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Addendum to Hydraulic Modelling Report

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1.0 Introduction

A hydraulic modelling study of the River Tyne was carried out during the year 2000 and early 2001 to assess the effect of construction of an immersed tube tunnel on the river. The key objective of the hydraulic modelling study was to facilitate assessment of the following:

- the potential for increased suspended sediment concentration in the river during the dredging and backfilling operation;
- the potential for contaminated sediment to be transported downstream and to settle on the Site of Special Scientific Interest (SSSI) area at the mouth of the river;
- change of tidal flow regime caused by the temporary works and its impact on the sediment transport regime;
- the backwater effect caused by the temporary works during the construction and its impact on the flood defence standard.

The report on the hydraulic modelling study was completed in March 2001. In summary, the hydraulic model showed that:

- a finite increase in suspended sediment would occur as a result of dredging, being most concentrated at the dredging site on neap tides when the potential to disperse the sediment is most diminished;
- the quantity of sediment which is likely to be deposited on the SSSI site would not be significant;
- the impact of the temporary works on river flows would be limited to the vicinity of the works;
- The backwater effect of the temporary works would have no significant impact on the flood defence standard.

The Report on hydraulic modelling was issued to interested parties including the Environment Agency and the River Tyne Riparian Owners and Occupiers Association. Comments received from these organisations are included as Appendix A, and relate largely to the possible impact on fish and fisheries owing to increased suspended sediment concentration in the river during dredging and backfilling. In response to these comments, this addendum provides further details and clarification on the following:

- cohesive processes;
- oxygen demand by the released sediment and dissolved oxygen concentration in the water column;
- saline intrusion and flow stratification;
- the effect of modelling a spring or neap tide, compared with a sequence of spring and neap tides as would occur in nature;

- possible variations in the sediment release rate from the proposed dredger;
- how much and where, sediment is likely to be deposited beyond the upstream boundary of the model.

These six issues are addressed in the following sections 2 to 7.

2.0 Cohesive Process

The made-ground and alluvial clay/silt layer, which is to be dredged from the immersion trench, consists of fine silt and organic matter. The cohesion that occurs in such fine material leads to a higher critical bed shear velocity for sediment entrainment, i.e. for sediment to be lifted off the bed of the river the water flow velocity will need to be higher than if there was no cohesion. It also produces a higher sediment fall velocity, i.e. cohesive sediment which is suspended in the water column will tend to stick together and therefore, being heavier, will fall out of the water column more quickly.

The hydraulic model does not take account of cohesive process. Hence, the hydraulic model may have assumed a sediment fall velocity, which is too low. This means that in practice, sediment will settle out of suspension sooner than assumed in the hydraulic model. Thus, the hydraulic model results in an over-estimation of suspended sediment concentration and an over-estimation in the length of time that sediment remains in suspension. If, as we would suppose, the sediment is in suspension for a shorter period then it will be transported over a shorter length in practice.

It may therefore be concluded that the effect of the cohesive process means that the hydraulic modelling results may be regarded as conservative i.e. actual suspended sediment concentrations are likely to be lower and sediment will be transported over a shorter distance.

3.0 Oxygen Demand/Dissolved Oxygen Concentration

The hydraulic model does not address the effect on dissolved oxygen level of sediment released into the water column as a result of dredging.

This matter has therefore been investigated separately by Posford Haskoning together with Newcastle University and the Environment Agency using the Agency's dissolved oxygen model of the river.

This issue is reported separately from this Addendum.

4.0 Saline Intrusion and Flow Stratification

Measurements taken during spring tides in April 2001 to obtain data for the calibration of the hydraulic model indicated that only minor flow stratification occurred. The Environment Agency has suggested that more significant flow stratification may occur during neap tides. The hydraulic modelling was based upon a two-dimensional depth integrated model; this type of model cannot provide accurate predictions of sediment movement during flow stratification as the vertical velocity profile is represented by an average velocity over the full depth i.e. there is no possibility of including different velocities at various depths.

