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Impact of the New Tyne Crossing on Dissolved Oxygen Concentrations in the Tyne Estuary

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1.0 Background

The proposed Tyne Tunnel construction will be cut and cover. During construction, material will be dredged from the estuary bed, to form a trench, into which the pre-cast tunnel segments will be placed. There are substantial deposits of organic material in the estuary resulting from many years of discharge of untreated domestic and industrial waste. The Environment Agency asked Posford Haskoning (formerly Posford Duvivier) /Arup to provide information that will allow an assessment to be made of the impact of the dredging operation on the Dissolved Oxygen (DO) levels in the estuary.

The initial request was to carry out benthal oxygen demand experiments in the region of the tunnel excavation trench. These tests were to be compatible with previous work carried out by the Department of Civil Engineering at Newcastle University in 1996. David Elliott, Senior Lecturer in Environmental Engineering was contacted by Steve Challinor, Posford Haskoning and asked to liaise with the Environment Agency on the type and number of tests to be carried out.

1.1 Oxygen Demand

All natural surface waters contain dissolved oxygen which is essential for the support of plant and animal life in the aquatic ecosystem. A typical maximum or saturated concentration, in un-polluted conditions is of the order of 9 mg/l. The difference between the actual DO level and the saturated value is usually referred to as the dissolved oxygen sag. The concentration of DO is a function of temperature and salinity and also of the balance between the sources and sinks of oxygen listed below.

Sources

Riverine Dissolved Oxygen

-Oxygen brought into the head of the estuary by the fresh water flow expressed in terms of mass per unit volume.

Seawater Dissolved Oxygen

- Oxygen brought into the estuary by tidal flow and by vertical density circulation currents expressed in terms of mass per unit volume.

Effluent Dissolved Oxygen

-Oxygen contained in effluent discharges expressed in terms of mass per unit volume.

Surface Re-aeration

-Oxygen transferred through the water surface from the atmosphere. The rate of mass transport of oxygen is proportional to the difference between the saturated oxygen level and the actual level at any point in time. The rate of re-aeration is expressed in terms of mass of oxygen transferred per unit area per unit time.

Sinks

Riverine Biochemical Oxygen Demand

-The suspended particulate and dissolved organic material carried into the estuary by the freshwater flow is naturally degraded by bacterial populations which use dissolved oxygen for respiration. The rate at which Biochemical Oxygen Demand (BOD) is exerted is expressed in terms of mass of DO required per unit volume per unit of time.

Polluting Discharge Biochemical Oxygen Demand

-The suspended particulate and dissolved organic material carried into the estuary by domestic and industrial discharges and contaminated surface runoff is naturally degraded by bacterial populations which use dissolved oxygen for respiration. The rate at which BOD is exerted is expressed in terms of mass of DO required per unit volume per unit of time.

Sediment or benthal Oxygen Demand

-Particulate organic material and dissolved organics that precipitate and form particulates may settle to the estuary bed before they are completely degraded.The surface layers of these benthal deposits continue to exert an oxygen demand on the water close to the estuary bed. The rate at which benthal oxygen demand is exerted is expressed in terms of mass of oxygen utilised per unit area per unit of time

Oxidation of Ammonia

-Ammonia discharged to the estuary is used as a substrate by a particular group of bacteria known as ammonia oxidisers. These organisms use dissolved oxygen in a similar way to those oxidising organic material. The rate at which this process takes place is much slower than that of BOD but may be expressed in the same terms as BOD

1.2 The effect of dredging

The main effect of dredging a trench for the new Tyne Tunnel will be to re-suspend some of the sediment lost during the transfer of the bulk material through the water column. Once in suspension the particulate organic fraction will be subject to advection and dispersion by the complex interaction of fresh water, tidal and densimetric flows. The particulate organic fraction will exert an oxygen demand over a significant volume of water whilst remaining in suspension. The particulate material will also be subject to gravitational settling and will be deposited back on to the bed of the estuary. The point of deposition will be dependent on the relative magnitude of the settling velocity and the advective and dispersive processes. Once resettled, the BOD associated with the organic particulate is removed from the main body of the water column. The settled material will, however, continue to exert a benthal oxygen demand as described above. There is no net increase in benthal demand from this redistributed material because it will be deposited over the existing organic deposits, thus preventing them from exerting their demand at the bed /water interface.

Similarly the dredging activity will not significantly affect the degree of benthal respiration in the estuary because the surface area of material removed from the trench is only a small fraction of the total bed area of the estuary (of the order of 0.3%).

The assumptions in the modelling work (Section 4.0) are that dredging makes no change in the total benthal demand but that the re-suspended material can exert an oxygen demand while remaining in suspension.

1.3 Terms of Reference

A meeting was held on Monday 4th 2001 June with Eddie Douglas of the Environment Agency, Jane Saul, Arup and Graham Shore, Posford Haskoning. It was resolved at this meeting that the original benthal tests required by the Environment Agency were inappropriate and that the suggestions made by David Elliott be followed subject to the agreement of Roger Invararity, who is responsible for the dissolved oxygen modelling work in the Environment Agency.

Following this meeting David Elliott was asked by Steve Challinor on the 14th June 2001 to provide a detailed proposal and a fee quotation based on the following scope of work:

- Liason with the Environment Agency to agree an approach for quantifying the oxygen depletion effects of the dredging of the immersed tube tunnel
- Advice to Posford Haskoning / Arup concerning sampling requirements (samples to be collected by Posford Haskoning / Arup)
- Analysis of samples
- Interpretation of analytical results, including an assessment of the impact of the dredging on the dissolved oxygen system in the River Tyne

A meeting was held on Friday 22nd June 2001 between David Elliott and The Environment Agency (Roger Inverarity) to determine the scope of the field and laboratory work. Following discussions held between Posford Haskoning / Arup and the Envoronment Agency on Monday 16th July 2001 a scope of work was agreed.

2.0 Scope of Work

A series of work packages were proposed that reflected the inherent uncertainty associated with predicting the cause-effect relationship between organic discharges and dissolved oxygen levels in a semi stratified estuary. Certain packages were conditional on the results obtained in the earlier work and were to be carried out only after a review by Posford Haskoning /Arup and the Environment Agency.

