data and to measure the response of the model.

Transportation of sand, being a non-cohesive material, is modelled using simple principles of erosion, deposition and mass balance. The theoretical models are well documented and are known to perform satisfactorily /4/, /5/, /9/, /11/.

Modelling of transportation of cohesive materials like silt and clay is more complex than modelling non-cohesive sediments. A number of models based upon various theoretical approaches exist, but the inherent simplifications of the complex dynamic processes involved mean that they do not always represent reality adequately /4/, /5/, /9/, /11/. A small change in input parameters or geometry can result in overstepping of a threshold, resulting in great changes in results.

4.1.3.1 Non-cohesive sediments (sand)

The important parameters for the sand model are grain size, shape factor, apparent roughness, density and settling velocity. A grain size of 0.2 mm was used for the non-cohesive sediment fractions present in most of the Tees Estuary, coarser sediments are probably not widely present.

The fact that the model is run with only one effective grain size for non-cohesive sediments is justified when test runs have indicated that the velocities are too low to erode sand and that transportation of such sediments is limited, when excluding waves, storms and vessel traffic. Sand will tend to stay where it falls out of suspension. This is also the view expressed in /2/, where it is found that re-suspension of sediments “does not take place in the Tees to any great extent”.

Based on grain size distribution data provided by EA and a previous study /2/ a conclusion was made that the uppermost 0-50 mm of the sediment in Seaton Channel consists of 92 % silt/clay and 8 % fine sand /2/ and /12/. The modelled results indicate a sand concentration of around 0.3-0.5 mg/l (average) in Seaton Channel. If one assumes that the suspended sediment grain size distribution “mirrors” the sediment distribution, and based on a median suspended sediment concentration of 10 mg/l /7/ a fine sand concentration of 0.3 mg/l represents 3-5 % of the distribution in the sediment which is quite close to the fraction in the sediment.

The theoretical settling velocity is calculated using Stoke’s law and Heywood tables where appropriate /4/, /5/. Dependent on the viscosity of the water, the theoretical settling velocity in still water for the chosen sand grain size was found to be 0.01-0.02 m/s. These values, however, yields zero concentration throughout the model after some time, indicating that the sand falls relatively fast out of suspension. This is known not to reflect the true processes in the Tees estuary, as the true settling velocity will be dependent on the degree of turbulent mixing in the water column. By reducing the settling velocity to 0.0003 m/s a stable model with plausible sediment concentrations and transportation as seen in /2/ and /3/ was reached.

The diffusion coefficient is a somewhat artificially introduced factor needed to avoid unnaturally steep gradients in sediment concentrations in the numerical model. The value chosen for the sand model (90 m^2/s) is well within the recommended value for modelling tidal estuaries /4/, /5/, /9/, /11/.

Boundary conditions at the seaward end were chosen as 15 mg/l. The boundary condition at the upstream end was also set at this value. Values from both /2/ and /3/ were used as basis. Concentrations at the seawards boundary are artificially high to make sure enough sediment reaches the study area. The conditions outside the mouth of the estuary may therefore be unreliable, but the relative changes due to the proposed developments at the TERRC site may still be estimated.

Table 4-5 SED2D Input parameters for non-cohesive sediments (sand)

Input parameters	Unit	Sand
Specific gravity	t/m^3	2.65
Sand grain size	mm	0.2
Grain shape factor	dimensionless	0.67
Thickness of sand layer	m	1
Sand grain roughness	dimensionless	0.5
Diffusion coefficients	m^2/s	90
Settling velocity	m/s	0.0003
Gravitational constant	m/s^2	9.806650
Boundary concentration, sea	mg/l	15
Boundary concentration, Tees	mg/l	15

4.1.3.2 Cohesive sediments (silt/clay)

Dependent on the shear stress exercised by currents on the sea bed, sediments deposit, erode or even peel off in layers. The shear stress at the bed is calculated by using the depth averaged water velocity from RMA2, calculating the theoretical velocity at the bed, and applying the sediment roughness defined as Manning's n.

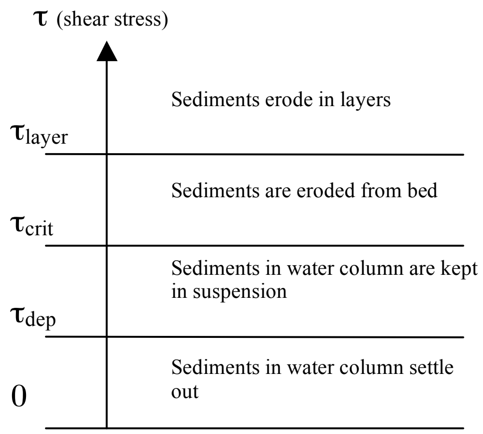


Figure 4-6 Cohesive sediment erosion/deposition dependent on shear stress

The boundary concentrations can be artificially high in order to re-create the processes within the Tees Estuary, but the relative impact from the proposed development at the TERRC site on the areas outside the estuary mouth may still be estimated. Results obtained for areas out with the Tees estuary mouth have to be used with care.

Table 4-6 SED2D Input parameters for silt/clay scenarios

Input parameters	**Units**	**Layer 1**	**Layer 2**	**Layer 3**	**Layer 4**
Layer thickness	mm	13	25	30	500
Critical shear stress, erosion τ_{crit}	N/m^2	0.25	0.38	0.65	0.85
Age	years	1	3	5	10
Critical shear stress, deposition τ_{dep}	N/m^2	0.045			
Erosion rate	$g/m^2/s$	0.1			
Settling velocity	m/s	0.000061			
Initial concentration	mg/l	22			
Boundary concentration, seawards	mg/l	30			
Boundary concentration, river	mg/l	35			

4.1.4 Sediment transport due to dredging

To determine suspended sediment plumes resulting from the dredging activities, a numerical model called SSFATE has been applied. Model runs have been made for both the backhoe dredge and the hopper dredge. Results are generated with each working alone, with the results then combined to show the impact of the two dredges working simultaneously. Plans call for the backhoe dredge to work for eight weeks around the clock, with the hopper dredge working for twelve weeks around the clock. However, each SSFATE simulation is for only two days since an equilibrium suspended plume is established by the end of two days of dredging. Simulations have been made for dredging during both neap and spring tides.

The first step in the application of SSFATE was to import an Arc View shape file showing the geographical boundaries of the study area.

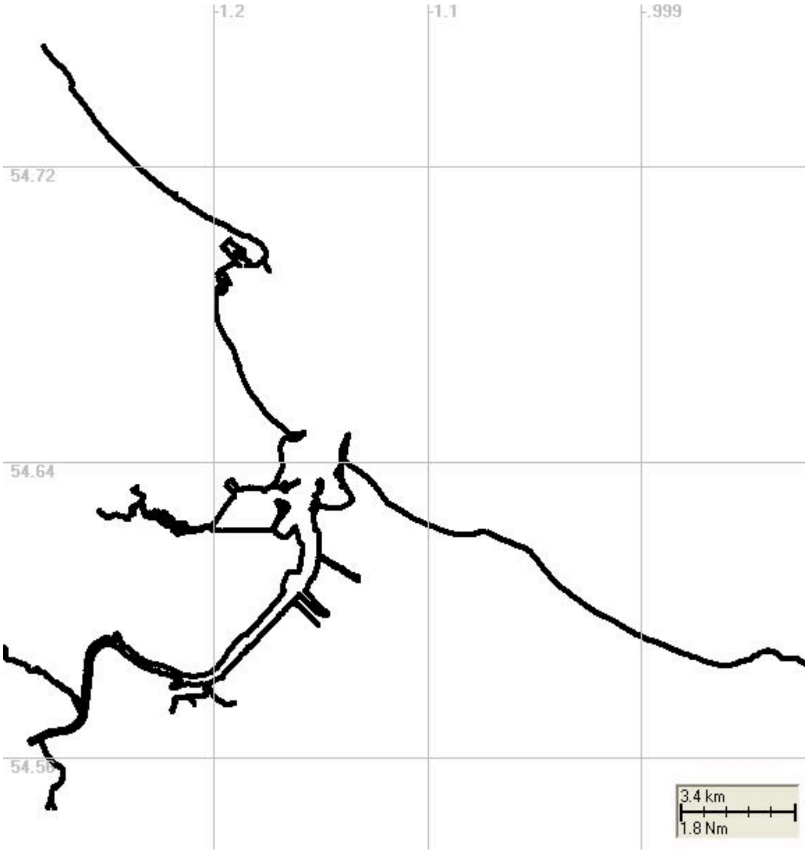


Figure 4-7 Geographical boundary of dredging model

This shape file was provided by DNV. Gridding tools in SSFATE were then employed to create a computational land/water grid. The next step was to modify SSFATE to accept a velocity file (provided by DNV) generated by the RMA2 numerical hydrodynamic model. The RMA2 finite element grid as shown in Figure 4-8 then became the currents grid employed by SSFATE. The sediment released by the dredging activity is simulated using particles, which are transported on the land/water grid through interpolation of the RMA2 velocities computed at the nodes of the RMA2 finite element grid.

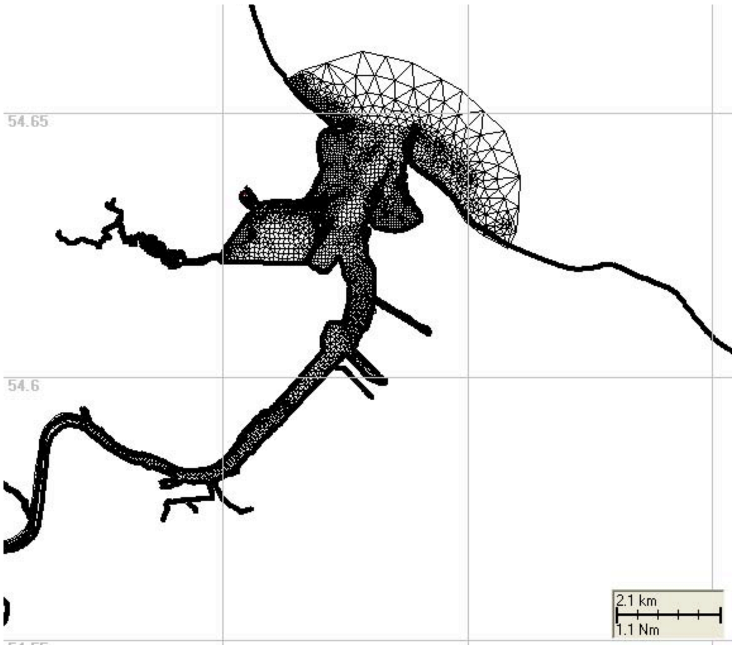


Figure 4-8 Modelling grid

The next step in the application of SSFATE was the representation of the sediment sources generated by the operation of the dredges. A backhoe dredge will be used in the areas labeled 1, 2, and 3 in Figure 3-1, whereas, a hopper dredge will be used in the Seaton Channel labelled 5 and the holding basin labelled 4. The dredging operation for the backhoe will continue around the clock for eight weeks. Dredging at a rate of 90 m^3 /hour will continue for 10 hours. A barge will then carry the dredged material to an open water disposal site. The round trip will take 2 hours. Dredging for another 10 hours will then begin. The hopper dredge will operate for 12 hours at a rate of 300 m^3 /hour around the clock. At the end of 12 hours of dredging, the dredge will transport the dredged material to the disposal site. This activity will take 1.5 hours. Dredging will then begin for another 12 hours. Both of these dredging activities are represented in SSFATE as line sources. The line sources for the backhoe are very short since the movement of the backhoe is expected to be small over a 10 hour dredging period. However, the line source for the hopper dredge runs from the entrance of the Seaton Channel into the turning basin. This line source is shown in Figure 4-9. Assuming that the hopper speed during dredging is 2 kts, it only takes about 30 minutes for the hopper to traverse the line source. Thus, the line source is traversed 24 times (representing 12 hours of dredging) during each dredging cycle.

Specification of the sediment source strength is an important part in the application of SSFATE. Based on sediment samples provided by DNV, it was assumed that 92% of the dredged material is clay and silt, with the remainder being sand. DNV also provided information that stated that about 20% of the sediments in the Tees Estuary is clay, Therefore, the final grain size distribution employed was 20% clay, 50% fine silt, 22% coarse silt, 5% fine sand, and 3% medium sand. Based on information obtained from McLellan, et al (1989), it was assumed that 3% of the sediment dredged by the hopper dredge would be released into the water column over the lower 1.5 m of the water column. For the backhoe, it was assumed that 8% of the dredged volume would be released uniformly over the entire water column. Data collected in Alaska showed that 10% was released during dredging with a backhoe in 15-20 ft of water (U.S. Army

Corps of Engineers 2000). John Land (personal communication) of Dredging Research Limited stated that his best estimate would be 6-8% of the dredged volume. Therefore, it was decided to use a release rate of 8% for the backhoe SSFATE simulations. Personal communication with Dr. Allen Teeter of CHT led to assuming that the bulk density of the sediments being dredged with a backhoe was likely to be about 1.6 g/cc, whereas the bulk density of material to be dredged in the Seaton Channel were more likely to be lower, e.g., 1.4 g/cc.

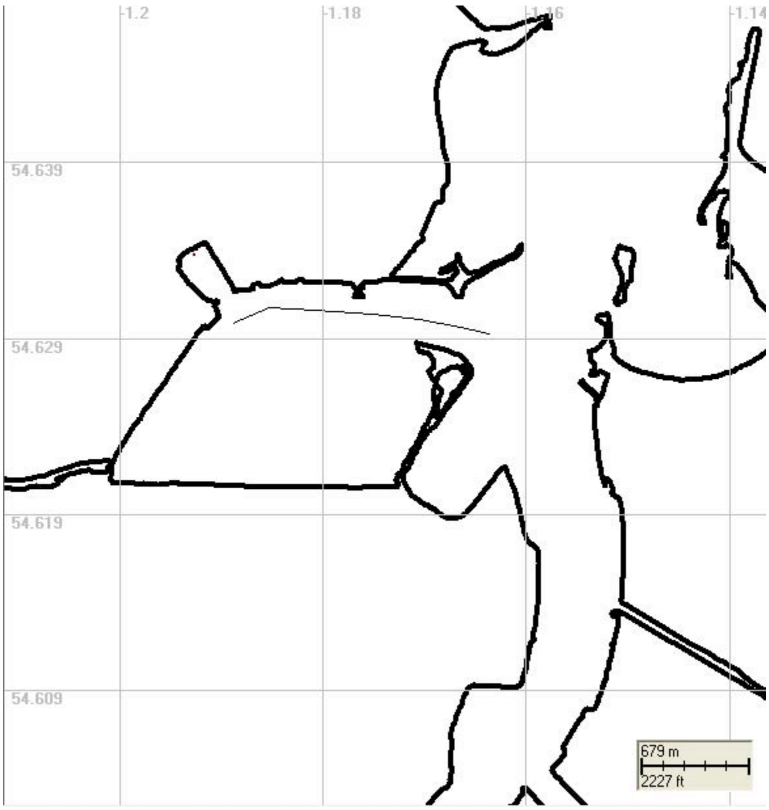


Figure 4-9 Line source for hopper dredge

The final input data required in the application of SSFATE were the velocities generated by the RMA2 model. DNV provided a 14-day record that began with a neap tide and then moved through a spring tidal cycle. Each simulation scenario lasted for 48 hours and was run using neap tide currents first and then spring tide currents.

4.1.5 Scenarios

Based upon the proposed developments at the TERRC site, the scenarios described below have been modelled. For scenarios which involves dredging the model grid has been manipulated to represent the new bathymetry (depth change) and the hydrodynamics and sediment transport have been calculated based on the new bathymetry.

1. Dredging of dock to -6.65 m LAT and holding basin to – 9.5 m LAT
2. Dredging of the dock to -6.65 m LAT and Seaton Channel to – 8.5 m LAT

3. Dredging of the dock to – 6.65 m LAT and quays 10 and 11 to – 12 m LAT (50 m off and along the length of the quays.
4. Dredging of the dock to -6.65 m LAT, Seaton Channel to -8.5 m LAT and quays 10 and 11 to -12 m LAT
5. Dock closed and holding basin dredged to -9.5 m LAT
6. Dock closed and Seaton Channel dredged to – 8.5 m LAT
7. Dock closed and quays 10 and 11 dredged to – 12 m LAT
8. Dock closed, Seaton Channel dredged to -8.5 m LAT and quays 10 and 11 dredged to -12 m LAT
9. Dock closed, Seaton Channel dredged to -8.5 m LAT and quays 10 and 11 extended and dredged to -12.5 m LAT

Emptying the dock for water is planned to be done by pumping water out of the dock at a rate of 1000 m^3/h (280 l/s). This scenario has not been considered because such small volumes will not have any impact on the velocities or flow pattern in the estuary.

In each of the scenarios listed above, the following items are considered and discussed:

- Modelling of the tidal flow and hydrodynamic regime;
- Modelling erosion (resuspension), particle transport and sedimentation;
- A qualitative description on possible impact on ecological habitats due to sediment erosion, sediment transport and sedimentation. This part will focus on the most relevant taxonomic groups in the estuary (for example breeding and feeding grounds for birds, seals and fish and possible impact on soft bottom fauna);
- Based on existing data regarding the distribution and contamination level of environmental toxins (metals- and organic toxins) combined with the modelling results (erosion, particle transport and sedimentation) will give a picture of the dispersion and sedimentation of contaminants in the estuary and channels. We have not included in this any modelling or quantification of contaminants release from the particles (particle state) to the water column (dissolved state) due to resuspension into to water column. Generally the major fraction of the contaminants will be particle bounded;
- The current sedimentation regime may affect the vessel movements in the estuary with time. This will be discussed and compared with possible impacts regarding vessel movements. This item will also cover possible need for maintenance dredging; and
- The modelling shall also consider the suspended sediment concentrations in light of the intake from the nuclear power station.

4.2 Impact on marine life

Impact on marine life has been evaluated due to changes in hydrodynamics and sedimentation regime as a result of the planned dredging operations at the TERRC facility. The level of contamination in the dredging areas and at Seals Sand has been mapped and compared with international sediment quality standards. Levels have been mapped for several metals (Ar, Cd, Cr, Cu, Hg, Ni, Pb and Zn), PCBs, PAHs and TBT in dredging area 1 to 4. On Seals Sands the level of metals mentioned above have been mapped. The levels of contamination have been compared with international sediment quality standards.

5 HYDRODYNAMIC AND SEDIMENT TRANSPORT MODELLING

5.1 Hydrodynamics and sediment regime in the Tees Estuary

5.1.1 Prevailing hydrodynamic regime

As discussed in Section 4.1.2.2 above and supported by /2/ the Tees Estuary below the Tees Barrage is highly influenced by tidal activity. Studying the water velocities at Teesport, for outflows at falling tides the velocities are only in the order of 20% higher than for inflows at rising tides, when using relatively high river inflows of 25 m^3/s. With the normal river flow of 6 m^3/s this difference is reduced. It is anticipated that high flow events change this picture for periods /2/. At Seaton Channel and Seal Sands, where the only freshwater inflow comes from Greatham Creek, the tidal flows are even more dominating.

The Tees Estuary is known to be stratified, especially at the upstream end near Tees Barrage. Further down towards Teesport and the estuary mouth the stratification is less marked /2/ and the freshwater layer on top is thin compared to the water depth. More chaotic mixing is evident here /3/. The “bottom” layer, representing 90 % of the water flow, is found to be dominant when it comes to sediment transportation, especially as the bulk of the sediments are found to originate from the seaward boundary /1/, /2/, /3/. For this study it is therefore believed that the accurate modelling of this “bottom” or main layer is most important.

For Seaton Channel and Seal Sands, the freshwater inflow from Greatham Creek is small, and this part of the estuary is not believed to be stratified to a great degree. The recent increase of algal mat growth in Seal Sands has been predicted to reduce the local flows with up to 20 % /2/.

In general, alluvial estuaries which are “in regime” i.e. the sediment budget is balanced and they have no net annual deposition, experience average velocities around 1 m/s. Velocities in the Tees estuary are in general well below this figure, creating deposition of sediments. These low velocities stem from the unnaturally large cross sectional area of the channel due to dredging. Sediments will deposit in the channels until the velocities increase enough to achieve a balanced sediment budget. As the velocities are low, sediments are less likely to be carried upstream to the upper reaches of the estuary, and larger fractions with higher settling velocities will tend to settle out at the downstream end. The effect on clay is somewhat alleviated by the tidal undercurrent ensuring that fractions with low settling velocities are carried further upstream.

5.1.2 Prevailing sediment regime

The main bulk of sediments originate from the seaward boundary /2/. Maintenance dredging of the Tees Estuary currently yields some 700,000 tonnes per year. The sediments are found to be both sand and silt/clay fractions. Both deep channels and mudflats are found to have sand and silt/clay, but are in general sandy rather than muddy. The sediments at the seawards end of Teesmouth consist mainly of sand /1/, /2/, /7/. Finer fractions stay in suspension longer and are transported further into the estuary. Most of the sediment is transported by rising tides at times of high wave action, such as storm events. In fact 90 % of siltation comes from the sea of which 45

% is sand. The study also showed strong stratification ensuring the upstream migration of finer particles “after disturbance by storms, shipping and dredging” /2/.

Previous studies /2/ shows that most sediment are carried into the estuary from the Tees bay from North Gare Sands on rising tides during storm events. 80 % of the sediment moves into the estuary during 7 months from October to April, with 60 % of transport occurring during 30 days of storm activity.

Within the last 10 years a decrease in the rate of sediment deposition has been noticed for the whole estuary, with a shift towards less dense material especially towards the seawards end of the estuary. This may stem from the construction of the Tees Barrage, from changes in weather patterns influencing the suspension of sediments in the Tees bay, from decreased maintenance dredging resulting in less suspended sediment, or from a combination of these possibilities. However, at the confluence of Seaton Channel and the Tees Channel, more material is settling out. It is thought that the supply of sand around the tip of the North Gare breakwater may have increased, spilling on to North Gare Sands and past the training wall towards Tees and Seaton Channels.

5.1.2.1 Suspended sediment

Suspended sediment is of high importance in the Tees estuary as little re-suspension of settled sediments occurs /2/. Carriage in suspension is thus the main pathway where sediments may spread to new locations, controlling erosion and sedimentation zones in the area and transport adsorbed/entrained pollutants. Data on suspended sediment cover 26 sampling points as shown in Figure 5-1. Median suspended sediment concentrations in the period 2003-2004 are shown in Figure 5-2 and Figure 5-3. The data show rather large variations in the suspended sediment concentration over one year, and will be influenced by several factors as waves, storms and ship movements. It is very probable that a highly industrialized estuary such as the Tees, the ship traffic will have a great influence on the suspended sediment concentration due to erosion by propeller currents. In addition, “extreme” events such as periods of storms and massive rainfall creates periods of high river flow, and wave erosion especially during winter storms have a high impact. Such events may be the most controlling factors regarding the sediment regime (erosion, entrainment and redistribution) in the area /1/, /2/, /13/.

Another important source of sediment re-distribution is the continuous dredging operations which have increased the concentrations of suspended sediments, affecting the sediment distribution in the estuary /2/. Both development and maintenance dredging create sediment plumes which, dependent on the hydrodynamic conditions at the time, may distribute various fractions of sediments up- and downstream at great lengths from the dredging area.

Based on data from throughout 2003 and early 2004 /7/ the median amount of suspended sediment varied from 4.5 mg/l at sampling point 1029 to 57 mg/l at sampling point 1347. There is also a great variation between different sampling dates on the sampling point ranging from < 1 mg/l up to 302 mg/l. The highest values are found on sampling point 1342 to 1348 which are located in and very near the TERRC facility and along the eastern boundary of Seaton Channel near the TERRC facility. The concentration seems to decrease somewhat downstream of the TERRC facility illustrated by sampling point 909 and 888 where the median concentration is 12.8 and 5 mg/l respectively.

Sampling point 1025 just upstream of the TERRC facility has a median concentration of 11 mg/l.

Sampling point 834 in Tees river has a median value of 7.8 mg/l and sampling point 817 out in the Tees bay has a median concentration of 7.3 mg/l.

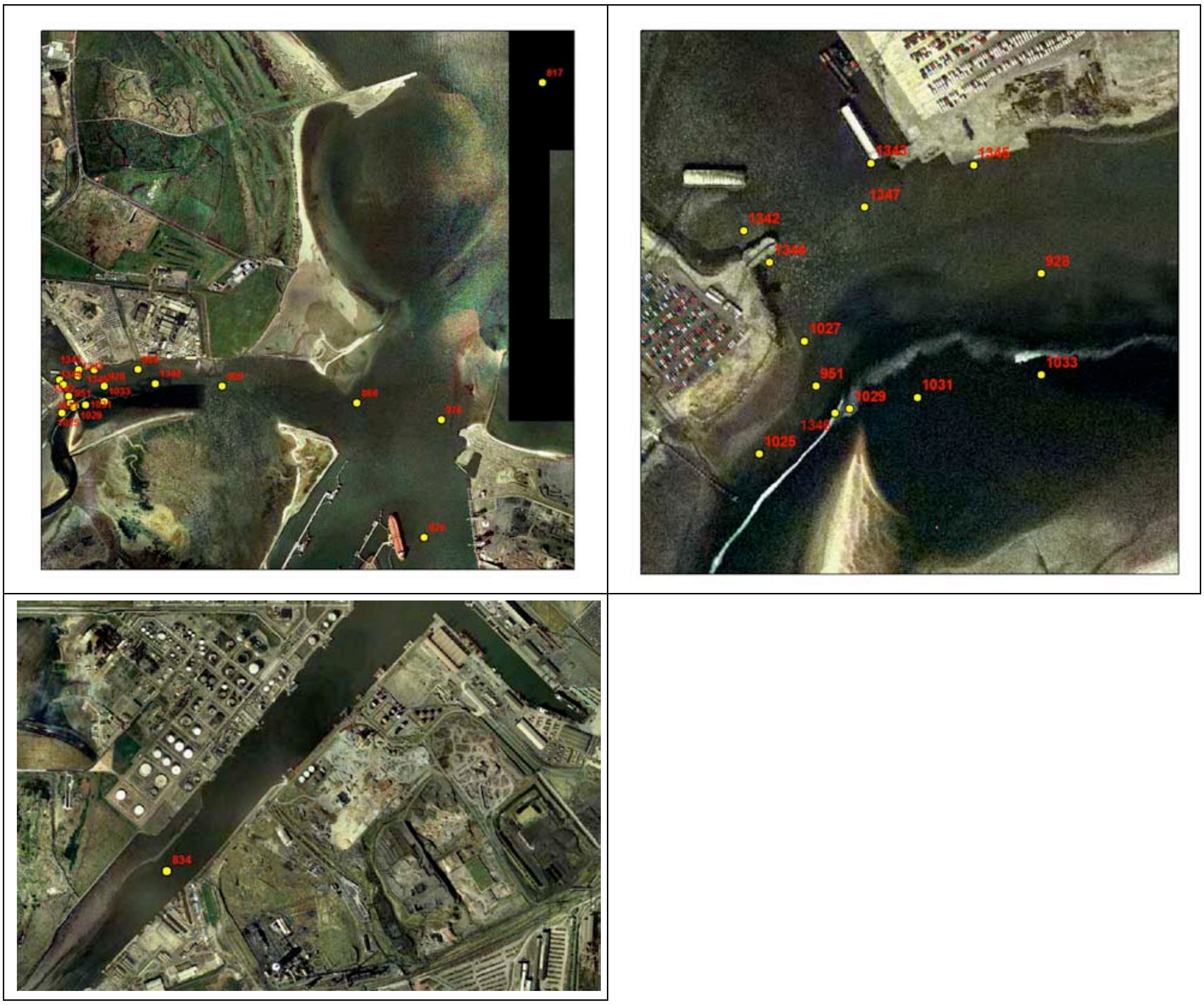


Figure 5-1 Sampling locations for suspended sediment. Data from EA

HR Wallingford /2/ points out that there is some characteristic form of variation with time during the tidal cycle. In the upper reaches (Billingham Reach) there is a tendency for the highest concentrations to occur around low water, indicating mainly river borne material. Further down at Middlesbrough Dock some material seems to arrive during ebb tide but the main source appear to arrive during the flood tide. Further down the estuary (Shell Jetty) the Billingham pattern is reversed indicating a source of material outside the estuary.

HR Wallingford /2/ also points out the relatively high contribution of silt and sand carried in to the estuary (1.5 Mm^3 in situ volume or 700 000 tones dry solids) from Tees bay compared to river borne transport estimated to 40 000 tones/year. The sand settles out in the lower estuary (chart 9 and 10 in /2/). The silt and clay are re-suspended by activities like shipping and dredging, as the near bed velocities are generally too low to erode deposited sediment. This means that deposited sediment will tend to stay where it falls out of suspension unless the sediment is disturbed some other way (dredging, shipping). Suspended sediments concentrations have been found to have declined somewhat since 1995 and are low, in the order of 10-30 mg/l.

University of Durham /1/ is focused on the erosion and sedimentation regime on Seal Sands, and lists some controlling factors regarding suspended sediment and sediment transport. See also Section 6.2 below.

- Since the commissioning of the Tees barrage tidal current velocities have decreased by approximately 10 % due to a decrease in tidal volume of 10 %
- Less fluvial sourced sediment is reaching the intertidal zone because settling behind the Barrage and conversely estuarine and marine sediment is unable to pass upstream of the barrage point.

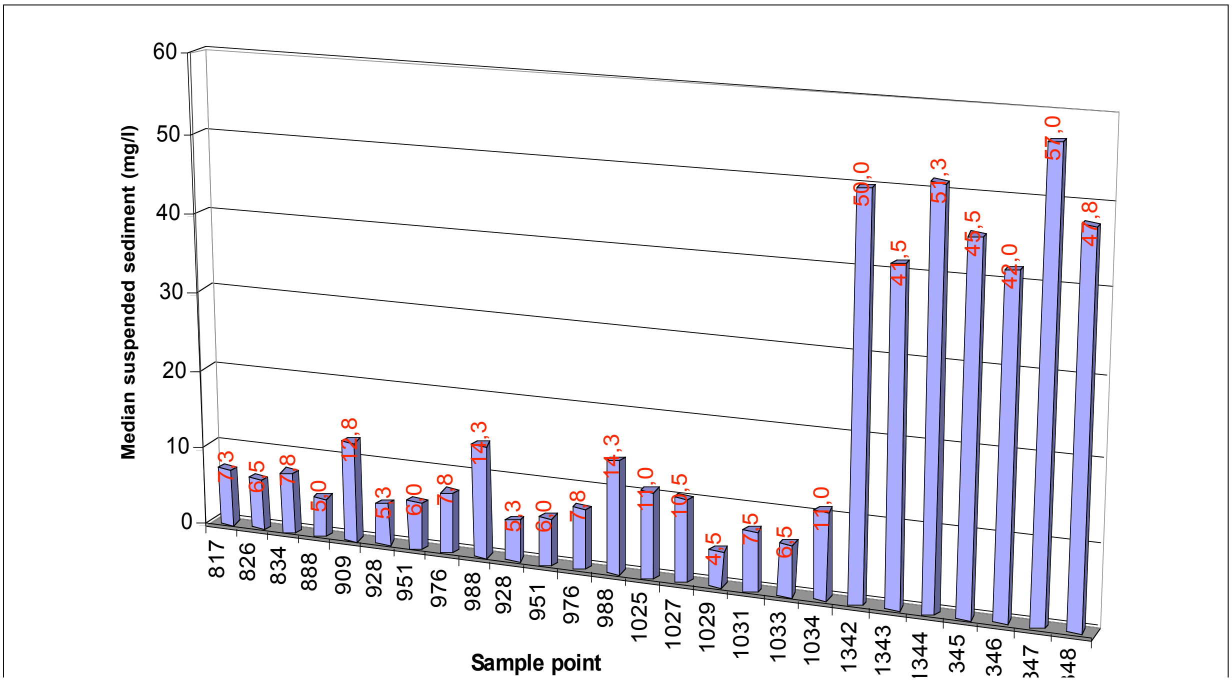


Figure 5-2 Suspended sediment concentrations mg/l (medians)

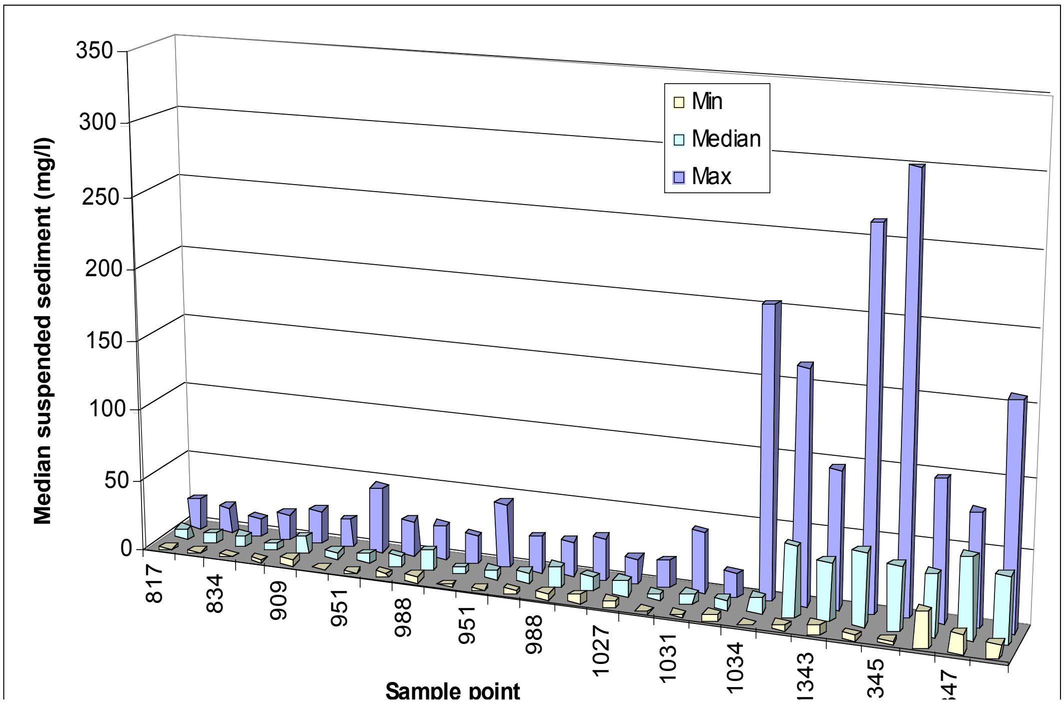


Figure 5-3 Suspended sediment sampling (medians)

5.1.2.2 Bed characteristic

Figure 5-4 shows an isoline plot of percent silt and clay (<63 µm) distribution based on the data from EA. The plot shows that the areas to be dredged, excluding the Dry/Wet dock, namely Seaton Channel, Holding basin and quays 10 and 11 contain a high proportion of silt and clay. Generally the percent of silt and clay varies from 50 % to over 90 % of the total grain sizes, when considering the dredging areas. The grain size data which this is based on gives no information of the amount of silt or clay in this fraction. HR Wallingford /2/ states that the percentage of clay throughout the estuary is fairly low at typically between 15-20 %, meaning that much of the fraction <63 µm can be defined as silt. It also means that a significant proportion contains a larger grain size. Based on this it is reasonable to assume that this is mainly fine sand.