When surface currents flow in the opposite direction to bed currents, sediments can travel in both directions even if the depth-averaged velocity is zero. Strong saline intrusion and flow stratification leads to transport upstream in the bottom layer of higher density seawater and downstream in the upper layer of lower density freshwater. Flow stratification is often the cause of upstream sediment transport in estuaries.

If significant flow stratification is occurring, the hydraulic model will have overestimated suspended sediment concentration near to the dredging site and will have underestimated the sediment transport distance.

The hydraulic model results indicate that suspended concentration levels are higher during neap tides than during spring tides. Hence, it may be concluded that the values of peak suspended sediment concentrations are pessimistic as lower values would result in practice due to flow stratification which is not reproduced in the model.

Sediment transport distance from the dredging site is likely to be greater during spring tide conditions than during neap tides. As flow stratification is thought to be minor during spring tides, the hydraulic model can be expected to be reasonably accurate in its representation of sediment excursion on spring tides.

5.0 Spring Tides v Natural Tidal Cycle

The hydraulic model illustrates a much greater particle excursion during spring tides than during neap tides. The average tidal flow in a spring tide is approximately twice as much as in a neap tide. Hydraulic modelling based upon repeating spring tides rather than on the natural tidal cycle demonstrates the "worst" spatial dispersion of the released sediment, and the "longest" sediment travel distance and sediment suspension period. In this respect the predictions are pessimistic.

During neap tides, when velocities are in opposite directions between the top and bottom layers due to flow stratification, the depth-integrated model produces lower water motion. The lower depth-averaged velocity yields a higher suspended sediment concentration near the dredger.

Therefore, the approach of using spring tides for sediment travelling distance and using neap tides for suspended sediment concentration near to the dredger may be considered as conservative; i.e. the worst case was taken for each scenario.

6.0 Sensitivity to Variations in Sediment Release Rate

The hydraulic modelling was carried out based upon a sediment release rate of 1kg/s resulting from dredging using either a backhoe dredger or an enclosed grab dredger. The reasons for selection of this sediment release rate are given in Appendix D of the Numerical Modelling Report. To check on the sensitivity of the modelling results to a variation in sediment release rate one of the numerical model "runs" has been repeated for a sediment release rate of 1.5kg/s

The dredging scenario which has been re-run, is for dredging fine silt (d_{50} = 10μm) in the middle of the navigation channel over six spring tidal cycles, assuming normal fluvial flow in the river. The scenario also supposes that no sediment, which is transported beyond the upstream boundary, will return on subsequent tidal cycles.
(ref: Section 6.4.2 of the Numerical Modelling Report)

A comparison of results is given below between a 1 kg/s release rate yielding 278.6 tonnes of sediment into the water column and a 1.5kg/s release rate yielding 417.9 tonnes of sediment into the water column.

Sediment Release Rate	Deposition Within the Model Domain		Leaving U/S Boundary		Leaving D/S Boundary		Remaining in Water	
Kg/s	%	Tonnes	%	Tonnes	%	Tonnes	%	Tonnes
1.0	10.6	29.5	38.5	107.3	8.2	22.9	42.7	119.0
1.5	11.7	48.9	41.8	174.7	12.2	51.0	34.3	143.3
Ratio		1:1.66		1:1.63		1:2.23		1:1.20

This comparison illustrates that if the sediment release rate due to dredging increases there is not a proportional increase in suspended sediment in the water column. A 50% increase in sediment in release rate corresponds to only a 20% increase in sediment in the water column. Hence the water quality does not diminish in direct proportion to an increase in sediment release rate.

7.0 Deposition Beyond the Upstream Boundary

The hydraulic model considers sediment being released into the river as a result of dredging assuming that sediment is evenly distributed through the water column as the dredging bucket or grab is lifted from the riverbed. The model does not consider the re-suspension of existing settled sediments, as re-suspension is part of the natural physical process of the river bed which takes place regardless of whether dredging is taking place. The sediment entrainment resulting from the natural re-suspension process is characterised by the background suspended sediment values (measured between 15ppm and 45ppm on 8 April 2001) which are added to the suspended sediment values arising due to dredging; the modelling report advised on this aspect.