The programme of work was designed to provide information related to the following:

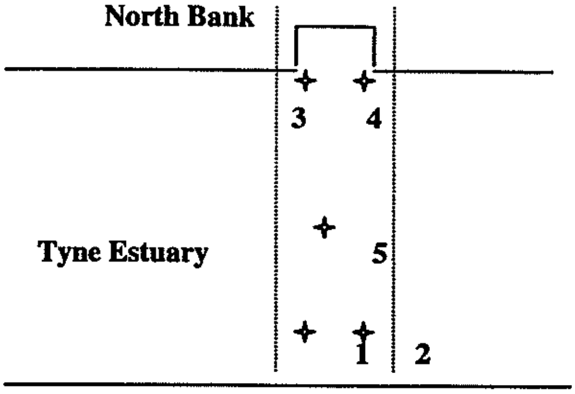
- Variation of organic content and Biochemical Oxygen Demand (BOD) with depth in the benthal deposit
- Variation of rate of oxygen uptake of deposits from different depths when suspended in the estuary water
- Relationship between BOD and settling rate for different particle sizes in the benthal deposit

The above information was sought to provide BOD load data, BOD decay rate coefficients and BOD removal rates by sedimentation, for use in the Environment Agency two dimensional Dissolved Oxygen (DO) model. This information was used together with the proposed method of working and the estimated loss of material to the water body during the dredging process (Posford Duvivier, 2001) to enable predictions to be made on the impact of dredging on DO levels in the estuary.

2.1 Sampling Regime

Five 3 metre cores were taken on the line of the proposed dredged tunnel trench. Two cores were close to the South Bank and two close to the North Bank. The fifth core was taken in the scoured navigation channel in the centre of the estuary. The positions of the sampling stations are shown in Figure 2.1.

Figure 2.1
Proposed Sampling Stations



The core samples were taken at the following positions:

Sample No.	Position
501	E433050 N565870
502	E433150 N565870
503	E433050 N566050
504	E433150 N566050
505	E433100 N565950

A cross section of the river showing the underlying geological formation is shown in Figure 2.2.

2.2 Work Packages

Samples of benthal deposits for laboratory analysis were provided by Posford Haskoning /Arup in the following form. From each sampling site core, seven separate one litre samples were extracted at 0.5m intervals and supplied in separate containers, representing seven depth positions within the 3m core.

Package 1

BOD samples require dilutions to be made to obtain satisfactory estimates. To minimise the chances of the results being indeterminate, tests were carried out on a grab sample of benthal deposits. A preliminary test for BOD, Suspended Solids (SS), Chemical Oxygen Demand (COD) and Volatile Total Solids (VTS) was made to estimate orders of magnitude and provide information on appropriate dilutions required for the main samples. A settling column analysis was carried out at this stage, the results of which changed the protocol for Package 3.

Package 2

Cores 501 and 503

Tests were carried out on seven samples from each core for BOD and SS to establish the variation in biochemical BOD relative to core depth. All BOD tests were carried out in replicates of three in order to estimate experimental variation in results and relate them to any perceived variation over depth.

Seven samples, one from each of the separate elements of the core samples, were tested for VTS to provide further evidence on the degree of variation in organic content relative to depth. These samples were tested for Rapid Oxygen Uptake Rate (ROUR).

An homogenised sample from each core was subjected to a 20 day BOD test to provide information on the Ultimate Oxygen Demand (UOD) and the 'fast' and 'slow' rates of degradation.

Homogenised samples from each core similar to the above were used in a settling column analysis to relate BOD to settling rates. In the proposal it was envisaged that a differencing procedure would be used. The protocol was changed from that in the proposal because the rate of settling was rapid leaving a relatively clear supernatant with negligible residual BOD. Preliminary tests showed that all particulates had a similar settling velocity. The following protocol was used:

- Five settling columns were used
- Step 1. The sample was dispersed in the body of the settling columns and a sample extracted for initial BOD and SS analysis.
- Step 2. The suspended material was allowed to settle and the supernatant removed at different time intervals from each column in turn. This enabled BOD and SS samples to be taken without disturbing the rate of settling in the first column.

Package 3

Core 505

BOD and SS tests were carried out on samples from three separate depths in the core to establish the potential BOD demand from the granular sub base in the centre of the estuary and to express that demand in terms of the mass of granular material. Following discussions with Posford Haskoning /Arup and The Environment Agency (Roger Inverarity) a full analysis at seven separate depths within the core was subsequently carried out (Package 3(a)). This analysis was equivalent to those carried out on cores 501 and 503.

Package 5

Cores 302 and 304

This package was a provisional item that depended on the outcome of Packages 1 – 3. Following discussions with Posford Haskoning /Arup and The Environment Agency (Roger Inverarity) it was agreed that testing of cores 302 and 304 was not required.

3.0 Results of Laboratory Analysis

These results summarise the contents of work packages 1, 2 and 3 together with the extra analysis requested for package 3(a).
The data on which the summaries are based are listed in Appendix 1.
The analyses of cores 501 and 503 and 505 for BOD, SS and VTS and ROUR are summarised in Tables 3.1, 3.2 and 3.3 also in Figures 3.1, 3.2, 3.3, 3.4 respectively.