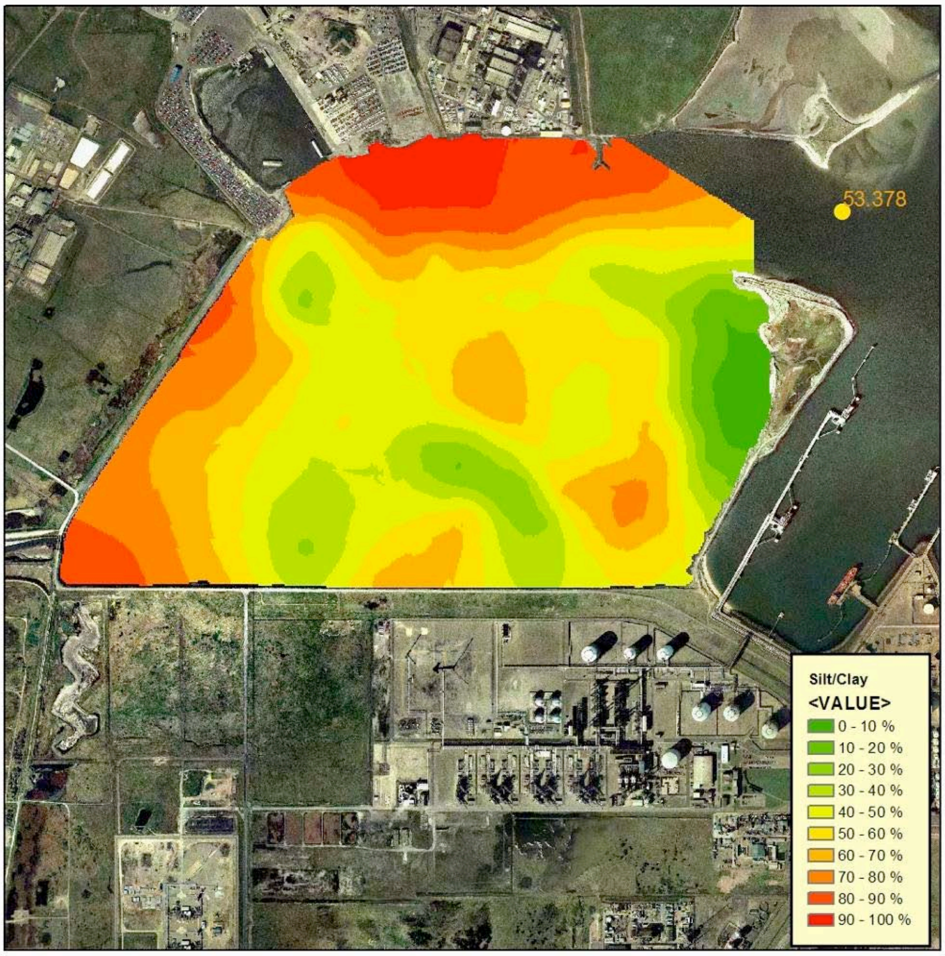


Figure 5-4 Percent silt/clay in the dredging areas and Seal Sands

A general description of the particle size distribution throughout the estuary is described by HR Wallingford /2/. At the furthest point upriver the sediment is mainly sand. In midst estuary it is a high proportion of silt, whilst in the entrance channel the sediment is again mainly sand. The sand is defined as fine sand with a grain size mainly in the range of 0.1 – 0.2 mm. It is worth noting however that the description is based on data from 1991.

University of Durham /1/ concludes that there is net accretion on Seal Sands of 0.0035 m^3/year/m^2 or 3.5 mm/year, net erosion on Bran Sands from 0.0 to 0.02 m3/year/m^2 or 20 mm/year, and net erosion on North Tees Mudflats of 0.02 m^3/year/m^2 or 20 mm/year. With regards to Seals Sands there is a uniform increase of the silt and clay fraction over the last 11 years (1992-2003).

5.2 Modelling results

Based on the proposed developments at the TERRC site and in Seaton Channel as described in Section 4.1.5 above, the following scenarios have been modelled:

Table 5-1 Definition of modelling scenarios

Case no	Description	Dock dredg/closed	Seaton Ch. dredged	Q10 & Q11 dredged	Tidal Cycle
0	Today – baseline	No	No	No	14 days
1	Dredg of dock (incl bund & HB)	Dredged	No	No	14 days
2	Dredg of dock and Seaton Channel	Dredged	Yes	No	14 days
3	Dredg of dock and Q10 and Q11	Dredged	No	Yes	14 days
4	Dredg dock, SC and Q10 & 11	Dredged	Yes	Yes	14 days
5	Dock closed (bund + HB dredg)	Closed	No	No	14 days
6	Dock closed dredg Seaton Channel	Closed	Yes	No	14 days
7	Dock closed dredg Q10 & Q11	Closed	No	Yes	14 days
8	D.Close, dredg SC, Q10 & Q11 (-12 m)	Closed	Yes	Yes	14 days
9	D.Close, dredg SC, Q10 & Q11 (-12.5 m)	Closed	Yes	Yes	14 days

Boundaries of dry dock, holding basin, Seaton Channel and quay 10 and 11 are defined in Figure 3-1 above. A series of reporting points are set up to quantify the changes in hydrodynamics and sediment regime as follows:

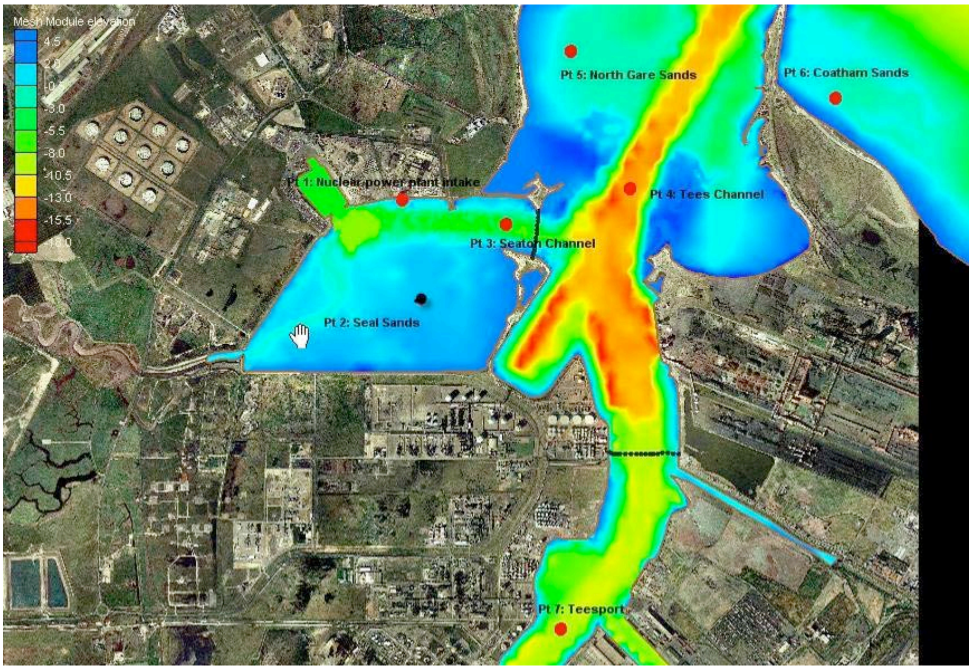


Figure 5-5 Locations of reporting points

Table 5-2 Definition of reporting points

Point No	Description	X-coordinate	Y-coordinate
1	Cooling water intake, nuclear power plant	452888	526745
2	Seal Sands	453020	526004
3	Seaton Channel	453653	526558
4	Tees Channel	454577	526823
5	North Gare Sands	454136	527849
6	Coatham Sands	456101	527500
7	Teesport	454062	523544

5.2.1 General impacts on Hydrodynamics

The general impact of the proposed developments of the TERRC site and Seaton Channel on hydrodynamics is described below.

5.2.1.1 Velocities

Figure 5-6, Figure 5-7 and Figure 5-8 describe the flow velocities in the estuary for Scenario 8 where the greatest changes in channel geometry are proposed. At time step 207.5 on a rising tide, a period of high velocities in the estuary, the highest velocities of 0.4 to 0.6 m/s are found in the entrance channel leading into Seaton Channel and river Tees. The velocities in Seaton Channel vary between 0.045 m/s in the upper reaches and up to 0.4 m/s in the centre of the channel at the most constricted parts. The velocities in the main river Tees are generally between 0.1 and 0.2 m/s. Some shallower parts in the main river reach velocities up to 0.3 m/s.

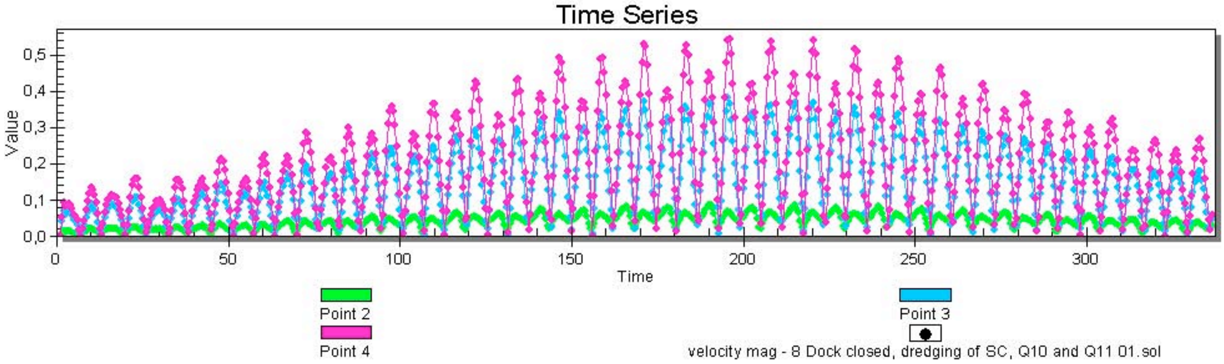


Figure 5-6 Velocity magnitude (m/s) for Pt 2 Seal Sands, Pt 3 Seaton Channel and Pt 4 Tees Channel for Scenario 8, see Figure 5-5

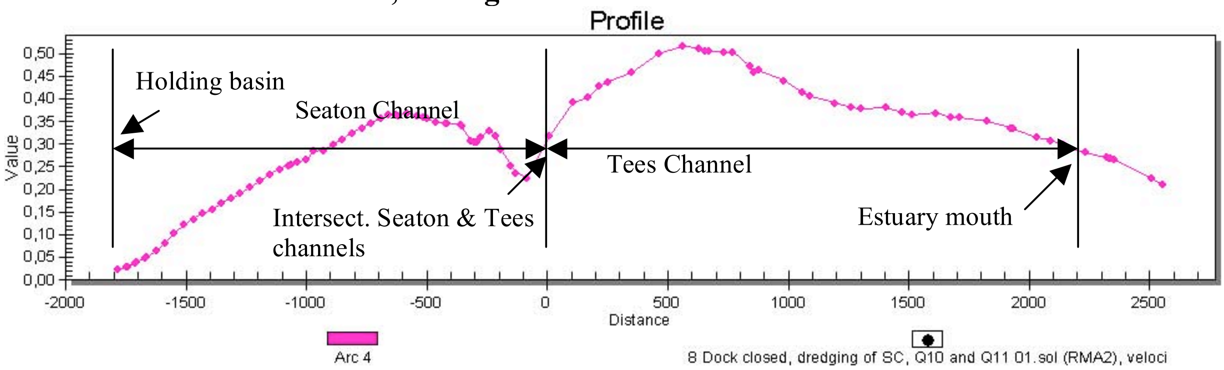


Figure 5-7 Velocity (m/s) transect from innermost reaches of Seaton Channel to the mouth of the estuary. Scenario 8 at T = 207.5 (hrs)

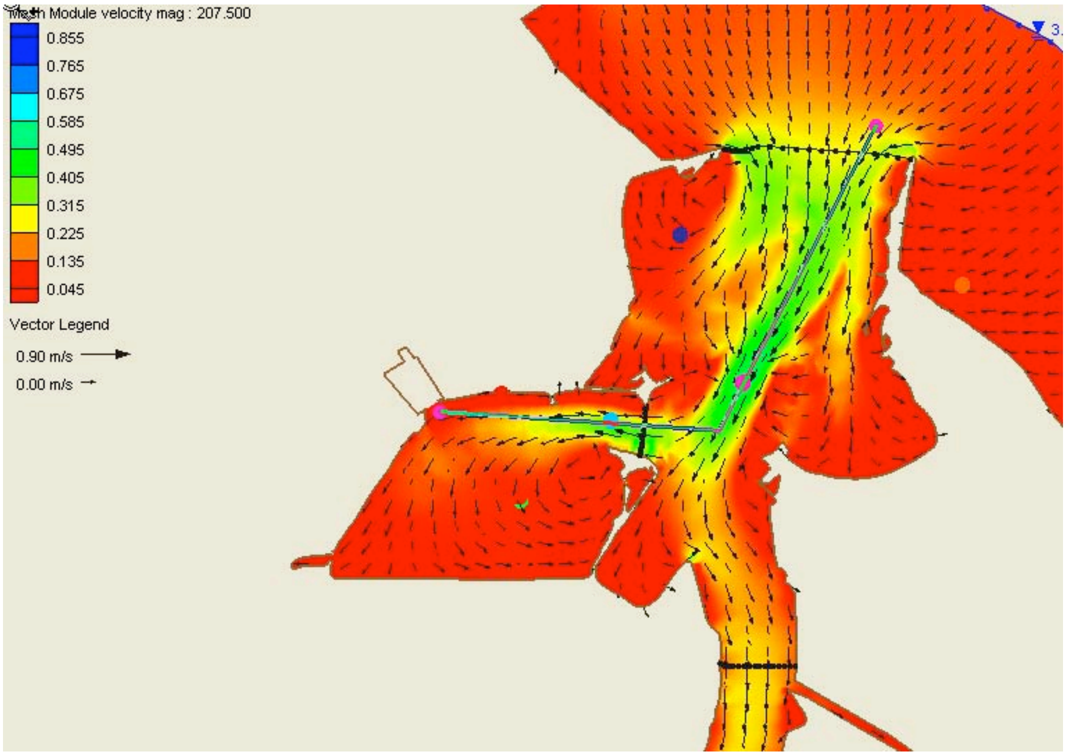


Figure 5-8 Scenario 8 Maximum tidal velocities (depth averaged), T = 207.5 (hrs), transect in Figure 5-7 shown.

Figure 5-9 shows the maximum changes in velocities in Seaton Channel, Seal Sands and Tees Channel from the baseline scenario (0) to the largest changes in geometry (8). At the downstream end of Seaton Channel, velocities are reduced in the order of 0.05-0.10 m/s due to the increased water depth. Baseline velocities in this area are in the order of 0.4-0.6 m/s, and the reduction is therefore about 12 %.

Immediately outside Seaton Channel velocities increase localized in the order 0.04-0.08 m/s due to the higher water volumes that are being moved.

The results indicate a decrease in the flow velocities due to the new bathymetry. This is natural because after dredging the tidal volume can pass trough a greater river cross section. Adjustments may be considered especially with regards to roughness of the sediment type which will be exposed after the dredging and which may alter the flow. There were no data available for the sediment type at the planned dredging depth so the calculations have been based on data covering 0-5 cm of the sediment.

All velocities presented are depth averaged.

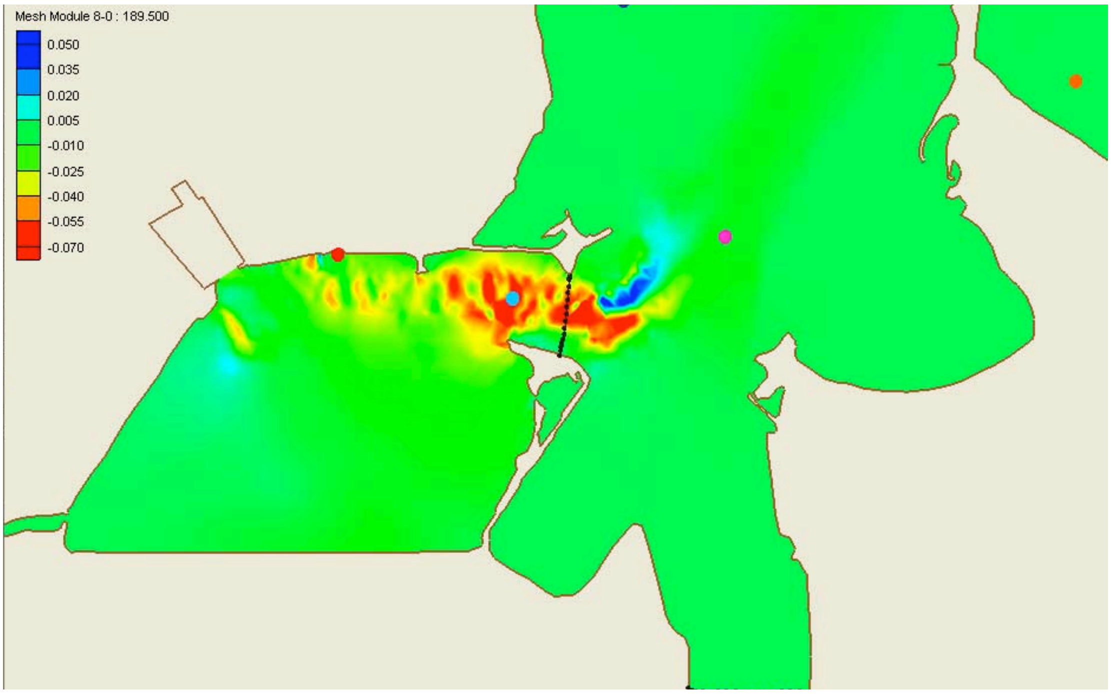


Figure 5-9 Max changes in velocities (depth averaged) at T = 189.5 (hrs) between scenario 0 and 8

Local maxima and minima as predicted by the model are due to bed undulations present in the Baseline scenario and may not reflect reality. Local extreme maxima and minima are therefore not taken into account, and only general changes are considered.

Table 5-3 Velocity difference maxima in % (depth averaged) between baseline (0) and scenarios 1 to 9.

Scenario	m/s	Pt 1 Nuclear PP intake	Pt 2 Seal Sands	Pt 3 Seaton Channel	Pt 4 Tees Channel	Pt 5 North Gare Sds	Pt 6 Coatham Sands	Pt 7 Teesport
0 abs. value	Max	0.047	0.096	0.469	0.552	0.074	0.028	0.206
	Min	0.000	0.002	0.002	0.002	0.003	0.000	0.001
	Average	*0.018*	*0.045*	0.189	0.216	0.039	0.012	*0.090*
1	Average	1.55E-05	-6.25E-05	3.64E-04	1.12E-04	9.81E-06	4.53E-06	-7.98E-07
	Avg. diff %	**0.09**	**-0.14**	**0.19**	**0.05**	**0.03**	**0.04**	**-0.00**
2	Average	-1.08E-03	-1.58E-03	-2.66E-02	-1.25E-04	4.16E-06	4.19E-06	9.36E-07
	Avg. diff %	**-6.00**	**-3.51**	**-14.07**	**-0.06**	**0.01**	**0.03**	**0.00**
3	Average	2.17E-04	-4.24E-04	3.26E-04	1.17E-04	1.20E-05	6.55E-06	3.58E-06
	Avg. diff %	**1.21**	**-0.94**	**0.17**	**0.05**	**0.03**	**0.06**	**0.00**
4	Average	-8.98E-04	-1.83E-03	-2.66E-02	-1.23E-04	2.52E-06	6.51E-06	-1.92E-06
	Avg. diff %	**-5.00**	**-4.07**	**-14.07**	**-0.06**	**0.01**	**0.05**	**-0.00**
5	Average	-1.07E-03	-1.35E-03	-7.99E-03	-2.77E-03	-1.59E-04	-6.25E-05	-4.93E-06
	Avg. diff %	**-5.94**	**-3.00**	**-4.23**	**-1.28**	**-0.41**	**-0.52**	**-0.01**
6	Average	-4.44E-03	-4.86E-03	-6.05E-02	-3.35E-03	-1.78E-04	-7.17E-05	-5.99E-06
	Avg. diff %	**-24.67**	**-10.80**	**-32.01**	**-1.55**	**-0,46**	**-0.60**	**-0.01**
7	Average	-9.36E-04	-1.63E-03	-8.01E-03	-2.76E-03	-1.60E-04	-6.39E-05	-7.69E-06
	Avg. diff %	**-5.20**	**-3.62**	**-4.24**	**-1.28**	**-0.41**	**-0.53**	**-0.01**
8	Average	*-2.01E-03*	*-2.97E-03*	-3.38E-02	-2.98E-03	-1.63E-04	-6.38E-05	*-2.94E-06*
	Avg. diff %	**-11.16**	**-6.60**	**-17.88**	**-1.38**	**-0.42**	**-0.53**	**-0.01**
9	Average	4.09E-03	-3.28E-03	-3.38E-02	-2.96E-03	-1.65E-04	-6.38E-05	-5.93E-06
	Avg. diff %	**22.72**	**-7.28**	**-17.88**	**-1.37**	**-0.42**	**-0.53**	**-0.01**

The differences for the various scenarios in relation to the absolute values for Scenario 0 (top row) show in general small changes in velocities. For instance, the average velocity between baseline and scenario 8 at Pt 1 Nuclear power plant intake decreases by 0.002 m/s from 0.018, an 11 % decrease, at Pt 2 Seal Sands the corresponding figure is 7 %. These points are in an area close to the proposed developments. At Pt 7 Teesport a decrease by 0.000003 m/s from 0.09 m/s is seen, a decrease of 0.003 %, which is negligible. The impacts on the hydrodynamic regime within the mouth of Seaton Channel are within 10 to 11 % in general, although some local areas may experience higher changes. Outside the mouth of Seaton Channel the changes in the hydrodynamic regime are negligible.

In Figure 5-10 the average changes between baseline (scenario 0) and the different scenarios are plotted for each location. As stated above Figure 5-8 shows that the greatest impact will be within the bounds of Seaton Channel (location 1, 2 and 3). It also shows that the greatest changes are related to scenario 6 (when the dock is closed and Seaton Channel is dredged) and 8 (Dock closed, Seaton channel and quays 10 and 11 dredged). The least changes in velocities can be seen for scenario 1 (Dock and Holding basin dredged) and 3(Dock and Quays 10 & 11 dredged).

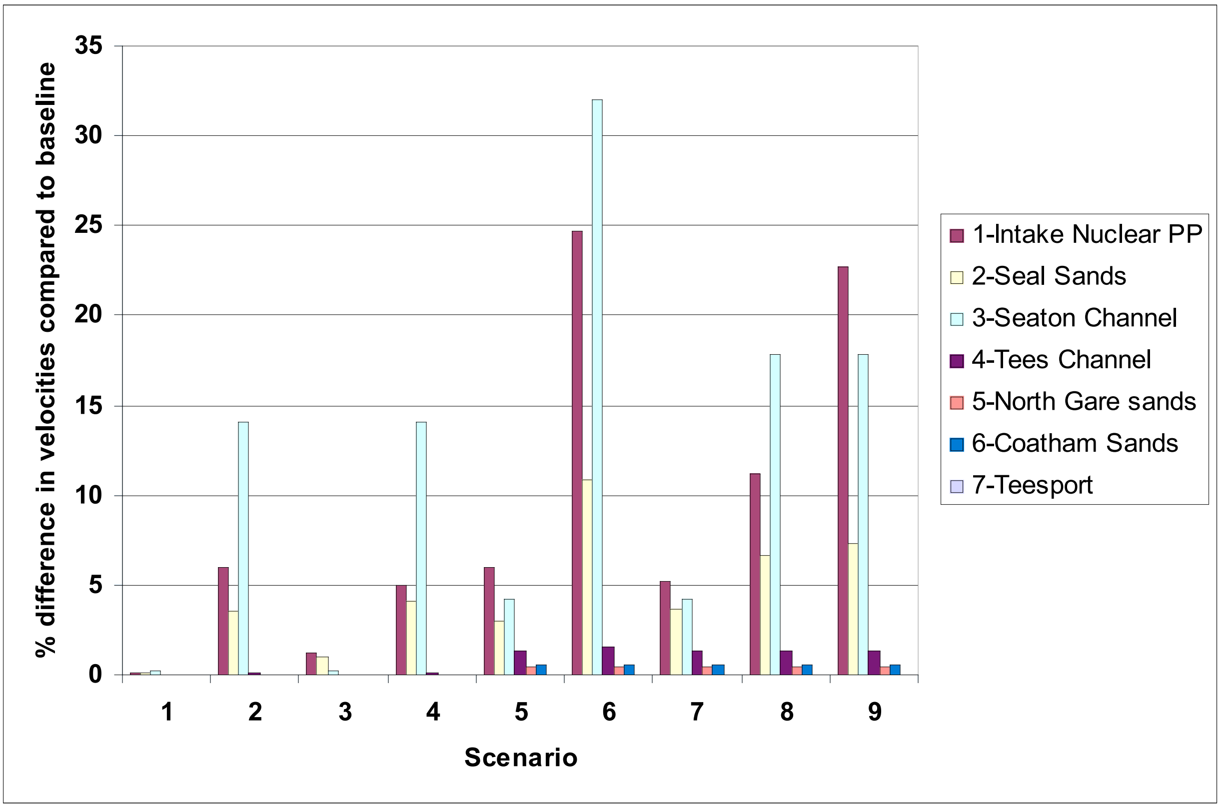


Figure 5-10 Average changes (%) in velocities between baseline and the different scenarios at each location

5.2.1.2 Bed shear stress

As explained in Section 4.1.3.2 above, sediments will erode from or deposit to the bed dependent on the shear stress acted upon it by the moving water. The shear stresses predicted for Pt 2 Seal Sands and Pt 3 Seaton Channel for Scenario 8 throughout the study period are presented in Figure 5-11 below.

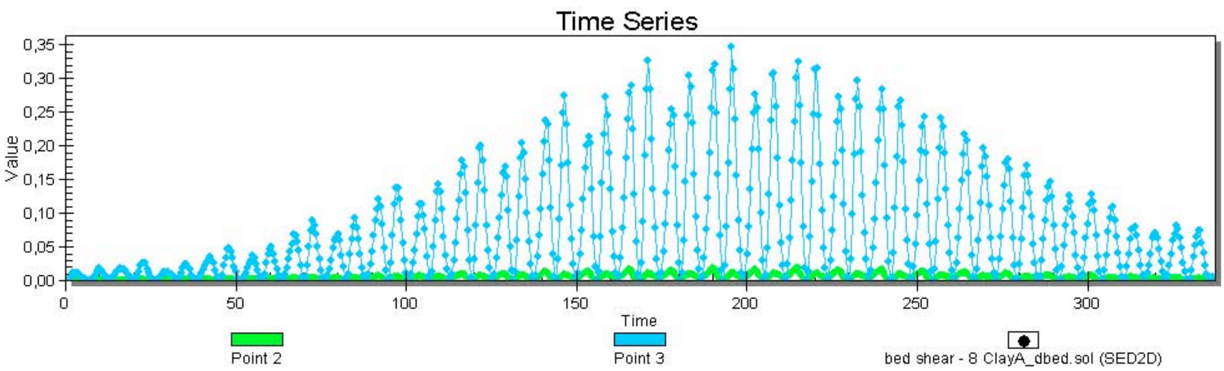


Figure 5-11 Shear stress (N/m^2) for Pt 2 Seal Sands and Pt 3 Seaton Channel for Scenario 8

The maximum shear stress magnitudes and distributions experienced in Scenario 8 are plotted in Figure 5-12 below.

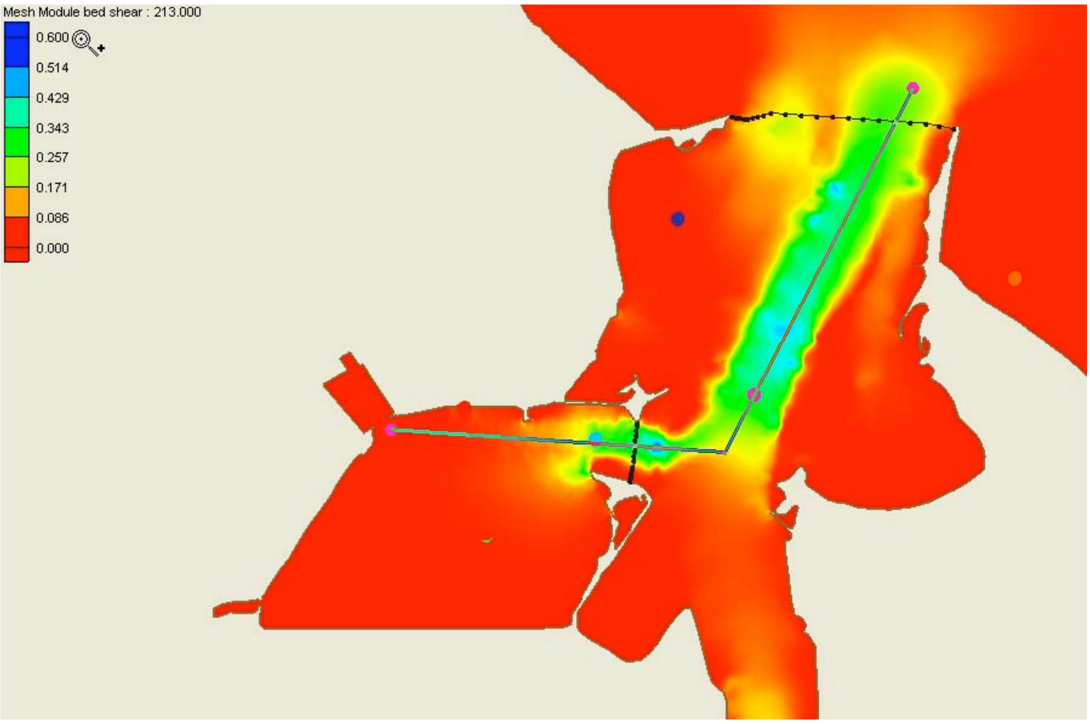


Figure 5-12 Maximum shear stress (N/m^2) acted upon bed for Scenario 8, at T = 213 (hrs). Transect indicated is plotted in Figure 5-13 below.

The maximum shear stress (at T = 213 hrs) along Seaton Channel, through Tees Channel and out towards the estuary mouth is plotted in Figure 5-13 below. A local maximum is seen in the most constricted part of the mouth of Seaton Channel. Constricted areas of Tees channel also experience high shear stress.

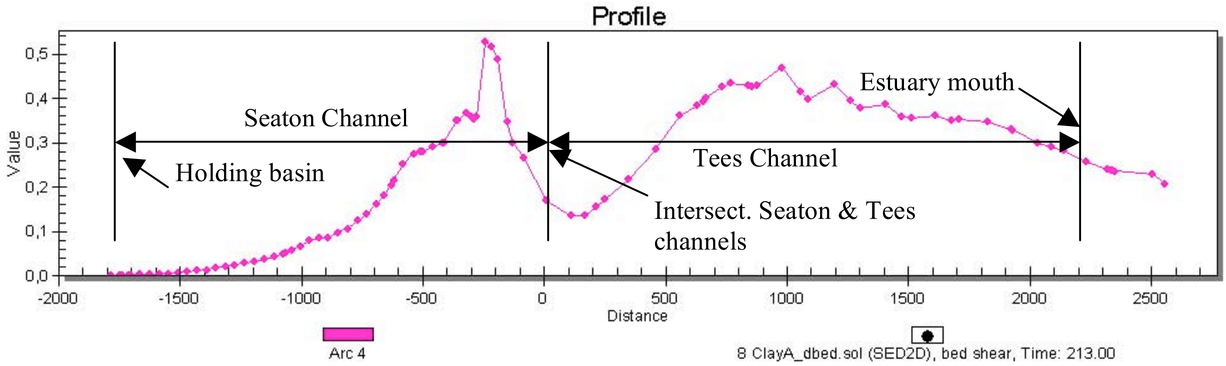


Figure 5-13 Maximum shear stress (N/m^2) for Scenario 8, at T = 213, from Seaton Channel to sea. Transect defined in Figure 5-12 above.

It can be seen from Figure 5-11, Figure 5-12 and Figure 5-13 that the maximum shear stress is below 0.1 N/m^2 on Seal Sands, in the inner reaches of Seaton Channel, and on most mudflats. The shear stress rises to around 0.5 N/m^2 and above for the outer parts of Seaton Channel and the constricted areas of Tees channel. Erosion of fine sediments may be the case here.

It is clear that the shear stress magnitude on Seal Sands is below the values required to initiate erosion, and also low enough for both sand and clay to deposit. In Seaton Channel the shear stress is high at high water velocities, and there is less likely that silt/clay will deposit in this area.

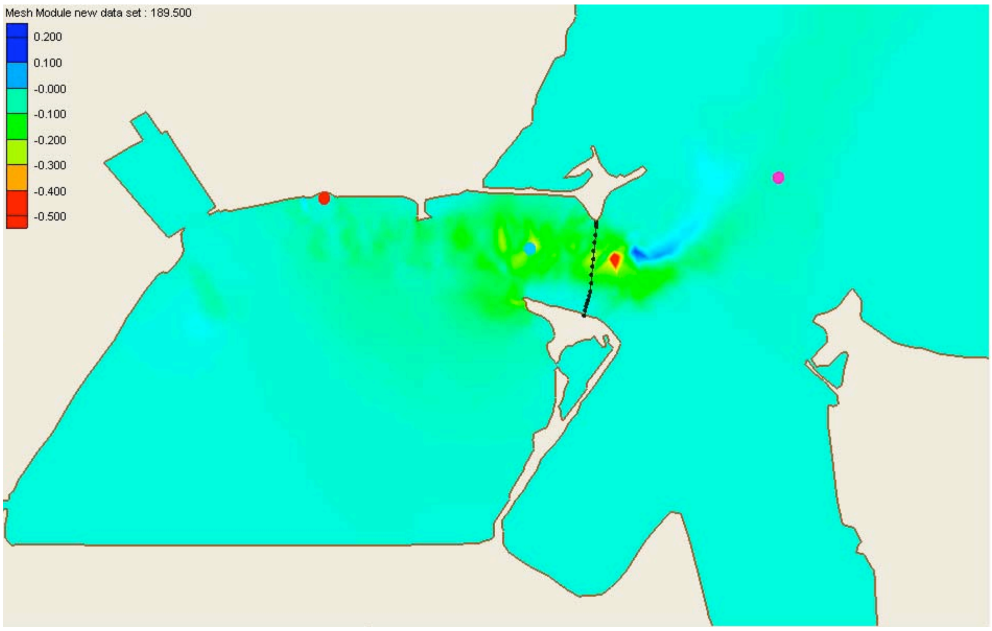


Figure 5-14 Maximum changes in bed shear stress (N/m^2) at T = 189.5 (hrs) from scenario 0 and 8.

The changes in shear stress from Scenario 0 to Scenario 8 are presented in Figure 5-14. Local maxima and minima as predicted by the model are due to bed undulations present in the Baseline scenario and may not reflect reality. Local extreme maxima and minima are therefore not taken into account, and only general changes are considered.

Predictions for each point and each scenario are presented in Table 5-4. Changes in bed shear are small, indicating no great change in sediment regime. However, some local changes occur. The average shear stress at Pt 1 Nuclear power plant intake changes by 0.0003 N/m^2 from 0.001, a decrease of 31%, which is appreciable. Corresponding figures for Pt 3 Seaton Channel are 39 %, which is natural as the velocities decrease due to increased depth. At Pt 2 Seal Sands the change is a decrease of 13 %. At Pt 7 Teesport the figure is 0.01 % which is negligible. Again, appreciable impacts are seen within the mouth of Seaton Channel, but changes outside are negligible.

