Section 5

Regional Physical Monitoring Programme

5. Physical Monitoring Studies

5.1. Aim

Box 23 The Aim of Regional Physical Monitoring Studies

The overall aim of the Physical monitoring studies proposed is:

To test the predictions made in the REA related to changes in dredging derived suspended and seabed sediment distribution and flux in the ECR, using a single regionally representative type site (473 East).

5.2. Assumptions

General considerations and constraints related to survey design and methodology for surveys in the ECR are provided in **Section 3**. Whilst physical conditions across the ECR vary slightly, the region is characterised by water depths greater than 30m and seabed that is almost entirely composed of mixed sands and gravels.

Hydrodynamic conditions are broadly similar across the region with sediment transport being dominated by tidal currents. Wave climate is also similar across the area with largest, and most frequent, waves propagating from the West Southwest. Maximum significant wave heights occur for a small proportion of the year (4m – 1.8% of total time) and largest waves are unlikely to significantly effect seabed physical processes in any of the proposed dredging permission areas.

Other than a gentle shallowing from West to East across the region, it does not exhibit any locally distinct hydrodynamic conditions that would result in significant differences in the type and scale of processes affecting the seabed across the region.

Volumes of fine sediment within the seabed sediments are low (<3-5%) for all dredging permission areas and whilst the proportion of sand, gravel and cobbles within the seabed varies between areas it is fair to assume at this stage that any sediment returned to the seabed will be of a similar composition for all dredging permission areas. Site specific particle size data are/will be available for all proposed dredging permission areas that are/will be suitable for describing differences between areas in the future as understanding develops.

The companies of the ECA will extract aggregate from the proposed DPAs using trailer dredging techniques that will not vary significantly between companies or DPAs. To undertake site specific physical studies at all proposed dredging permission areas is unrealistic in terms of the time required and the associated costs.

The ECA have therefore decided that a regional type site (Area 473 East) will be studied in detail in order to provide physical process data that will be suitable for application to all ECR dredging permission areas. It is therefore assumed that the resulting impacts of the dredging process in all areas, in terms of the direct seabed impact and secondary effects of sediment returned the seabed, will be similar across the region.

Bearing in mind the above information, it should be noted that the following assumptions have been made in planning the physical monitoring studies in the ECR:

- **Area 473 East is representative of all dredging areas in the ECR.**
- **Conclusions arising from the monitoring of Area 473 East will be transferable to all proposed dredging permission areas in the ECR following adaptation using site specific monitoring data.**
- **Whilst there is obviously some spatial variation, seabed sediments and physical environmental conditions are broadly similar across the ECR.**
- **Dredging processes and techniques to be employed are similar across the ECR.**
- **The proposed regional monitoring is additional to requirements of routine site specific monitoring.**

The assumptions upon which the physical monitoring studies have been based are necessary to provide a start point from which the studies can be undertaken.

Data from site specific monitoring of DPAs, undertaken by individual licence holders, will subsequently be used to adapt the results of the regional type site studies in Area 473 East thereby informing management of dredging activities at all other ECR DPAs.

The regional physical monitoring studies are primarily designed to determine the scale of impacts resulting from screened and overspilled sediment (Photo – BMAPA).

5.3. Overview of Methods

The following approach will be employed to test the REA predictions:

- **Hypotheses erected based on the predictions of the REA.**
- **Hypotheses tested using data resulting from the following survey methods:**
    - **High resolution (500kHz) side scan sonar**
    - **Swathe bathymetry**
    - **Clamshell grab sampling**
    - **Camera imaging at grab locations**
    - **Video transects**
    - **Sediment tracers**
    - **Minipods**
    - **ADCP**
    - **Water samplers**
    - **Laser particle sizing**
    - **Sedimentological analysis using statistical techniques**
- **Surveys will be undertaken on a single intensively dredged area (473 East) where screening is permitted.**
- **Surveys to take place every 6 months during the first 2 years of dredging, with frequency reviewed from Year 3 onwards.**

The methodology for each study has been informed by impact hypotheses for extraction activities in the ECR. Whilst hypotheses are provided for all physical monitoring studies at this stage, subsequent amendments of the tracer study may not adopt this approach.

An overview of Baseline to Year 5 activities is provided in **Tables 5 and 8**.

Where possible, a brief consideration of potential thresholds has been given in the physical monitoring studies however, it is proposed that the results of the physical monitoring will be used to inform development of specific physical and biological monitoring thresholds during the first 5 years of dredging.

5.4. Seabed Sediment Study

Aim

Box 24 The Aim of the Regional Seabed Sediment Study

The primary aim of the seabed sediment study is:

To test the REA prediction of sea bed sediment deposition and transport in the ECR (Posford Haskoning, 2003) (Figure 11), which will permit a clear detailed understanding of scale and types of sea bed impact arising from deposition of fine sediment liberated by dredging and allow dredging process adjustment if required.

Summary

The study will be conducted on the following basis (see **Figure 12** for survey plan):

- **Carried out on a single, high production dredging site where screening is occurring – Area 473 East.**
- **Baseline survey before dredging begins (Figure 12).**
- **Repeat surveys to be take place every 6 months during first 2 years dredging, frequency to be become annual during year 3 of study (to be reviewed if required).**
- **Side scan sonar and swath bathymetry data supplied from routine site specific monitoring and additional studies if required.**
- **Coverage of sidescan and swath bathymetry to be extended to 3km beyond the Northeast boundary of Area 473 East and 1km beyond the Southwest boundary.**
- **Baseline Seabed samples using hydraulic clamshell grab and supported by sea bed camera imagery throughout the initial 4-5 years. Repeat surveys using clamshell grab and/or box corer where appropriate.**
- **Photographs taken at all grab sites.**
- **7 video transects as shown on Figure 12.**
- **Minipods or ADCP used to measure currents for a representative time period during first repeat survey.**
- **Detailed sediment gradings and statistical sedimentological analysis undertaken to identify distribution and sorting trends.**
- **Result used to build seabed sediment transport model for ECR.**
- **Reporting to take place within 4 months of each survey and to include comparison with REA model.**

Hypothesis to be Tested

The approach is designed to provide a first order comparison of the actual deposition and transport measured in the study with that predicted in the REA. The study has been designed to investigate whether the seabed sediments deposited as a result of dredging, are transported and accumulate differently to the predictions of the REA, or whether there is a good comparison with the REA model (**Figure 11**). In addition, the sampling strategy has been extended beyond that designed to detect REA predicted effects, to ensure that unpredicted seabed sediment fluxes can be detected, should they occur.