Table 3.1
Samples from Different Strata in the Cores

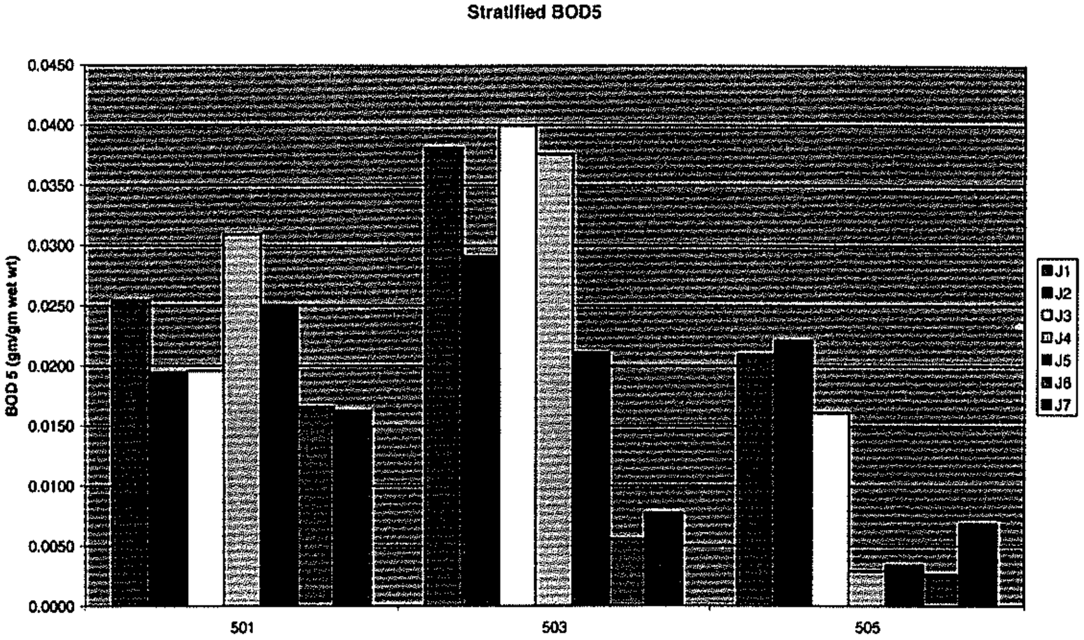
All concentrations are expressed in gm/gm of wet weight and rates in gm/gm/hr								
Sample	**Core 501**		**Core 503**		**Core 505**		**Core 505**	
J1	BOD	0.0254	BOD	0.0381	BOD	0.0209	BOD	0.0142
	SS	0.4013	SS	0.4579	SS	0.3347	SS	0.2906
	VTS	0.1122	VTS	0.1400	VTS			
	ROUR	0.0044	ROUR	0.0047	ROUR	0.0039		
J2	BOD	0.0194	BOD	0.0291	BOD	0.022		
	SS	0.3727	SS	0.4556	SS	0.3615		
	VTS	0.1115	VTS	0.1300	VTS			
	ROUR	0.0033	ROUR	0.0060	ROUR	0.0011		
J3	BOD	0.0196	BOD	0.0399	BOD	0.0161		
	SS	0.4612	SS	0.4809	SS	0.2828		
	VTS	0.1209	VTS	0.1400	VTS			
	ROUR	0.0043	ROUR	0.0060	ROUR	0.0013		
J4	BOD	0.0309	BOD	0.0376	BOD	0.0029	BOD	0.0053
	SS	0.4833	SS	0.4244	SS	0.1300	SS	0.0641
	VTS	0.1330	VTS	0.1200	VTS			
	ROUR	0.0047	ROUR	0.0060	ROUR	0.0005		
J5	BOD	0.0247	BOD	0.0211	BOD	0.0034		
	SS	0.4764	SS	0.2253	SS	0.1963		
	VTS	0.1176	VTS	0.0900	VTS			
	ROUR	0.0011	ROUR	0.9935	ROUR	0.0010		
J6	BOD	0.0166	BOD	0.0056	BOD	0.0026		
	SS	0.5249	SS	0.1167	SS	0.1628		
	VTS	0.1339	VTS	0.0600	VTS			
	ROUR	0.0017	ROUR	0.0013	ROUR	0.0004		
J7	BOD	0.0162	BOD	0.0077	BOD	0.0069	BOD	0.004
	SS	0.4806	SS	0.0607	SS	0.1014	SS	0.1510
	VTS	0.1280	VTS	0.0200	VTS			
	ROUR	0.0022	ROUR	0.0004	ROUR	0.0005		

Table 3.2
Homogeneously Mixed Samples from Cores 501, 503 and 505

All concentrations are expressed in gm/gm of wet weight and rates in gm/gm/hr					
Mixed Samples					
Core 501		Core 503		Core 505	
BOD20	0.2810	BOD20	0.1912	BOD20	
BOD5	0.0224	BOD5	0.1767	BOD5	0.0168
ROUR	0.0028	ROUR	0.0034	ROUR	0.0027
COD	0.0890	COD	0.1612	COD	0.2094
SS	0/4925	SS	0.3267	SS	0.5752

Table 3.3
Settling Column Supernatant Samples

All concentrations are expressed in gm/gm of wet weight and rates in gm/gm/hr						
Time Period	Core 501		Core 503		Core 505	
24hr	ROUR	0.00001	ROUR	0.00002	ROUR	0.00005
	COD	0.0055	COD	0.0043	COD	0.0022
	SS	0.0007	SS	0.0006	SS	0.0003
5hr	ROUR	0.00003	ROUR	0.00008	ROUR	0.00000
	COD	0.0063	COD	0.0042	COD	0.0026
	SS	0.0019	SS	0.00127	SS	0.0009
1hr	ROUR	0.00008	ROUR	0.00008	ROUR	0.00004
	COD	0.0142	COD	0.0083	COD	0.0061
	SS	0.0072	SS	0.0046	SS	0.0039
0.25hr	ROUR	0.00011	ROUR	0.00009	ROUR	0.00003
	COD	0.0395	COD	0.0167	COD	0.0104
	SS	0.0183	SS	0.0092	SS	0.0071