Table 5-4 Bed shear stress difference maxima (%) between baseline and scenarios between baseline (0) and scenarios 1 to 9.

Scenario	N/m^2	Pt 1 Nuclear PP intake	Pt 2 Seal Sands	Pt 3 Seaton Channel	Pt 4 Tees Channel	Pt 5 North Gare Sds	Pt 6 Coatham Sands	Pt 7 Teesport
0 abs. value	Max	0.007	0.045	0.684	0.729	0.017	0.003	0.111
	Min	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Average	*0.001*	*0.010*	*0.154*	0.157	0.006	0.001	*0.029*
1	Average	1.61E-06	-8.49E-05	6.33E-04	1.69E-04	2.62E-06	6.89E-07	-6.90E-07
	Avg. diff %	**0.2**	**-09**	**0.4**	**0.1**	**0**	**0**	**0**
2	Average	-1.34E-04	-7.47E-04	-5.14E-02	-1.57E-04	1.12E-06	3.57E-07	1.24E-06
	Avg. diff %	**-13**	**-7**	**-33**	**-0.1**	**0**	**0**	**0**
3	Average	-1.83E-07	-2.37E-04	5.84E-04	1.72E-04	3.17E-06	7.76E-07	2.14E-06
	Avg. diff %	**0**	**-2.4**	**0.4**	**0.1**	**0.1**	**0**	**0**
4	Average	-1.42E-04	-8.52E-04	-5.14E-02	-1.53E-04	5.97E-07	6.21E-07	-2.88E-08
	Avg. diff %	**-14**	**-8**	**-33**	**-0.1**	**0**	**0**	**0**
5	Average	-1.65E-04	-6.37E-04	-1.27E-02	-4.00E-03	-4.89E-05	-6.55E-06	-2.82E-06
	Avg. diff %	**-17**	**-6**	**-8**	**-2.6**	**-0.8**	**-0.7**	**0**
6	Average	4.24E-04	2.05E-03	8.83E-02	4.94E-03	5.65E-05	1.11E-05	2.21E-06
	Avg. diff %	**42**	**21**	**57**	**3.2**	**0.9**	**1**	**0**
7	Average	-1.77E-04	-7.44E-04	-1.27E-02	-3.99E-03	-4.89E-05	-6.79E-06	-4.00E-06
	Avg. diff %	***-18***	**-7**	**-8**	**-2.5**	**-0.8**	**-0.7**	**0**
8	Average	*-3.05E-04*	*-1.31E-03*	*-6.03E-02*	-4.28E-03	-4.98E-05	-6.65E-06	*-1.77E-06*
	Avg. diff %	**-31**	**-13**	**-39**	**-2.7**	**-0.8**	**-0.6**	**0**
9	Average	3.27E-04	-1.53E-03	-7.50E-02	-3.33E-03	-4.41E-05	-6.63E-06	-3.53E-06
	Avg. diff %	**33**	**-15**	**-49**	**-2.1**	**-0.8**	**-0.6**	**0**

In Figure 5-15 the average changes in bead shear between baseline (scenario 0) and the different scenarios are plotted for each location. Figure 5-15 shows that the greatest impact will be within the bounds of Seaton Channel (location 1, 2 and 3). This is in the dredging areas and is also the area with the largest changes in velocities. It also shows that the greatest changes are related to scenario 6 (when the dock is closed and Seaton Channel is dredged) and 8 (Dock closed, Seaton channel and quays 10 and 11 dredged). The least changes in velocities can be seen for scenario 1 (Dock and Holding basin dredged) and 3(Dock and Quays 10 & 11 dredged). It is important to underline that estimated shear stress after dredging is somewhat artificial, because the bed is assumed to be completely flat reflecting the proposed dredging depth.

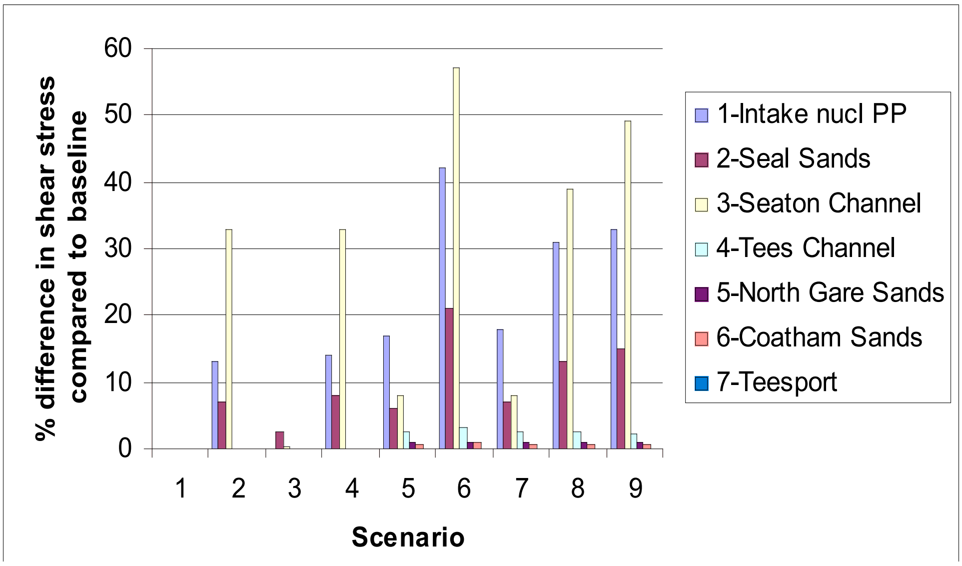


Figure 5-15 Average changes (%) in shear stress between baseline and the different scenarios at each location

5.2.2 General impacts on sediment concentrations

The general impact of the proposed developments of the TERRC site on sediment concentrations is described below.

The main sediment source is the sea, both for cohesive sediments and for non-cohesive sediments, as can be seen in Figure 5-16, Figure 5-17, Figure 5-20 and Figure 5-21. A generally higher concentration together with a domination of tidal processes over river inflow ensures that the influx from the sea is dominant. This is supported by /2/.

5.2.2.1 Selected sediment concentrations, sand

The suspended sediment concentration of sand (at T=210) along Seaton Channel, through Tees Channel and out towards the estuary mouth is plotted in Figure 5-16 and Figure 5-17. There is a gradually decrease from the estuary towards Seaton Channel and the Dock. This reflects that the main source is the estuary and that sand gradually falls out of suspension.

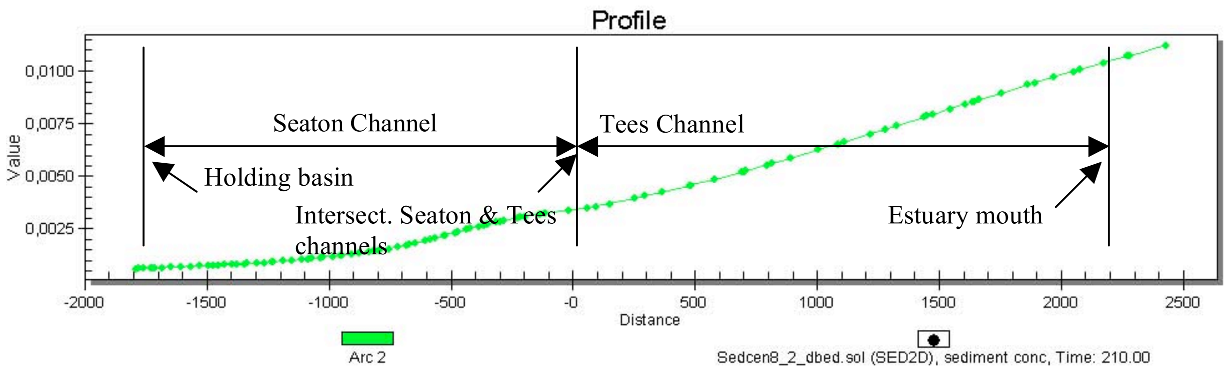


Figure 5-16 Sediment concentration (mg/l) profile, sand, from upstream Seaton Channel to estuary mouth. Sand, scenario 8, T = 210 (hrs)

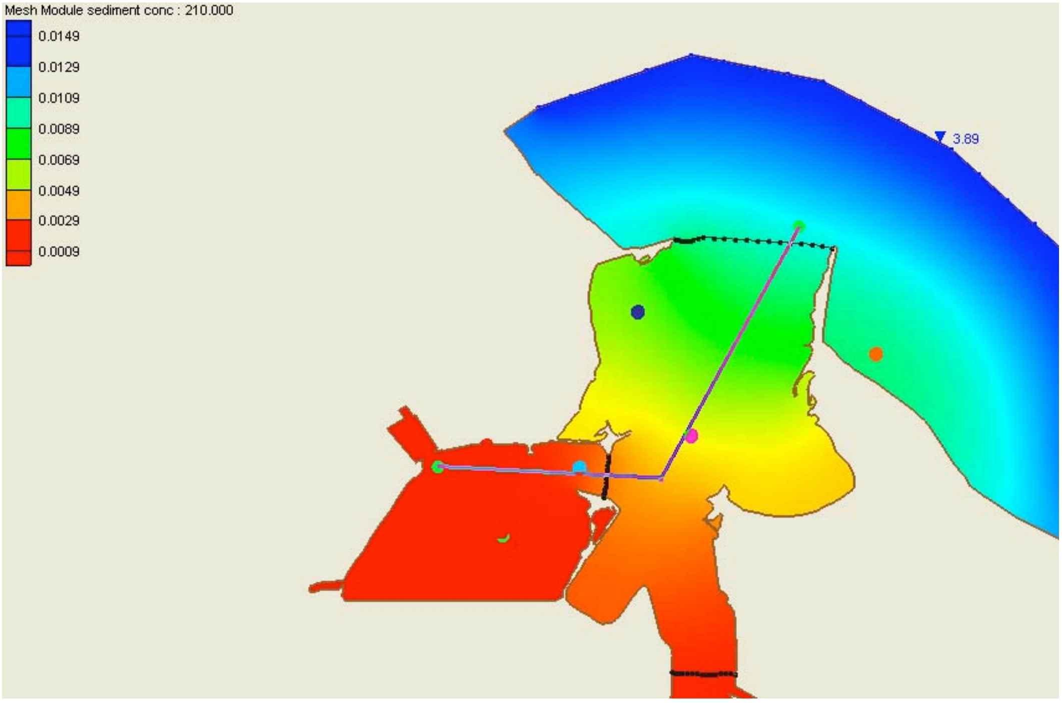


Figure 5-17 Corresponding plot of sediment concentrations (mg/l) for sand, scenario 8, T = 210 (hrs). Transect plotted in Figure 5-16 above indicated

Sand concentrations at Pt 1 nuclear power plant intake and Pt 2 Seal Sands are shown in the Figure below for Scenario 8. It is seen that the concentration of suspended sand varies greatly within the tidal cycles, but that maximum concentrations (as tabulated above) are low, less than 1 mg/l.

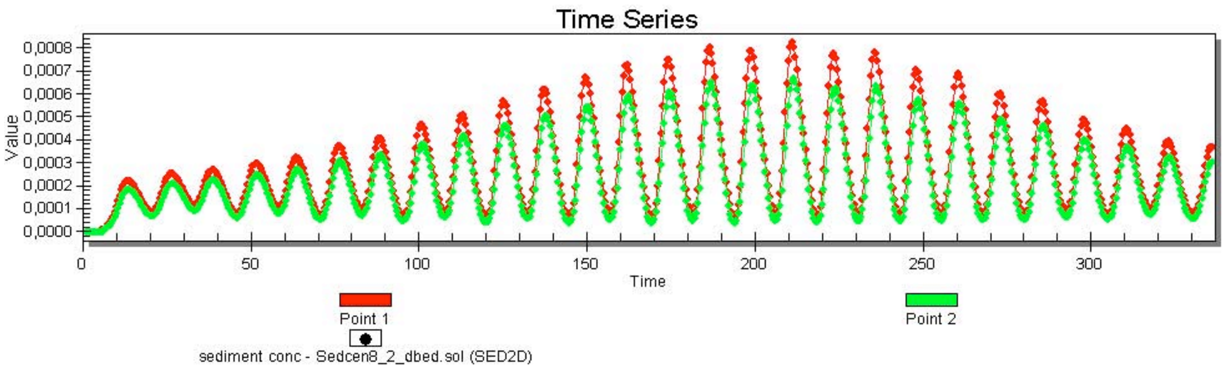


Figure 5-18 Sand concentrations (mg/l) at Pt 1 (nuclear power plant intake) and Pt 2 (Seal Sands) for Scenario 8

Maximum concentrations differences for sand between scenario 0 and 8 is plotted in Figure 5-19. In general the differences are very small and the differences are only a few percent. The differences are most prominent in the lower reaches of Seaton Channel.

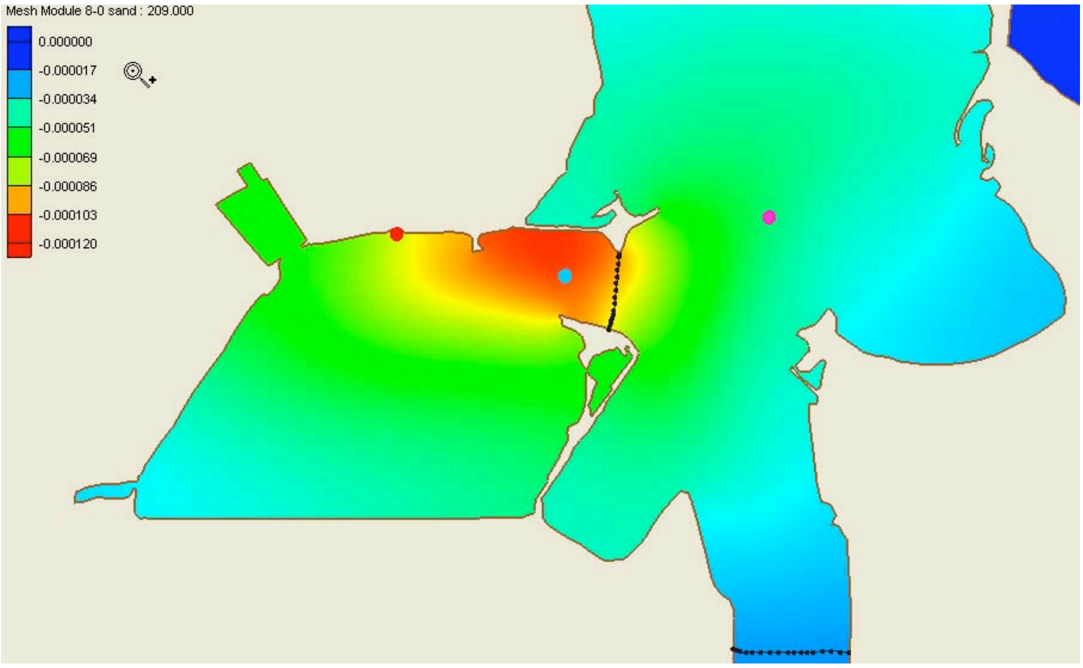


Figure 5-19 Maximum concentration differences, sand, at T = 209 (hrs), scenario 0 and 8

5.2.2.2 Selected sediment concentrations, silt/clay

The suspended sediment concentration of silt/clay (at T=210 hrs) along Seaton Channel, through Tees Channel and out towards the estuary mouth is plotted in Figure 5-20 and Figure 5-21. There is a gradually decrease from the estuary towards Seaton Channel and the Dock.

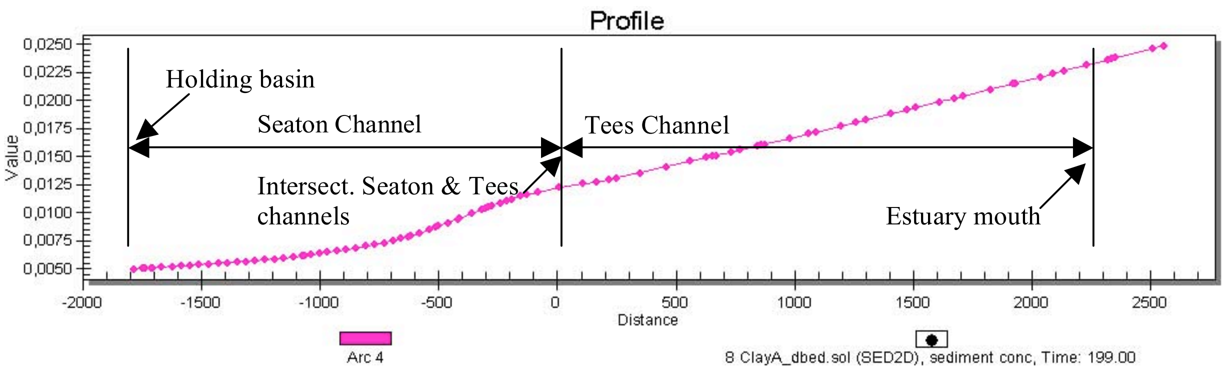


Figure 5-20 Sediment concentration (mg/l) profile, clay, from upstream Seaton Channel to estuary mouth. Scenario 8, T = 199 (hrs)

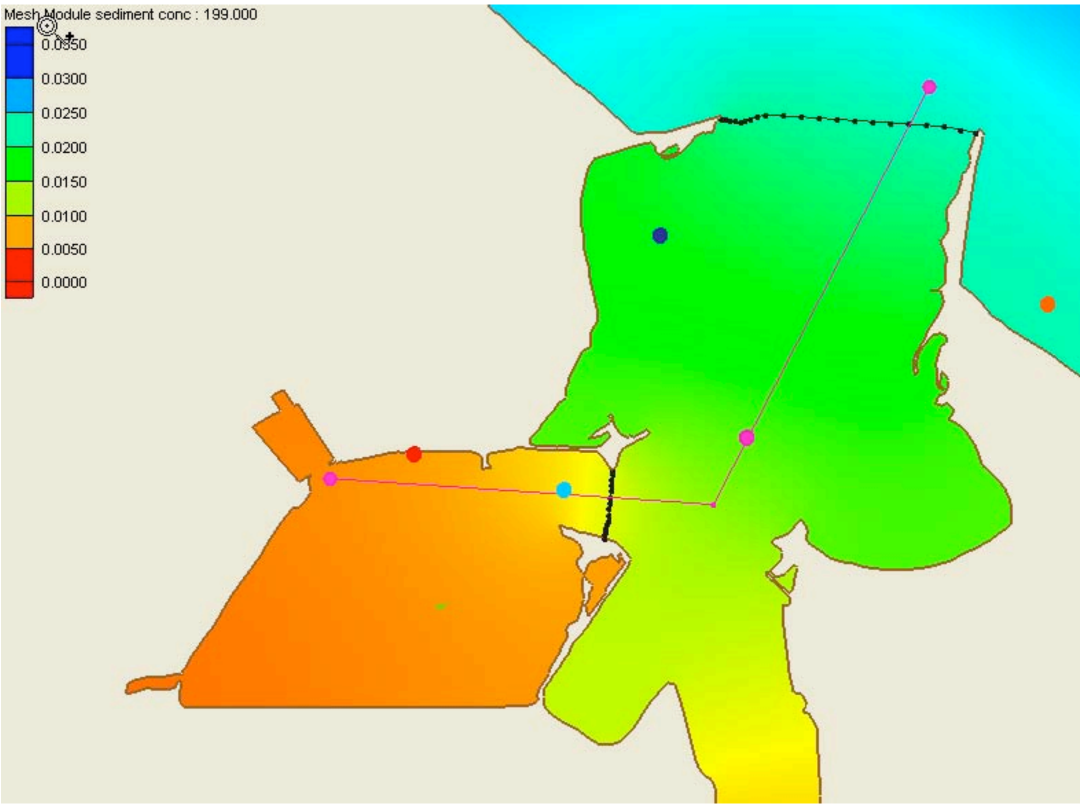


Figure 5-21 Corresponding plot of sediment concentrations for clay, scenario 8, T = 199 (hrs). Transect plotted in Figure 5-20 above indicated.

Silt/clay concentrations at Pt 1 nuclear power plant intake and Pt 2 Seal Sands are shown in the Figure below for Scenario 8. It is seen that the concentration of suspended sand varies greatly within the tidal cycles. Maximum concentrations at Pt 1 Nuclear power plant intake and Pt 2 Seal Sands are in the region of 5-6 mg/l, depending on the stage of the tidal cycle and under the modelled conditions.

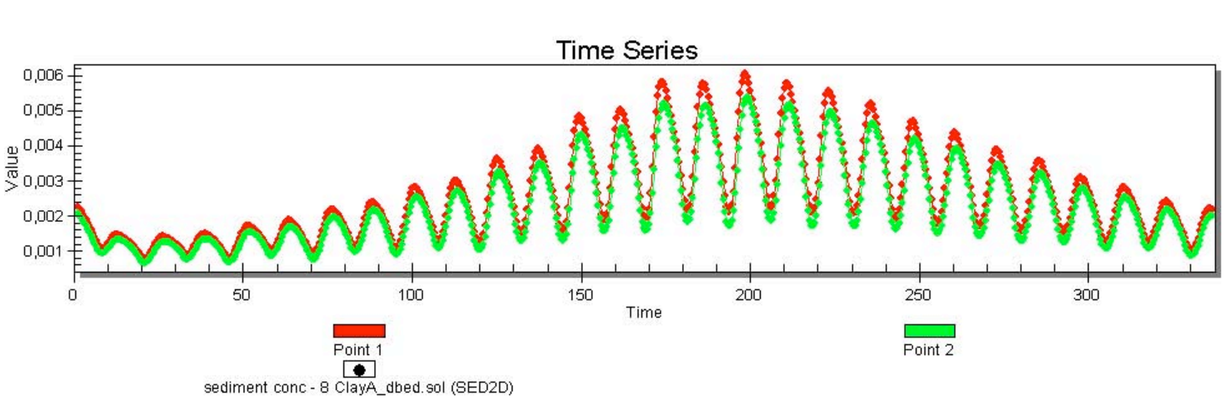


Figure 5-22 Clay concentrations (mg/l) at Pt 1 Nuclear power plant intake and Pt 2 Seal Sands, for Scenario 8

Maximum concentrations differences for silt/clay scenario 0 to 8, is plotted in Figure 5-23. As for sand the differences are most prominent in the lower reaches of Seaton Channel, but the affected area is much smaller. The area of greatest change is where the bead shear stress is relatively high and where the model indicates erosion of the silt/clay bed defined in the model runs.

Figure 5-23 Maximum changes in concentrations for clay, T = 189.5 scenario 0 and 8

Detailed impacts on hydrodynamics, sediment concentrations, and deposition rates / erosion potential are presented in Appendix E.

5.3 Conclusions – hydrodynamics and sediment transport modelling

The dynamic response of the model to the changes in geometry with the modelled processes is described in Figure 5-24.

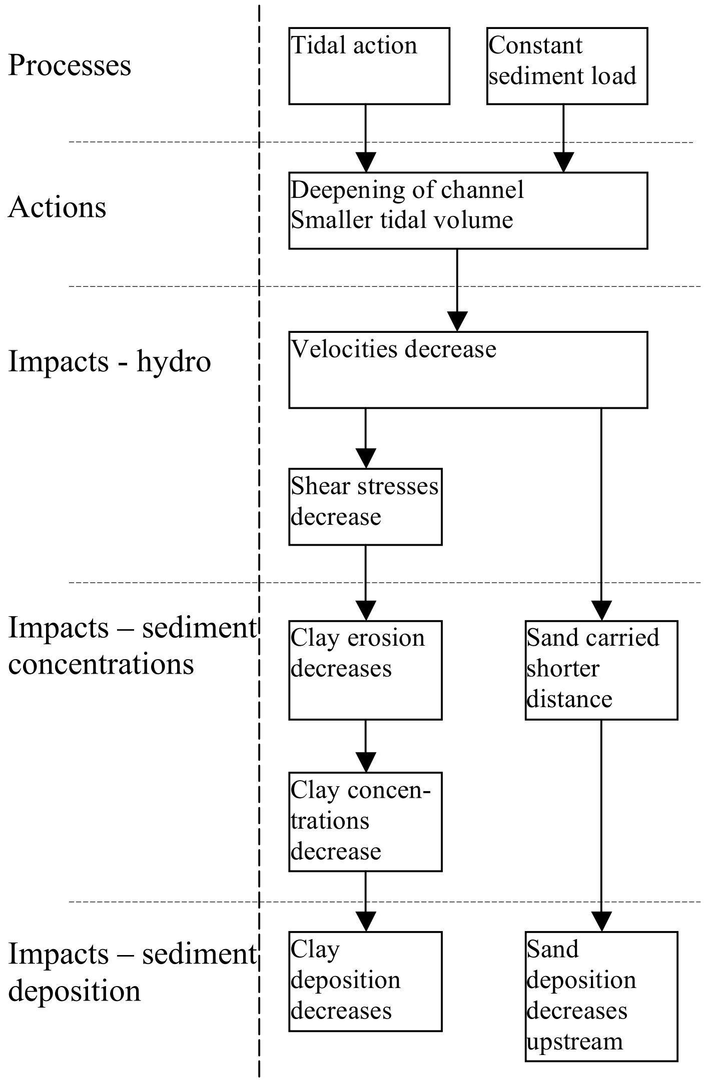


Figure 5-24 Dynamics of hydrodynamic and sediment transportation model

The model is set up to investigate the relative impact of changes in channel geometry as a result of the proposed developments at the TERRC dry dock and in the nearby estuary.

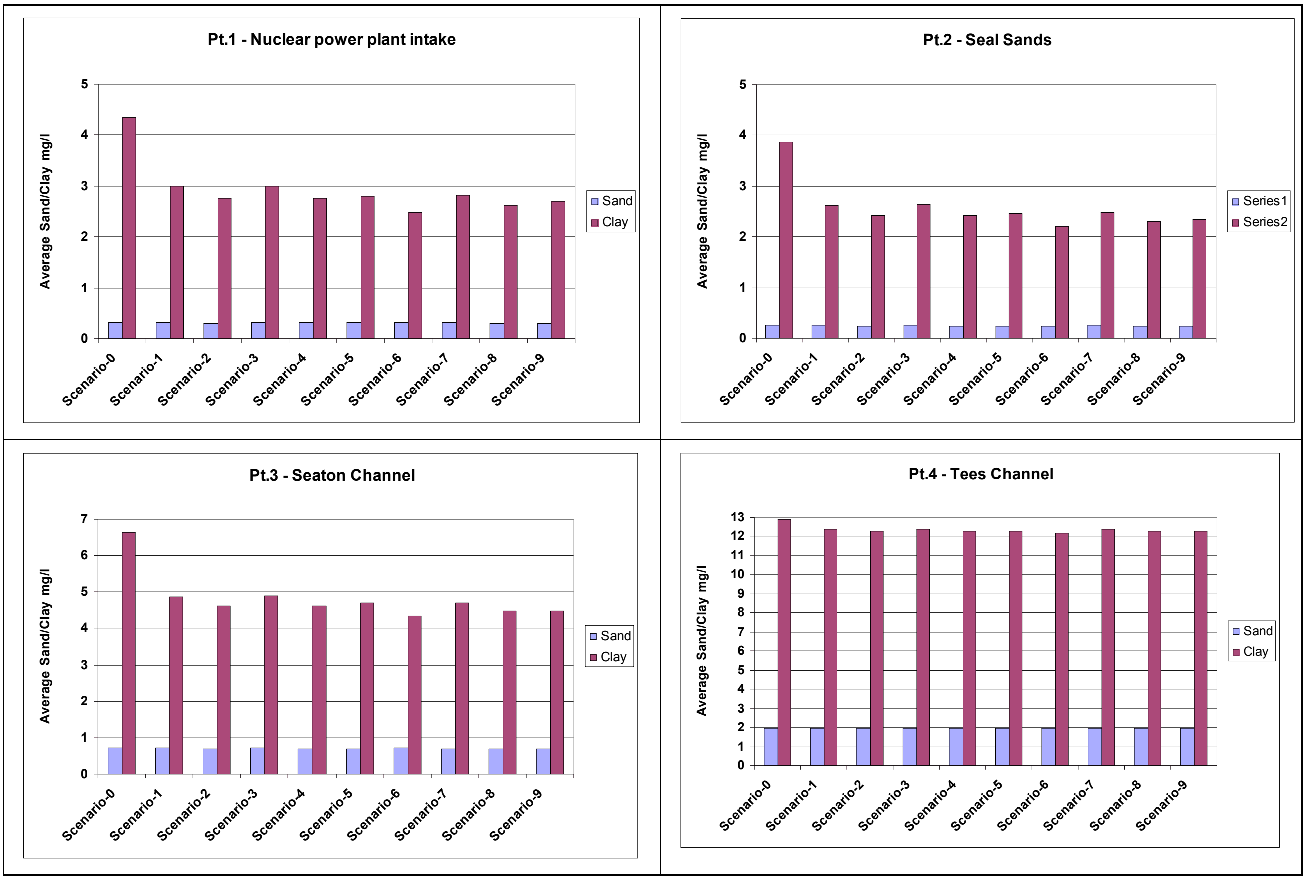
As the relative impacts are of interest, the only process modelled is the action of tidal forces and constant river flow, applying a constant sediment concentration. Other processes contributing to water flow and sediment suspension such as storms, waves, traffic and dredging will produce a much more complex model and results, masking the important relative difference.

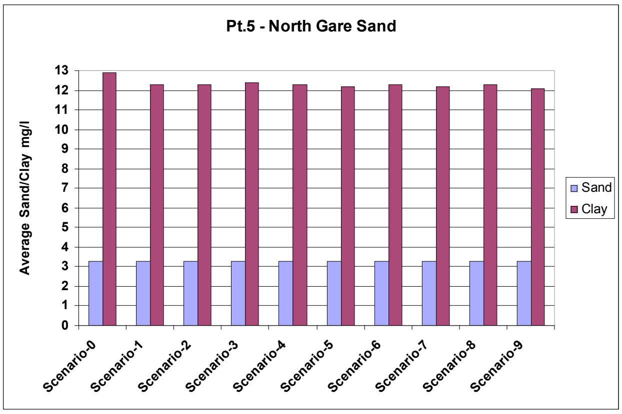
Throughout the various scenarios, changes are made in the geometry to reflect the dredging and closing of the dry dock, dredging of the holding basin, various quays, and Seaton Channel. It is seen that the water velocities in general decrease as the tidal volume is decreased when the dry dock is closed, and when the cross sectional area of the channel is decreased. Corresponding decreases in shear stresses on the bed are detected.

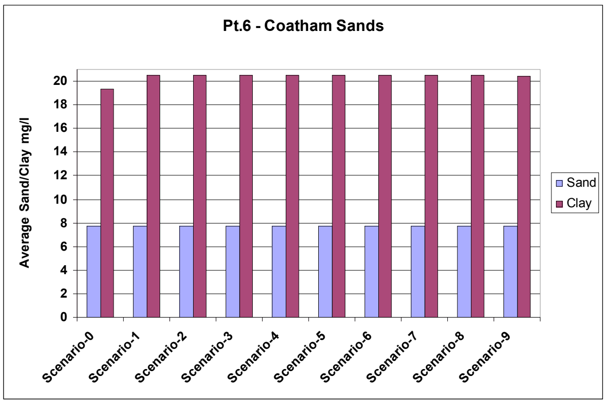
For modelling of sand, the decreased velocities mean that the sand is carried a little shorter upstream, and the deposition rate here decreases. The differences are very small as the baseline carriage of sand upstream is small. This is also reflected in the true sediment found further up Seaton Channel which contains less sand, see Figure 5-4. As seen in Figure 5-25 the differences for sand concentrations between the different scenarios are negligible.

The clay model, however, is effectively lined with a clay bed all over, including areas where the shear stress is too high for clay to be present. A somewhat “false” erosion of clay in these areas suspends sediments that are transported to other areas. Throughout the scenarios the shear stress decreases, also decreasing the concentration of clay sediments in the water column. Less clay is therefore available to deposit elsewhere, and the clay deposition rate decreases in general. This is the reason why the concentration of clay decreases for scenario 1 to 9 compared to the baseline, as seen in Figure 5-25. The differences between scenarios 1 to 9, however, are relatively small. The differences are small outside the bounds of Seaton Channel which reflect the changes in velocities.

The influence of other processes is discussed further in Section 10 below.







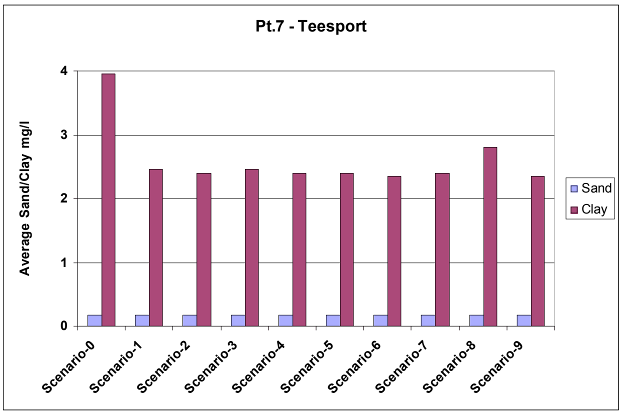


Figure 5-25 Differences in suspended sand and clay concentrations (mg/l) between different scenarios

6 REVIEW OF PREVIOUS STUDIES AND DATA SETS

The dry dock has previously been used for the construction and disassembly of ships and offshore structures. Until 1963 the site was used for shipbuilding, later for construction of offshore structures. Throughout the late 1960's and 70's Seaton Channel was dredged several times in order to float out offshore structures, and maintenance dredging has been carried out intermittently. In 1985 the Albuskjell platform was remediated and recycled at the site, and several other structures have been recycled after this.

6.1 HR Wallingford 2002 /2/

In 2001 HR Wallingford was contracted by the Environment Agency to investigate possible reasons for the decline in numbers of feeding birds at Seal Sands. Changes in sedimentation patterns and the subsequent increases in algal mat densities were believed to have had detrimental effects on feeding capacity, with the numbers of sediment feeders such as Shelduck and Dunlin falling dramatically.

The Tees estuary has been extensively modified over the last two and a half centuries, with straightening and deepening of the main channel, and extensive reclamation of intertidal mudflats. A total of 3100 Ha have been reclaimed, leaving at present 470 Ha of intertidal foreshore.

Seaton Channel has been dredged routinely, with some additional dredging for the float-out of several oil rig modules constructed at the dry dock in the 1970's and 80's. Seaton Channel is at present dredged to some degree.

In 1990-91, Halcrow and HR Wallingford undertook a strategic review of dredging and siltation, showing that the estuary was dredged more than necessary for navigation, resulting in the estuary being gradually deepened. A computer model showed that the river contributed little sediment relative to contributions from the Tees bay. Most of the sediments are of marine origin, coming from the sea with incoming tides when already suspended by waves, in fact 90 % of siltation comes from the sea of which 45 % is sand. The study also showed strong stratification ensuring the upstream migration of finer particles "after disturbance by storms, shipping and dredging".

Most sediment originates from North Gare Sands on rising tides during storm events. 80 % of the sediment moves into the estuary during 7 months from October to April, with 60 % of transport occurring during 30 days of storm activity.

The construction of the Tees Barrage in 1995 has decreased the tidal volume by 10 %, with an expected long term sediment deposition decrease of 10 %. The Barrage was not expected to have any significant effects in Seaton Channel, because the tidal volume and circulation there would not be affected.