As with the plume study, if results show a pattern of sediment deposition and transport comparable with or less extensive than the REA model then the REA model of plume dispersion shall be accepted. If, following analysis of the results of the study, the extent of dredging derived seabed sediments is shown to be significantly greater than the REA prediction then dredging management shall be reviewed and may be further restricted until further studies are completed. If the effects of the plume are less extensive than predicted then amendment of dredging management (eg screening restrictions) may need to be discussed.

To this end the following hypothesis will be tested in the first instance:

Physical Monitoring Impact Hypothesis 1

Ho The composition, deposition, distribution and transport of fine sediment liberated by the dredging process differs from that predicted in the REA model and will result in seabed sediment bedforms that differ from the REA model.

Ha The composition, deposition, distribution and transport of fine sediment liberated by the dredging process is as predicted in the REA model.

Methodology

The REA predicts that dredging derived sediments returned to the environment via screening equipment and spillways will settle to the seabed and be reworked as bedload into a sand sheet, ripples and sand streaks, predominantly in the direction of the tidal residual (Northeast).

A study of seabed sediment will take place in Area 473 East, every 6 months during Years 1 and 2 of dredging. The frequency of surveys will be reviewed following this period.

Cargos from Area 473 East may be screened. In order to monitor source terms related to the plume study, records of each cargo will be kept noting:

- **Loading time**
- **Volume of sediment/water pumped**
- **Screening methods employed**
- **Tonnage loaded**

Dredging will only take place within the loading area shown in **Figure 12** for the duration of the initial 5 year monitoring programme in Area 473 East.

A variety of geophysical, sediment/geotechnical, ground discrimination and biological sampling techniques will be adopted to detect any reworking of seabed sediments deposited as a result of the dredging operations.

Interpretive charts at 1:5000 scale will be produced after each survey and will be compared with both the pre-dredge baseline description of the area and also the predictions of the REA. The tracer study will proceed in parallel in order to determine sediment transport rates and the degree to which reworking of deposited sands occurs. Results from the benthic sampling programme will be compared with the results from seabed sediment studies. Results will be used to assess seabed sediment change and implications for benthic ecology in terms of habitats and community structure. The volume of sediment derived from dredging will be calculated.

Mapping of Seabed Features

High frequency sidescan sonar (500kHz) and swathe bathymetry data will be acquired over the area shown in **Figure 12**. The area of the survey will extend up to 1km from the Southwest boundary of the dredging area in order to track any seabed sediments that may be transported into the study area as a result of natural processes. The survey area will extend up to 3km to the Northeast of the dredging area in order to map the area of the seabed that will potentially be influence by the deposition and reworking of sands returned to the environment by the dredging process. Line spacing will produce full coverage of the survey area, with some overlap between lines, and tie lines will be employed to enable a regional setting to be established.

A sidescan sonar mosaic will be produced of the area together with an interpretation of the seabed features in relation to the baseline survey. Swathe data will be draped over the interpretation to highlight any changes in sand distribution and evolving bedform fields and their orientations relative to the tidal residual. Bathymetric difference plots will be produced to highlight the depth changes in the dredged area and surrounds, relative to the baseline and previous surveys.

Ground Truthing, Seabed Sediment and Biological Recording

Seabed Sampling – A total of 74 sediment grab samples will be taken using a hydraulic clamshell grab at locations shown in **Figure 12** (final seabed sampling array still under discussion). These will be subject to faunal analysis, particle size analysis and statistical testing techniques in order to determine changes in sediment and biological character relative to the pre-dredge baseline. Statistical techniques will include univariate analysis and multivariate techniques relevant to sediment parameters such as, sorting, skewness and kurtosis and biological parameters, including primary variables and a number of derived indices.

Still Camera Imagery – At each sample site, prior to grab sampling, a photograph will be taken to accompany the particle size data yielded from the seabed sediment sample. The photograph will be interpreted and added to the interpretive chart.

Video – To assist in the interpretation of the sidescan sonar data and to determine the scale of lateral dispersion of plume sediments, 7 video transects will be recorded as shown in **Figure 12**. . The video transects will be interpreted in relation to changes in seabed character, both in terms of sediments and ecology, if possible, and the results added to the interpretive chart.

Minipods – Providing a safe location can be established minipod(s) will be deployed over a 1 month period to record currents and bedload transport. At this stage it is envisaged that minipods will be deployed at the locations shown in **Figure 12**. Deployment is planned to coincide with the first repeat seabed sediment survey scheduled for Spring 2006. Data from the minipods will assist in interpretation of the bedload transport regime derived from the sidescan sonar.

Baseline Assessment

A programme of sampling and data interpretation has been scheduled that will provide the baseline description of sedimentary environment within and surrounding Area 473 East.

The planned programme of works is described more fully in the draft SOP for works as appended to this version of the Blueprint (**Annex 3**).

The baseline description of the area will be based on data resulting from the following activities:

- **Interpretation of high resolution sidescan sonar mosaics of the area.**
- **Seabed photography and hydraulic clamshell grab sampling of 74 sites (Figure 12).**
- **Logging of sediment composition within the upper 30-50cm of seabed sediment.**
- **Sub-sampling of sediment grab samples for subsequent lab analysis of sediment characteristics and benthic infauna.**
- **Recording of video footage along 7 transects.**
- **Use of seabed profiling camera to describe the *in situ* characteristics of the seabed surface.**

Following this programme of sampling a baseline description of the area will be completed, incorporating previous data from prospecting and other baseline surveys, including data from the regional ecological monitoring programme undertaken in August-September 2005.

5.5. Screening and Overspill Discharge Study

Aim

Box 25 The Aim of the Screening and Overspill Discharge Study

The aim of the screening and overspill discharge study is:

To provide source term data related to the volume, rate of discharge and particle size distribution of sediment returned to the seabed via screening equipment or dredger hopper spillways.

Summary

The study will be undertaken on the following basis:

- **Carried out in Year 1 of dredging.**
- **Undertaken in conjunction with plume study – Area 473 East.**
- **Both screening and overspill discharges to be analysed.**
- **Sampling of suspended solids from discharges to calculate volume sediment returned to environment.**
- **Sampling at regular intervals throughout the duration of the load.**
- **Measurement of discharge rate, solids concentration and PSD.**
- **Use of seabed sediment/geotechnical data (PSD) from dredge run.**
- **Records of dredge location, duration, draghead and seabed depths.**
- **Measurement of dredger dimensions.**

Hypothesis to be Tested

The data generated by the screening and overspill discharge study will provide source data that will be utilised in both the plume and seabed sediment studies. Whilst the data that is generated by screening and overspill discharge study will ultimately be used to inform those studies, it will be possible to test basic hypotheses related to the nature of the screened and overspilled sediment as follows:

Physical Monitoring Impact Hypothesis 2

Ho There is no significant difference between the composition of the screened sediment compared to overspilled sediment.