Update Graphs

Figure 3.1

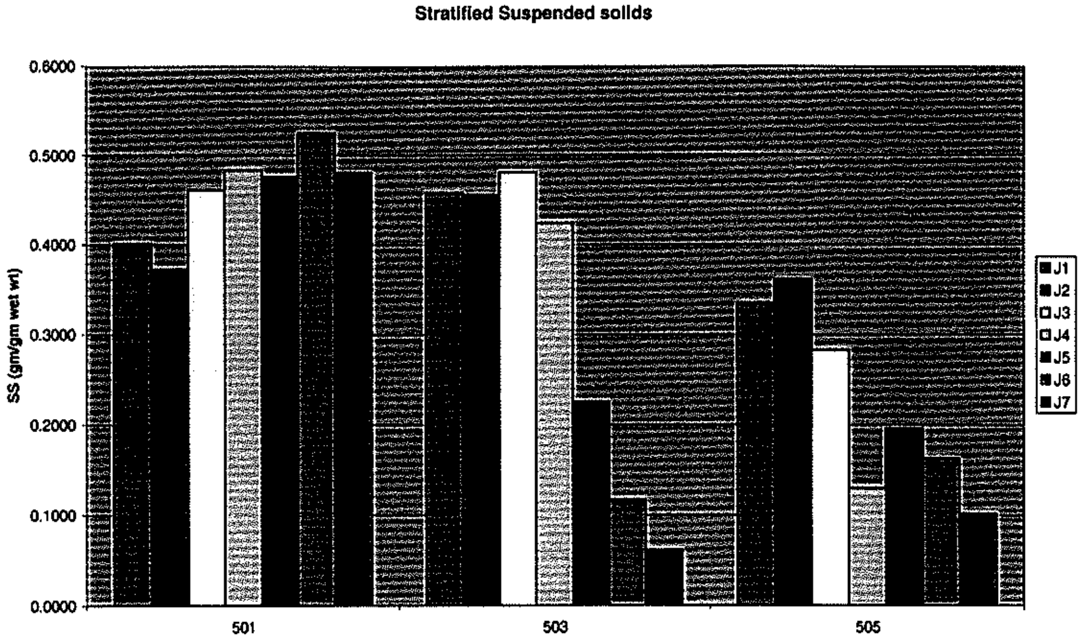


Figure 3.2

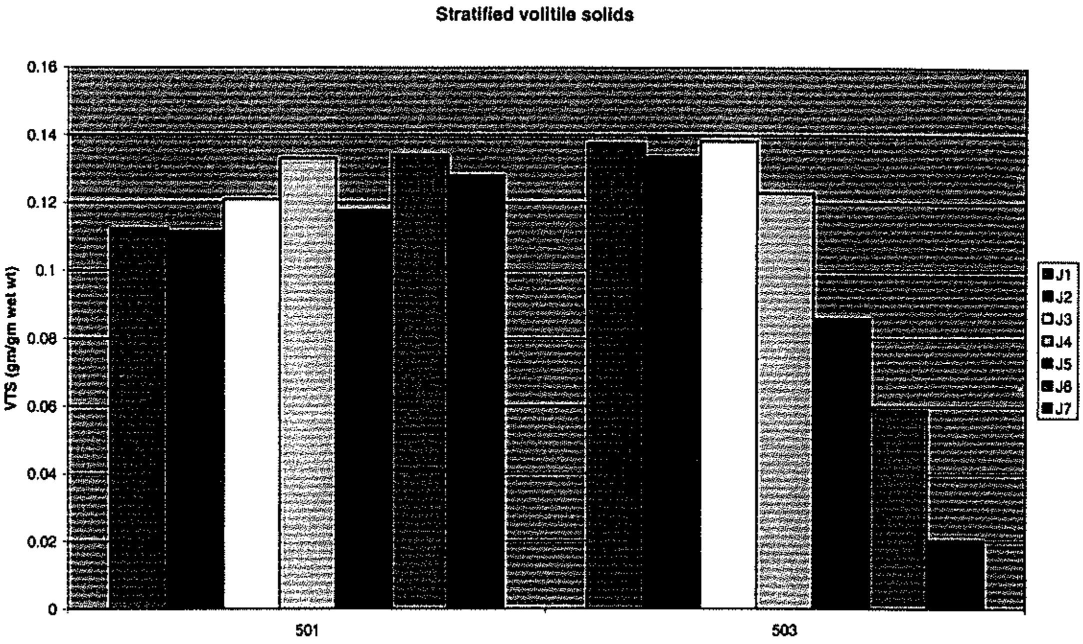


Figure 3.3

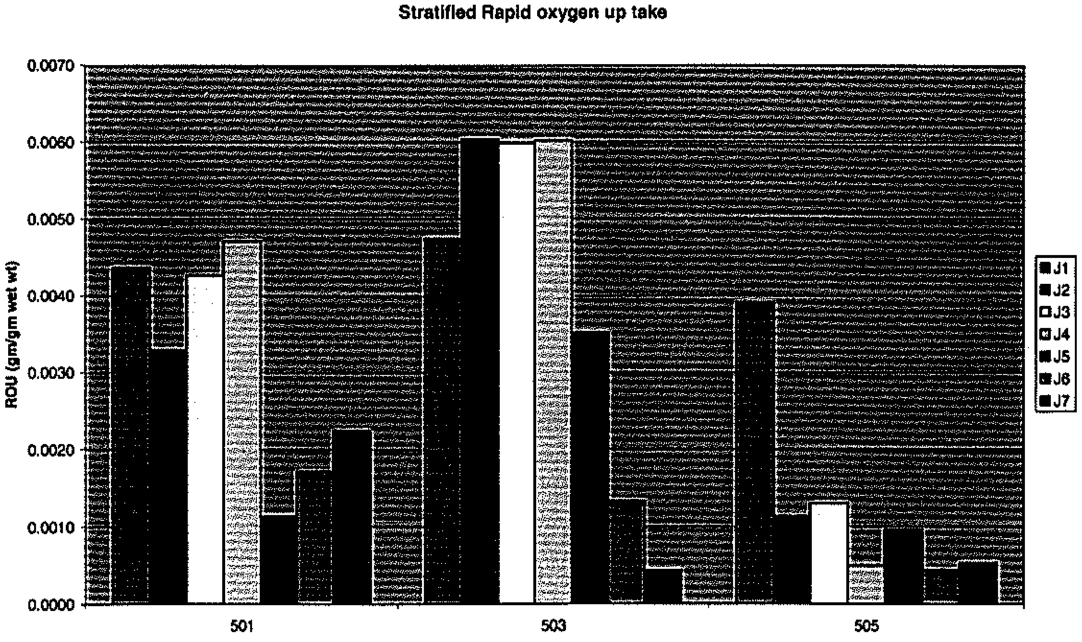


Figure 3.4

The results of the settling column analyses for cores 501 and 503 are given in Figures 3.5, 3.6, 3.7, 3.8 respectively