Sedimentation rates are reported to have decreased in the last 10 years, with a shift towards less dense materials at the seawards end of the estuary. In addition to the construction of the Tees Barrage, possible reasons may be changes in weather patterns, decreased dredging rates or a combination of reasons. At the confluence of Seaton Channel and the Tees, however, an increased rate of deposition has been noticed, possibly due to changes at the North Gare breakwater. Sediment deposits at the edge of the Seaton turning area are reported to collapse into the dredged area, restricting ship movements.

In fact the dredging quantities reported for “Chart 9” (see Figure 3-8 above) have doubled lately, although the total annual deposition quantities for the whole Tees estuary are calculated to have decreased from 1.5 Mm^3/y in the years around 1986-1991 to 0.95 Mm^3/y for 1995-2001. This calculation is, however, based upon dredged quantities, and may simply be a product of privatisation of the Porch Authority and an efficiency improvement of dredging, so that cost savings on dredging operations have resulted in a reported drop in deposition rates. If indeed dredging has fallen below deposition rates, the bed levels are rising and the Tees estuary is silting up. It is reportedly the view of dredging staff that dredging rates are too low to sustain target depth.

The observed accretion of sand fractions on Seal Sands, which is believed to be the reason for the deterioration of the feeding conditions for seabirds, and thus the decline in bird numbers, may be alleviated by deepening Seaton Channel to create a sediment trap.

The general findings regarding Seal Sands conclude that the reclamation of Seal Sands in the mid 1970’a created an accumulating mud bank over the original profile of sand. The elevation of Seal Sands continued to rise, although at a reducing rate as shallower water increased the local wave erosion. On the other hand, the shelter offered by the training wall along Seaton Channel, the artificial spit along the Philips oil terminal and the reclaimed area reduced wave fetch and wave erosion. Algal mats established and have spread lately, further stabilising the sediments. The supply of sand has increased. Adding to this, the general deposition rate of say 1.35 Mm^3/y (post-barrage) being in excess of the 1 Mm^3/y dredged, it is clear that the estuary is silting up. Although not an immediate danger, without intervention Seal Sands may in long terms be transitioned into a salt marsh.

Further detailed points from the study:

- Sand and silt are carried into the Tees estuary from the sea during storms. Annual rates are in the order of 1.5 Mm^3/y or 700,000 tonnes.
- Sand settles out in the lower parts of the estuary
- Silt and clay may be carried further upstream by gravitational action (tidal undercurrent) and re-suspension by dredging and shipping activities
- Only 40,000 tonnes/year originate from the river, with some sand settling out in upper reaches and silt being carried further downstream.
- The recent increase in deposition of sand fractions on Seal Sands may stem from North Gare Sands where sand is bypassing the breakwater to ”spill” further into the estuary
- Other reasons may be changes in coastal drift due to changes in wave climate; breakdown of a slag shoal off North Gare Breakwater; breaches in the slag embankment protecting Seaton Channel and the turning circle
- The trend of sand accretion at Seal Sands may be stemmed by dredging of Seaton Channel, creating a sediment trap.

6.2 Durham University 2003 /1/

A study of the sediment dynamics in the lower Tees was commissioned by the Environment Agency in 2003. The work was aimed at providing a base for reviewing policies and applications for trade effluent and sewage discharges into the estuary. Sediment dynamics between June 2003 and March 2004 were studied.

Based upon repeat sampling of the upper 2 cm of intertidal sediments on 70 sites on Seal Sands from 1992 to 2003, a systematic change in grain size distribution is evident. Seal Sands have evidently been accreting sediments since the 1970’s. Predictions from HR Wallingford from 1966 regarding sedimentation rates and characteristics have come true. Since 1992 sampling shows a trend towards finer sediments, possibly from dredging operations. This is somewhat in contradiction to the findings from HR Wallingford presented in Section 6.1 above (although this also mentions that theoretically, the impacts of the barrage, changes in maintenance dredging etc. could cause sediment fractions to become finer).

Mapping of algal mats shows that areas covered by *Enteromorpha Sp.* have increased from 10 % in 1992 to 50 % of the Seal Sands intertidal area in 2003. The spreading of the algal mats may have been aided by detachment and transportation by wave action.

Six sediment cores were analysed to reconstruct the sediment history of Seal Sands. Sedimentary sequences obtained were analysed by transecting ^{137}Cs and ^{210}Pb levels through the cores. All cores showed net accretion since the beginning of the 20th century. Some showed sediment disturbance events believed to be man-made, as no major natural changes have occurred in the estuary lately.

Three locations were analysed for diatom records, indicating that before 1964, some areas were soft mudflats, and one area was firmer. All areas have gradually become elevated, better drained and firmer. The high abundance of epiphytic diatoms in sediments predating 1950 showed that macro algae were present at this time. Around 1960 macro algae density was drastically reduced, but levels have risen since then. Conditions for macro algae were evidently severely impacted in the 1960-70’s, most likely by land reclamation programmes.

Levels of heavy metal pollution were high from 1920 to 1970, most elements have declined since then. Vanadium and Chromium peaked in the 1970’s, and Titanium levels remain high today. Fine grain sediments buried beneath the surface on Seal Sands contain significant concentrations of heavy metals that may be toxic to flora and fauna if disturbed.

6.3 Other data sources

In June 1995 Zeneca /3/ undertook a survey of the Tees estuary to map the following data at five locations:

- Current speed and direction
- Salinity, temperature, dissolved oxygen and pH at the surface, at 0.5 m depth and at every 1.0 m interval to the bed, at half hourly intervals for a period of 12.5 hours for each day in a full tidal cycle
- Meteorological observations, tidal height and freshwater flow data for the period in question
- Suspended solids samples hourly for two days, at 1 m intervals to the bottom

- Inorganic nitrogen ½-hourly at 0.5 m depth, mid depth and 1.0 m off the bottom on 4 days
- Biological oxygen demand hourly at 0.5 m depth and 1.0 m off the bottom on 2 days
- Dissolved metals at 0.5 m depth, ½-hourly on one day
- Cyanide at 0.5 m depth hourly on one day
- Volatile organics at 0.5 m hourly on 2 days

The survey locations were Teesport, Smiths Dock, Transporter Bridge, Billingham Reach and Old River Tees, representing various locations along the River Tees and the estuary.

Data were tabulated for neap and spring tidal cycles.

The Environment Agency /7/ supplied further base data regarding bathymetry, currents, sediment distribution and quality, suspended sediment, temperature, salinity, tidal elevation and water quality.

PD Teesport /6/ provided access to the most recent dredging control charts for a detailed bathymetry of the dredged areas. The bathymetry was supplemented by the EA bathymetry data /7/, by digitizing areas of the Chart 2566 – Tees and Hartlepool Bays /8/, and from other maps of land areas.

7 MODELLING OF DREDGING OPERATIONS - SSFATE

For the backhoe dredging, four separate locations of the dredging were assumed. Location 1 was set to be in the back end of the dredging area labelled 1 in Figure 3-1. Location 2 was taken near the middle of Area 1. Location 3 was taken in the middle of Area 2 in Figure 3-1 and location 4 was taken in the middle of the area labelled 4. These four locations should yield results fairly representative of dredging using a backhoe. The hopper dredge operates along the dredging line shown in Figure 4-9. With the four locations for the backhoe dredging and the hopper line location, 5 dredging operations were simulated. With each simulation being conducted during first a neap tide and then during a spring tide, a total of 10 different SSFATE simulations were made.

SSFATE provides several type of output. These include animations of suspended sediment concentrations and particle movements for each individual sediment fraction as well as for all fractions taken together. Animations are an extremely effective way of looking at model results, however, unless AVI files are made, one needs the SSFATE model to view the animations. For this report it was decided that the most meaningful way of illustrating the model result was a picture of the suspended sediment plume showing the maximum concentrations computed anywhere in the water column during the simulation for all sediment fractions taken together. As one moves away from the dredging source, the plume is composed of only fine silt and clay particles, with the coarser material being deposited near the dredging site. Pictures of the bottom deposition contours are also presented for each scenario.

7.1 Backhoe Dredge Results

Figure 7-1 shows the maximum sediment concentrations in the plume resulting from dredging at Location #1, i.e., in the back of Area #1 during a neap tide. Since flow velocities are very small in this area, the plume is of limited extent. It can be seen that maximum total suspended sediment concentrations of 1000 mg/l are exceeded very near the source. With the plume being defined by concentrations greater than 5-10 mg/l, it can be seen that the plume extends for about 60 m from the dredge. Figure 7-2 shows the bottom deposition of the released sediments as a mass per unit area. Figure 7-3 shows the same simulation during a spring tide period. Although the plume is still fairly small (maximum extent of 125 m), with the larger velocities generated during a spring tide the plume is larger than that generated during a neap tide. The maximum concentration for the spring tide plume is also greater than 1000 mg/l very near the dredge. Bottom deposition is shown in Figure 7-4.

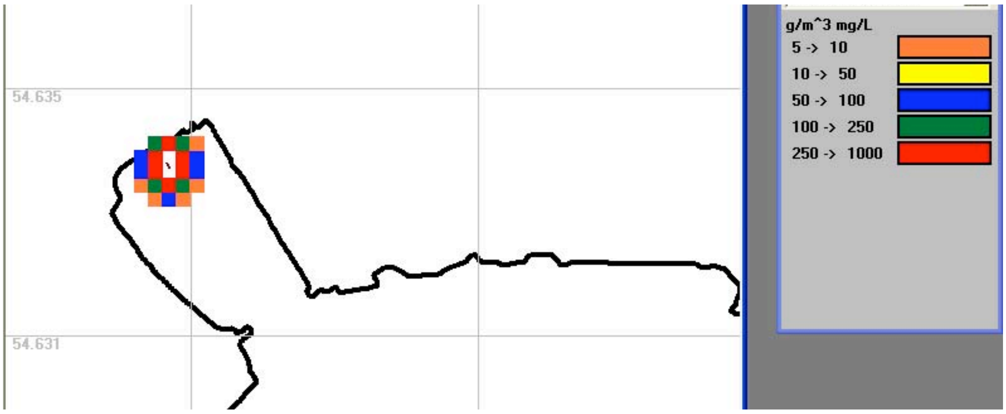


Figure 7-1 Maximum total suspended sediment concentrations (mg/l) for backhoe at location 1 in Area #1 during a neap tide

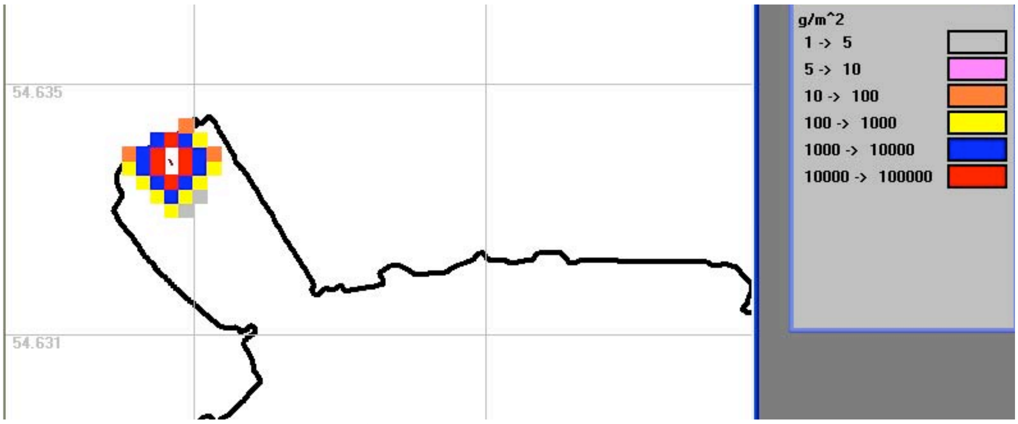


Figure 7-2 Bottom deposition (g/m^2 after 2 days of dredging) for backhoe at location 1 in Area #1 during a neap tide

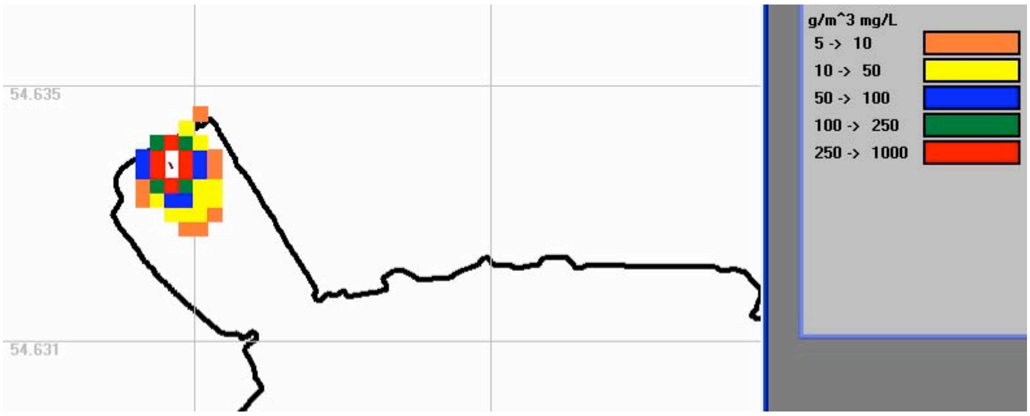


Figure 7-3 Maximum total suspended sediment concentrations (mg/l) for backhoe at location 1 in Area #1 during a spring tide

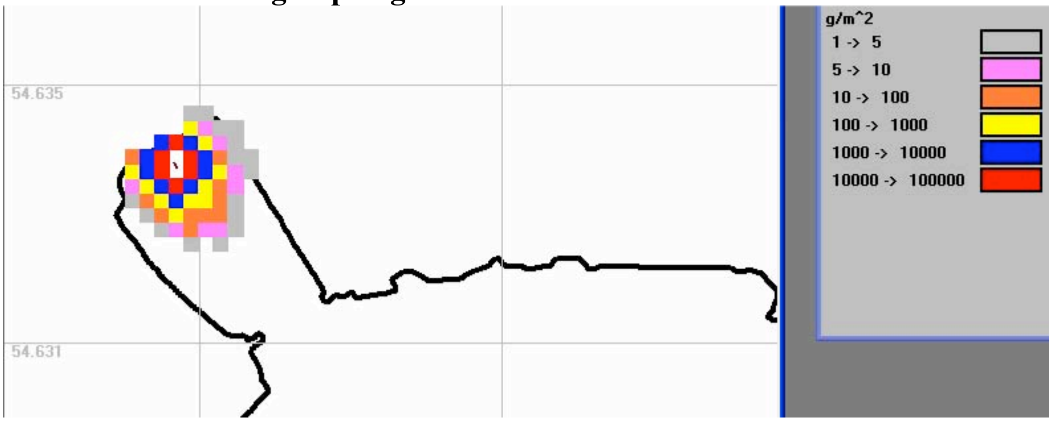


Figure 7-4 Bottom deposition (g/m^2 after 2 days of dredging) for backhoe at location 1 in Area #1 during a spring tide

As the dredging proceeds toward the middle of Area #1, Figure 7-5 shows that for a neap tide the plume is contained within Area #1 with a maximum extent of 170 m and maximum concentrations near the dredge in excess of 1000 mg/l. Figure 7-6 illustrates the bottom deposition. For dredging during a spring tide, Figure 7-7 displays the suspended sediment plume of maximum concentrations. Note that now the plume is very much larger and moves out of Area #1. Maximum concentrations near the dredge are still higher than 1000 mg/l, with the extent of the plume being about 1000 m. The bottom deposition is shown in Figure 7-8.

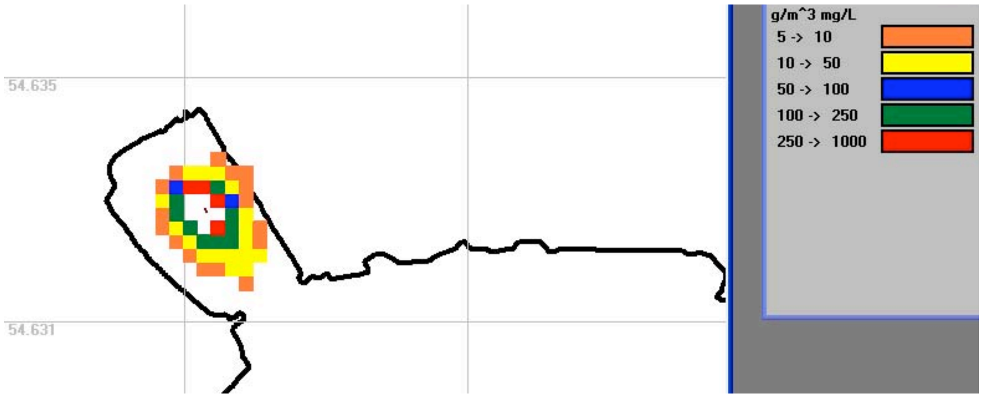


Figure 7-5 Backhoe dredging, Location #2, neap tide, max sediment concentrations mg/l.

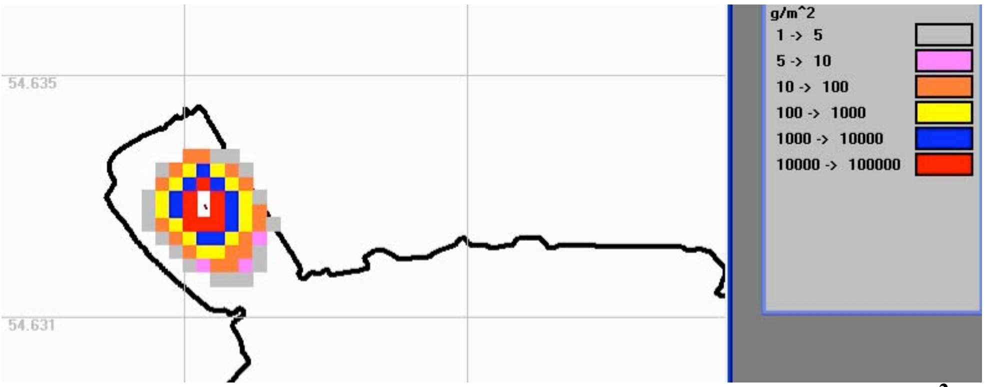


Figure 7-6 Backhoe dredging, Location #2, neap tide, sediment deposition g/m^2 after 2 days of dredging.

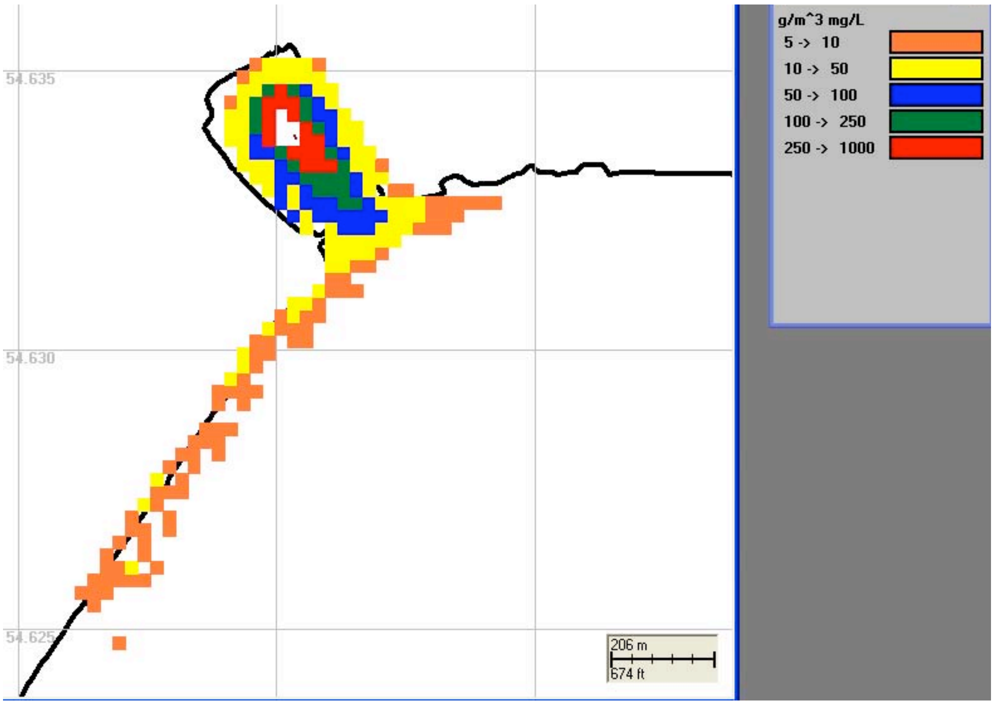


Figure 7-7 Backhoe dredging, Location #2, spring tide, max sediment concentrations mg/l.

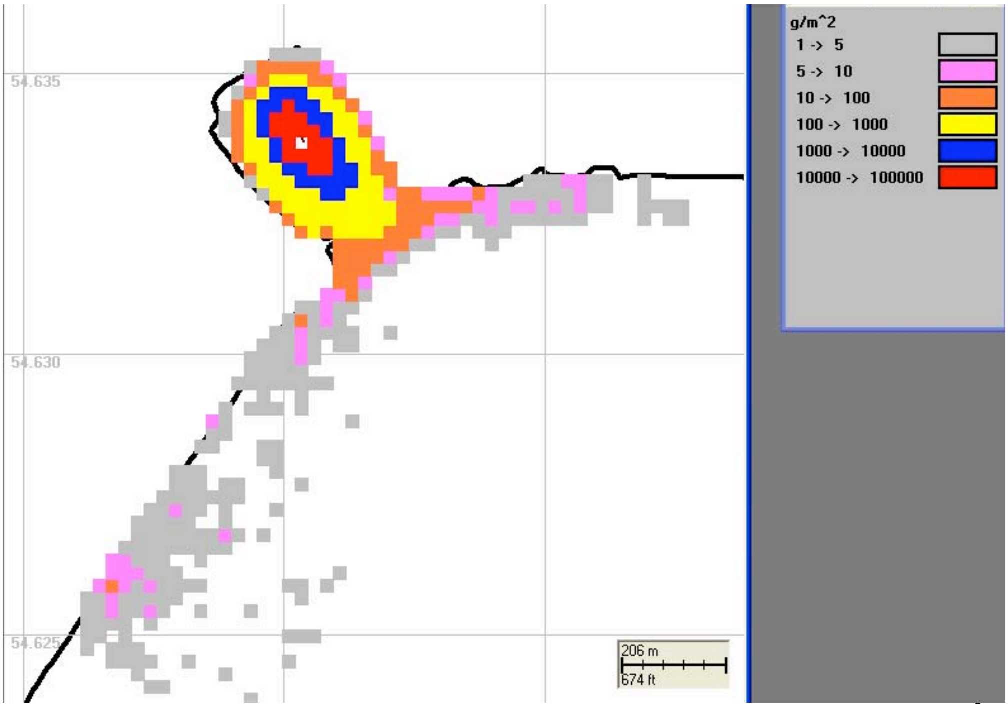


Figure 7-8 Backhoe dredging, Location #2, spring tide, sediment deposition g/m^2 after 2 days of dredging.

For dredging in Area #2, both the neap and spring tide simulations generate significant plumes, shown in Figure 7-9 and Figure 7-11 respectively. Maximum concentrations very near the dredge are again in excess of 1000 mg/l for both plumes. Again, due to much larger currents, the spring tide plume extends much farther than the neap tide plume, e.g., 1000 m versus 400 m. Bottom deposition contours for both plumes are shown in Figure 7-10 and Figure 7-12, respectively.

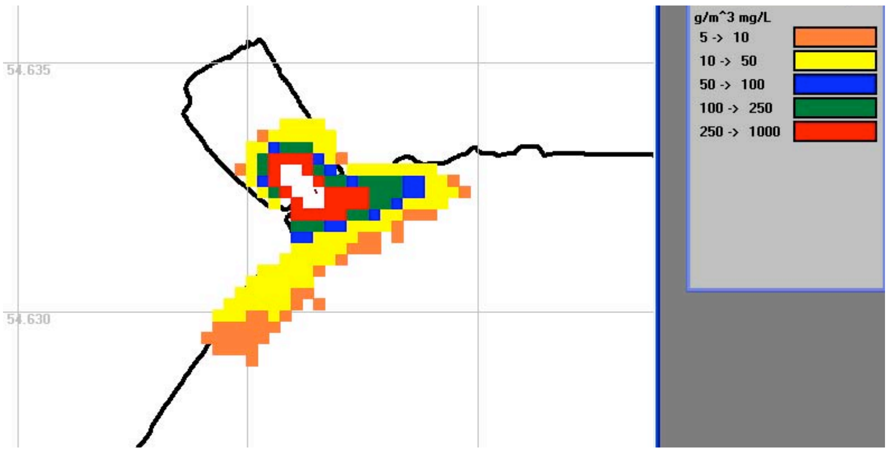


Figure 7-9 Backhoe dredging, Area 2, neap tide, max sediment concentrations mg/l

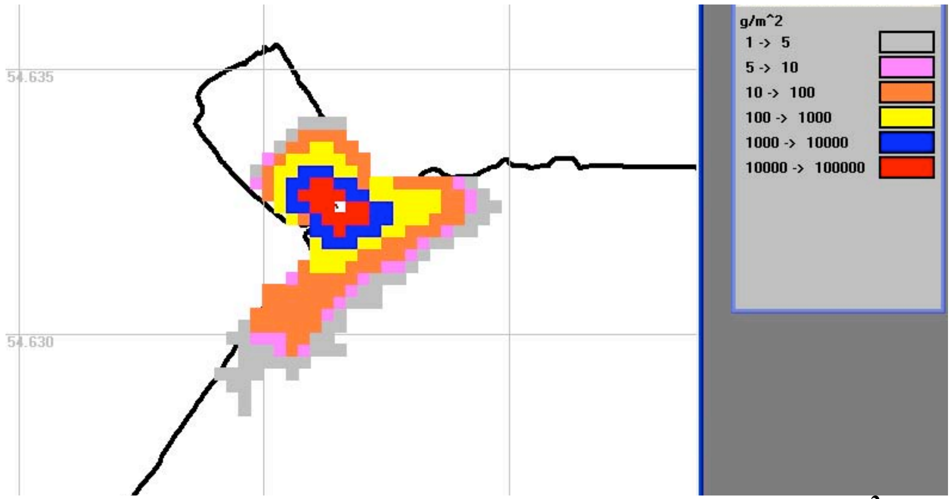


Figure 7-10 Backhoe dredging, Area 2, neap tide, sediment deposition g/m^2 after 2 days of dredging.

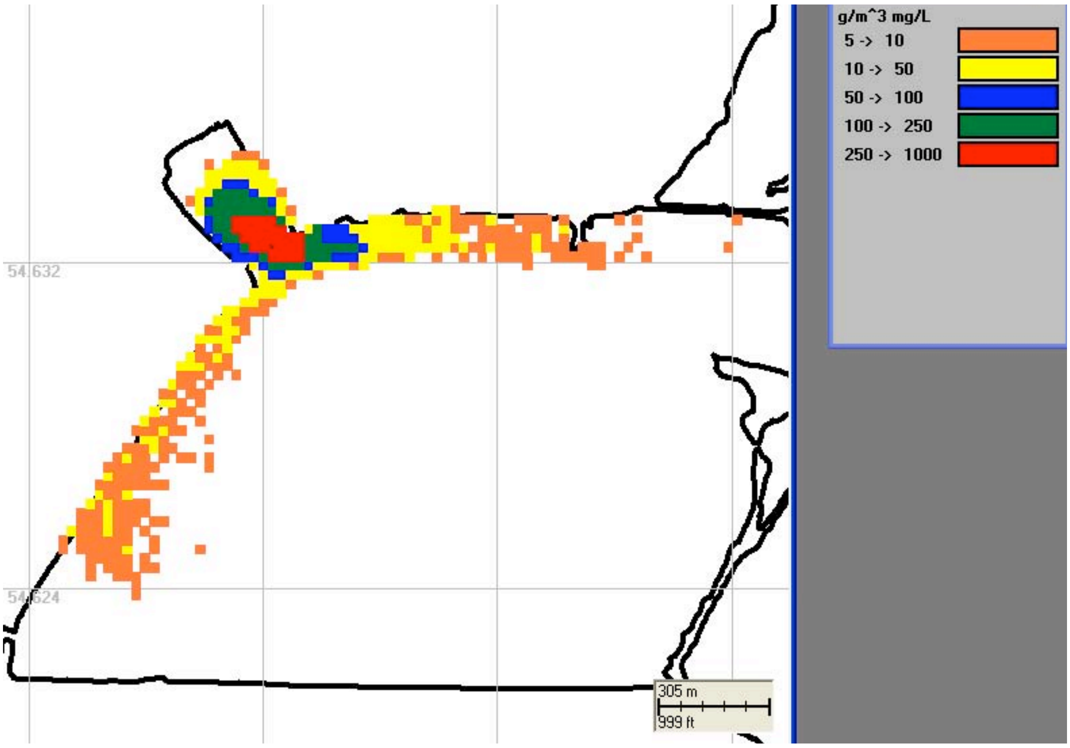


Figure 7-11 Backhoe dredging, Area 2, spring tide, max sediment concentrations mg/l.

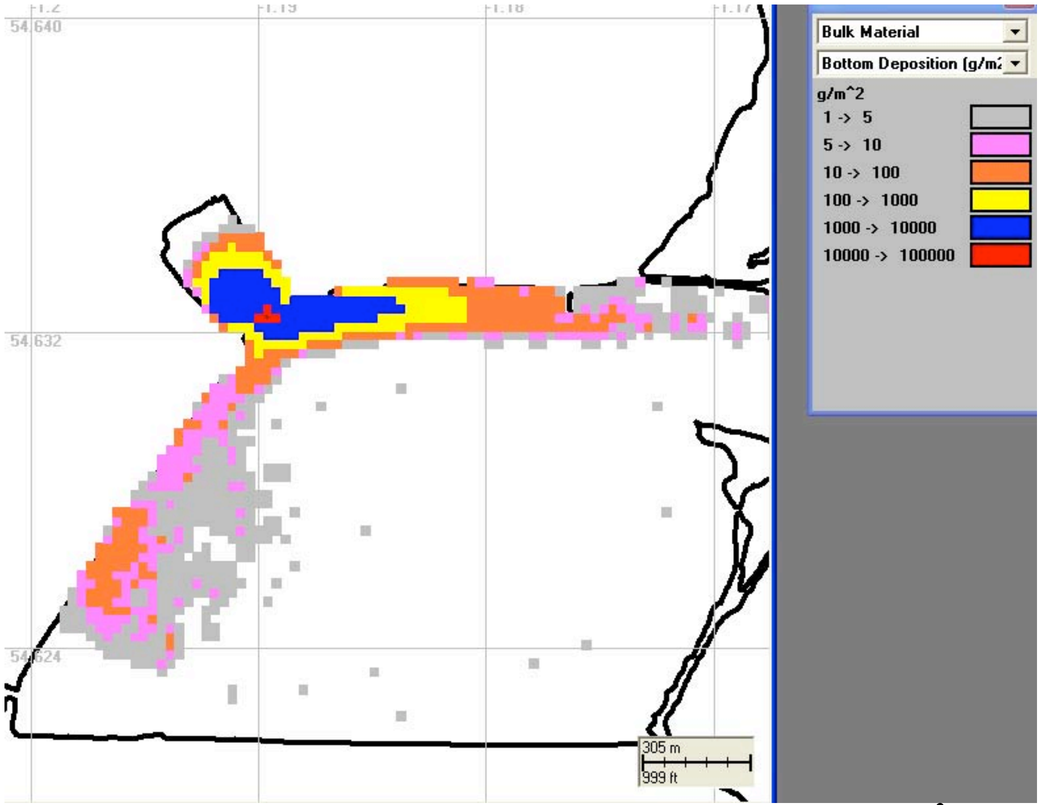


Figure 7-12 Backhoe dredging, Area 2, spring tide, sediment deposition g/m^2 after 2 days of dredging.

Results from dredging with a backhoe in Area #3 are shown in Figure 7-13 to Figure 7-16. Again, as would be expected, the spring tide plume is much longer (1100 m versus 350 m) and larger than the neap tide plume. Maximum concentrations are now less than 1000 mg/l very near the source for both plumes.

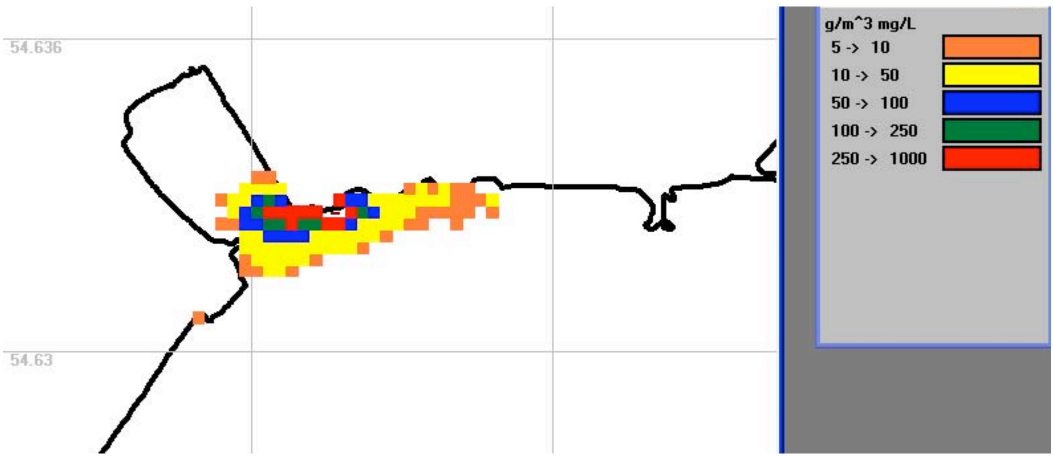


Figure 7-13 Backhoe dredging, Area 3, neap tide, max sediment concentrations mg/l.

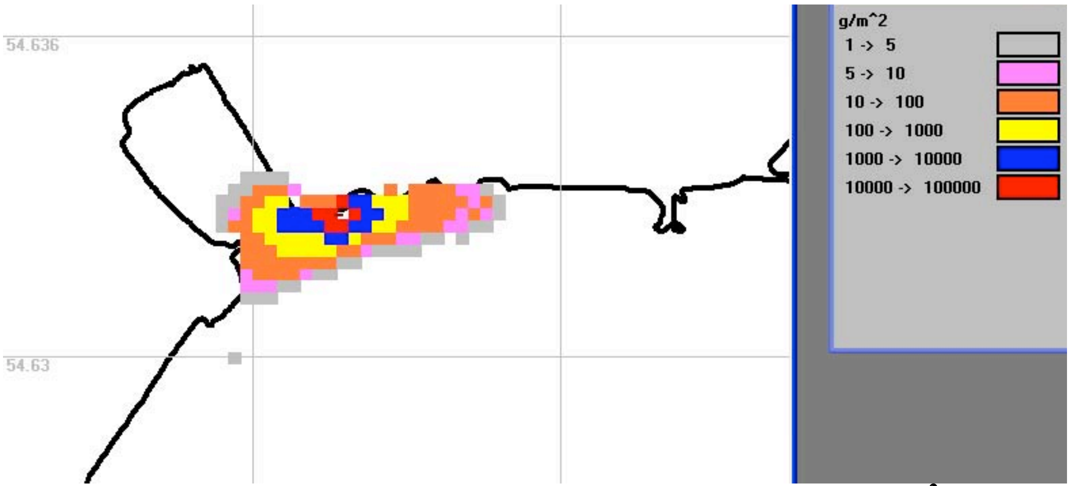


Figure 7-14 Backhoe dredging, Area 3, neap tide, sediment deposition g/m² after 2 days of dredging.