Ha Sediment returned to the seabed from the screening process is composed of particles with a significantly different particle size distribution (less silt and clay particles) than the sediment returned to the seabed via the dredger spillways, as predicted in the REA.

Physical Monitoring Impact Hypothesis 3

Ho There is no significant difference between the volume of the screened sediment compared to overspilled sediment.

Ha Higher volumes of sediment are returned to the seabed from the screening process than are returned to the seabed via the dredger spillways, as predicted in the REA.

It should also be possible to investigate the effects of variation in seabed sediment PSD on the nature of sediments that are discharge via screening plant and spillways. Bearing this in mind further hypotheses may be tested that investigate the relationship between in situ seabed sediments and screened/overflowed sediment. This has the potential to allow prediction of the volumes of sediment that will be screened/overspilled from a certain area based on seabed sediment sample data.

Methodology

The study will take place in Year 1 of dredging in Area 473 East. Whilst it is described separately the Screening and Overspill Discharge Study will form a component of the Plume Study.

Sampling will be carried out to determine the solids concentration of screening discharges and overspill discharges. Sampling will be carried out during two separate dredging events – a fully screened cargo and an unscreened cargo using the same dredger and cargo volume on each occasion.

Measurement of Solid Concentration in Overflow Discharge

The loss of sediment from hopper overflow requires measurement of:

- **The rate of overflow (m3/sec)**
- **The solids concentration (mg/l)**
- **The particle size distribution**

The practical problems of overflow measurement are manifold. The rate of flow (Q) will be assumed to be the rate of flow through the suction pipes (minus the screening discharge) and the dredger used for the trials therefore must be equipped to measure this flow (with formal evidence of the calibration and uncertainty in this measurement).

The solids concentration and particle size distribution can only be measured using water sampling and subsequent analysis in the laboratory. Optical devices, density-measuring devices or devices such as LISST will be corrupted because of the severe air bubble entrainment present in the system.

The remaining options are pump-sampling and “bottle” water sampling. Pump water sampling could be used to provide a continuous stream for sampling. However, some consideration must be given to the resulting effects of non-isokinetic sampling. Bottle water sampling could be taken in the hopper very close to the overflow but this may give rise to inaccuracy because it will be difficult to align the bottles with the flow (especially. noting that flow paths may be different for different particle sizes).

The most practical approach is likely to be large-volume tube samplers outside of the hopper and dredger in the overflow discharge. Safe access to the overflow is therefore essential - not all vessels will be suitable. Further complications result from the consideration that the overflow from each of the spillways will vary independently throughout the loading time due to the pitch and roll of the vessel. Measurements will therefore need to be taken at more than one spillway (and all if possible).

Detailed records of flow (Q) and mixture density (?) in the suction pipe will be required together with TDS records (in full) throughout the dredging cycle. These will be used as a comparison with the water sampling data. It is recognised that there are inaccuracies inherent in the Q/? and TDS measurements but there is little that can be done about this except to select a vessel with recently-calibrated and well-maintained measurement systems.

Procedure

1 Sample suspended solids in overflow at agreed time intervals, factor by measured suction pipe(s) flow rate to derive rate of solids release throughout overflow period. Integrate to derive total loss.
2 Use TDS system in conjunction with suction pipe(s) Q/? measurements to develop alternative estimated rate of solids release throughout overflow period.

Samples should be used to determine particle size distribution of sediment.

Supplementary data requirements (assuming full Q/? and TDS measurements already available):

1 Geotechnical data - depending on site characteristics, it may be possible to collect a series of simple grab samples along the length of the area to be trailed.
2 Track plot and times.
3 Draghead depths and bed depths.
4 Data concerning the dimensions of the dredger and hopper, draghead and suction pipe screen mesh, etc.

Measurement of Solid Concentration in Screening Discharge

The loss of sediment from screening requires measurement of:

- **The rate of discharge (m3/sec)**
- **The solids concentration (mg/l)**
- **The particle size distribution**

The scientific interest surrounding screening from an impact point of view is currently greater than that associated with the overflow (for aggregate dredging) but the practical problems of screening measurement are even more severe than those of the overflow because of the greater discharges (and danger) associated with screening. The practical problems of sampling require large samples to be taken either by fitting an engineered “diversion tube” to the discharge (which can then be directed to suitable large containers) or by using a barge to collect the discharge. These samples could then be analysed for total solids and PSD. This does not, however, solve the problem of measurement of the water discharge of the screening.

Procedure

1. Sample suspended solids in screening at agreed frequent intervals.
2. Devise method of evaluating the water discharge at times of sampling.

Determine particle size distribution of sediment in representative samples.

Supplementary data requirements (assuming full Q/? and TDS measurements already available):

1. Geotechnical data - depending on site characteristics, it may be possible to collect a series of simple grab samples along the length of the area to be trailed.
2. Track plot and times.
3. Draghead depths and bed depths.
4. Data concerning the dimensions of the dredger and hopper, draghead and suction pipe screen mesh, etc.

Current Plans for Timing of Study

Work on the screening and overspill study will commence when dredging commences in Area 473 East. Upon issue of a licence to extract from Area 473 East the ECA will develop the methodology for the study and issue an SOP document to describe the nature of the works to be carried out. It is anticipated that granting of a licence to dredge Area 473 may occur within the next 6 months therefore the results of the screening and overspill study will be available for use in the first annual review of monitoring scheduled to take place in May/June 2006.

5.6. Plume Study

Aim

Box 26 The Aim of the Regional Plume Study

The primary aim of the focused plume study is:

To test the REA model prediction of water column concentrations of fine sediment (very fine sand, silt and clay) within plumes generated by dredging. Determine levels of deposition and re-suspension of plume-derived sediment in order to permit a clear and detailed understanding of the distribution, scale and types of water column and sea bed impact arising from plumes, in order to inform dredging process adjustment if required.

Summary

The study will be conducted on the following basis:

- **Carried out during Year 1 of operational dredging.**
- **Carried out on a single test site – Area 473 East.**
- **Two discrete dredging events to be tested; one cargo screened, one cargo unscreened.**
- **The methodology shall be capable of detecting re-suspension of plume sediments.**
- **Monitoring will employ vessel-based techniques & seabed minipods, water samplers and ADCP array to monitor plume.**
- **The measured plume will be compared with REA model and site specific modeling within 6 months of survey.**
- **Interpretation of the study results will be used to develop a plume modeling tool capable of informing dredging management and regulatory decision making.**

Hypotheses to be Tested

This approach will allow all eventualities to be investigated, ie whether the plume generated by dredging is more/less extensive than that predicted in the REA, or whether there is a good comparison with the REA model.