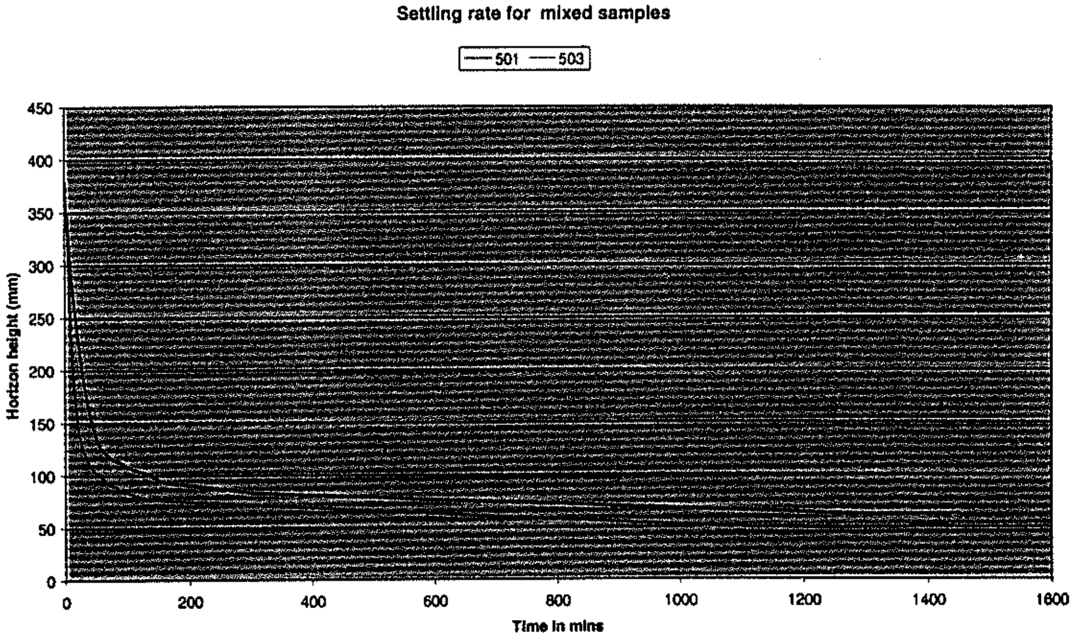


Figure 3.5

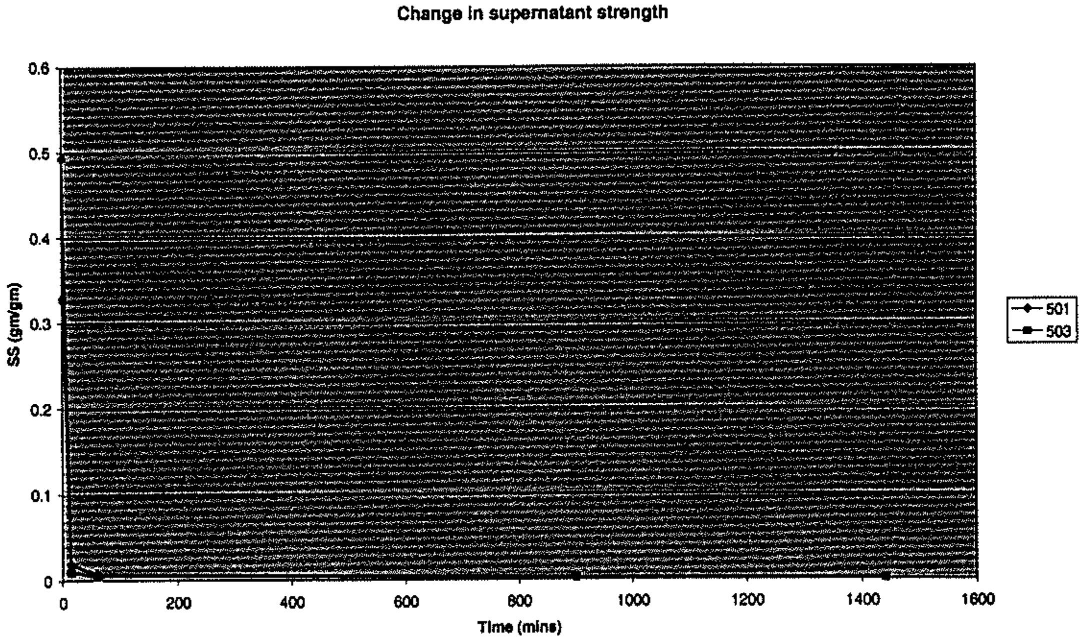


Figure 3.6

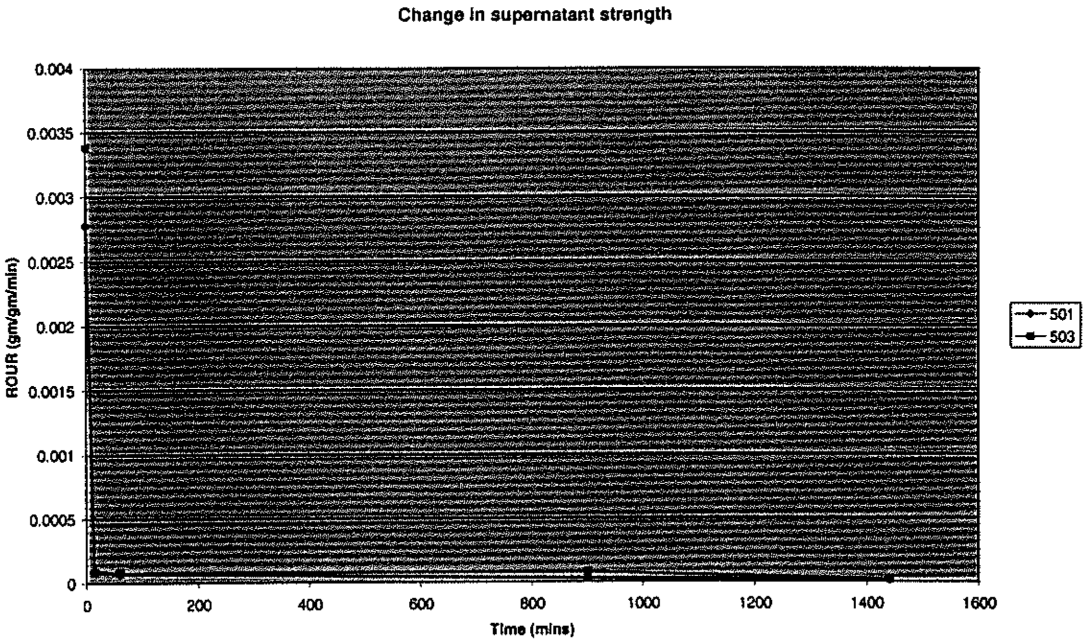


Figure 3.7

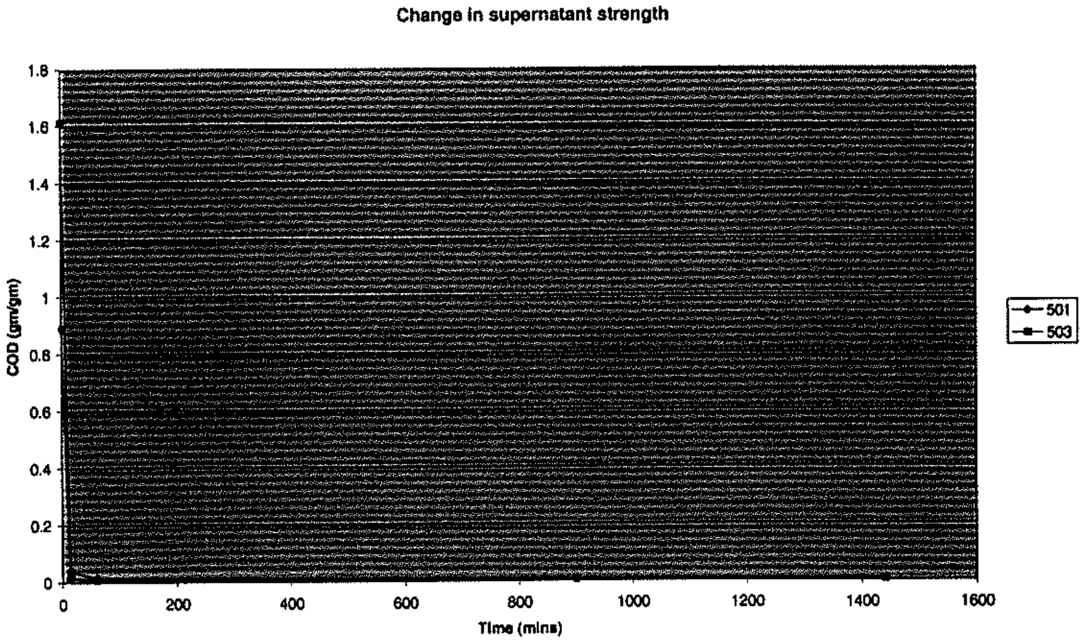


Figure 3.8

3.1 Discussion of Results

3.1.1 Biochemical Oxygen Demand

Inspection of Figure 3.1 indicates that cores 501 and 503 have similar levels of BOD (expressed as gm BOD/gm of wet weight of the river bed sediment). Indications from the reduced sampling of core 505 suggested that lower BOD values were present (This led to a request by the Environment Agency for a full evaluation of core 505 to check the initial results). The concentrations in the surface samples in core 505 suggest that they are taken from the organic silt layer and that the lower layers are taken from the underlying gravels which have a lower organic content. Samples in the lower layers of core 505 have lower BOD concentrations and suggest that the core punched through the organic silt into the gravel beds. The BOD concentrations for core 501 indicate that all the samples are representative of the organic silt. Average values of the BOD concentrations were calculated for both the organic silt material and the underlying gravel beds using the sample values from the appropriate levels in the cores. These values were combined with estimates of the release of material during the dredging process to obtain an estimate of the BOD load on the estuary during the dredging period.

Layer	**Average BOD$_5$ Value** (g/g wet weight)
Alluvial Clay and Silt[1]	0.02655
Sand and Gravel[2]	0.00566

[1] Average of all values from core 501 and the top 5 layers from core 503

[2] Average of the values from core 505 and bottom 2 layers from core 503

The BOD$_{20}$ results were found to be approximately 1.4 times the BOD$_5$ values which indicates that the majority of the BOD may be deemed as 'fast' (see Section 4.4).

3.1.2 Rapid Oxygen Uptake

The benthal deposits are known to contain highly-reduced products of anaerobic degradation. In order to investigate whether a short term chemical oxygen demand occurs when the sediment is disturbed during dredging, a ROU analysis was carried out on mixed suspensions of the bed material. The equipment used enables ROU values to be obtained over a maximum period of 30 minutes. The purpose of this work was to establish the ROUR. The average slope of the line obtained over this period is an indication of the ROUR. During the analysis it was found that after 30 minutes all the demand had not been exerted. Re-aeration enabled further readings to be taken.

The water quality model (see section 4.0 for description) used by the Environment Agency does not include the equations to model the ROU as a chemical oxygen demand with rapid kinetics. Hence the ROUR has not been estimated and an assumption was made to estimate the ROU over a 3hr period. This time period was considered long enough for the ROU to be exerted but short enough so as not to 'double' count with the longer term exertion of BOD.

Layer	**Average BOD Value** (g/g wet weight)
Alluvial Clay and Silt	0.003
Sand and Gravel	0.0008

3.1.3 Settling Column Analysis