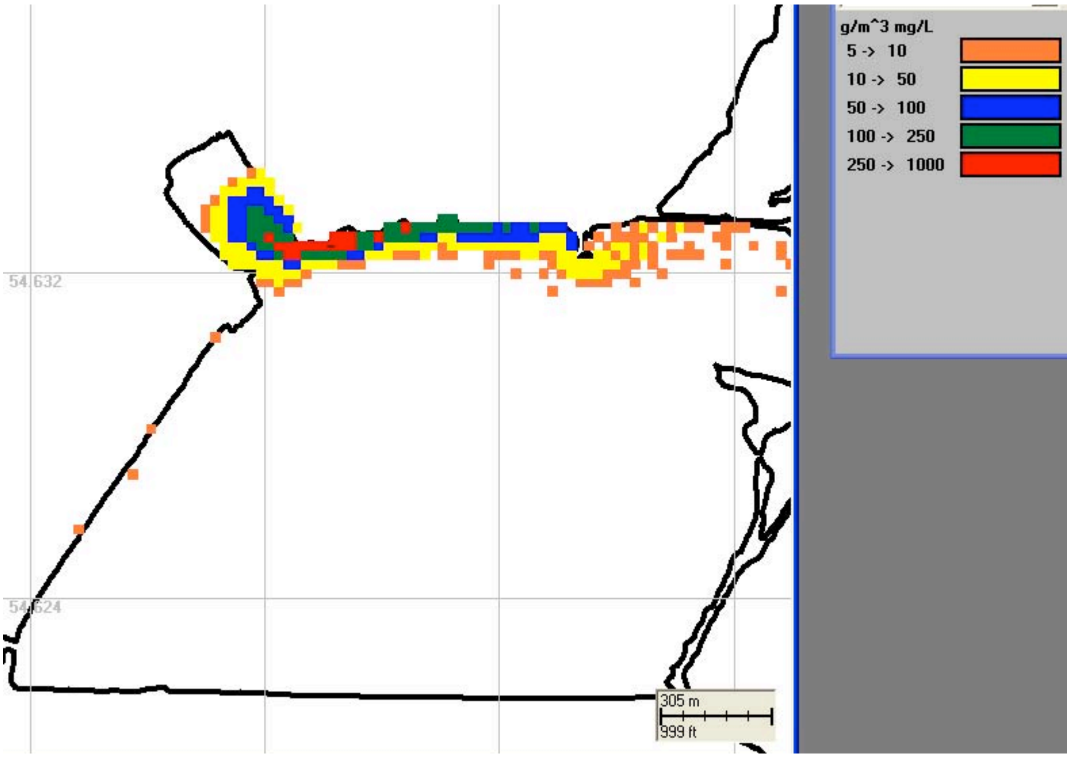


Figure 7-15 Backhoe dredging, Area 3, spring tide, max sediment concentrations mg/l.

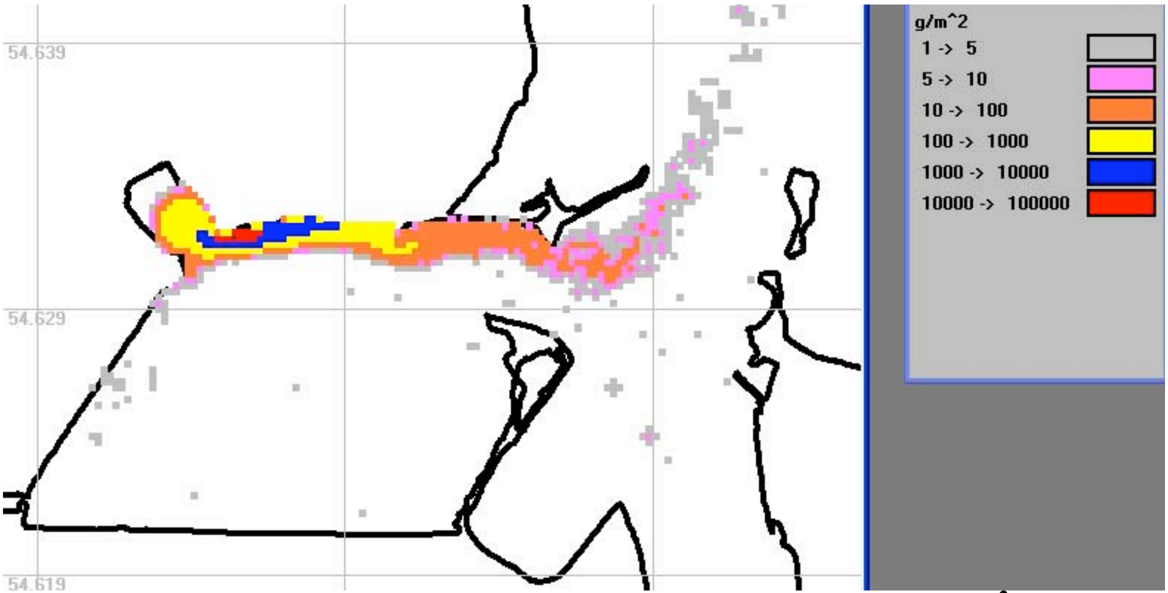


Figure 7-16 Backhoe dredging, Area 3, spring tide, sediment deposition g/m^2 after 2 days of dredging.

7.2 Hopper Dredge Results

Figure 7-17 and Figure 7-19 show the maximum concentration of suspended sediment plumes generated from the hopper dredging during a neap and spring tide, respectively. As for the backhoe dredge, the plume created during spring tide dredging is much larger than that created during a neap tide. Maximum concentrations are less than 1000 mg/l for both plumes along the dredging line. The spring tide suspended sediment plume extents all the way to the boundary of the RMA2 model grid. Some intrusion into the Tees River can be observed for the spring tide plume. Bottom deposition for both plumes is shown in Figure 7-18 and Figure 7-20, respectively.

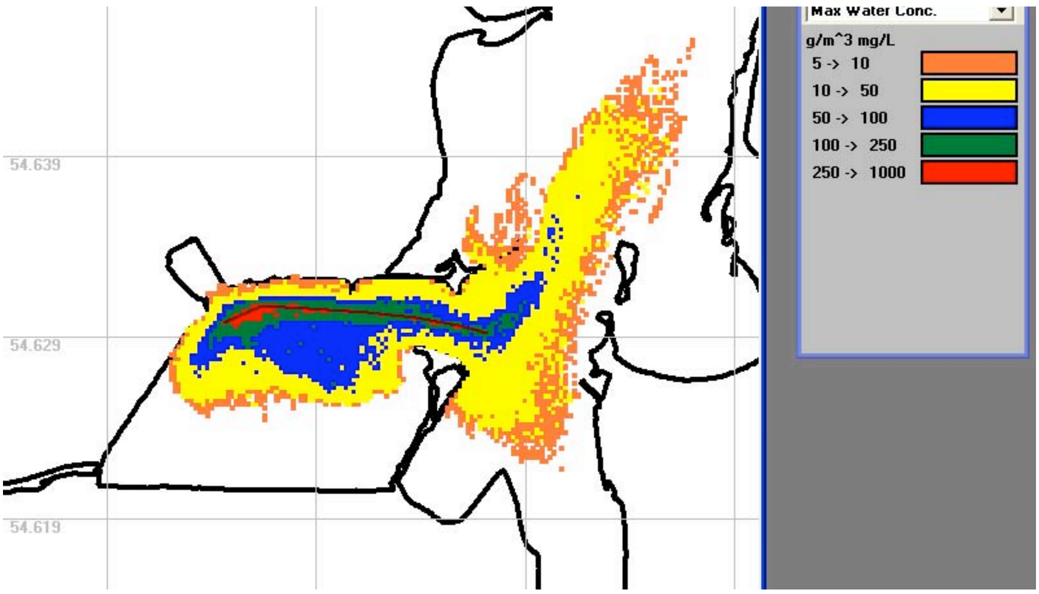


Figure 7-17 Hopper dredging, neap tide, max sediment concentrations mg/l

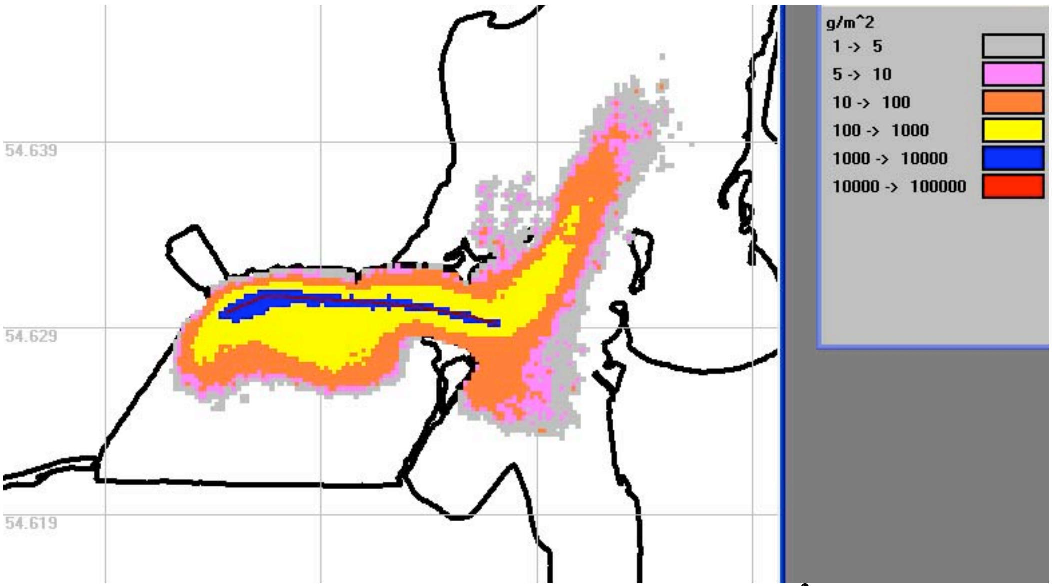


Figure 7-18 Hopper dredging, neap tide, sediment deposition g/m^2 after 2 days of dredging.

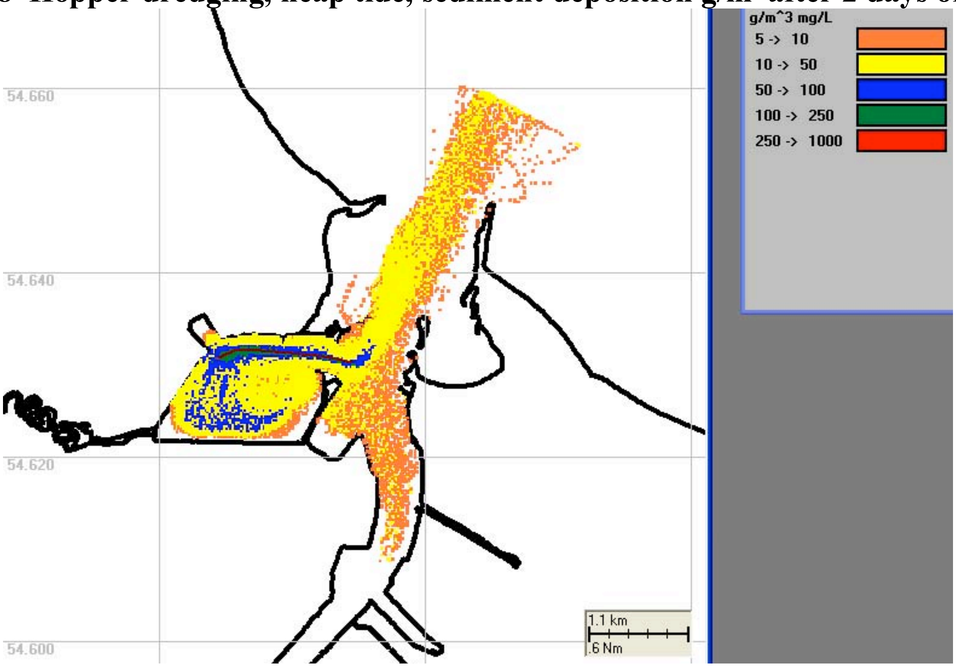


Figure 7-19 Hopper dredging, spring tide, max sediment concentrations mg/l

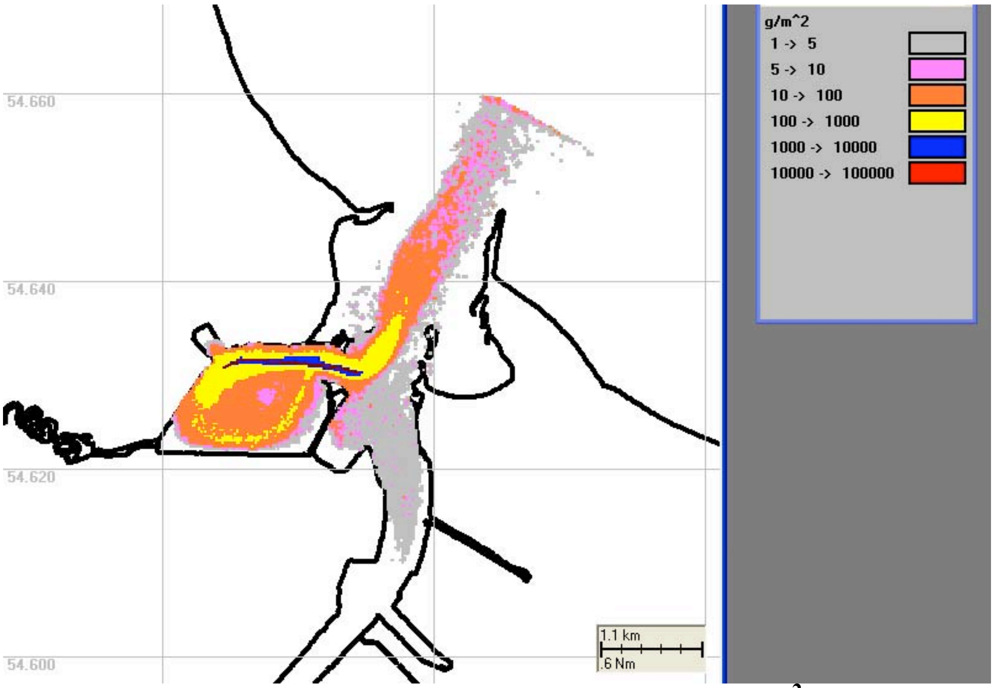


Figure 7-20 Hopper dredging, spring tide, sediment deposition g/m^2 after 2 days of dredging.

7.3 Backhoe and hopper dredges operating simultaneously

Figure 7-21 shows a superposition of the maximum concentration plumes when the hopper dredge and the backhoe dredge are both operating at the same time. It can be seen that little interaction occurs when the backhoe operates in Area #1. Some interaction does occur when Areas #2 and #3 are being dredged while the Seaton Channel is being dredged, but the interaction doesn't significantly increase the maximum concentrations of the suspended sediment plume generated from only one dredge operating at a time.

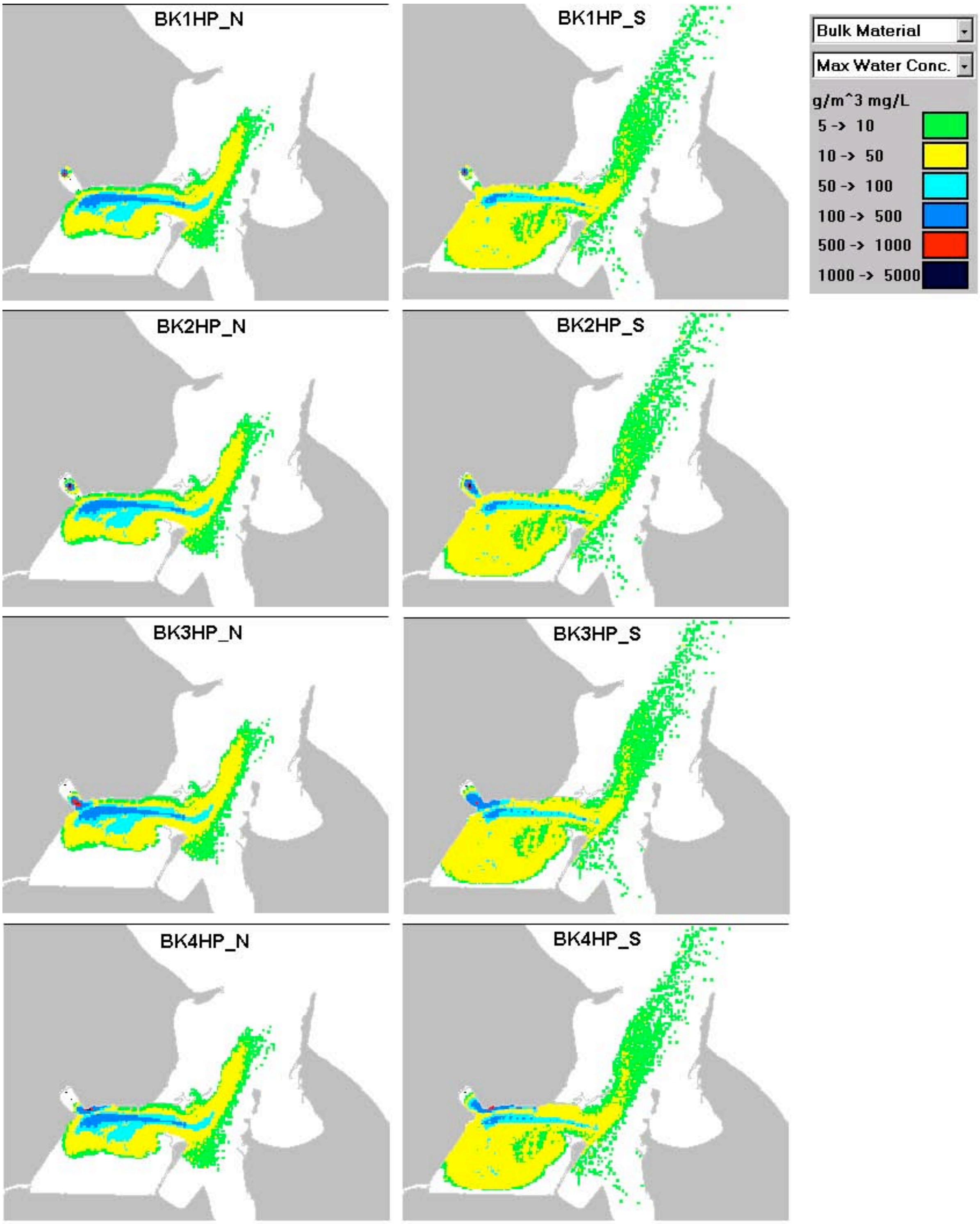


Figure 7-21 Superposition, max concentration plumes hopper operating in Seaton Channel and backhoe in dredging area 1 to 4 on neap (N) and spring (S) tides

8 DESCRIPTION OF NATURAL RESOURCES

8.1 Important areas

The Teesmouth NNR covers an area of about 355 ha on the northern side of the Tees Estuary. It comprises the North Gare Sands, Seaton Common and the Seal Sands mudflats. The North Gare has an extensive sandy beach and dunes protected by an artificial breakwater. During spring and summer, the dunes are studded with brightly-coloured flowers. Large numbers of wading birds, including Knot, are seen for much of the year. In winter Snow buntings are found in the sand dunes and Short-Eared Owls are occasionally seen hunting.

To the south lie the tidal mudflats of Seal Sand, the largest area of intertidal mud between the Humber estuary and Holy Island. Thousands of waders and ducks feed here during low tide and seals bask on sunny days. The Reserve boasts the only regular breeding colony of common seals on the north-east coast of England. The mudflats are too dangerous for human access.

COATHAM MARSH, REDCAR

Coatham Marsh is a 134 acre nature reserve established in 1982 by the Tees Valley Wildlife Trust on land leased from British Steel. The reserve comprises 50 acres of ancient marsh traversed by a freshwater fleet, which flows into the Tees at Bran Sands, and is bounded by 80 acres of grazed meadows, artificially created mounds and two freshwater lakes. The range of habitats and the reserve's proximity to the Tees Estuary has attracted over 200 species of birds and a rich diversity of flora. A 'scrape' (or pool) has been created on the west marsh to yield an additional feeding area for wetland birds, particularly during the migration periods in the winter.

Adjacent coastal habitats at Coatham Sands and the South Gare include nationally important sand dune habitats and are of international importance for bird life.

RAMSAR SITES

The Teesmouth and Cleveland Coast Ramsar are important for supporting substantial numbers of waterfowl, with about 1 % of the British population. The nearest Ramsar site to the north is the Firth of Forth and to the south the Humber Estuary.

8.2 Invertebrates, benthic fauna

The benthic community has three claims to importance for environmental monitoring. It is in close contact with the sediment, in and on which many pollutants accumulate (heavy metals, organic particles and some organic compounds). These contaminants can directly inhibit the growth or survival of the more sensitive species, thus reducing species diversity, abundance or biomass.

Secondly, the benthos provides the main food source for the more visible animals which exploit an aquatic habitat, such as wading birds and fish. It follows that the greater the productivity and biodiversity of the benthos in the Tees estuary, the greater will be the numbers and variety of birds and fish which it can support. Finally, the benthos can accumulate contaminants from its environment which may then be concentrated at higher levels in the food chain.

At least 90 species have been identified, with an average of 70 being present at any one time. Some of these, particularly the marine and estuarine worms, may be present at high densities.

There has been an unmistakable increase in the biodiversity of the estuarine macro fauna since 1979. The number of species present in any particular area tends to fluctuate from year to year, but over a period of time each area of the Tees estuary has become more biodiverse.

Nematodes are a major component of the benthic meiofauna. Historically, a few tolerant nematode species have dominated the communities present in the Seaton Channel sediments. The population densities of these species have declined as conditions have improved and the communities have usually increased in species richness with the appearance of more sensitive estuarine species.

8.3 Fish

There is no quantitative information available on the fish populations of Teesbay. The number of fish species present in the upper (tidal and brackish) regions of estuaries is naturally low. However, the potentially high benthic productivity within an estuarine environment can support a large biomass of fish coupled with a relatively low diversity of species.

Six groups of fish can be defined on the basis of their behaviour in estuaries:

- Freshwater fish that occasionally enter brackish water.
- Estuarine species that spend their lives in the estuary.
- Migratory species (Eel, Salmon, Sea trout)
- Marine species that pay regular seasonal visits to the estuary (usually as adults)
- Marine species that use the estuary primarily as nursery ground
- Opportunistic visitors that appear irregularly and with no apparent necessity to do so

The Tees estuary is an important habitat for many fish species for different reasons. The estuary provides a large sheltered area of shallow water exploited by juvenile fish such as plaice which graze the intertidal and sub-tidal benthic invertebrates. It also provides a potentially productive source of epibenthic invertebrates which feed juvenile and adult demersal fish. Finally, the estuary is an extensive area through which migratory fish must move between the sea and the freshwater reaches of the Tees.

The Tees estuary has three fish communities that can be recognised.

- The Coastal and Lower estuary communities- represented by the largest number of species, both inshore fish and invertebrate species such as Red Gurnard, Dragonet, Pink Shrimp, Edible Crab, and more typical estuarine residents such as the Viviparous Blenny (eelpout) and Flounder.
- The Middle estuary communities- dominated by fewer species such as Dab and Plaice. Also, in the case of the Tees estuary, those versatile species able to tolerate stressful conditions e.g. Flounder, Brown shrimp and Shore Crab.
- The upper estuary communities- fewer species, limited to fish such as eel and flounder which are able to tolerate low salinities- from brackish water to freshwater. Intrusion by freshwater fish in the uppermost tidal reaches, e.g. Dace, Eel and Roach.

Changes in fish populations with time are difficult to detect with the relatively small trawl samples from the Tees area.

8.4 Birds

The coastal marshes and intertidal mudflats of the Tees estuary support populations of waterbirds which are of national and international importance. The Teesmouth area supports populations of a lot of different species of waders, including Ringed Plover *Charadrius hiaticula*, Knot *Calidris canutus*, Redshank *Tringa totanus*, Sanderling *Calidris alba*, Lapwing *Vanellus vanellus*, Dunlin *Calidris alpine*, Bar- tailed Godwit *Limosa lapponica* and Curlew *Numenius arquata*.

The site comprises mudflats that are of great ornithological importance attracting large numbers of migratory wildfowl birds. Of internationally importance is Shelduck *Tadorna tadorna.* In addition, sizeable flocks of Mallard *Anas platyrhynchos*, Teal *Anas crecca*, Wigeon *Anas Penelope*, Pochard *Aythya ferina*, Goldeneye *Bucephala clangula* and Tufted Duck *Aythya fuligula* congregate to roost and feed during cold spells. Different species of Gulls and two species of tern, Common Tern *Sterna hirundo* and Little Tern *Sterna albifrons*, nest regularly around the Tees Estuary and several other Terns are regular visitors. All are migrants.

Total wader populations are generally greater on larger estuaries, whereas bird densities are greater on smaller estuaries. Teesmouth has followed the general trend with wading bird densities increasing as the remaining area of mudflats decreased. Food availability is a major factor in the ability of the estuary to support a large and diverse waterbird population. The birds need a minimum daily energy intake to survive. This means that there must be adequate sustainable populations of invertebrate prey. These prey items in turn are dependent on such parameters as the particle size of the mudflat substrate, pollution levels, its exposure, food availability and salinity.

Another change which has possibly affected Dunlin feeding areas is the increasing firmness of the sediments and increase in coverage of green algae, especially *Enteromorpha* over parts of Seal Sands. Dunlin seldom feed on algae-covered areas (/30/).

Despite the recent decline in Knot populations at Teesmouth, the five-year average of maximum counts is still above the accepted international level.

Although land claim in the 19th an early 20th century almost certainly reduced water-bird populations by eliminating their habitat, since 1960 man has directly had only a limited detrimental effect on the bird populations of the Tees estuary. In contrast, industrial sites have provided formerly limiting habitat requirements for a number of bird species.

8.5 Seals

Two species of seal are common in the Tees area, the Common Seal *Phoca vitulina* and the Grey Seal *Halichoerus grypus*. The Common Seal frequents estuaries and sheltered coastlines hauls out on sandbanks on a falling tide and pups in June or July on intertidal sandbanks. The Grey Seal tends to frequent rocky coast, but may also haul out on sandbanks. Grey Seals tend to be wide ranging but Common Seals usually feed close to their haul-out sites. Data from INCA show a steady increase in the seal population during the last 15 years. In the last 5 years the Common Seal population have been steady with small fluctuations. Each year Common Seal pups are born on Seal sands and successfully weaned.

Table 8-1 Maximum numbers of Common Seals, Common Seal pups and Grey Seals recorded on Seal Sand from 1999- 2003.

Year	No. of Common Seal	No. of Common Seal pups	No. of Grey Seal
1999	56	5	28
2000	70	4	27
2001	71	5	27
2002	71	6	30
2003	58	5	26

8.6 Contamination in the study area

8.6.1 Definitions

MPC	Maximum Permissible Concentration. Concentration above which the risk for the ecosystem is considered unacceptable, i.e. a concentration above which more than 5% of the species in the ecosystem might be affected (/20/).
NC	Negligible Concentration. Concentration below which the risk of the ecosystem is considered negligible (/20/).
ISQG	Interim Sediment Quality Guidelines according to the Canadian Environmental Quality Guidelines (/21/). Concentration below which the risk of the ecosystem is considered negligible.
PEL	Probable Effect Level according to the Canadian Environmental Quality Guidelines (/21/).
Acceptable risk limit	Concentration above which the risk for the ecosystem is considered unacceptable, i.e. a concentration above which more than 5% of the species in the ecosystem might be affected (/24/).

8.6.2 Contamination level

The level of contamination in the dredging areas and at Seals Sand has been mapped and compared with international sediment quality standards. Levels have been mapped for several metals (Ar, Cd, Cr, Cu, hg, Ni, Pb and Zn), PCBs, PAHs and TBT in dredging area 1 to 4 (see Appendix A, Appendix B, Appendix C and Appendix D. On Seals sand the level of metals mentioned above have been mapped.

The sediment quality standards that have been used for metals, PCBs, PAHs and TBT are presented in Table 8-2, Table 8-3,

Table 8-4 and Table 8-5 respectively. Concentrations of contaminants are generally below recommended risk limits for effects on the ecosystem. The exceptions are for the following PAHs: benzo(a)pyrene, Acenaphthylene, Anthracene and Benzo(a)anthracene (see Appendix D). These PAHs are found in concentrations that exceeds the Probable Effect Level (PEL) according to the Canadian Environmental Quality Guidelines (/21/).

Table 8-2 Maximum Permissible Concentrations (MPC) and Negligible Concentrations (NC) for metals in sediments (/20/). Values are given in mg/kg in standard sediments (10% organic matter and 25% clay).

Metals	MPC mg/kg	NC mg/kg
Arsenic (Ar)	190	31
Cadmium (Cd)	30	1,1
Chromium (Cr)	1720	116
Copper (Cu)	73	36
Iron (Fe)		
Mercury (Hg)	26	0,56
Nickel (Ni)	44	35
Lead (Pb)	4800	132
Zink (Zn)	620	145

Table 8-3 Maximum Permissible Concentrations (MPC) and Negligible Concentrations (NC) for PCBs in sediments (/23/).

PCB	MPC µg/kg o.c.	NC µg/kg o.c.	Acceptable risk limit µg/kg
CB#105	26	0,26	
CB#118	25	0,25	
CB#153	151	1,51	
CB156	55	0,55	
Planar PCBs (CB#118)	5	0,05	

Table 8-4 Probable Effect Level (PEL) and Interim Sediment Quality Guidelines (ISQG) for PAHs in sediments according to the Canadian Environmental Quality Guidelines (/21/). Values are given in mg/kg dry weight.

PAH	PEL mg/kg	ISQG mg/kg
Acenapthene	0,0889	0,00671
Acenapthylene	0,128	0,00587
Anthracene	0,245	0,0469
Benzo(a)anthracene	0,693	0,0748
Benzo(a)pyrene	0,763	0,0888
Chrysene	0,846	0,108
Dibenz(a,h)anthracene	0,135	0,00622
Fluoranthene	1,494	0,113
Fluorene	0,144	0,0212
Naphthalene	0,391	0,0346
Phenanthrene	0,544	0,0867
Pyrene	1,398	0,153

Table 8-5 The acceptable risk limit for TBT is proposed by Breedveld (/24/). Values are given in µg/kg dry weight (sediments with 1% organic carbon).

Organotins	Acceptable risk limit, µg/kg
TBT	35

9 IMPACT ON SHIP MOVEMENTS

See Section 3.2 above regarding maintenance dredging of Seaton Channel including the holding basin, and the dry dock.

In order to ensure safe navigation for ships, changes in channel geometry should be monitored regularly. In order to maintain depths as described in Section 3.1, an estimated 23,000 m^3 must be dredged annually from Seaton Channel and the holding basin. The dry dock, when open, requires dredging of a further 12,500 m^3.

The sedimentation rate in Seaton Channel, the holding basin and the dry dock may rise when the bed level is lowered. Lower water velocities and shear stress will promote settling and reduce any erosion. It is also possible that finer sediments settle upstream, and Seaton Channel may act as a sand trap for sand currently reaching Seal Sands from North Gare Sands /2/.

Any vessel entering the channel must have at least 0.5 m under keel clearance /19/. Figure 4-3 shows levels of Mean High Water Spring 5.5 m LAT and Mean High Water Neap (4.3 m LAT).

At present, the depth in Seaton Channel is -3.5 m LAT /19/. At Mean High Water Spring a vessel with draft

$$3.5 + 5.5 - 0.5 = 8.5\ m$$

may enter the channel. Assuming the level in the holding basin is the same as in the channel, however, the vessel must satisfy 0.5 m under keel clearance at the Lowest Astronomical Tide (LAT = O), such that the maximum draft for mooring vessels in the Holding Basin at present is

$$3.5 + 0 - 0.5 = 3.0\ m$$

Seaton Channel is proposed dredged to -8.5 m LAT, such that a vessel with draft

$$8.5 + 5.5 - 0.5 = 13.5\ m$$

may pass at Mean High Water Spring.

The Holding Basin is proposed dredged to -9.5 m, such that a vessel with draft

$$9.5 + 0 - 0.5 = 9.0\ m$$

may be anchored there at the Lowest Astronomical Tide.

Quay 10 and 11 are proposed to be dredged to -12 m LAT, such that a vessel with draft

$$12.0 + 0 - 0.5 = 11.5\ m$$

may be moored there at the Lowest Astronomical Tide.

The dry dock is proposed dredged to -6.65 m LAT, so that a vessel with draft

$$6.65 + 5.5 - 0.5 = 11.65\ m$$

may be floated in at the Mean High Water Spring, provided it can be positioned such that it is not damaged creating a hazard when the high water recedes. If securing of the vessel will take considerably longer, it may be floated in at Mean High Water Neap and must have a draft of

$$6.65 + 2.0 - 0.5 = 8.15\ m$$

in order to stay safely afloat for securing during Mean Low Water Neap. A vessel with draft

$$6.65 + 0 - 0.5 = 6.15 \text{ m}$$

may be moored in the dry dock during the Lowest Astronomical Tide.

In short, after the proposed modifications to the channel and dry dock, a vessel with draft 11.5 m may be towed in Seaton Channel at Mean High Water Spring, be moored at Quay 10 or 11 during the Lowest Astronomical Tide for partial dismantling, and may be floated into the dry dock at Mean High Water Spring provided the vessel can be positioned and secured safely to chocks at the sea bed immediately before the high water recedes.

10 DISCUSSION

10.1 Sediment transportation

The hydrodynamic and sediment transportation processes predicted by the computer model has been discussed in Section 5.3 above, but is recapitulated here, expanded with considerations related to other natural processes not included in the computer model.