If the plume study results show a plume comparable with or less extensive than the REA model then the REA model of plume dispersion shall be accepted. If, following analysis of the results of the study, the plume is shown to be significantly greater than the REA prediction then dredging management and screening activities will be reviewed, possibly resulting in further studies. Conversely, if the effects of the plume are less extensive than predicted then amendment of screening restrictions will be reviewed. To this end the study has been designed to test the following hypotheses:

Physical Monitoring Impact Hypothesis 4

Ho The nature (depth averaged concentrations of suspended sediment) and spatial extent of the plume generated by dredging is different from that predicted in the REA model and subsequent studies.

Ha The nature and extent of the plume generated by dredging is as predicted in the REA model.

Physical Monitoring Impact Hypothesis 5

Ho Deposition and resuspension of plume sediments is different from that predicted in the REA model.

Ha Deposition and resuspension of plume sediments is as predicted in the REA model.

Methodology

Dynamic plume

Both the source term (shape and concentration) of the passive plume resulting from loss of fine sediment in the overflow and the footprint (area and thickness) of screened material on the bed are a function of the dynamic plume processes that occur when sediment water mixtures are discharged from the dredger.

The discharge of both overflow and screening onto the water surface (as opposed to discharge through the dredger hull) will however reduce the significance of the dynamic phase since significant mixing will occur on impact and moreover the ship-side spill of overflow through a number of discharge points means that the overflow plume will be much more mixed and diffuse (compared to that through a central hull spillway).

If the (weak) dynamic plume does not move downwards sufficiently rapidly the propeller wake will impact on the dynamic plume mixing it rapidly through the water column. It is of interest as to whether the overflow plume and/or the screening plume form a dynamic plume which escapes the propeller wake and whether these plumes are distinct or blend into one another.

Two methods exist to examine the fate of the dynamic plume. Each supplies different, but complementing, information about the plume.

1 The first method is to tow an ADCP immediately across the stern of the trailer as it passes (see sketch below). The ADCP must be towed below the propeller wake of the ship. Assuming that the survey vessel can pass behind the ship at a distance of, say, 5-10 metres, we estimate that the ADCP will need to be towed at a depth of 15 metres or more to avoid wake problems (trailer half-loaded).

This method produces ADCP backscatter results, which when calibrated with water samples and using calibration software (such as SEDIVIEW) will produce an estimate of the size of the dynamic plume passing under the sensor (which then by considering the degree of dilution produces an estimate of concentration). It should be noted that the calibration procedure is "approximate" because the dynamic plume itself cannot be sampled.

The best alternative is to calibrate in an old (>15 minutes) overflow plume which inevitably introduces some error potential. There is an additional practical problem in this case in that the plume of interest may pass above the sensor owing to the surface release and the reduced initial momentum.

2 The second method of monitoring the dynamic plume is for side-scan sonar to be directed sidewise at the dynamic plume as a survey vessel sails alongside the dredger. This produces a single snap shot of the dynamic plume from which the (lower and near) edges of the dynamic plume can be defined, allowing the path and rate of dilution mixing of the dynamic plume to be deduced.

Passive Plume

The measurements described in the preceding sections relate to the source terms of the passive plume. This section relates to measurement of concentrations and of the limits of the passive plume itself. For these measurements a ship-mounted ADCP should be used (in combination with appropriate back-scatter calibration software such as SEDIVIEW) to make transects of the passive plume produced by the dredger. This exercise would continue in combination with the measurements outlined above during the dredging period. These measurements will require water samples in combination with use of laser particle sizer for calibration of the ADCP back-scatter output.

Interpretation and Application of Plume Monitoring Data

This section forms an outline for modelling studies arising from the proposed field measurements. The modelling studies described below are designed to deliver a modelling tool, calibrated on the basis of the proposed ECR field measurements, which can then be used to provide input to management and regulatory decisions arising from any future changes in the utilisation of the ECR dredging areas.

For this outline of the proposed modelling studies it is assumed that the model developer and the organisation using the model for studies relating to future management of the resource will be a single organisation.

The methodology below should be seen in the light that the principle issues of concerns arising from the proposed dredging in the ECR arise from the longer term dispersion of screened sediment (and to a lesser extent overflowed sediment) settling onto the seabed. Matters relating to the dispersion of the turbid plume have been established as a lesser concern. Thus, as well as providing information about fine sediment plumes, the proposed modelling studies should also provide a means for predicting the initial footprint of the sandy material resulting from screening. This then forms an input to the longer term dispersion studies.

Required components of the model system

The model studies should deliver a model or combination of models which can be calibrated on the basis of the proposed ECR field measurements and which can be used to predict the following information for the proposed dredging operation.

- **The discharge rate, concentration and PSD of sediment released into the water column from the overflow.**
- **The discharge rate, concentration and PSD of sediment released into the water column from screening (if screening is undertaken).**
- **The temporal and spatial dispersion of suspended sediment arising from the passive plume caused by overflow and screening.**
- **The initial footprint of sandy material arising from screening (if screening is undertaken) and overflow.**

The last bullet point relates to the input conditions for the assessment of dispersion of sand over the longer term. This long term dispersion is itself outside the scope of the plume modelling but the input conditions to any such assessment could be derived from plume modelling studies.

It is envisaged that any predictive model system which could assist the future management of the aggregate resources in the ECR would be composed of the following components.

1. A sub-model of the screening process.
2. A sub-model of the hopper process.
3. A sub-model of the near-field mixing zone that occurs upon release of the screened/overflowed material.
4. A sub-model of the dispersion of the passive plume which should have the capacity for combining the effects of dredging by a number of dredgers at different locations.
5. A sub-model of the screening footprint.
6. An optional sub-model of the long term dispersion of fine sediment over a number of years.

It is important that the system is well described and documented in order to be transparent and subject to review. It is envisaged that the passive plume sub-model should have the ability to simulate over the scale of a spring-neap cycle and should not be limited to modelling dispersion over a few tides. Sub-models 3 and 4 above will also require flow model input to drive the passive dispersion models. The model developer should describe how suitable flow model input will be derived.

Phased Approach to Model Development

The general approach to the development of the model system outlined below is a phased approach. It is suggested that the modelling be composed of three phases:

Phase 1 Comparison of the existing model with the ECR field data with little development or calibration (in practice some adjustment to the field data will be required). If the model is a good representation this process will be one of validation and subsequent phases will not be required.

Phase 2 Calibration of the model to the ECR field data. In this case there will significant calibration of the existing model parameters using the field data and perhaps some changes to the routines in the model. However, significant redevelopment of the model is unlikely.

Phase 3 In the case that the calibration of the existing ECR model using the filed data results in a ‘poor’ model fit further work will be undertaken on model development.