The settling column analysis (Figures 3.5 – 3.8) indicated that the suspended sediment settled rapidly and left minimal COD or ROUR in the supernatant. The sediment acted as a single sized suspension with particles all settling at the same velocity. The average particle settling rate was estimated at 0.9 mm/sec. The results indicated that most of the BOD is related to the particulate material. For modelling purposes it was assumed that 97% of the BOD was particulate and 3% soluble. The settling rate used in the model underestimates the rate found in the laboratory analysis, however the model rates were left unchanged to provide a worst case scenario.

4.0 Water Quality Model

4.1 Background

The Environment Agency water quality model, 'Tyne-2dv', was used for the prediction of the consequences of dredging activity in the estuary, to enable direct comparisons to be made with predictions based on existing base line data. Tyne-2dv was developed from HR Wallingford's 'Tideway-2dv' and includes both hydrodynamic and water quality components. It has been calibrated by the Environment Agency using data from targeted surveys and from continuous water quality monitors. Its main use by the Environment Agency has been to investigate seasonal dissolved oxygen depletion in the upper estuary and the impact on this of improving effluent quality from Howdon sewage treatment works. The components of the model are described below (Inverarity, 2001).

4.2 Model Description

The Tyne is a long, narrow, relatively deep estuary which may be considered to be partially stratified in terms of the changes in salinity concentration between surface and bed. Pollutants discharged to the estuary are subject to the same mixing processes as the salt and hence the variation in concentration of parameters such as BOD and DO are much greater over the depth of the water column than with distance across the estuary. It may be assumed that variations in water quality across the width of the estuary are negligible.

The model is a dynamic two dimensional description of the estuary system. It predicts variations with time of water movement and water quality along the estuary length and through the depth of the water column assuming complete mixing in the lateral dimension. The estuary is tidal from the Tynemouth piers to Wylam and is modelled as 65 contiguous longitudinal elements each 500m long. The vertical dimension is represented by 19 layers of fixed depth through which the water surface moves in response to changes in the tide height. The top 12 layers that accommodate the changing water surface are 0.5m thick followed by two layers of 0.75 m and the remainder of 1.5 m. The bottom cell may be thicker than 1.5m if there is insufficient depth to accommodate two whole layers.

The processes governing the concentration of DO in the estuary, included in the model are:

DO SINKS	Riverine Biochemical Oxygen Demand Polluting Discharge Biochemical Oxygen Demand Sediment Oxygen Demand Oxidation of Ammonia
DO SOURCES	Riverine Dissolved Oxygen Seawater Dissolved Oxygen Effluent Dissolved Oxygen Surface Re-aeration Artificial aeration

The model is fully described in the HR Wallingford Report EX4034 (May 1999), 'Tees Estuary Water Quality Model and Tyne Estuary Water Quality Model; TIDEWAY-2DV User Guide'.