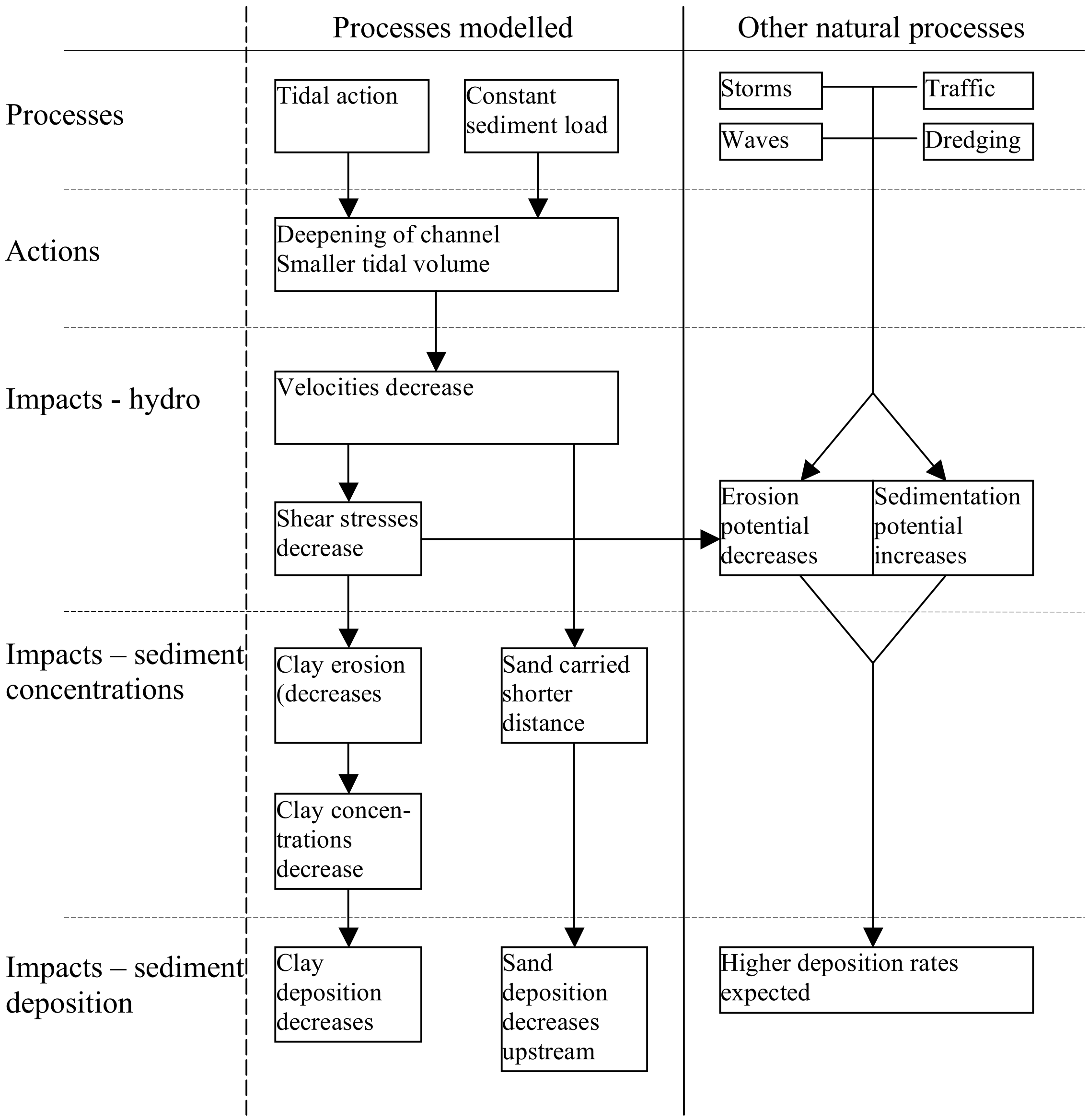


Figure 10-1 Expanding dynamics of model to other natural estuarine processes

The hydrodynamic and sediment transportation processes predicted by the computer model has been discussed in Section 5.3 above, but is recapitulated here, expanded with considerations related to other natural processes not included in the computer model.

The hydrodynamic model predicted lower velocities in certain areas due to lower tidal volume when closing the dry dock, and due to a larger cross-sectional area in which to convey the tidal volumes when the channel bed was lowered. A corresponding decreased shear stress was found to decrease (false) erosion, with lower concentrations of clay in the water column and ultimately lower deposition of clay in general. Sand was found not to be affected to a great degree, if anything it was not carried so far upstream.

The decrease in velocity, and as a result a decrease in shear stress, will decrease the potential for erosion, and increase the potential for sedimentation. Although little or no clay sediments are present in the high shear areas, as the model shows, if clay is introduced it will probably erode. The potential for erosion is there, but will decrease. Correspondingly, the potential for sedimentation will change. Even if no sediment is present in the water column, the potential for deposition increases with decreasing shear stress. This increase in sedimentation potential is not correctly presented in the modelling results, as the decrease in erosion decreases the amount of sediment available in the water column for deposition.

See Figure 10-1 when considering other natural sediment sources and processes in the estuary, the sedimentation pattern may change. Suspended sediment is in reality not only introduced by tidal processes, but also from more unpredictable events like storms, wave erosion, local sedimentation patterns, traffic and dredging. Dredging operations, as modelled in Section 7 above, produce far higher concentrations of suspended sediment that, dependent on the tidal condition, may extend considerable distances. Indeed, dredging of the Tees estuary is a “continuous operation” /2/, so higher concentrations of suspended sediment may be expected over time, see Figure 5-2 and Figure 5-3.

As the sedimentation potential increases, the suspended sediments not considered in the computer model will take advantage of this potential and settle in areas where the shear stress is lowered, see Figure 5-14. Seaton Channel, and to a lesser extent Seal Sands, may experience a higher sedimentation rate.

The sediment “fractions” may also change from sand to finer sand, silt and clay. The boundary for where clay and silt can be present will probably be shifted downstream.

More sand may be trapped in Seaton Channel, stemming the present migration of sand to Seal Sands, which has been identified as a possible cause of loss of bird feeding capacity /2/.

It is important to realise that the Seaton Channel with Seal Sands, the TERRC dry dock and Greatham Creek form a semi-closed hydrodynamics and sediment “sub-cell” within the Tees estuary. The artificial barriers at the north of Seaton Channel and at the east of Seal Sands enclose the bay and all water and sediment interchange has to come through a relatively narrow channel. Seaton Channel and Seal Sands receive sediments largely from North Gare Sands and the sea /3/.

It is seen that the hydrodynamic characteristics and corresponding sediment transportation processes are influenced to some within the bounds of Seaton Channel. Out with the bounds of Seaton Channel the hydrodynamics and sand transportation regime are unchanged.

10.2 Dredging

It is believed that for the assumptions made concerning the sediment source strengths and grain size fractions SSFATE computations realistically represent suspended sediment plumes that will be generated by the two dredging operations; namely, a backhoe and a hopper dredge. Maximum total suspended sediment concentrations can exceed 1000 mg/l for the backhoe dredge, but are less for the hopper dredge. In all cases, the concentrations drop off quickly away from the dredge.

The size of the sediment plumes are significantly larger when dredging during a spring tide versus dredging during a neap tide. The size of the plumes generated by the hopper dredge can be an order of magnitude larger than those generated by the backhoe.

For the case of both dredges operating simultaneously, there will be little interaction of the suspended sediment plumes when the backhoe is operating in Area #1. However, some interaction will occur when dredging Areas #2 and #3 with a backhoe with the hopper dredge operating at the same time.

Some of the released sediments for both the backhoe and the hopper dredge are transported into the shallow areas south of the Seaton Channel. There is very limited intrusion of sediments into the Tees River for any of the scenarios simulated. However, during the ebb portion of a spring tide, suspended sediments can be transported out to the sea as a result of the hopper dredge activity.

10.3 Impact on marine life

10.3.1 Impact of changes in hydrodynamics and sediment transportation

As described above in chapter 10.1 the different scenarios that have been modelled predicted lower water velocities and a corresponding decrease in shear stress within the bounds of Seaton Channel. As a result of this the potential for erosion decreases and the potential for sedimentation increases in this area. Outward the bounds of Seaton Channel the hydrodynamics and sediment transportation regime are not significantly changed.

At the same time it can be seen from the model runs that the maximum shear stress is below 0.1 N/m^2 on Seal Sands, in the inner reaches of Seaton Channel, and on most mudflats. This means that the shear stress magnitude on Seal Sands is below the values required to initiate erosion, and also low enough for both sand and clay to deposit. In Seaton Channel, especially in the lower parts, the shear stress is high (above 0.5 N/m^2) at high water velocities and silt/clay will probably not deposit over long periods.

The modelling results also show lower maximum and average clay concentrations in the water column within the bounds of Seaton Channel, and lower annual deposition rates for clay compared to baseline. The changes in sand concentrations and deposition rates are very limited. This means a total reduction in average sediment concentration and annual deposition rates, but also a proportionate increase in the percent of sand and larger fractions in the total sediment load. The reality in these results can be questioned as several other processes as storms, waves, traffic and dredging contribute to the sediment load in the water column and thereby the annual deposition rates of both clay and sand. Looking at the contribution to the sediment load in the water column from the proposed dredging operations these are by far dominating compared to the sediment loads generated from the natural processes that were modelled. As the heavier fractions are settling out relatively quickly, the silt and clay fractions are those that are contributing to the increased sediment loads over the largest areas. Dredging is taking place almost continuously in the Tees estuary due to i.e. maintenance dredging. As a result of this it is very difficult to conclude on the effects of changes in sediment load and deposition rates due to the modelled changes in hydrodynamics. But in general changes in sediment concentrations and annual deposition rates as predicted in the model will not have significant effects on the benthic fauna that are an important food source for both fish and birds. A general reduction in annual deposition rates may have positive effects by slowing down the accretion of sediments on Seal Sands that has been observed since the 1970ties (/1/ and /2/).

Based on the reduced potential for erosion and an increased potential for sedimentation, especially in the outer parts of Seaton Channel, it is possible that the sediment trapping efficiency of Seaton Channel will increase. This was also predicted by HR Wallingford (/2/). The sediment trapping efficiency in this area will increase for the larger fractions as sand due to the generally high shear stress in the area. This may decrease the amount of sand entering into the inner parts of Seaton Channel and Seal Sand and thereby have a positive impact on the sedimentation regime at Seal Sands, as bird feeding conditions on Seal Sands have been deteriorating due to the more recent accretion of sand fractions (/2/).

10.3.2 Impact of dredging operations

Maximum concentration of sediments in the water column within the bounds of Seaton Channel predicted by the modelling of the hydrodynamics was 22 mg/l. The average sediment concentrations in the baseline and after any modelled scenario, was in the range from 2-8 mg/l within the bounds of Seaton Channel. The dredging operations are modelled to yield sediment concentrations up to 1000 mg/l close to the source of the plume, but the concentrations drop quickly below 100 mg/l as the heavier fractions settles out. These results show that the sedimentation regime and the sediment load in the water column within the bounds of Seaton Channel will be dominated by the dredging operations as long as these are undertaken.

The backhoe dredging operations generally affect Seaton Channel, both the inner and outer parts, but mainly on the north side of the channel. Areas affected by sediment concentrations above 50 mg/l are limited.

The hopper dredge operation will affect both inner and outer parts of Seaton channel, the whole of Seal Sands and parts of Tees river. In large areas of Seaton Channel the sediment concentrations will be between 50-100 mg/l. Centrally in the channel the concentrations will be over 100 mg/l and up to 1000 mg/l. On Seal Sands the dredging operations are modelled to yield concentrations up to 100 mg/l in the water column, but in general the sediment concentrations are modelled to be in the range of 10-50 mg/l. For the case of both dredges operating simultaneously, there will be little interaction of the suspended sediment plumes when the backhoe is operating in dredging Area 1. However, some interaction will occur when dredging areas 2 and 3 with a backhoe with the hopper dredge operating at the same time. But the interaction doesn't significantly increase the maximum concentrations of the suspended sediment plume generated from only one dredge operating at a time.

Different species of fish have a varying ability to withstand high concentrations of inert suspended material. Experiments with marine fish have shown that demersal fish are more tolerant whereas filter feeding species are more sensitive. (/28/). Hessen (/24/) concluded that fish, focusing on trout, can withstand considerable acute particle exposure (~1000 mg/kg) without effects like higher mortality or gill damage occurring. But in marine waters several species of fish have been observed to avoid areas of high particle concentrations (/25/). The high concentrations of sediments in the water column during the dredging operations may cause resident and/or migratory fish species to avoid Seaton Channel in this period.

Common Seal and Grey Seal are not believed to be directly affected by the increase in sediment concentrations in the water column (/27/), but may be indirectly affected if fish is avoiding the area. The area affected by the increased sediment concentrations is in general limited to Seaton Channel and Seal Sands. Grey Seals tend to be wide ranging in their search for food and are not believed to be significantly affected by fish avoiding this area. Common Seal usually feed closer to their haul-out sites. But studies show that Common Seal have 95% of their activity within an area of 10 km^2, and that the size of their home range is dependent on where the seals normally find their food and weather conditions (restricted movement during periods of bad weather). If there are other areas than Seaton Channel where the food availability is sufficient within their home range, as is most probably the case here, the Common Seal is not believed to be directly or indirectly affected by the increased sediment concentrations. Effects of noise and visual disturbance are not evaluated in this report.

Dredging area 4 and 5 with the hopper dredge will lead to a significant increase in sediment load in the water column in Seaton Channel and on parts of Seal Sand. As the more coarse particles are settling out quickly, the sediments load affecting Seal sands will mainly be finer sediments as silt and mud. The deposition rate on Seal Sands will generally be in the range of 5-50 gram/m^2 per day (see Figure 7-18 and Figure 7-20). After 12 weeks of dredging this is equivalent to 420-4200 g/m^2. Only the lighter fractions of the sediments are anticipated to deposit on Seal Sands. These findings support the results in (/1/) where the authors describe a trend towards finer sediments on Seal sands, possibly from dredging operations. Dredging operations in general always have an impact on the benthic fauna. The fauna in the dredging areas are removed and the fauna in areas of high sedimentation due to the dredging operations are disturbed, significantly in the near proximity of the operation. Close to the operation where the deposition rates are high, the fauna will most probably be buried by the depositing sediments. Further away the fauna will be disturbed. Re colonization of less disturbed areas are normally a relatively rapid process, whereas re colonization of the central parts of Seaton Channel will take longer time. It can be anticipated that the fauna at Seal sand will be disturbed by the increased deposition rates, but it is difficult to say to which degree. To do this it is necessary to have a good knowledge of the existing fauna. As dredging operations have been going on in the area for several years it is probable that the fauna reflect these type of disturbances both in Seaton Channel on possibly on Seal Sands.

Concentrations of several metals (Ar, Cd, Cr, Cu, hg, Ni, Pb and Zn), PCBs, PAHs and TBT in dredging area 1 to 4 has been mapped and compared against international recognised risk limits for effects on the ecosystem. The concentrations of contaminants are generally below recommended risk limits for effects on the ecosystem. The exceptions are for the following PAHs: Acenaphthylene, Anthracene, Benzo(a)anthracene and Benzo(a)pyrene (see Appendix D). This means that there is a high probability of effects on the ecosystem due to the measured PAH contamination. For the above mentioned PAHs, levels above the risk limit have been observed in all dredging areas (bulk samples), generally from the surface down to 1 m sediment depth. Five meters down in the sediments the level of contamination is below the risk limit for effects on the ecosystem. The risk limit is only slightly exceeded for Benzo(a)anthracene, by a factor of max

1,2 for Benzo(a)pyrene, by a factor of max 1,9 for Acenaphthylene and by a factor of max 14,2 for Anthracene. These very high levels of Anthracene are only found in the surface layer of the sediments. Further down (0.5 m and 1 m) the level only exceeded the risk limit by a factor of max 1,7. High levels of Anthracene is generally associated with petroleum related sources, whereas Benzo(a)anthracene and Benzo(a)pyrene are associated with combustion of fossil fuels (/29/).

It is not known whether the high levels of Acenaphthylene, Anthracene, Benzo(a)anthracene and Benzo(a)pyrene in the bulk samples is due to a generally high level in all dredging areas or if only specific areas have these high levels. Nor is it known if the levels of these PAHs also are generally high in Seaton Channel and Seal Sands sediments. The dredging operations will contribute to the spreading of PAH contaminated sediments that have concentrations that exceed the ecosystem risk limit. Data on sediment concentration of organics are however sparse, and nothing is known about the concentration of organics in the areas the sediment will be transported to, for example Seal Sand. Shellfish and other invertebrates generally accumulate PAHs and thereby contribute to the exposure of animals that feed on these organisms. Animals higher up in the food chain, like fish, birds and seals, have the ability to metabolise these compounds and thereby reduce the chance of significant effects.

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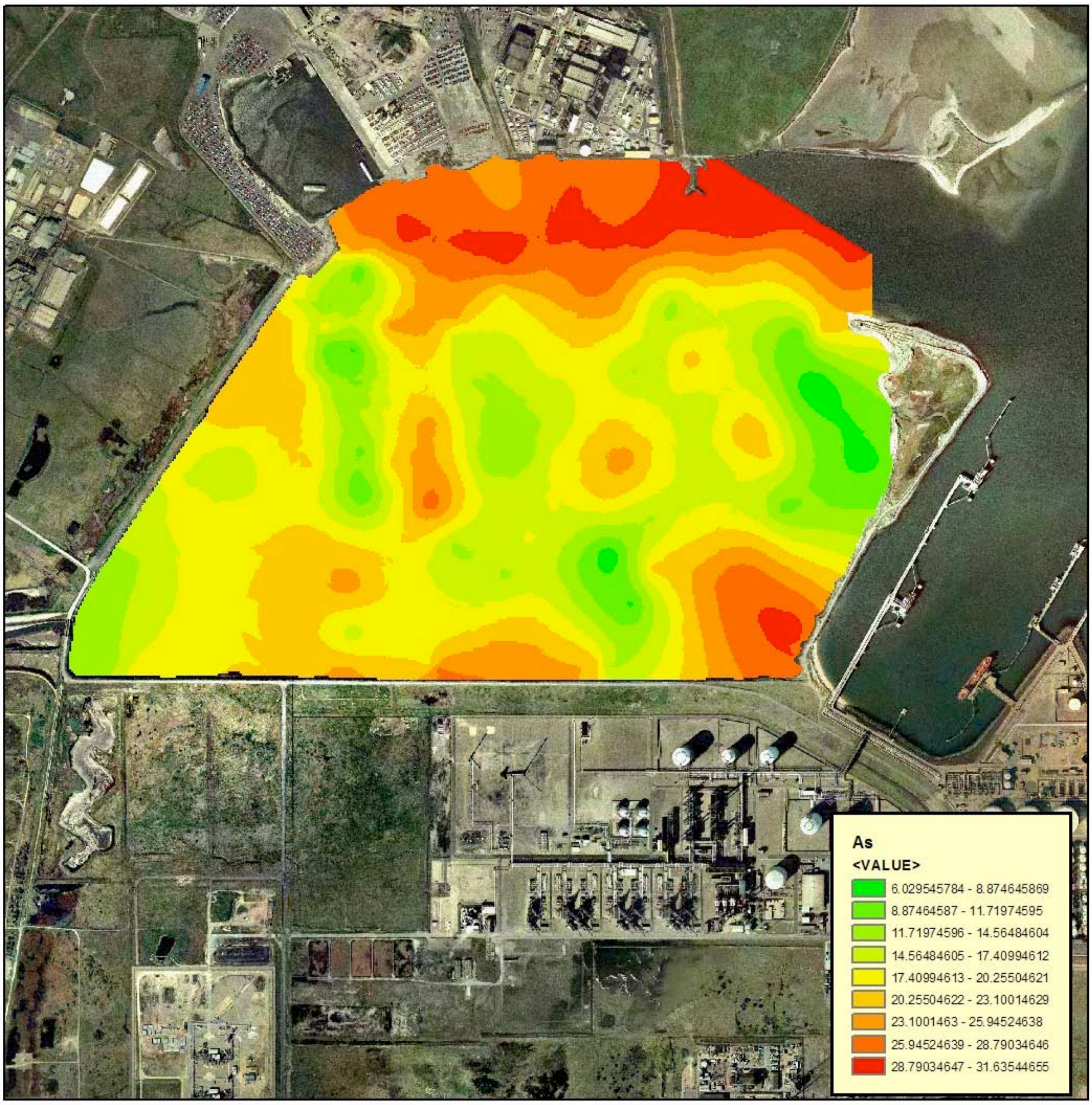
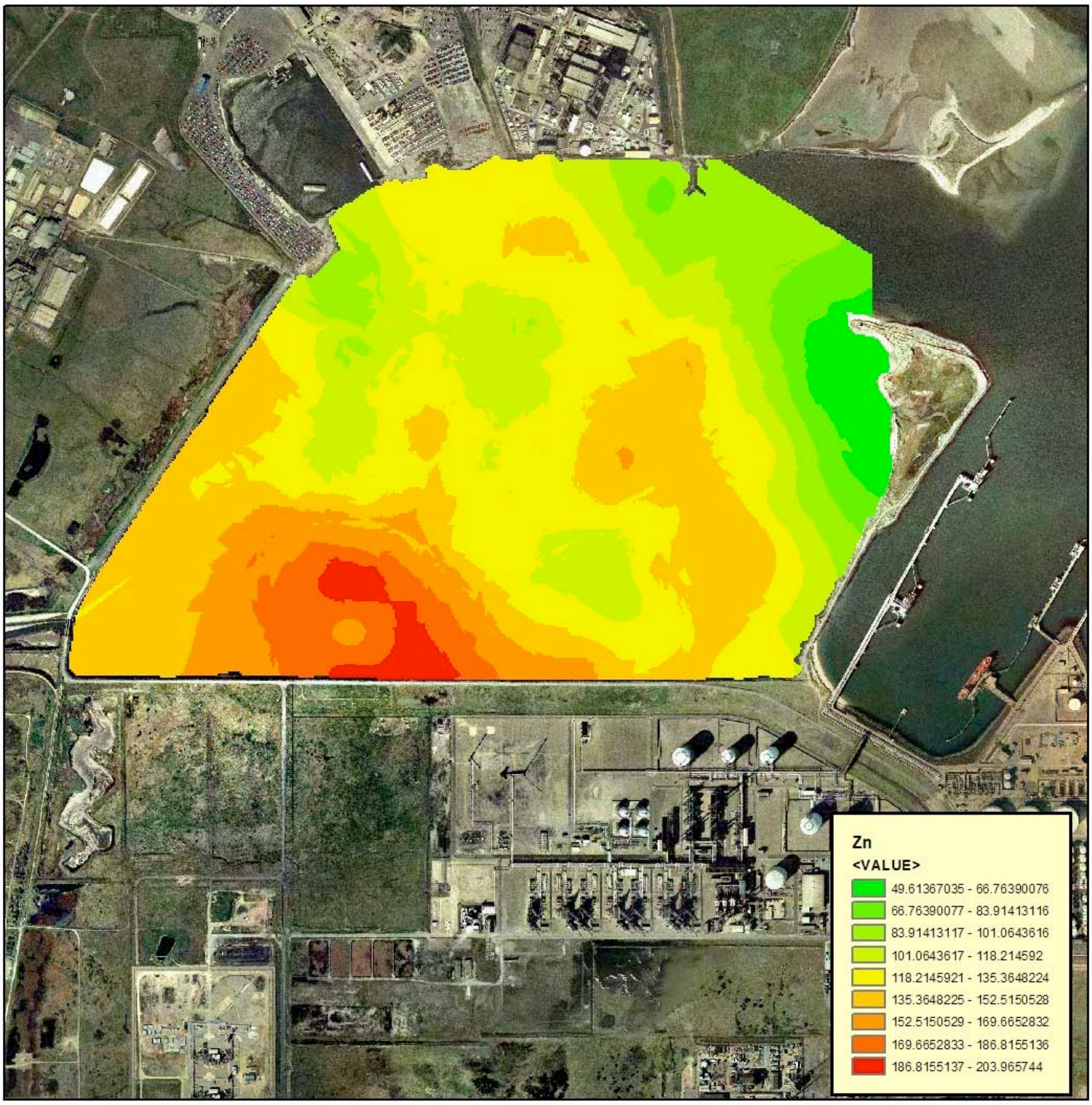
APPENDIX

A

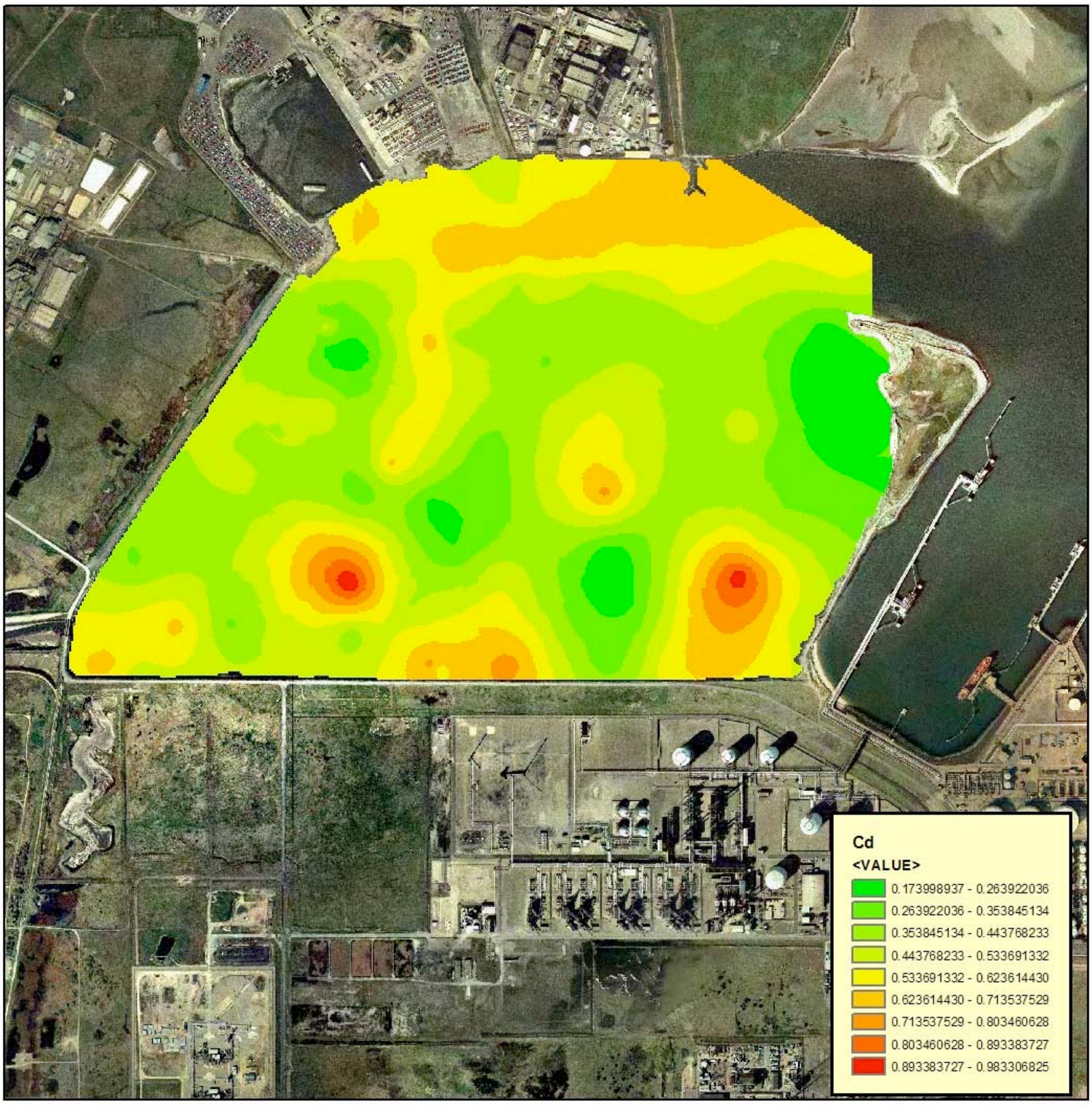
METAL CONCENTRATIONS IN SEDIMENTS



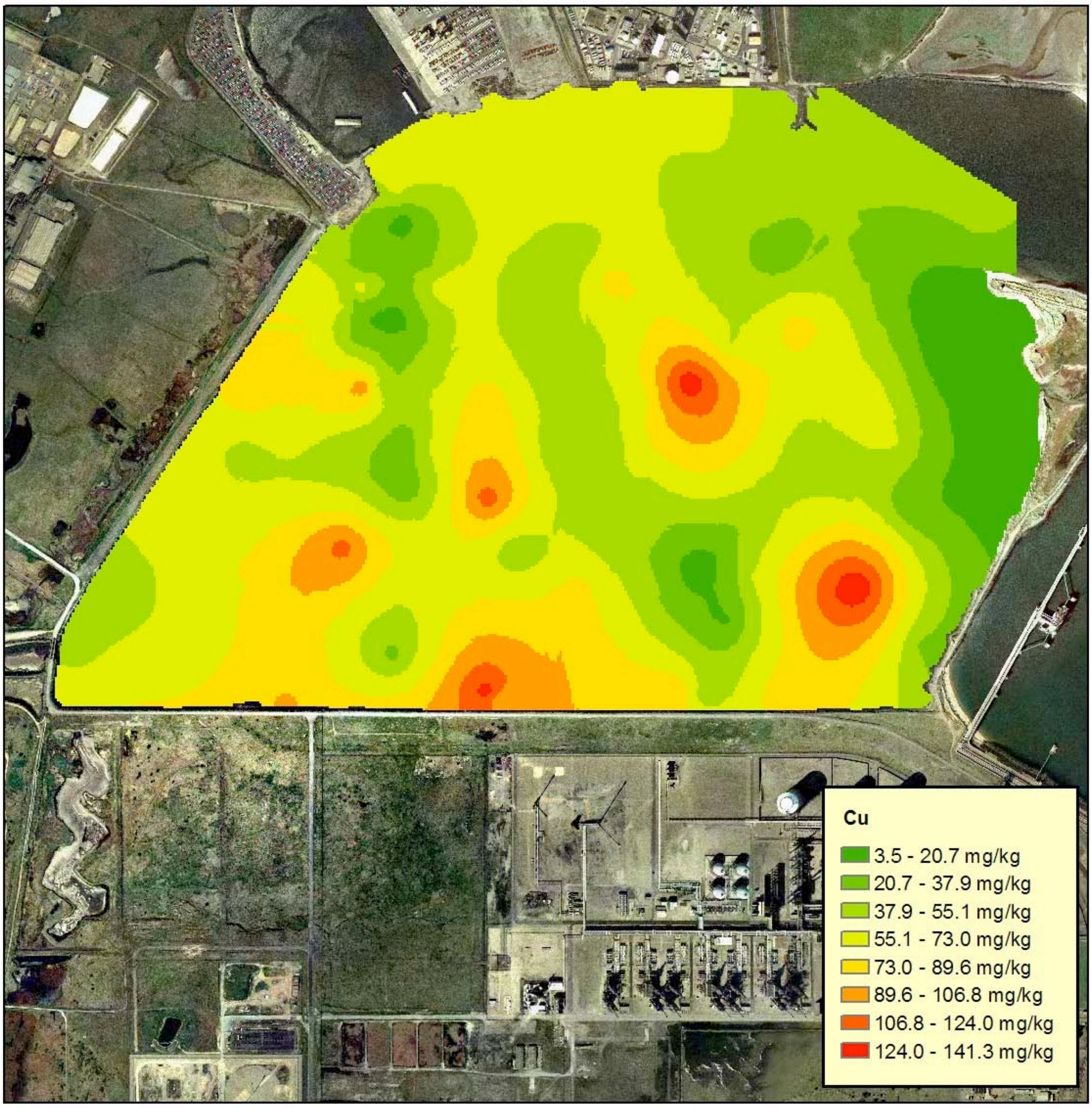
Concentrations of arsenic (mg/kg dry weight) in sediments on Seal Sand and in Seaton Channel (/1/and /7/).



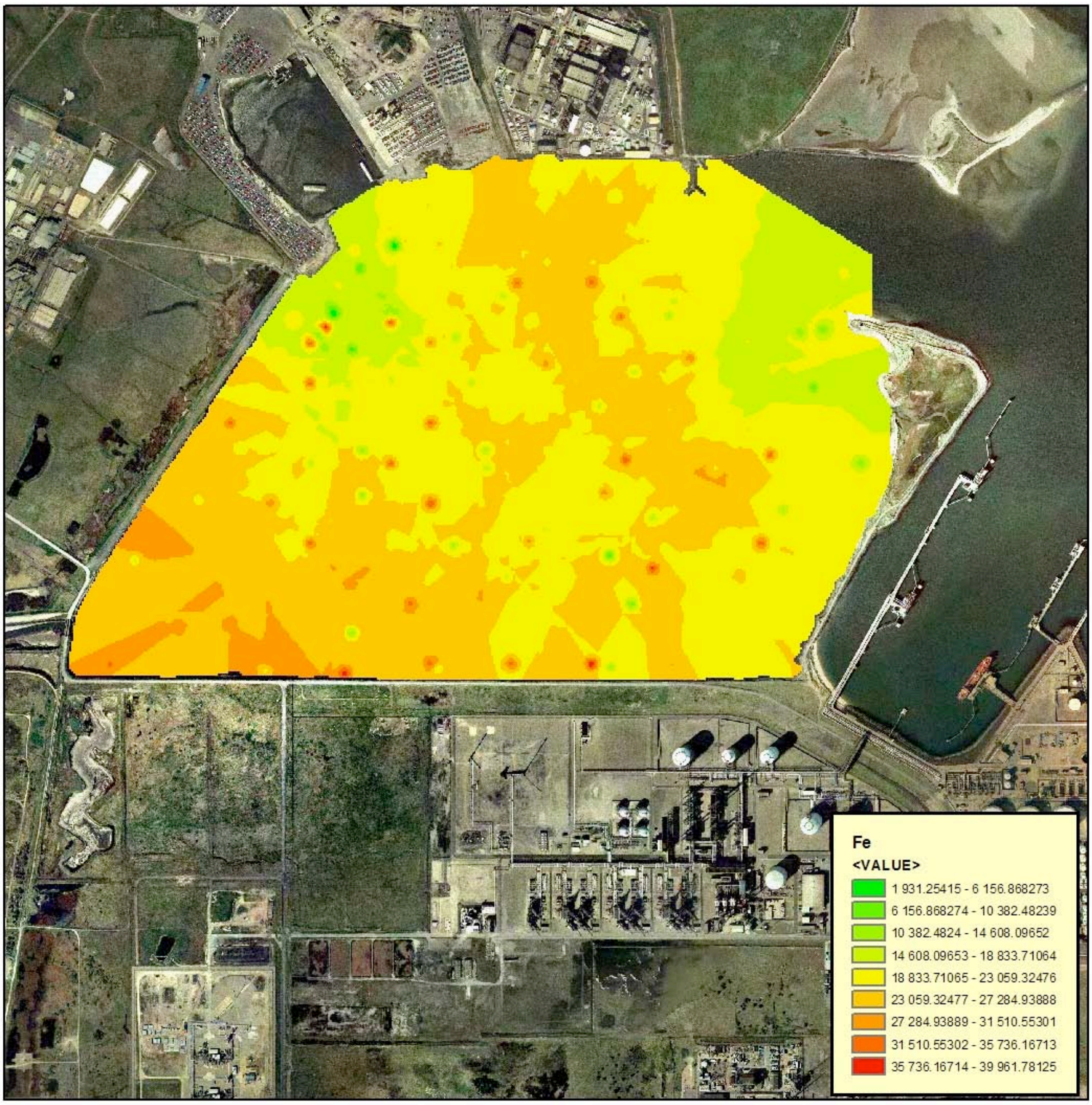
Concentrations of Zink (mg/kg dry weight) in sediments on Seal Sand and in Seaton Channel (/1/and /7/).