It is likely that both Phases 1 and 2 will be required. It is less certain whether Phase 3 will be necessary. It is therefore proposed that an outline plan for Stage 3 is agreed in the first instance that can subsequently be refined if required. It is also recommended that a plan is formulated by the ECA and TWG prior to plume monitoring field work in the event that field data retrieval is inadequate.

5.7. Tracer Study

Aim

Box 27 The Aim of the Regional Tracer Study

The overall aim of the proposed tracer study is:

To provide data and advance knowledge and understanding in the following key areas;

- **Settling of discharged sediment through the water column – specifically the manner in which sediment released from a dredger as a result of screening/overflow is distributed at the seabed following settling under particular conditions.**
- **Sediment movement at the seabed – specifically the way in which the distribution of discharged material at the seabed alters through time as a consequence of the complex interaction of processes such as dispersion, advection and burial.**

Summary

More specifically the study will:

- **Determine how screened sediment released from a dredger at a specific site and under specific conditions might be expected to be distributed at the seabed following settling through the water column.**
- **Determine whether, under specific hydrodynamic conditions, different particle sizes (within the range to be rejected during screening) exhibit different distributions at the seabed following settling through the water column. Such data will allow model predictions presented within the REA to be tested (e.g. the prediction that fine to medium sand will be transported up to ~1km prior to deposition).**
- **Measure changes in the spatial distribution of sediment (tracer) at the seabed to provide an estimate of sediment transport velocity and to determine whether different particle sizes show evidence of moving at different velocities. This will allow model predictions presented within the REA to be tested (e.g. the prediction that transport of sheet sediments will be principally to the Northeast and that beyond the sheet, sands derived from dredging will be found for a further 2km (approximately)).**

- **Understand how the distribution of discharged material at the seabed alters through time as a consequence of the complex interaction of processes such as dispersion, advection and burial.**
- **Determine whether transport velocities estimated in Autumn / Winter are higher than those estimated in Spring / Summer.**
- **Provide data related to the dredging input which may be compared to background fluxes.**

The study has been designed in order to provide data on the physical environment following a period of dredging. These data can then be compared with pre-dredge information, allowing change to be identified. The study seeks to indentify the scale and rate of change occurring progressively during the dredging as a function of several successive trace searches being undertaken. The study will also provide input to the seabed sediment research.

Hypotheses to be Tested

The scope of the tracer study will provide source term information that will inform the findings of the seabed sediment study and regional physical monitoring as a whole. The results of the tracer work will therefore also assist in overall testing of the seabed sediment hypothesis. The tracer study will provide quantitative data related to the behaviour of the tracer particles that should enable the following hypothesis to be tested in support of the overall seabed sediment study:

NB Pending the outcome of ongoing discussions the tracer study may subsequently not employ specific impact hypothesis.

Physical Monitoring Impact Hypothesis 6

Ho Measured tracer particle transport at the seabed does not occur in a direction as predicted in the REA seabed sediment model.

Ha Measured tracer particle transport at the seabed occurs in a direction as predicted in the REA seabed sediment model.

Physical Monitoring Impact Hypothesis 7

Ho Tracer particle transport at the seabed will result in a distribution and range of seabed sediment bedforms different to those predicted in the REA seabed sediment model.

Ha Tracer particle transport at the seabed will result in a distribution and range of seabed sediment bedforms as predicted in the REA seabed sediment model.

Physical Monitoring Impact Hypothesis 8

Ho The rate of transport of tracer particles of a range of grain sizes is different to that predicted in the REA seabed sediment model.

Ha The rate of transport of tracer particles of a range of grain sizes is as predicted in the REA seabed sediment model.

Methodology

It is envisaged that the findings of the tracer study will be used in conjunction with the other seabed sediment studies and forms part of a suite of physical monitoring studies. The majority of the studies will be carried out on Area 473 East (which is assumed to be representative of the ECR) but other site specific studies will also be undertaken and may inform the regional monitoring programme. The tracer injection study is a specialist study and standard procedures do not exist. The proposed methodology reflects best practice and the outline methods are described. The methodology will be refined prior to the survey but the major issues are addressed below.

It should be remembered that the tracer stusy is an innovative contribution to assist in the understanding of sediment transport associated with dredging impacts. It is not an isolated academic research project but an application of a technique designed to provide complementary information to the understanding of sediment processes in the ECR.

Choice of Tracer Type

A range of different types of sand sized sediment tracers are available, these include magnetic particles, man-made resin grains with fluorescent dyes incorporated into them and natural sand particles covered with fluorescent coatings. In order to perform well as a sediment tracer a material must satisfy certain key criteria, these can be summarised as follows:

- **The tracer must be easily distinguishable from the indigenous material at the site and be detectable at low concentrations for the duration of the study.**
- **The amount of tracer present at a given location and time must be accurately measurable, and if it is hoped to use the spatial integration method to derive a transport rate then the vertical distribution of tracer within the bed must also be quantifiable.**
- **The behaviour of the tracer must closely match that of the sediment that is the focus of the study, in order to achieve this physical characteristics such as particle size and specific gravity must also be matched.**
- **The character of the tracer must not change during the study (e.g. particles should not split or be abraded resulting in a progressive change in grain size).**
- **The tracer must not be harmful to the marine environment; and,**
- **The cost of the tracer must not be prohibitively high.**

It is also a key requirement for the present study that the approach used is 'tried and tested'. Based upon these criteria, it is proposed that coated sand tracers will be used for the study. Such tracers have the following performance characteristics:

- **They are easily detectable as a range of different colours can be used, all of which fluoresce under UV light and, under the anticipated experimental conditions, the particles' fluorescent coating is expected to remain detectable for up to 6 months (the actual figure will depend upon the rate at which sediment moves, which is presently unknown).**
- **Low concentrations can be detected (individual grains).**
- **Quantification of the amount of tracer present and its vertical concentration distribution can be achieved accurately by collection and analysis of sediment samples.**
- **The particle size distribution of the tracer can be matched extremely closely to that of the indigenous sediment as can the specific gravity of the tracer (S.G. to within 2%).**
- **As the tracer particles are essentially sand grains they will not fracture or break in a way which is unrepresentative of the indigenous material.**
- **The tracer is not harmful to the marine environment (its release is licenced by DEFRA).**
- **It is cost effective relative to other approaches.**

The performance of coated fluorescent tracers is well known as they have been in use for many years (early work was undertaken in the 1960s).

Background Survey

As already described, it is important that the tracer particles are easily distinguishable from indigenous material at the study site, if this is not the case then serious errors can arise during measurement of the tracer distribution at the seabed. It is known that certain types of both shell and seaweed fluoresce; hence, prior to coating any of the tracer it is important that samples of the bed sediments from across study area are collected and tested to establish whether they contain any fluorescent material.