4.3 Model Limitations

As with all models, Tyne-2dv simplifies the processes operating in the real world. The model does not attempt to describe variations across the width of the estuary. For the purposes of modelling dissolved oxygen, this is generally acceptable because the rates of the oxygen sink processes are slow relative to the lateral mixing processes.

The longitudinal resolution of the model is 500m. In effect, any input to the model is assumed to mix instantaneously into the discharge cell, which is assumed to be at the surface. The assumption of surface discharges is generally valid for discharges of effluent from the banks, since these will generally be non-saline and thus buoyant. It is probably less appropriate for a dredging input, since this is likely to be distributed through the water column. However the surface discharge assumption gives a worst case scenario in terms of material remaining in suspension longer and hence providing more time to exert its oxygen demand. It has been assumed that all suspended material that settles out on the bed no longer contributes to the suspended BOD but is characterised by the benthal oxygen demand.

The resolution of the model, its inability to predict lateral variation and the assumed surface discharge mean that variations of dissolved oxygen close to the dredging operation will be poorly described. In essence, the model gives an insight into the mid- and far-field effects over relatively long timescales. It does not and cannot elucidate short term, local effects.

River flows and estuarine temperatures for all model runs were based on the relatively dry period of 1995- 96, since this is considered likely to lead to worst case conditions. Later, runs were performed with modified river flow datasets, excluding a significant spate in mid-November.

The BOD, suspended solids and ammonia concentrations of the Howdon sewage treatment works effluent are based on monitoring results from the Environment Agency, obtained since the introduction of secondary treatment at the end of 2000. The effluent is modelled, pessimistically, as containing zero dissolved oxygen. This assumption produces a negative blip in surface DO concentration in the estuary receiving element. The same effluent data for Howdon are used for all model runs and so the same blip appears in all simulations.

In the absence of reliable predictions of sediment oxygen demand (SOD) for 2005-'06, the longitudinal profile of SOD has been based on summer measurements reflecting the conditions prevailing up to the year 2000. These absolute values of SOD are likely to be pessimistic, both because reductions are expected as a consequence of secondary treatment at Howdon and because the values relate to summer conditions. These factors mean that the predicted dissolved oxygen regimes are likely to be worse than will actually occur in the winter of 2005-'06. Again, the effect will be the same for simulations of background conditions as for those with dredging.

4.4 Model Output

The model was run for an extended period of 60 days using temperatures and flows, representing either winter or summer conditions. Output from the model is in the form of DO concentrations for each segment in the estuary at hourly intervals over the modelling period. Data for each segment were analysed to produce the following statistical parameters for the segment: Mean, Minimum, Maximum, 5 percentile, 10 percentile, 50 percentile, 90 percentile and 95 percentile. Examples of the Mean, 5 percentile and 90 percentile values are plotted in Figures 7.1 to 7.4 for different model runs. The minimum values and the 5 percentile values are assumed to represent the worst case scenarios on which the conclusions on the impact of dredging on the DO sag are based. The 5 percentile values are those that are not exceeded for 5 percent of the total run time.

5.0 Estimates of Input Loads from Dredging Operations

The laboratory analysis of core samples has provided information on the likely oxygen demand of sediment released into the water column during the dredging process. This has been characterised as two components, BOD and ROU. A report by Dredging Research Ltd, Appendix D to "New Tyne Crossing Numerical Modelling Report" (Posford Duvivier, 2001), gives estimates of the amount of sediment released to the water column during the dredging process. Posford Haskoning have provided a programme, giving the number of days over which dredging of each of the "silt & clay" and "sand & gravel" layers. These pieces of work have been combined to estimate instantaneous rates of release of BOD and ROU and, from these, daily loads (Inverarity, 2001).

5.1 Dredging Programme

The following quantities and dredging schedule were provided by Tom Rea of Posford Haskoning.

Clay and Silt	60,308 m^3 by closed grab @ approximately 130 m^3/hr between 7am and 7pm over a period of 33 days
Sand and Gravel	132,263 m^3 by backhoe @ approximately 406 m^3/hr between 7am and 7pm over a period of 23 days

5.2 Sediment Release Rates (Posford Duvivier,2001)

Clay and Silt	20 kg/m^3 (2,600 kg/hr)
Sand and Gravel	6 kg/m^3 (2,436 kg/hr)

5.3 Biochemical Oxygen Demand Release Rates

The following BOD release rates were estimated from the laboratory analyses and the release rates in section 5.2 above.

Clay and Silt	2,600 kg/hr x 0.02655kg BOD/kg = 69.03 kg BOD/hr = 19.2 gm/s
Sand and Gravel	2436 kg/hr * 0.00566 kg BOD/kg = 13.79 kg BOD/hr = 3.83 gm/s

5.4 Rapid Oxygen Uptake Release Rates

Clay and Silt	2600kg/hr * 0.003 kg/kg	= 7.8 kg/hr	= 2.167gm/s
Sand and Gravel	2436 kg/hr * 0.0008kg/kg	= 1.95 kg/hr	= 0.542 gm/s

5.5 Estimated Model Input Loads from Dredging

Saturated DO assumed to be 9 mg/l

Clay and Silt	61 mg/l fast particulate BOD 2mg/l fast soluble BOD 1.68 mg/l DO 0.3 cumec flow
Sand and Gravel	12mg/l fast particulate BOD 0.7 mg/l fast soluble BOD 7.19 mg/l DO 0.3 cumec flow

The model allows discrimination of BOD into particulate and soluble fractions and both of these fractions may be split into "fast" and "slow" fractions. "Fast" BOD typically has a reaction rate constant of the order of 0.23 per day and "slow" BOD a fifth of this value. From the laboratory work, the 5-day BOD arising from re-suspension of sediment was approximately 70% of the 20-day BOD, which implies that all the BOD can be considered as "fast". Further the BOD of the supernatant liquor after settlement was small compared with the BOD of whole samples: this has been accommodated in the model by assuming that approximately 97% of the BOD is particulate.

Rapid Oxygen Uptake (ROU) it has been included as a negative supply of oxygen, effectively assuming that ROU is instantaneous. Given the relative rates of BOD and ROU and the relatively constant rate of input, this is thought to be a reasonable approximation.