Sedimentation, may be considered as being transported in two discrete stages. The "first-stage" occurs as sediment settles out of the water column and this continues for approximately 2-3 days after completion of dredging. The "second stage" occurs if sediment re-suspends. The "second-stage" transport may occur over a prolonged period as the process of re-suspension and settling repeats until the sediment is deposited in an area of low flow velocity.

A control volume model was used to estimate the quantity of sediment which is likely to deposit upstream of Low Walker as a result of "first-stage" transport. This was to provide an estimate of sediment retention beyond the upstream limit of the 2-D hydrodynamic model. The control volume model calculates the change of tidal water volume upstream of Low Walker in response to the change of tidal elevation downstream, deriving the water exchange rate at the Low Walker model boundary. The bed levels upstream of Low Walker were obtained from the Admiralty chart and the longitudinal bed profile taken from a report "Hydraulic and Sediment Survey of the Estuary of the River Tyne, July 1961" by the Department of Civil Engineering, University of Durham.

The control volume model shows that under spring tidal conditions, approximately 17% of the suspended sediment (sediment size 10µm) that passes the upstream boundary is likely to deposit upstream of Low Walker. On the basis that 38% of released sediment moves out of the upstream boundary on each tide (based on the scenario of dredging fine silt in the middle of the navigation channel over six spring tidal cycles), an estimated 6.5% (i.e.17% of 38%) of released sediment is likely to deposit upstream of Low Walker during the "first stage" transport.

In the long term, the "first stage" sediment which is deposited upstream of Low Walker may re-distribute by the re-suspension process; equally, the material deposited downstream of Low Walker may migrate upstream as a result of flow stratification.

It is unlikely that all the sediment that is deposited downstream of Low Walker would migrate upstream beyond Low Walker. The "dividing point" may be near the ship Swinging Area at Jarrow Slake (approximately 1 km downstream of the Tyne Tunnel), where the river channel widens and deepens. Supposing that 50% of the sediments deposited in the area down to the Swinging Area will eventually migrate further upstream, it is estimated that approximately 37% of the released sediment in total would end up upstream of Low Walker. About 34% would remain downstream of Low Walker and 29% would move out of the mouth of the river. This is an approximate and conservative estimation based on the 42-tidal cycle simulation of spring tides.

Figure 1 illustrates an estimation of the final distribution of released fine silt after 23 days of dredging (release rate 1 kg/s) under the scenario outlined above. The total estimated amount of 659 tonnes deposited upstream of Low Walker may be regarded as a conservative figure as it is based upon spring tidal cycles only and is not based upon the natural tidal cycle which would transport sediment over a shorter distance.

It is not possible to use the control volume model to estimate the location where sediment will eventually settle upstream of Low Walker. From the Environment Agencies observations of the nature of the river banks from the weir at Wylam to Low Walker, the main area of the sediment deposition is likely to be in the wider section of river between the Swing Bridge and Scotswood Bridge. Upstream of Scotswood Bridge the river banks generally have scour protection indicating that there is reduced likelihood of sediment deposition.

8.0 Conclusions

The following conclusions are drawn:

8.1 The effect of the cohesive process means that the hydraulic modelling results may be regarded as conservative i.e. actual suspended sediment concentration may be lower and sediment is likely to be transported over a shorter distance.

8.2 The issues concerning oxygen demand and dissolved oxygen are the subject of a separate report.

8.2 If flow stratification occurs during neap tides (in practice), the hydraulic model values of peak suspended sediment concentration are likely to have been overestimated.

8.3 The approach of using spring tides to assess sediment travelling distance and using neap tides to assess suspended sediment concentration near to the dredger may be considered as pessimistic.

8.4 Variation in the sediment release rate due to dredging is not directly proportional to variations in suspended sediment in the water column. A 50% increase in sediment release rate from 1kg/s to 1.5kg/s is likely to result in only a 20% increase in suspended sediment. Hence the water quality does not diminish in direct proportion to an increase in sediment release rate.

8.5 The total volume of sediment deposited upstream of Low Walker is unlikely to exceed 659 tonnes. It is anticipated that the majority of this sediment will be deposited between the Swing Bridge and the Scotswood Bridge.