Existing sidescan sonar data will be used to identify the different types of seabed that exist over the area to be dredging and the near-field region (ie the area where sediment movement is predicted to occur to the NE and SW – however studies will be concentrated within a rectangle 2km by 0.65km extending to the NE of the test dredge site). Having identified the different bed types, a sample grid will be set up to ensure that all of these are sampled representatively (i.e. the number of samples collected corresponds to the total area occupied by that bed type; and, sample sites are distributed evenly over each region). It is proposed that of the order of 100 samples will be collected but this number may be increased or decreased according to the variability indicated by the sidescan data (and/or the variability exhibited by the samples themselves during recovery).

Samples will be collected using a large clamshell grab and/or box corer and will be taken to a depth which ensures that the boundary between the mobile and immobile sediment layers is captured. Upon recovery, the samples (which will be depth-referenced) will be shipped as rapidly as possible to a laboratory where they will be scanned with a UV light to identify any fluorescent particles present. If fluorescent material is found then this will be photographed to allow its colour to be compared to the colours of fluorescent coating that are available. Once it has been photographed the fluorescent material will be dried in an oven at 80ºC (the temperature used for drying sediment prior to grainsize analysis) to establish if this alters the character of the fluorescence, once cooled the material will be re-photographed.

By adopting this approach any risk of the results being compromised as a result of naturally occurring fluorescent particles will be minimised.

Tracer Specification

Based on the information within the REA, basic calculations have been carried out in order to estimate the quantity of tracer it will be necessary to inject during the study; these indicate that approximately 2.5 tonnes of tracer should be released during the first tracer injection. However, the model presented in the REA has limitations (as do all models).

The model is designed to provide information on the main changes that are expected to occur at the seabed as a consequence of dredging. It does not deal with the detailed processes responsible for these predicted changes. It is information regarding these detailed processed (e.g. rate of dispersion, advection and burial of sediment) that are required in order to be able to provide a more robust assessment of the quantity of tracer required. The present level of uncertainty is such that the 2.5 tonnes of sediment indicated from the basic calculations undertaken to date could disperse to the extent that it is undetectable in a matter of days, or alternatively a significant proportion of it could still be detectable weeks/months after injection. In addition to processes such as dispersion, advection and burial influencing the way in which the tracer is distributed at the seabed it is also possible that quantities of the tracer will be dredged (although net sediment transport is expected to be to the NE, dispersion will mean that some tracer will also travel to the SW).

The uncertainties that exist in relation to the way in which the tracer will behave following injection is acknowledged and measure are proposed to mitigate against the uncertainty as far as possible. Two type of mitigation are proposed:

1 Further desk studies will be undertaken prior to injection in an attempt to improve the calculations undertaken to date. Detailed modelling work will not be undertaken but expert opinion will be sought on the detailed processes governing the sediment transport at the site.
2 Depending on the outcome of the desk study and following the first tracer injection, the knowledge gained will result in the optimisation of the design of the main part of the study.

Consequently on completion of the desk study it will be decided whether to inject 2.5 tonnes of tracer or increase the amount injected (provision to inject up to 5 tonnes has already been made and further increases will be considered as required). Based on the outcome of injection 1 a decision will be made on the structure and feasibility (cost/benefit in terms of data return) of undertaking a second tracer injection.

If the tracer does become undetectable after a relatively short period of time following the first injection, this outcome will still provide information on the importance of advection and dispersion relative to burial at the site (albeit qualitative) and further studies can be designed to investigate this.

Fluorescent coatings will be applied to the tracer material to allow identification of particles in seabed sediment samples.

It is important that the particle size of the tracer material used closely matches that of the sediment that is the focus of the study. For the purposes of the present investigation the sediment of interest is that which will be rejected during dredging operations. According to Posford Haskoning (2003) ~80% of this material will be >300µm in diameter (**Figure 3**). It is also an objective to understand how different particle sizes behave (e.g. their relative transport distances). In order to meet these requirements, it is proposed that four different particle size classes will be injected, these being: 150µm to 300µm; 300µm to 600µm; 600µm to 1.2mm; and, 1.2mm to 2.4mm, each of which will be labelled with a different colour of fluorescent coating. This tracer size range allows the vast majority of the rejected material to be represented (~85% according to the sample particle size distribution (**Figure 3**)). Equal weights of each of the four sizes will be injected (i.e. 625kg of each, for injection 1 assuming that 2.5 tonnes is used in total).

During the tracer manufacturing process, quality assurance checks will be carried out to ensure that =90% of the material produced is within the specified size range for each of the size classes. Similarly, QA checks will be made on the specific gravity of the tracer to ensure that it is within 5% of that of the natural (uncoated) sediment (~2.65). The sediment will also be viewed under a microscope to ensure that grains are properly tagged with fluorescent coating.

Tracer Injection

The first of two tracer injections will occur within 1 year of the start of dredging. The first injection will occur at t0 (probably spring 2006) after the study site will have been actively dredged for several months. Rejected sediment will already have had the opportunity to be deposited on the seabed and be transported. It is expected that net transport will be towards the north east, however, this will be checked using sidescan sonar and bathymetric survey prior to injection. The results of such surveys will ultimately determine where the tracer is injected. Prior to injection, the tracer will be washed with a dilute solution of biodegradable detergent to rid it of any hydrophobic properties. Injection will be via the reject chutes of a dredger, just beyond the north eastern boundary of the test dredge site, on a neap tide, as slack water ends and the flood begins.

This strategy is designed to allow the tracer to mimic the dispersion of material rejected from the dredger and limit the amount of sediment that settles within the test dredge site (hence minimising the potential for the tracer to be dredged following its release). Following the tracer release, dredging of the test site will continue. At present the second tracer injection is planned for approximately seven months after the first, however, this assumes that the tracer from the first injection is traceable for several months (which may not be the case). As discussed the second injection may involve a larger quantity of tracer than used in the first injection.

Timing of Tracer Searches (sampling exercises) and Number to be Undertaken

As described previously, the objectives of the study include determination of how screened material released from a dredger might be expected to be distributed at the seabed following settling. To achieve this objective it is essential that the first sampling exercise begins as soon as the tracer has finished settling (theoretically this will be approximately 1hr and 10mins after tracer injection). It is also an objective to measure changes in the spatial distribution of tracer at the seabed to provide an estimate of sediment transport velocity (excluding transport due to settling from the dredger). Hence, a minimum of two tracer searches are required. The main factors influencing the decision of when to conduct the second search are as follows:

i) The size of the area the tracer was found to be dispersed over at the time of the last search.
ii) The proportion of the tracer that could be accounted for at the time of the last sampling exercise.
iii) The level of confidence with which sediment transport at the site has been predicted.
iv) The length of time that was required to sample the tracer distribution during the last search.