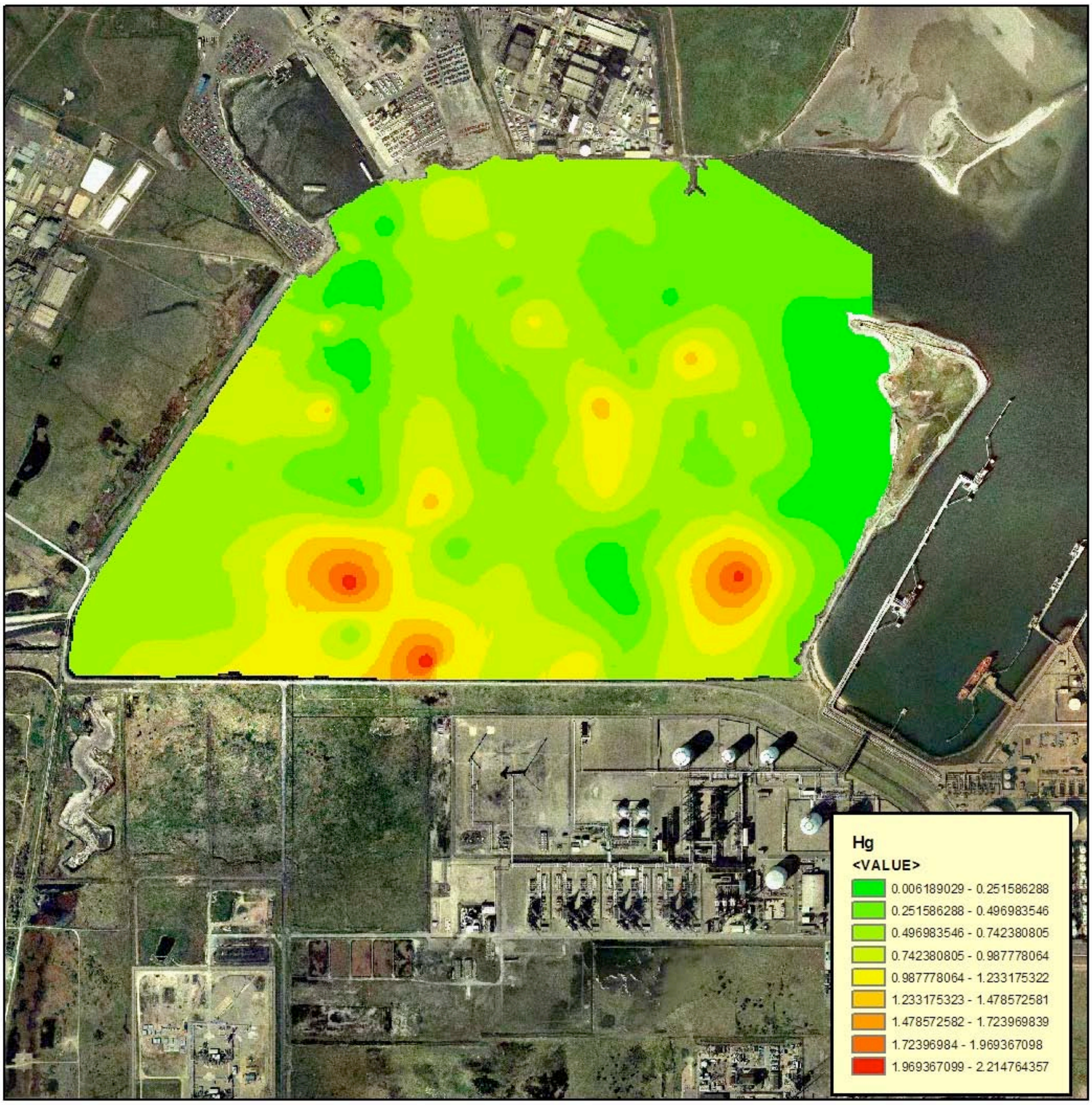
Concentrations of Cadmium (mg/kg dry weight) in sediments on Seal Sand and in Seaton Channel (/1/and /7/).



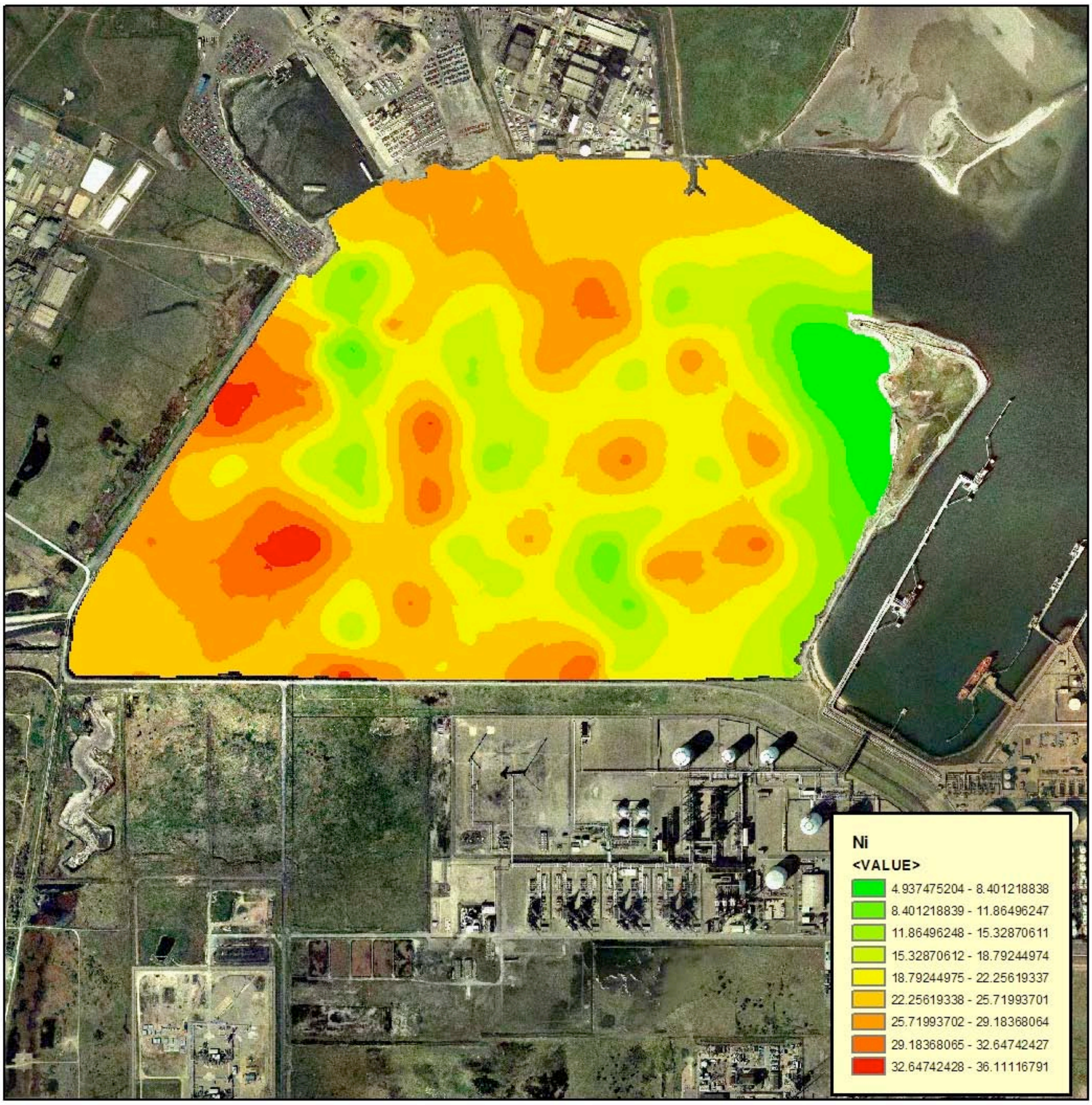
Concentrations of Copper (mg/kg dry weight) in sediments on Seal Sand and in Seaton Channel (/1/and /7/).



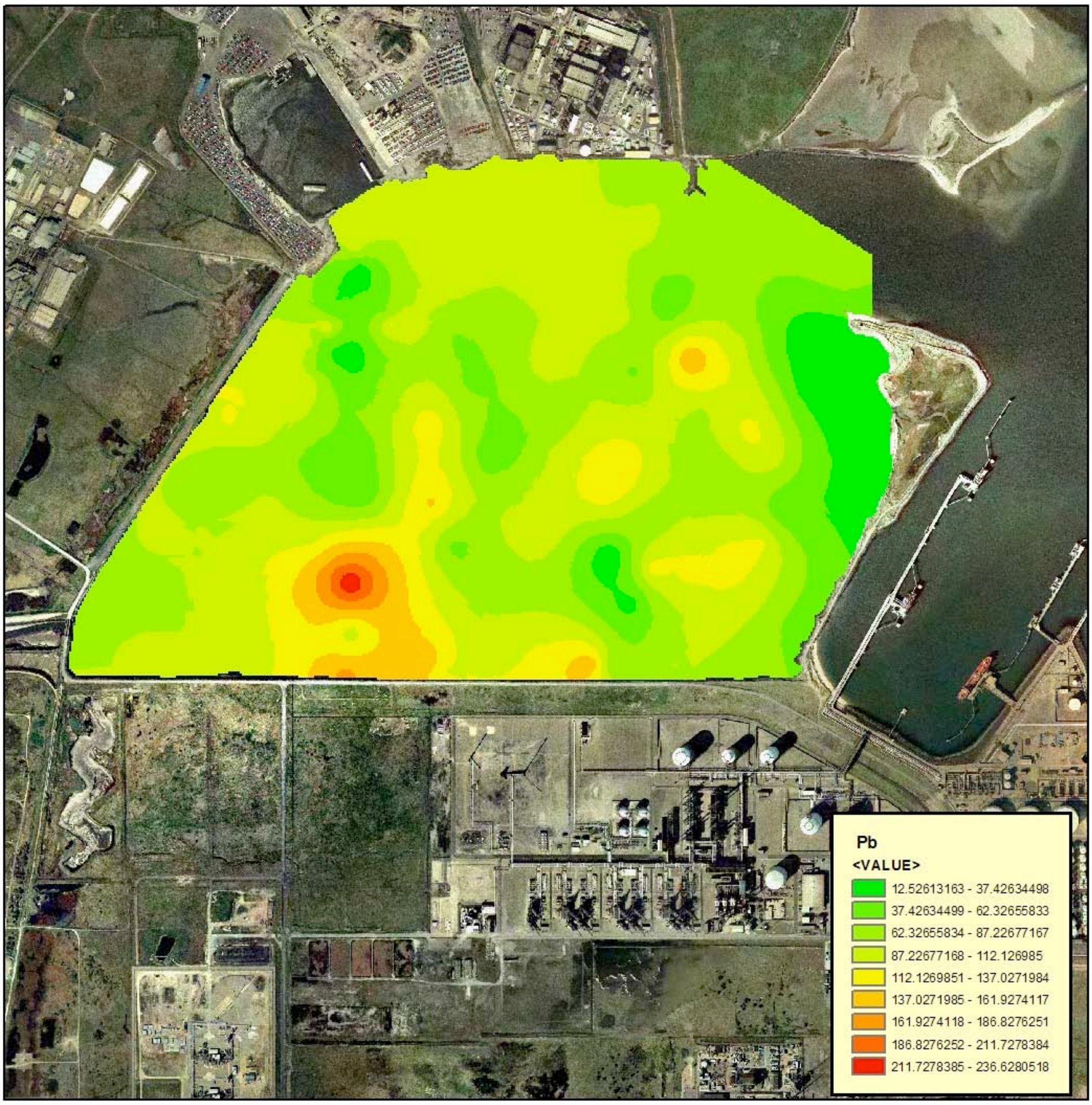
Concentrations of Iron (mg/kg dry weight) in sediments on Seal Sand and in Seaton Channel (/1/and /7/).



Concentrations of Mercury (mg/kg dry weight) in sediments on Seal Sand and in Seaton Channel (/1/and /7/).



Concentrations of Nickel (mg/kg dry weight) in sediments on Seal Sand and in Seaton Channel (/1/and /7/).



Concentrations of Lead (mg/kg dry weight) in sediments on Seal Sand and in Seaton Channel (/1/and /7/).

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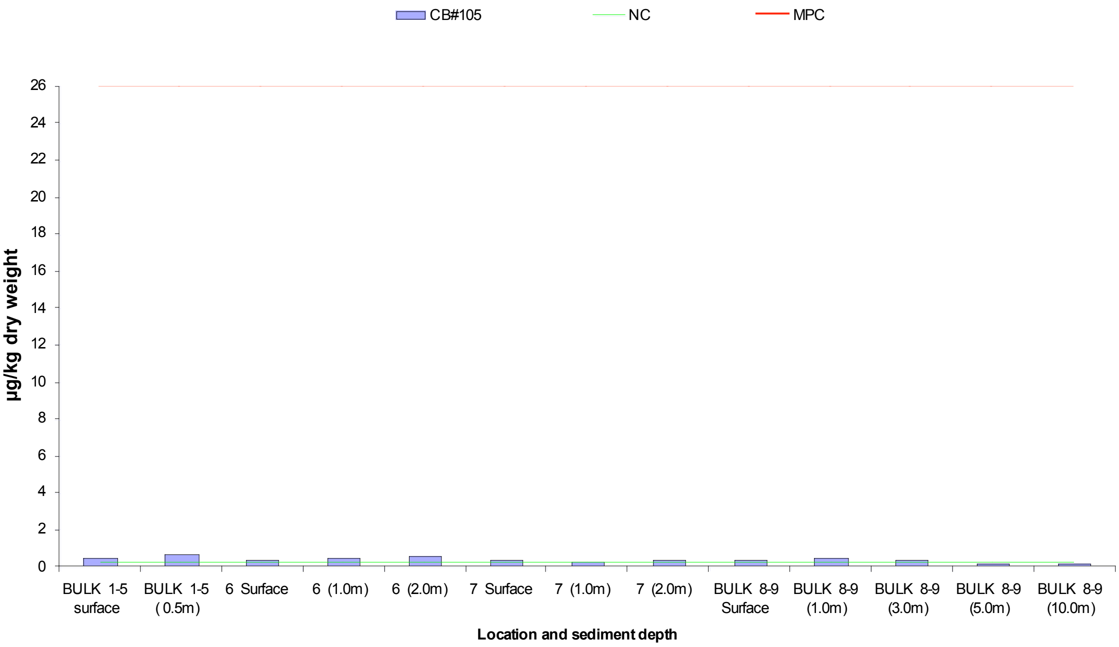
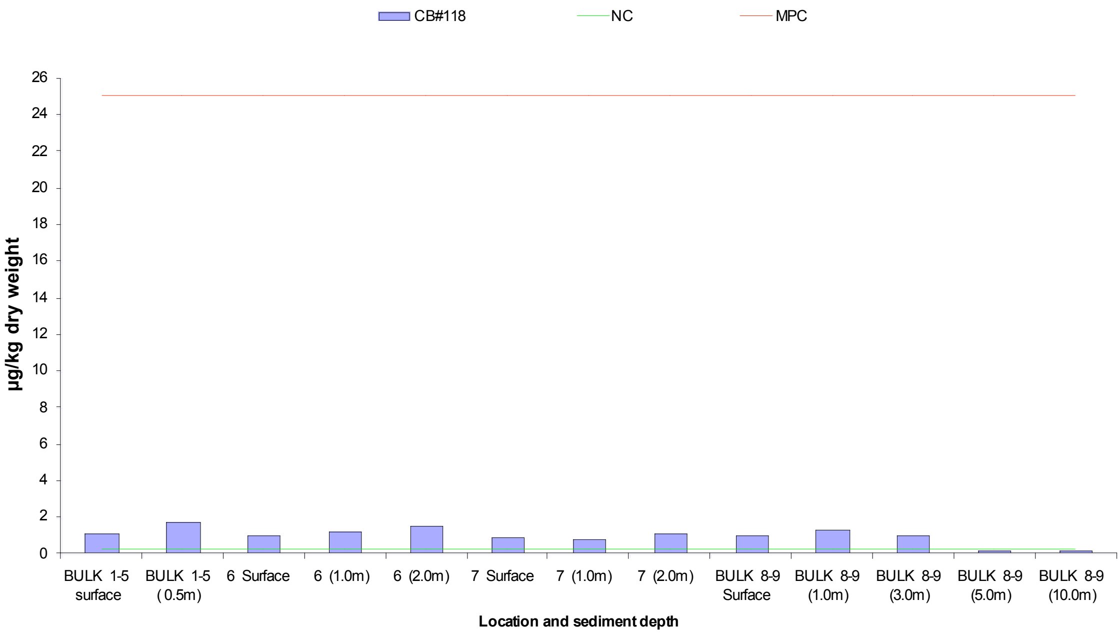
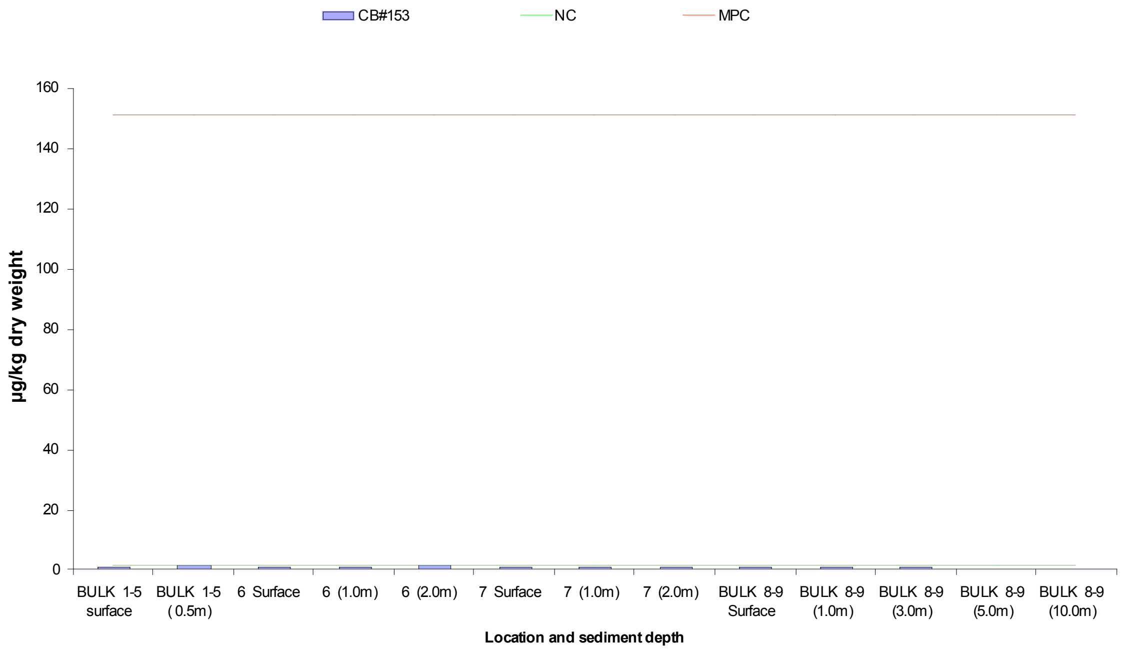
APPENDIX
B
PCB CONCENTRATIONS IN SEDIMENTS



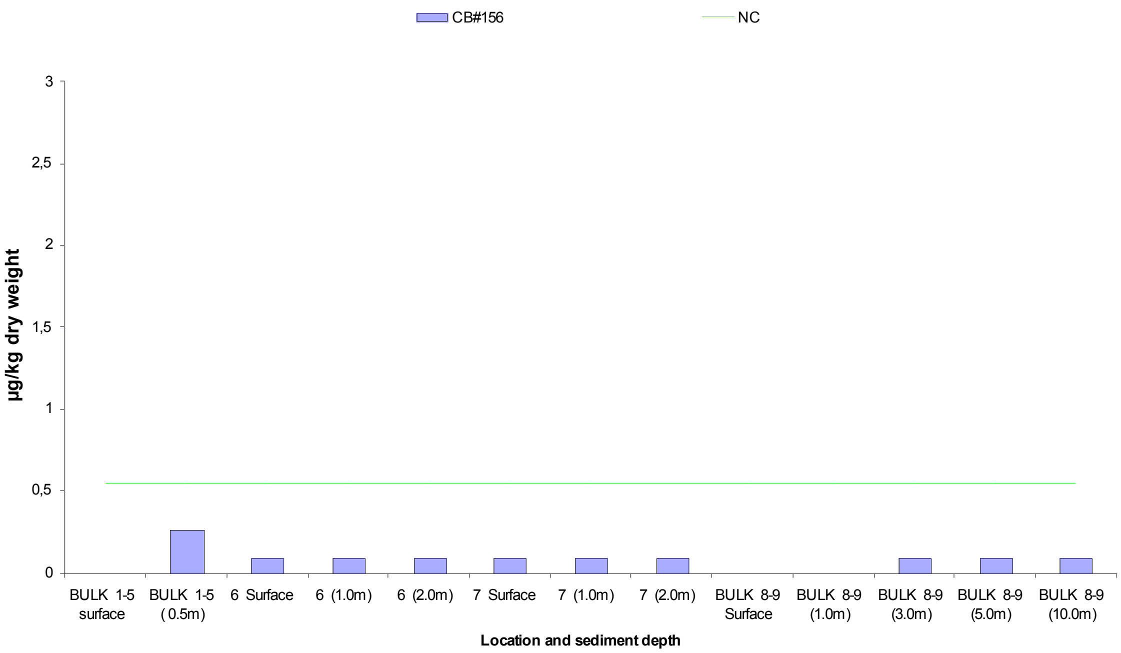
Concentration of CB#105 (µg/kg dry weight) in dredging areas 1 to 4. Sediment quality thresholds are given as Negligible Concentration (NC) and Maximum Permissible Concentration (MPC) according to the Dutch National Institute of Public Health and the Environment (/23/).



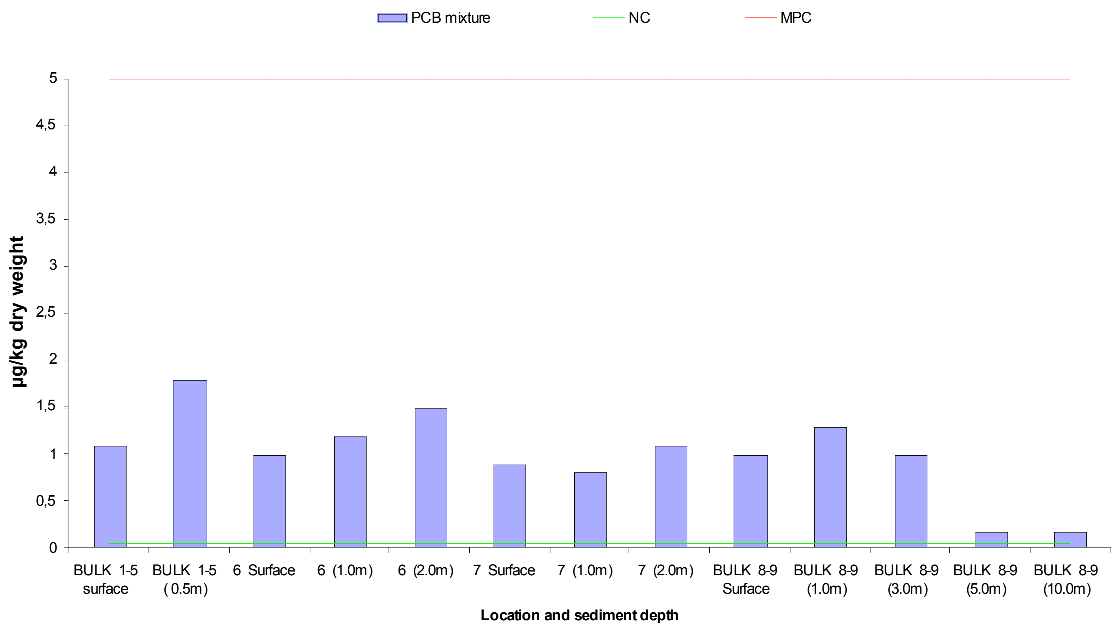
Concentration of CB#118 (µg/kg dry weight) in dredging areas 1 to 4. Sediment quality thresholds are given as Negligible Concentration (NC) and Maximum Permissible Concentration (MPC) according to the Dutch National Institute of Public Health and the Environment (/23/).



Concentration of CB#153 (µg/kg dry weight) in dredging areas 1 to 4. Sediment quality thresholds are given as Negligible Concentration (NC) and Maximum Permissible Concentration (MPC) according to the Dutch National Institute of Public Health and the Environment (/23/).



Concentration of CB#156 (µg/kg dry weight) in dredging areas 1 to 4. Sediment quality thresholds are given as Negligible Concentration (NC) and Maximum Permissible Concentration (MPC) according to the Dutch National Institute of Public Health and the Environment (/23/).



Concentration of CB#118 (µg/kg dry weight) representing the mixture of planar congeners in dredging areas 1 to 4. Sediment quality thresholds for the mixture of planar congeners are given as Negligible Concentration (NC) and Maximum Permissible Concentration (MPC) according to the Dutch National Institute of Public Health and the Environment (/23/).

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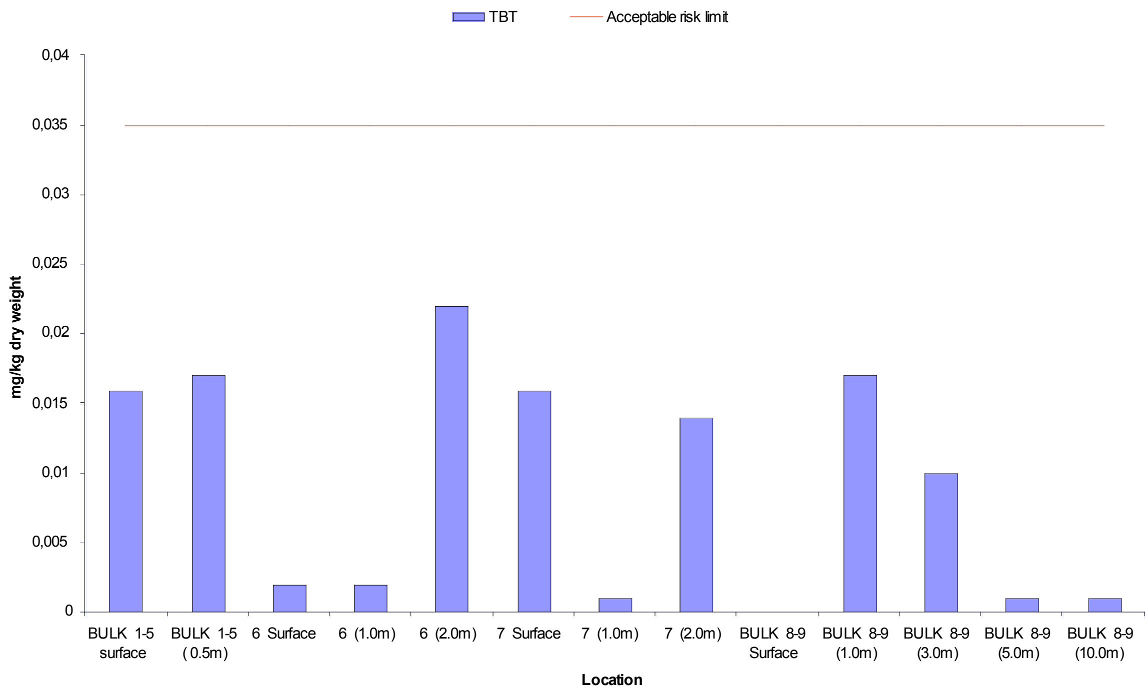
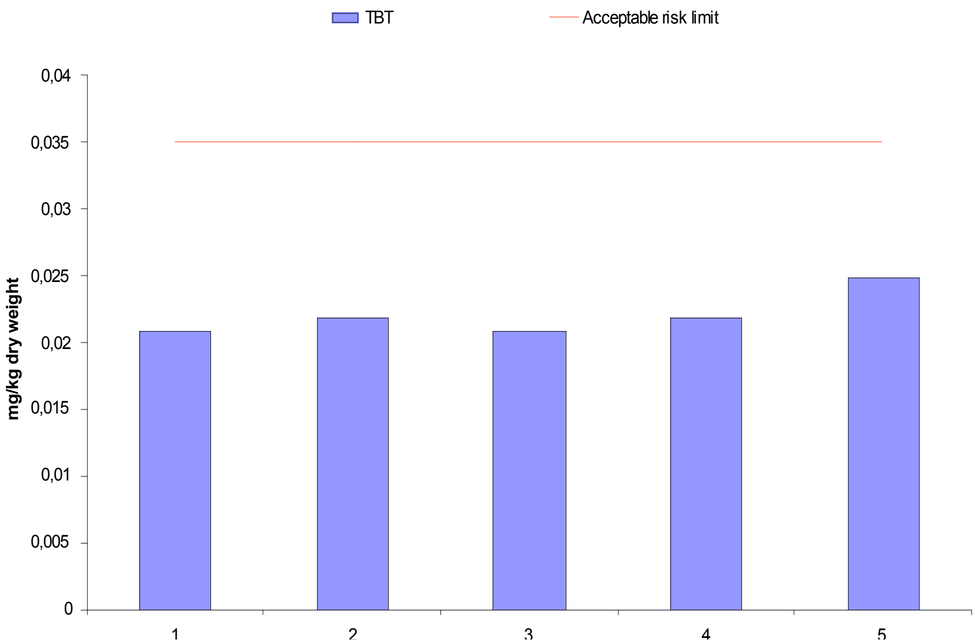
APPENDIX
C
TBT CONCENTRATIONS IN SEDIMENTS



Concentration of TBT (mg/kg dry weight) in dredging areas 1 to 4. Sediment quality thresholds are given as Acceptable risk limit proposed by Breedveld (/24/).



Concentration of TBT (mg/kg dry weight) in dredging area 4; Seaton Channel. Sediment quality thresholds are given as Acceptable risk limit proposed by Breedveld (/24/).

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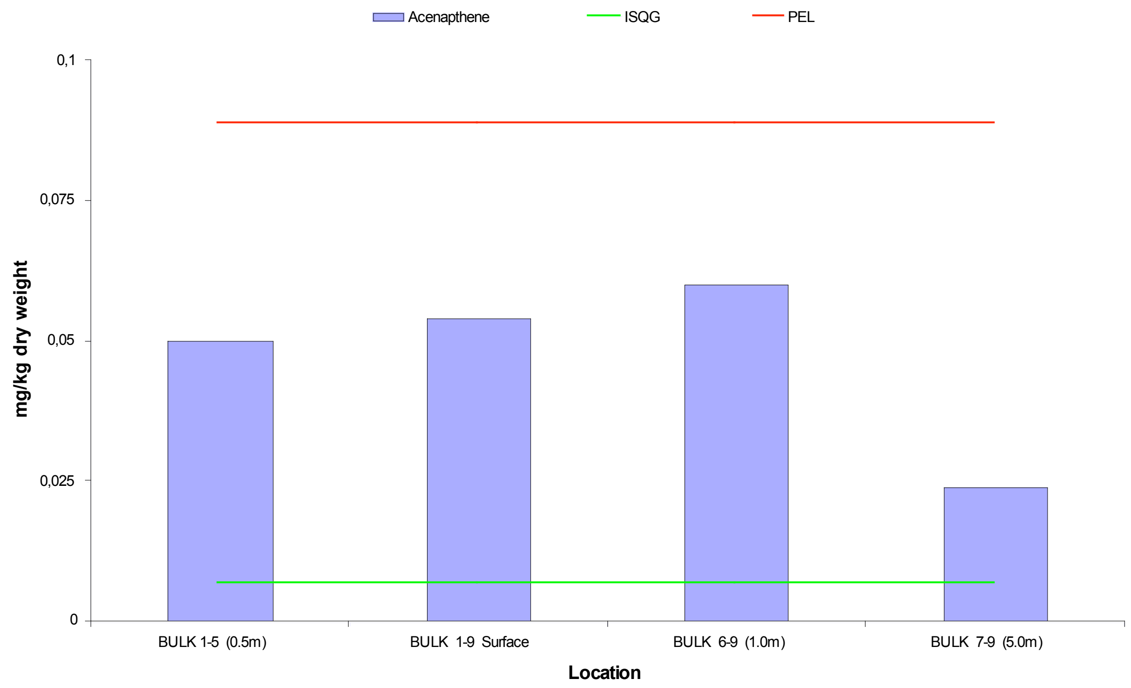
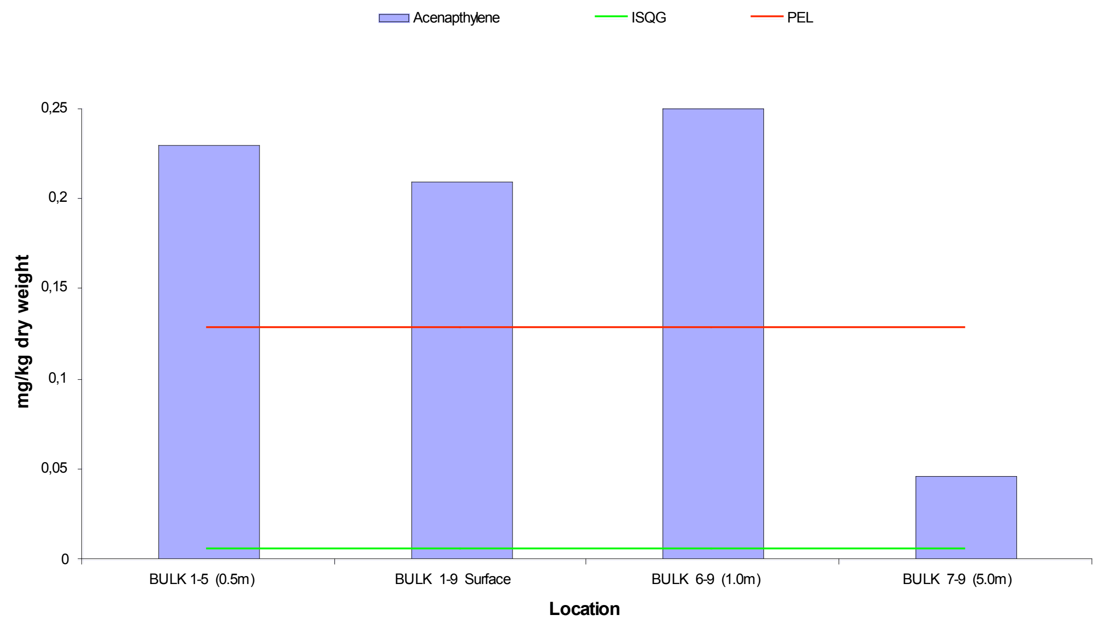
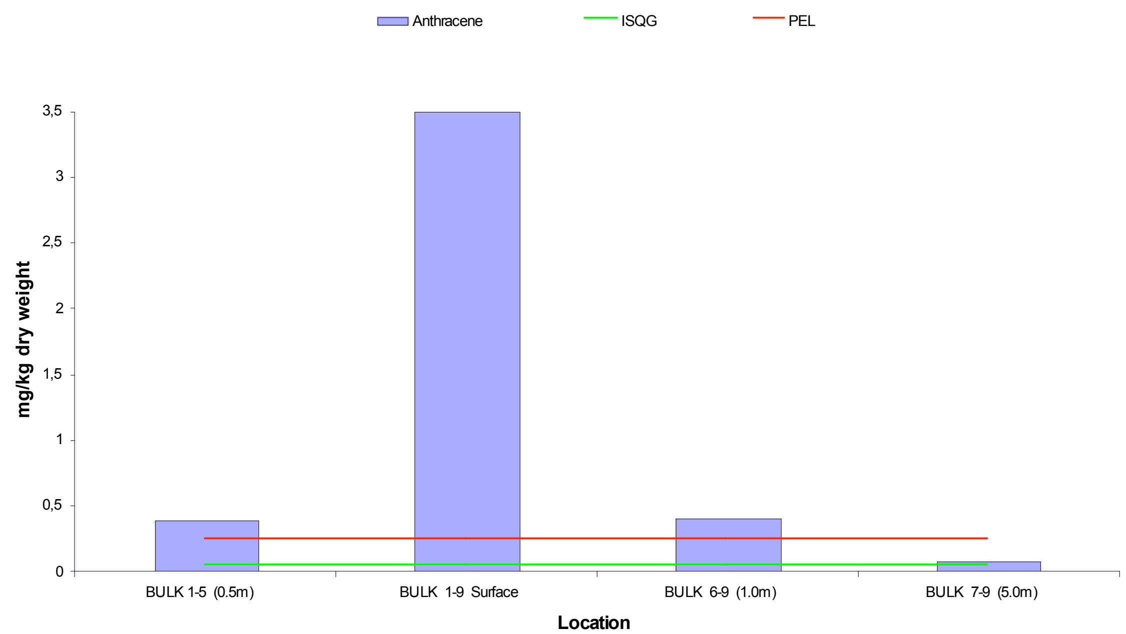
APPENDIX
D
PAH CONCENTRATIONS IN SEDIMENTS



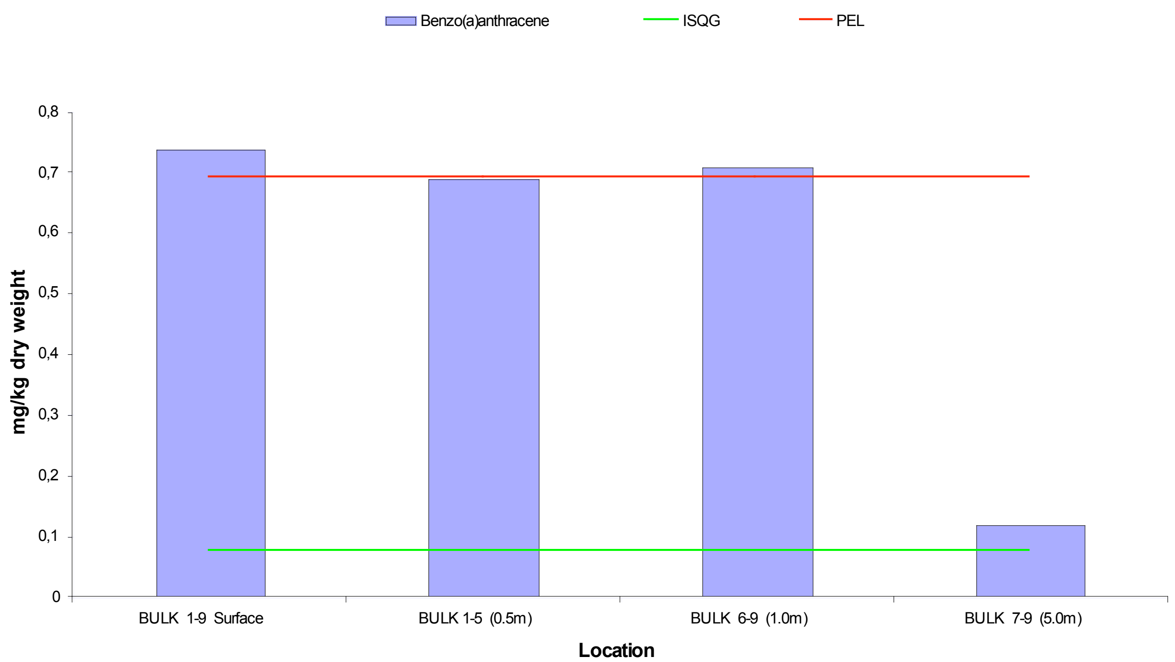
Concentration of Acenaphene (mg/kg dry weight) in dredging areas 1 to 4. Sediment quality thresholds are given as Interim Sediment Quality Guidelines (ISQG) and Probable Effect Level (PEL) according to the Canadian Environmental Quality Guidelines (/21/).



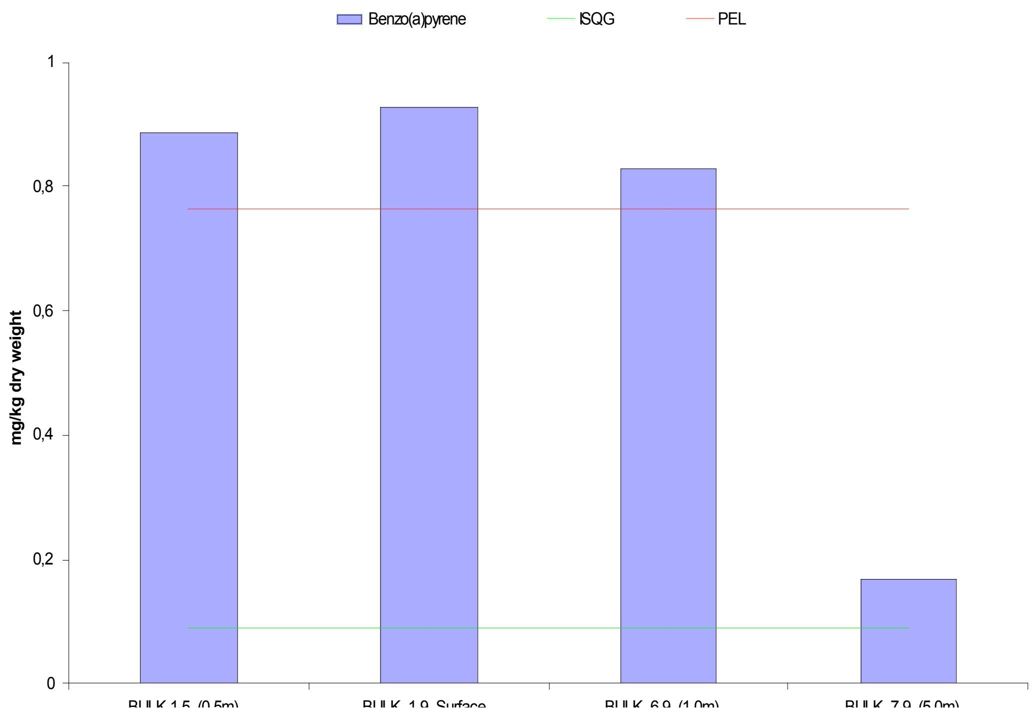
Concentration of Acenaphthylene (mg/kg dry weight) in dredging areas 1 to 4. Sediment quality thresholds are given as Interim Sediment Quality Guidelines (ISQG) and Probable Effect Level (PEL) according to the Canadian Environmental Quality Guidelines (/21/).



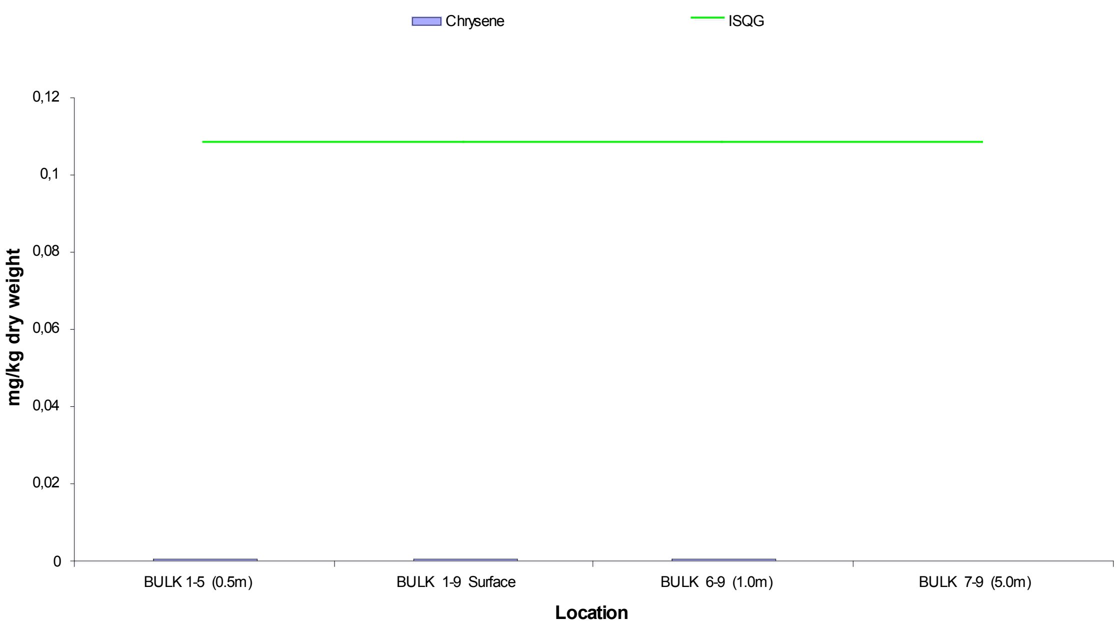
Concentration of Anthracene (mg/kg dry weight) in dredging areas 1 to 4. Sediment quality thresholds are given as Interim Sediment Quality Guidelines (ISQG) and Probable Effect Level (PEL) according to the Canadian Environmental Quality Guidelines (/21/).



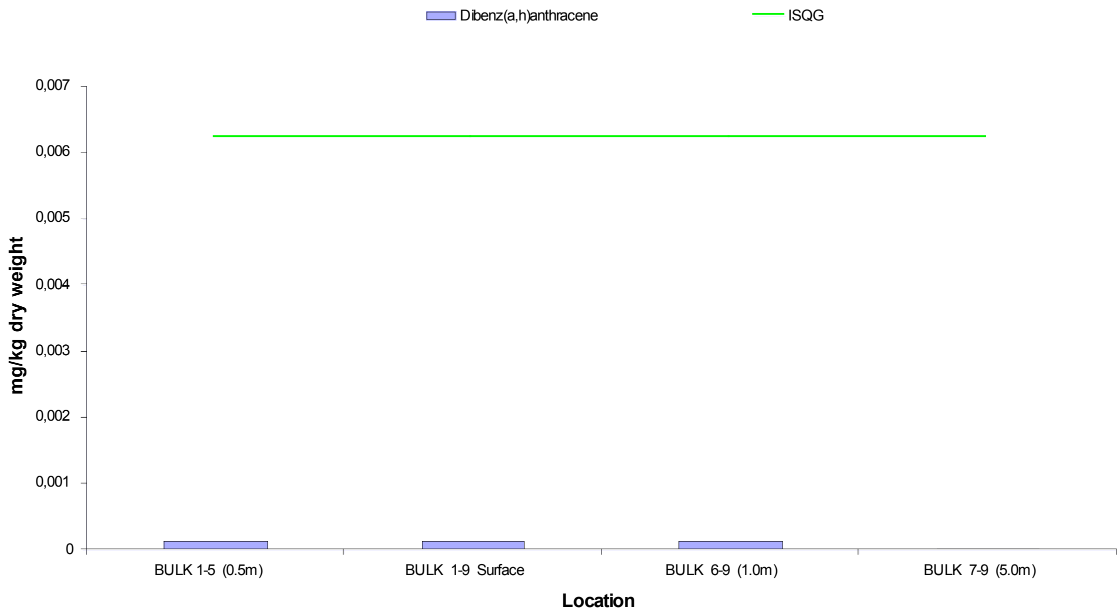
Concentration of Benzo(a)anthracene (mg/kg dry weight) in dredging areas 1 to 4. Sediment quality thresholds are given as Interim Sediment Quality Guidelines (ISQG) and Probable Effect Level (PEL) according to the Canadian Environmental Quality Guidelines (/21/).



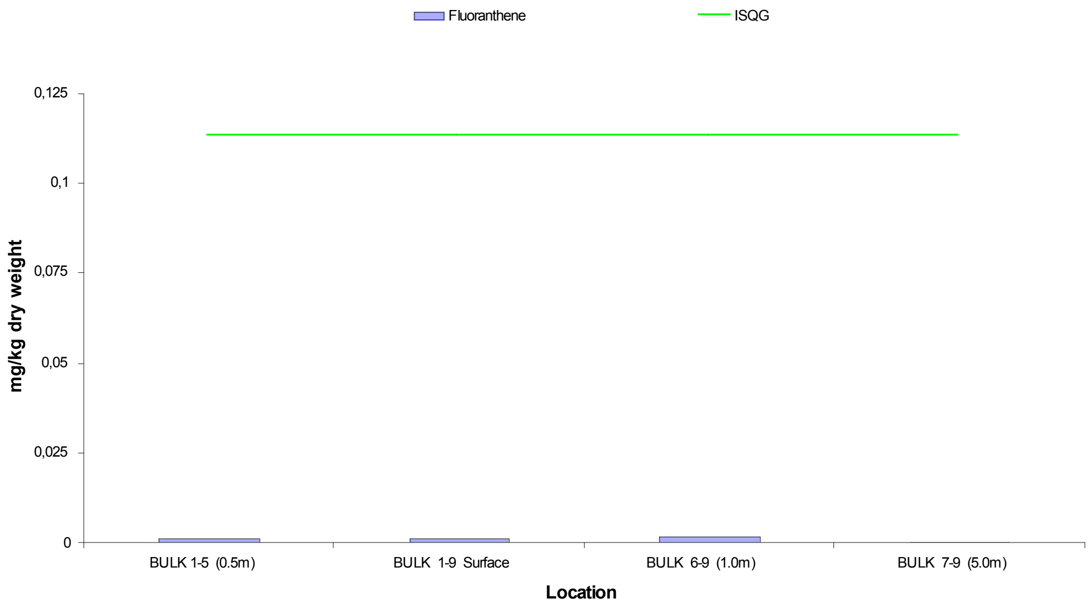
Concentration of Benzo(a)pyrene (mg/kg dry weight) in dredging areas 1 to 4. Sediment quality thresholds are given as Interim Sediment Quality Guidelines (ISQG) and Probable Effect Level (PEL) according to the Canadian Environmental Quality Guidelines (/21/).



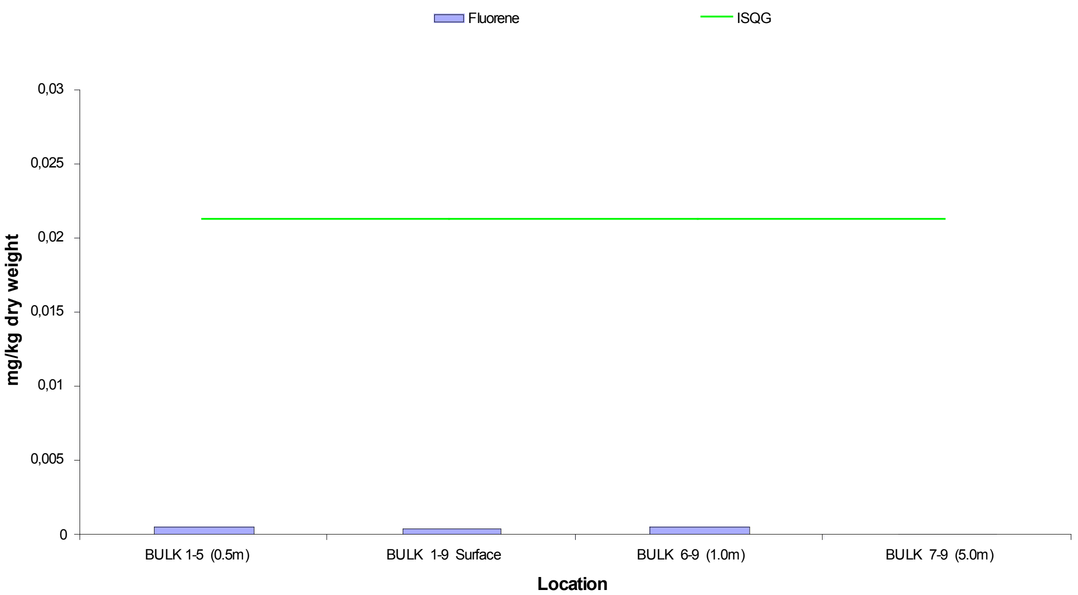
Concentration of Chrysene (mg/kg dry weight) in dredging areas 1 to 4. Sediment quality thresholds are given as Interim Sediment Quality Guidelines (ISQG) according to the Canadian Environmental Quality Guidelines (/21/).



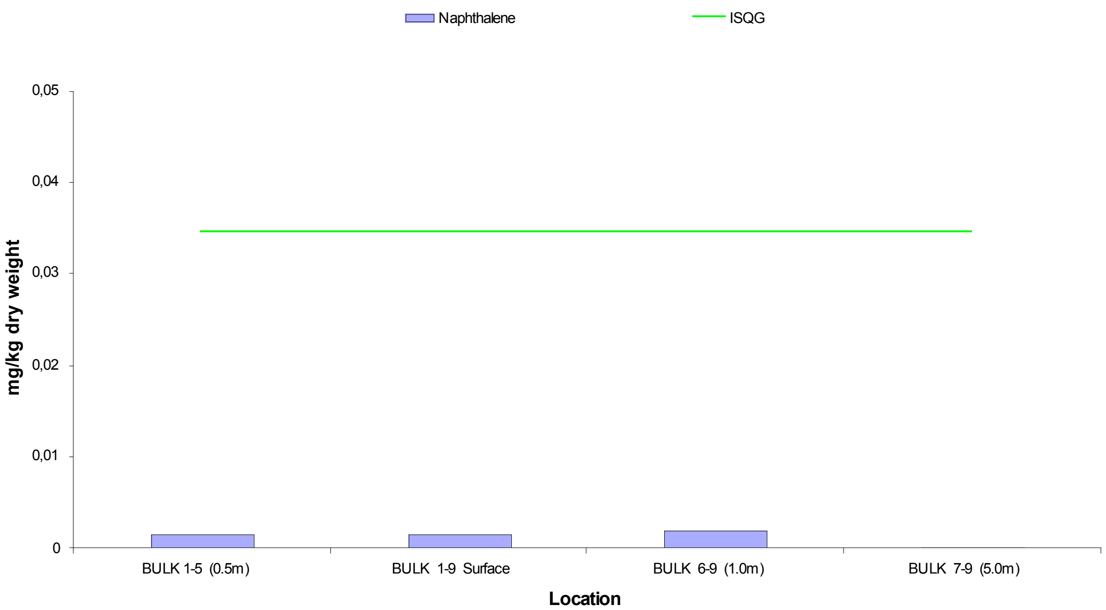
Concentration of Dibenz(a,h)anthracene (mg/kg dry weight) in dredging areas 1 to 4. Sediment quality thresholds are given as Interim Sediment Quality Guidelines (ISQG) according to the Canadian Environmental Quality Guidelines (/21/).



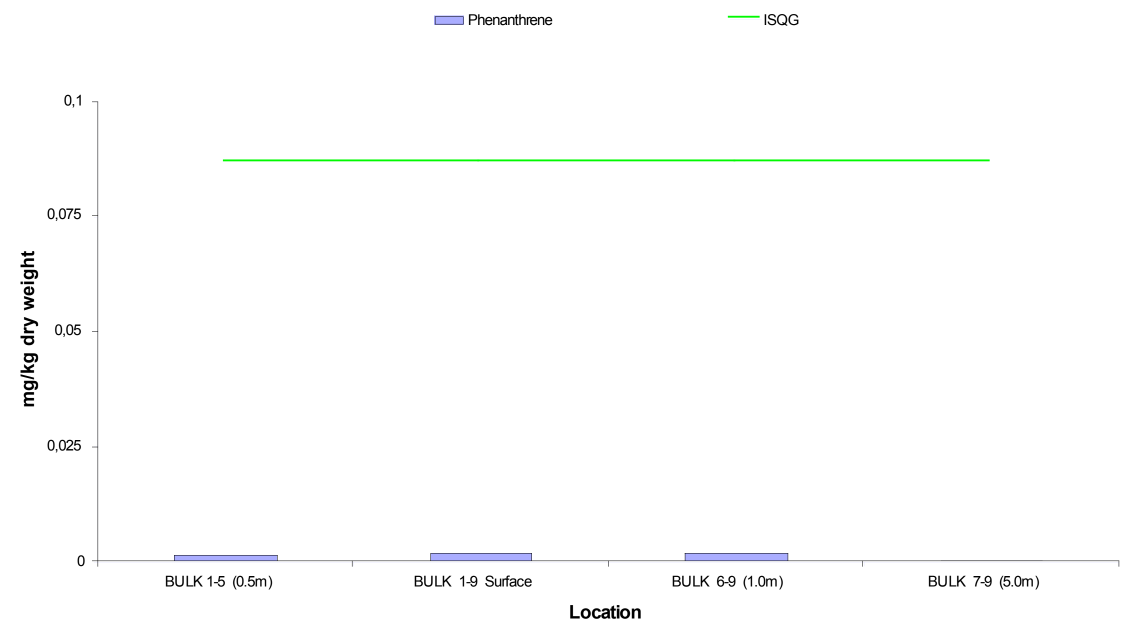
Concentration of Fluoranthene (mg/kg dry weight) in dredging areas 1 to 4. Sediment quality thresholds are given as Interim Sediment Quality Guidelines (ISQG) according to the Canadian Environmental Quality Guidelines (/21/).



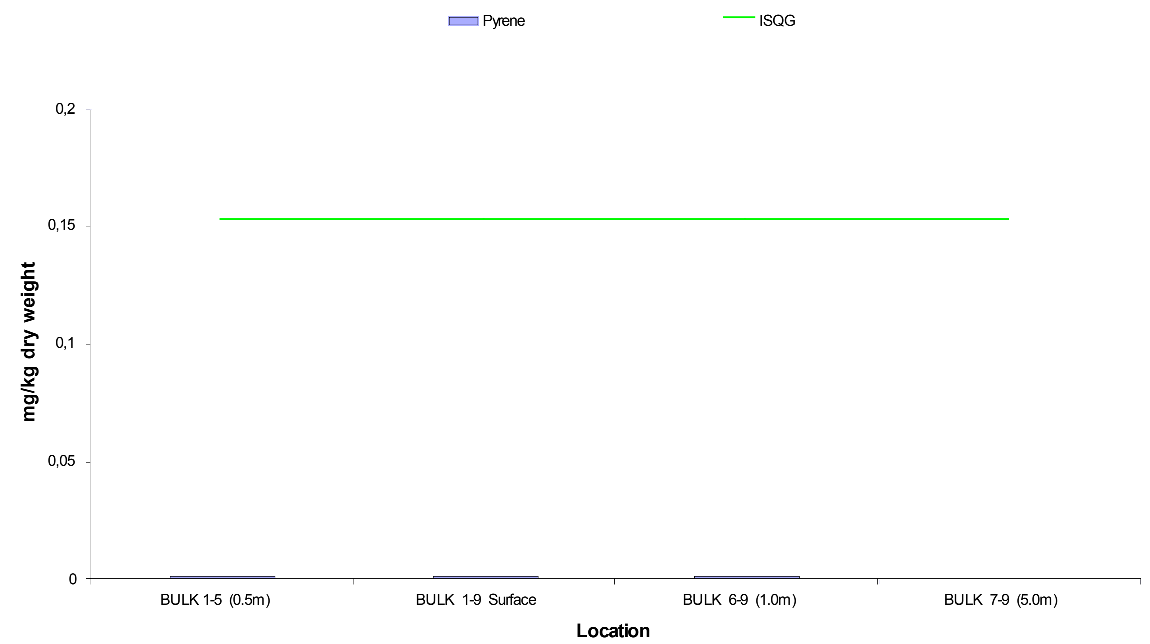
Concentration of Fluorene (mg/kg dry weight) in dredging areas 1 to 4. Sediment quality thresholds are given as Interim Sediment Quality Guidelines (ISQG) according to the Canadian Environmental Quality Guidelines (/21/).



Concentration of Naphthalene (mg/kg dry weight) in dredging areas 1 to 4. Sediment quality thresholds are given as Interim Sediment Quality Guidelines (ISQG) according to the Canadian Environmental Quality Guidelines (/21/).



Concentration of Phenanthrene (mg/kg dry weight) in dredging areas 1 to 4. Sediment quality thresholds are given as Interim Sediment Quality Guidelines (ISQG) according to the Canadian Environmental Quality Guidelines (/21/).



Concentration of Pyrene (mg/kg dry weight) in dredging areas 1 to 4. Sediment quality thresholds are given as Interim Sediment Quality Guidelines (ISQG) according to the Canadian Environmental Quality Guidelines (/21/**).**

APPENDIX
E

HYDRODYNAMIC AND SEDIMENT TRANSPORTATION MODELLING DETAILED IMPACT ON OBSERVATION POINTS

Pt 1 Nuclear power plant intake

Case	Description	V_{max} (m/s)	C_{max} (mg/l)	C_{avg} (mg/l)	Δ depos. rate*
0	Baseline	0.047	0.89 sand 13.1 clay	0.31 sand 4.34 clay	100% sand 100% clay
1	Dredging of dock and holding basin	0.047	0.89 sand 7.21 clay	0.32 sand 2.99 clay	100% sand 64% clay
2	Dredg dock and Seaton Channel	0.049	0.85 sand 6.37 clay	0.30 sand 2.75 clay	97% sand 59% clay
3	Dredg doc, and Q10/Q11	0.046	0.90 sand 7.23 clay	0.32 sand 3.00 clay	101% sand 63% clay
4	Dredg dock, SC and Q10/Q11	0.043	0.85 sand 6.38 clay	0.31 sand 2.76 clay	98% sand 58% clay
5	Dock closed	0.045	0.86 sand 6.67 clay	0.31 sand 2.80 clay	98% sand 60% clay
6	Dock cl, dredged Seaton Channel	0.044	0.86 sand 5.52 clay	0.31 sand 2.49 clay	98% sand 55% clay
7	Dock cl, dredged Q10/Q11	0.043	0.86 sand 6.69 clay	0.31 sand 2.82 clay	99% sand 60% clay
8	Dock cl, dredged SC and Q10/Q11	0.040	0.82 sand 5.99 clay	0.30 sand 2.62 clay	95% sand 55% clay
9	Dock cl, dredged SC and Q10/Q11 extended	0.050	0.84 sand 6.20 clay	0.31 sand 2.55 clay	96 % sand 55 % clay

* in % of deposition rate for Scenario 0

Pt 2 Seal Sands

Case	Description	V_{max} (m/s)	C_{max} (mg/l)	C_{avg} (mg/l)	Δ depos. rate*
0	Baseline	0.096	0.72 sand 11.1 clay	0.25 sand 3.86 clay	100% sand 15.6 clay
1	Dredging of dock and holding basin	0.095	0.71 sand 6.36 clay	0.25 sand 2.62 clay	101% sand 67% clay
2	Dredg dock and Seaton Channel	0.091	0.68 sand 5.64 clay	0.24 sand 2.42 clay	97% sand 60% clay
3	Dredg doc, and Q10/Q11	0.094	0.72 sand 6.38 clay	0.25 sand 2.63 clay	101% sand 67% clay
4	Dredg dock, SC and Q10/Q11	0.091	0.69 sand 5.66 clay	0.24 sand 2.42 clay	98% sand 60% clay
5	Dock closed	0.092	0.69 sand 5.91 clay	0.24 sand 2.47 clay	98% sand 62% clay
6	Dock cl, dredged Seaton Channel	0.092	0.69 sand 4.95 clay	0.24 sand 2.21 clay	98% sand 55% clay
7	Dock cl, dredged Q10/Q11	0.092	0.70 sand 5.94 clay	0.25 sand 2.48 clay	99% sand 63% clay
8	Dock cl, dredged SC and Q10/Q11	0.089	0.67 sand 5.33 clay	0.24 sand 2.30 clay	96% sand 57% clay
9	Dock cl, dredged SC and Q10/Q11 extended	0.090	0.68 sand 5.45 clay	0.24 sand 2.30 clay	96 % sand 57 % clay

* in % of deposition rate for Scenario 0

Pt 3 Seaton Channel

Case	Description	V_{max} (m/s)	C_{max} (mg/l)	C_{avg} (mg/l)	Δ depos. rate*
0	Baseline	0.469	2.12 sand 19.9 clay	0.71 sand 6.65 clay	100% sand 100%**clay
1	Dredging of dock and holding basin	0.470	2.12 sand 11.7clay	0.71 sand 4.88 clay	100% sand 51%** clay
2	Dredg dock and Seaton Channel	0.402	2.07 sand 11.0 clay	0.70 sand 4.63 clay	96% sand 32%** clay
3	Dredg doc, and Q10/Q11	0.470	2.12 sand 11.7 clay	0.71 sand 4.89 clay	100% sand 51%** clay
4	Dredg dock, SC and Q10/Q11	0.402	2.07 sand 11.0 clay	0.70 sand 4.63 clay	96% sand 31%** clay
5	Dock closed	0.449	2.07 sand 11.2 clay	0.70 sand 4.70 clay	98% sand 42%** clay
6	Dock cl, dredged Seaton Channel	0.402	2.07 sand 10.0 clay	0.71 sand 4.35 clay	98% sand 43%** clay
7	Dock cl, dredged Q10/Q11	0.449	2.07 sand 11.2 clay	0.70 sand 4.71 clay	98% sand 42%** clay
8	Dock cl, dredged SC and Q10/Q11	0.383	2.02 sand 10.6 clay	0.69 sand 4.49 clay	98% sand 22%** clay
9	Dock cl, dredged SC and Q10/Q11 extended	0.390	2.05 sand 11.0 clay	0.70 sand 4.65 clay	96% sand 35%**clay

* in % of deposition rate for Scenario 0
**As erosion of cohesive sediments occurs at this point, silt/clay deposits will not be sustained and this type of sediment will not exist here. The negative deposition rate therefore shows the change in erosion potential at this point.

Pt 4 Tees Channel

Case	Description	V_{max} (m/s)	C_{max} (mg/l)	C_{avg} (mg/l)	Δ depos. rate*
0	Baseline	0.552	4.93 sand 23.4 clay	1.96 sand 12.9 clay	100% sand 100%**clay
1	Dredging of dock and holding basin	0.552	4.93 sand 21.2 clay	1.96 sand 12.4 clay	100% sand 63%** clay
2	Dredg dock and Seaton Channel	0.552	4.93 sand 21.2 clay	1.96 sand 12.3 clay	98% sand 63%** clay
3	Dredg doc, and Q10/Q11	0.552	4.93 sand 21.2 clay	1.96 sand 12.4 clay	100% sand 63%** clay
4	Dredg dock, SC and Q10/Q11	0.552	4.92 sand 21.2 clay	1.96 sand 12.3 clay	100% sand 63%** clay
5	Dock closed	0.545	4.89 sand 21.0 clay	1.95 sand 12.3 clay	99% sand 60%** clay
6	Dock cl, dredged Seaton Channel	0.545	4.89 sand 20.9 clay	1.96 sand 12.2 clay	98% sand 60%** clay
7	Dock cl, dredged Q10/Q11	0.545	4.89 sand 21.0 clay	1.95 sand 12.4 clay	99% sand 60%** clay

Case	Description	V_{max} (m/s)	C_{max} (mg/l)	C_{avg} (mg/l)	Δ depos. rate*
8	Dock cl, dredged SC and Q10/Q11	0.545	4.88 sand 21.0 clay	1.95 sand 12.3 clay	99% sand 60%** clay
9	Dock cl, dredged SC and Q10/Q11 extended	0.545	4.88 sand 21.0 clay	1.95 sand 12.3 clay	99% sand 60%** clay

* in % of deposition rate for Scenario 0
**As erosion of cohesive sediments occurs at this point, silt/clay deposits will not be sustained and this type of sediment will not exist here. The negative deposition rate therefore shows the change in erosion potential at this point.

Pt 5 North Gare Sands

Case	Description	V_{max} (m/s)	C_{max} (mg/l)	C_{avg} (mg/l)	Δ depos. rate*
0	Baseline	0.074	6.48 sand 23.4 clay	3.28 sand 12.9 clay	100% sand 100% clay
1	Dredging of dock and holding basin	0.074	6.48 sand 21.2 clay	3.28 sand 12.3 clay	100% sand 98% clay
2	Dredg dock and Seaton Channel	0.074	6.48 sand 21.2 clay	3.28 sand 12.3 clay	100% sand 98% clay
3	Dredg doc, and Q10/Q11	0.074	6.48 sand 21.2 clay	3.28 sand 12.4 clay	100% sand 98% clay
4	Dredg dock, SC and Q10/Q11	0.074	6.48 sand 21.2 clay	3.28 sand 12.3 clay	100% sand 98% clay
5	Dock closed	0.073	6.45 sand 21.0 clay	3.28 sand 12.2 clay	100% sand 98% clay
6	Dock cl, dredged Seaton Channel	0.073	6.48 sand 21.0 clay	3.28 sand 12.3 clay	100% sand 97% clay
7	Dock cl, dredged Q10/Q11	0.073	6.45 sand 20.9 clay	3.28 sand 12.2 clay	100% sand 98% clay
8	Dock cl, dredged SC and Q10/Q11	0.073	6.45 sand 21.0 clay	3.27 sand 12.3 clay	100% sand 97% clay
9	Dock cl, dredged SC and Q10/Q11 extended	0.545	6.45 sand 21.0 clay	3.27 sand 12.3 clay	100% sand 97% clay

* in % of deposition rate for Scenario 0

Pt 6 Coatham Sands

Case	Description	V_{max} (m/s)	C_{max} (mg/l)	C_{avg} (mg/l)	Δ depos. rate*
0	Baseline	0.028	9.80 sand 22.4 clay	7.70 sand 19.3 clay	100% sand 100% clay
1	Dredging of dock and holding basin	0.028	9.80 sand 23.9 clay	7.70 sand 20.5 clay	100% sand 107% clay
2	Dredg dock and Seaton Channel	0.028	9.80 sand 23.9 clay	7.70 sand 20.5 clay	100% sand 107% clay
3	Dredg doc, and Q10/Q11	0.028	9.80 sand 23.9 clay	7.70 sand 20.5 clay	100% sand 107% clay
4	Dredg dock, SC and Q10/Q11	0.028	9.80 sand 23.9 clay	7.70 sand 20.5 clay	100% sand 107% clay

Case	Description	V_{max} (m/s)	C_{max} (mg/l)	C_{avg} (mg/l)	Δ depos. rate*
5	Dock closed	0.028	9.79 sand 23.9 clay	7.70 sand 20.5 clay	100% sand 107% clay
6	Dock cl, dredged Seaton Channel	0.028	9.79 sand 23.9 clay	7.70 sand 20.5 clay	100% sand 107% clay
7	Dock cl, dredged Q10/Q11	0.028	9.79 sand 23.9 clay	7.70 sand 20.5 clay	100% sand 107% clay
8	Dock cl, dredged SC and Q10/Q11	0.028	9.79 sand 23.9 clay	7.70 sand 20.5 clay	100% sand 107% clay
9	Dock cl, dredged SC and Q10/Q11 extended	0.545	9.79 sand 23.9 clay	7.70 sand 20.5 clay	100% sand 107% clay

* in % of deposition rate for Scenario 0

Pt 7 Teesport

Case	Description	V_{max} (m/s)	C_{max} (mg/l)	C_{avg} (mg/l)	Δ depos. rate*
0	Baseline	0.206	0.40 sand 10.4 clay	0.17 sand 3.95 clay	100% sand 7.82 clay
1	Dredging of dock and holding basin	0.206	0.40 sand 5.02 clay	0.17 sand 2.45 clay	100% sand 48% clay
2	Dredg dock and Seaton Channel	0.206	0.40 sand 4.85 clay	0.17 sand 2.40 clay	100% sand 46% clay
3	Dredg doc, and Q10/Q11	0.206	0.40 sand 5.02 clay	0.17 sand 2.45 clay	99% sand 48% clay
4	Dredg dock, SC and Q10/Q11	0.206	0.40 sand 4.85 clay	0.17 sand 2.40 clay	99% sand 46& clay
5	Dock closed	0.206	0.39 sand 4.86 clay	0.17 sand 2.40 clay	99% sand 46% clay
6	Dock cl, dredged Seaton Channel	0.206	0.40 sand 4.61 clay	0.17 sand 2.34 clay	99% sand 43% clay
7	Dock cl, dredged Q10/Q11	0.206	0.39 sand 4.87 clay	0.17 sand 2.40 clay	98% sand 46% clay
8	Dock cl, dredged SC and Q10/Q11	0.206	0.39 sand 4.73 clay	0.17 sand 2.80 clay	98% sand 45% clay
9	Dock cl, dredged SC and Q10/Q11 extended	0.206	0.40 sand 4.61 clay	0.17 sand 2.34 clay	99% sand 43% clay

* in % of deposition rate for Scenario 0

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