It is estimated that sampling of the tracer distribution during the first search (iv) will take 1-2 days. This period is acceptable when it is considered that ideally there should be no movement of the tracer between the beginning and the end of a sampling exercise, and it may lead to a degree of error in the results. In order to minimise the size of the error relative to the changes in the tracer distribution being measured it is desirable to maximise the time interval between the first and the second searches. However, it is also the case that predictions of the likely sediment transport at the site are, at the present stage, very basic (iii) and as a result it is difficult to predict how rapidly the tracer will be transported and dispersed (and it may even disperse to undetectable levels before the first search has been completed).

Such uncertainty ideally requires that the period between the first and second searches should be short if large quantities of the tracer are not to be lost. Given these two conflicting requirements it is presently felt that a period of approximately 3 weeks between the first and the second searches would be appropriate, however, no firm decision will be made until factor (i) is known and factor (iv) is confirmed (i.e. no decision will be made until the first search has been completed). Knowledge of factor (ii) is unlikely to be available in time to influence the decision on the timing of the second search.

In deciding whether to carry out more than two tracer searches it is necessary to consider the following:

- **Will the sampling be sensitive enough and cover a large enough area to allow a high proportion of the tracer injected to be accounted for?**
- **Increasing the number of searches undertaken has the potential to increase the level of confidence in the findings.**
- **The greater the number of tracer searches undertaken, the greater the cost of the study.**

Having considered the potential for additional searches to add confidence to the findings of the study, and the cost implications of additional searches, the maximum number of searches to be undertaken per injection is 4. Clearly it is not possible to predict whether sampling is likely to be sensitive enough to make a particular search worthwhile until the results of the preceding sampling exercise are available, hence, the decision whether to carry out searches 3 and 4 will be made during the study.

Should it be decided that searches 3 and 4 are to be undertaken then the scheduling (timing) of these should take into account the same factors that were considered in order to decide when search 2 should be conducted (see above).

Number and Spatial Distribution of Samples

When determining the number of samples to be collected during a particular tracer search and the spatial distribution of these, the objective is to have a sampling design which provides sufficient data to allow the actual distribution of the tracer to be determined accurately. However, without knowing the actual distribution of the tracer, or having an accurate prediction of it, it is extremely difficult to design an efficient sampling strategy.

Most studies (this one included) have limitations on the amount of time that is available for each search (see earlier comments on search duration and the implications of this for accuracy) and the amount of money that is available for sampling and sample analysis, and it is these factors which usually determine the number of samples to be taken and their spatial distribution.

Despite the challenges associated with designing sampling strategies, it is possible to make certain predictions about the way that sediment tracers will behave in the marine environment and these predictions can be used to potentially improve sampling strategies. A number of key predictions (and the implications of these in terms of sampling design) are presented below.

Prediction 1

The distribution of tracer material at the seabed will be linked to the character of the seabed (i.e. its relief and sedimentology).

Consequences in Terms of Study Design

Detailed mapping of the character and composition of the seabed (using side-scan sonar and bathymetric survey techniques) will be undertaken for the whole of the area that the tracer is likely to disperse over and the data collected will be used to guide the design of each sampling exercise. The quantity of tracer likely to be found on different “zones” of the seabed will be predicted and these predictions will be checked in the early stages of the sampling (low accuracy assessments of the quantity of tracer present in each sample can be achieved relatively quickly on-board the survey vessel). Based on the results of these checks, foci for the remainder of each sampling exercise will be identified.

Prediction 2

Where bedforms exist, there will be potential for variability in terms of tracer concentration on small spatial scales (e.g. it is possible that tracer concentrations in the toughs of sandwaves will always be higher than concentrations on the adjacent sandwave cests).

Consequences in Terms of Study Design

It will be necessary to determine whether such variability exists and if it does the variability will need to be quantified. Also, if variability is found, then for each sample collected from an area where bedforms exist it will be necessary to determine whether the sample was collected from a crest, trough or from somewhere between the two. It is proposed that a camera will record the seabed sampling device (grab or corer) taking the sample. It will therefore be possible to determine from where on a bedfom the sample has been collected. For each “zone” of the seabed where bedfoms exist a line of closely spaced samples will be used to determine whether small scale variability in tracer concentration occurs and to quantify this. Collection of such data will benefit the analysis and interpretation of the tracer concentration data collected.

Prediction 3

The movement of the tracer is likely to be such that the highest tracer concentration gradients will occur perpendicular to the tidal flow (i.e. for the present study gradients to the NW and SE are likely to be steeper than those to the NE and SW). Also tracer gradients in the direction that net transport occurs are likely to be shallower than those in the opposite direction (i.e. for the present study it is likely that the gradient to the SW is likely to be steeper than that to the NE).

Consequences in Terms of Study Design

The distribution of the screened sediment at the seabed prior to commencement of the tracer study and the early phases of the first sampling exercise should be used to ascertain whether the predicted patterns in tracer concentration gradient occur. The spacing between samples should be linked to tracer concentration gradient that occurs, where the steepest gradients are found the distance between samples should be at its least.

Prediction 4

Tracer concentration gradients are likely to become less steep as time since injection increases.

Consequences in Terms of Study Design

The early phases of sampling exercises 2, 3 and 4 should be used to ascertain whether the predicted pattern in tracer concentration gradient occurs. The spacing between samples should be linked to tracer concentration gradient that exists; as a consequence, if the pattern is confirmed then as time since injection increases (i.e. for each successive search exercises) the spacing between samples should increase.

Key information for the design of the sampling grid is knowledge of where the boundary of the tracer distribution lies (i.e. knowledge of how far the tracer has travelled both parallel to the tidal axis and perpendicular to it). Such information can only be obtained by sampling in the field; below is a description of how this will be achieved for the second tracer search following injection 1, along with other details of the strategy for the search. The general approach for identifying the likely boundary of the tracer distribution (sections (i), (ii) and (iii) below) will be common to all searches undertaken, including search 1.

i) Samples will be collected along a line parallel to the tidal axis at 180m intervals, starting at the position that the highest tracer concentration was found during the previous search (referred to as the starting position from now on). Material from each sample will undergo analysis immediately following recovery (on board the vessel) to determine whether any tracer is present. Sampling will continue along the said line until 5 successive samples with no tracer present have been collected (i.e. sampling will continue for 900m beyond the position at which tracer was last found, both to the NE and the SW of the injection site). The choice of 5 successive samples is arbitrary, but it is loosely based upon the fact that net transport distances of the order of 2km are predicted by Posford Haskoning (2003).

ii) At the most north easterly site to contain tracer, samples will be taken at 60m intervals to the northwest and southeast of the “tidal axis line” at right angles to it. Sampling will continue until 5 successive samples with no tracer present have been collected either side of the “tidal axis line”.

iii) The procedure described in (ii) will also be undertaken at a site midway between the starting position and the last site at which tracer was found to the NE.

iv) The information on the distribution of the tracer provided by the activities described in (i), (ii) and (iii) will be used with the data collected during search 1 and the principles described earlier in the this section to determine the smapling design.

v) In all orientations (for all searches) the grid will extend beyond the position at which tracer is last found. One sample containing no tracer will be collected in each orientation.

As already described, it is anticipated that as distance from the centre of the tracer distribution (the highest concentrations) increases, and time since injection increases, it may be possible to increase the spacing between samples. The basis of this assumption is the prediction that the tracer distribution will become less variable over small space scales as time since injection and distance from the centre of the tracer distribution increase.

However, a complicating factor is the fact that the conceptual model for the behaviour of the sediments predicts that they will accumulate in patches and streaks from approximately a kilometre beyond the planned injection site. If this occurs, and the tracer moves into this “dispersed zone”, then the tracer distribution may be as variable in this area as it is where tracer concentrations are highest, in which case there would be no justification for increasing the spacing between samples. If there is no strong case for increasing the spacing between samples (in the form of hard data from previous searches) then spacing should not and will not be increased.

Sample Analysis

Upon arrival at the analysis lab each sample will be logged in (i.e. a record will be made of the identification number of each sample received). The samples will then be separated into those to be analysed and those to be stored. In situations where two samples from the same box core / grab are to undergo analysis, these will be analysed together. The sample analysis will consist of the following stages, although this procudre may be amended prior to issue of final methodology for the tracer study:

- **Each sample will be split into 5cm depth intervals starting at the top of the core;**
- **Each 5cm depth interval (or pair of 5cm depth intervals if 2 sub-samples from the same box core are being analysed) will be spread over a screening table and scanned with a UV light to check whether there is any tracer present;**
- **If tracer is present within a 5cm depth interval then the material will be dried at 80oC in an oven and then weighed;**
- **Once a sample is dried and weighed, counting of the number of fluorescent particles present of each colour will be undertaken, this will be automated if large numbers of tracer grains are present and this aspect of the analysis will be tightly controlled with daily QA checks being undertaken to ensure that the results of the counting are accurate and repeatable;**

- **A percentage of dried samples will undergo checks to determine how closely the particle size of the tracer material present matches that of the sediment it is incorporated into, such checks can be used to provide information on how representatively the tracer is behaving;**
- **If no tracer is found to be present within a 5cm interval during screening then the material will simply be bagged and labelled and stored (in case it is needed for future reference); similarly, once samples containing tracer have undergone counting they too will be bagged, labelled and stored;**
- **The weight measurements and counts of number of tracer grains per depth interval for each core or pair of cores will be logged on paper records initially which will be transferred to electronic files on a daily basis (all paper records will be kept in case they are needed for future reference).**

Data Analysis

The data analysis will be undertaken in the following stages for each tracer search.

1. The particle count data derived from the laboratory analysis of core samples will be expressed as number of grains per unit dry weight of sample.
2. The particle counts per unit dry weight (tracer concentration measurements) will then be plotted as an overlay onto a chart of the search area showing interpreted sidescan sonar data for the region. Separate overlays will be prepared for each of the 4 different particle sizes of tracer and for each of the depth intervals for which data exist.
3. The “point data” for tracer concentration referred to above will then be contoured using a software package such as Surfer and the data plotted onto a chart showing an interpretation of the sidescan sonar data. Again, separate overlays will be prepared for each of the four tracer particle sizes and for each depth interval. Also, depth integrated contour plots will be prepared for each of the 4 particle sizes and a depth integrated plot will be derived for all tracer grains (regardless of size).
4. Checks will be performed to ensure that the results of the contouring are logical when considered alongside the sidescan sonar data interpretation: if it is considered that they are not then the parameters of the contouring procedure will be altered. It may be necessary to seed the contouring grid with data taken from the sidescan interpretation to ensure that the boundaries identified by the sidescan sonar survey are taken into account during the contouring procedure. It may also be necessary to apply correction factors to some data collected in bedform fields to allow for any variability in concentration found to be associated with the features.

5. All of the data for a particular tracer particle size will then be used to plot a 3D representation of the whole of the tracer distribution for this size (i.e. covering its full vertical depth within the bed). A 3D representation of the distribution of all of the tracer (regardless of size) will also be prepared.
6. For each of the tracer sizes injected, the contoured data will be used to estimate the proportion of the injected tracer that has been accounted for as a consequence of the sampling.

Having completed stages 1 to 6 above for each of the searches, the data will be used to calculate the average transport velocity of the tracer for the period between injection and each search.

Such calculations are routine and involve the following simple stages:

- **Calculation of the position of the tracer centroid (centre of mass) at the time of each search.**
- **Calculation of the distance between the centroid position and the injection position at the time of each search.**
- **Calculation of the bearing of the tracer centroid position from the tracer injection site for each search.**
- **Calculation of the length of time that passed between tracer injection and the tracer search.**
- **For each search divide centroid travel distance by time since injection to derive average travel distance in the direction given by the bearing.**

For each search average velocities will be calculated for each of the 4 tracer sizes, as well as average velocities being calculated for the tracer as a whole.

The results of the data analysis described above will then be used to interpret the following.

1. How the screened sediment released from a dredger was distributed at the seabed following settling through the water column.
2. Whether different particle sizes (within the range to be rejected during screening) exhibited different distributions at the seabed following settling through the water column; allowing model predictions presented within the REA to be tested (e.g. the prediction that fine to medium sand will be transported up to ~1km prior to deposition).
3. How the spatial distribution of sediment (tracer) changes through time.
4. What the average direction and velocity of transport is for the tracer and whether different particle sizes exhibit different average velocities or are transported in different directions. Such interpretations will allow model predictions presented within the REA to be tested (e.g. the prediction that transport of sheet sediments will be principally to the NE).

5. Transport velocities measured following injection 1 will be compared with those measured following injection 2 in order to determine whether tracer velocities in autumn / winter differed from those in spring.

5.8. Thresholds

No specific thresholds related to the physical monitoring studies are proposed at present. It is intended that thresholds related to the effects of extraction on the environment of the ECR will be developed in the first 5 years of activity.

The review and discussion of results from the first two years of monitoring will be fundamental in directing the effort needed to develop thresholds for use in the longer term.

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