Dredging was assumed to begin on 1 November 2005. Dredging would then occur of "silt & clay" for 33 days and of "sand & gravel" for a further 23 days. The two types of material were characterised by different BOD and ROU values.

6.0 Model Simulation Runs

6.1 Initial Simulation Runs

The model was set up to simulate tidal conditions for the winter of 2005-'06, the intended period of dredging.

The model was run for 87 days from High Water Spring Tide on 5 October 2005 to allow stability to be attained before any output was generated. Output was started for all model runs on 1 November 2005. The output files have been condensed into statistical summaries and longitudinal plots of mean, 5-percentile and 95-percentile DO concentrations.

The background model run included all these factors and was labelled **06arup01**.

Initially, the dredging input was simulated as an effluent with flow and all quality parameters varying with time. This method was used to simulate the dredging input occurring between 7am and 10pm each day. Flow of the input was set at 0.3 m^3/sec during this period and at zero outside it. The BOD concentration was set as a constant value to give the correct daily mass load during this 15 hour period. ROU was simulated by assuming that the dissolved oxygen concentration of this input would otherwise be 9mg/l and by deducting the ROU value from this. This run was labelled **06arup02a**.

A review of the statistical summary of the output from **06arup02a** showed high maximum values in some areas and the longitudinal plots of summary statistics were "noisy". This indicated incipient numerical instability within the model, which was tentatively attributed to an effect of the rapid variations in the dredging input. Additional model runs were therefore undertaken, using a different means of describing this input.
The results for **06arup02a** are not considered further because of the instabilities in the model output.

6.2 Follow-up Simulation runs

An alternative means of describing an input within the model is as a daily-varying flow value with constant quality parameters. This ignores diurnal variations in dredging effort. The daily dredging BOD and ROU loads were spread over 24 hours rather than 15 hours. This method was used in all subsequent simulations. It has been assumed that the continuous discharge is a reasonable representation of the intermittent discharge because the full effect of the BOD is exerted over a relatively long time period compared with the interval of no discharge. In effect the fluctuations in the discharged are assumed to be smoothed out over the period during which the BOD is exerted.

Two methods of describing the dredging loads were employed. In **06arup03**, ROU was simulated by reducing the dissolved oxygen content of the 0.3 m^3/sec associated with the dredging input. In **06arup04**, ROU was simulated by means of an aeration device adding a negative load of oxygen to the bottom of the estuary while the dredging input was assumed to be saturated with oxygen.

A second "background conditions" run, **06arup05**, was performed. This used the same dredging input as **06arup03** but with the BOD set to zero and dissolved oxygen set to 100% saturation. This would account for any impact on the predicted DO of the hydrodynamic effects of the 0.3 cumecs artificially added with the dredging input.

Because the river flow data set encompassed a significant spate on 15-16 November, in the middle of the period of "silt & clay" dredging, modified versions of the **06arup03** and **06arup05** scenarios were run. These, labelled **06arup03a** and **06arup05a** respectively, used a river flow data set in which flows during this spate were reduced to more normal values, effectively removing the spate.

Finally, **06arup06** and **06arup07** were set up to simulate the estuary during June and July 2006, respectively with and without dredging. For these runs, an alternative description of the SOD profile was used, which accounts for a 33% reduction resulting from the introduction of secondary treatment at Howdon STW. This is felt to be a reasonable estimate of the likely reduction after five years and, from previous modelling, is likely to increase dissolved oxygen in the upper estuary by approximately 1mg/l. The effects of the assumed SOD will be the same in both simulations.

This gives the following four pairs of simulations where the only difference within the pairs is the dredging input (base condition given first).
06arup05 vs **06arup03** winter, ROU as DO depletion in dredging input
06arup05 vs **06arup04** winter, ROU as negative oxygenation
06arup05a vs **06arup03a** winter, spate removed, ROU as DO depletion in dredging input
06arup07 vs **06arup06** summer, ROU as DO depletion in dredging input

7.0 Discussion of Results

For each of the pair of simulations identified above, the tabulated summary statistics of dissolved oxygen concentration for the "with dredging" simulation have been subtracted from those for the "background" simulation. These tabulated differences are appended to this report (Appendix 2). A positive value in one of these tables means that the value of that statistic in a particular model cell is higher in the "background" simulation than that in the "with dredging" simulation.

The structure of these tabulated differences is:

- For each pair of outputs that have been compared, there are six pages of results.

- The first page contains header data.
- Four subsequent pages contain eight blocks for the eight summary statistics in the order listed on the header page. The first line on each page identifies the depth layer to which it pertains. Within each block, there are 65 values, one for each model element, in the order:

  ```
   1  2  3  4  5  6  7  8  9 10
  11 12 13 14 15 16 17 18 19 20
  21 etc.
  ```

  Where element 1 is at the Tynemouth piers and element 65 is at Wylam

  The dredging input load occurs in element 15.

- The last page contains only two blocks. The first gives the differences between the maximum values predicted for any layer within each element and the second the differences between the minima.

In all cases, the predicted differences are small. The largest differences in three of the four pairs of simulations occurs for the minima in the surface layer at the point of dredging, the cell into which the input load is discharged. The exception to this is **06arup04**, the run in which ROU was modelled as negative oxygenation, where the largest credible differences occur near the bed, approximately 5km upriver. However, this run also shows "noisy divergence" from its background simulation (**06arup05**) in the uppermost reaches of the estuary, suggesting the presence of numerical errors in the model output. The output from 06arup04 is considered to be too 'noisy' to be used as a basis for prediction.

The model output data for the differences between runs **06arup3a** and **06arup5a** are considered to represent the 'worst' case conditions for the proposed dredging period and are tabulated in Appendix 2

The output data for the differences between runs **06arup06** and **06arup07** predict the effect on DO concentrations if dredging were to take place in the summer period are also tabulated in Appendix 2.

Statistical summaries of the results for the period 1 November to 30 December 2005 for runs **06arup 3a** and **06arup5a** are plotted in Figures 7.1 and 7.2. Similar plots for summer conditions (1 June to 30 July 2006) for runs **06arup06** and **06arup07** are shown in Figures 7.3 and 7.4. These plots show the longitudinal variation of the 5-percentile, mean and 95-percentile dissolved oxygen concentration have been plotted. These are presented in groups of four, representing near-surface conditions, mid-depth conditions, near-bottom conditions and depth-averages for a given simulation.

The plotted statistics show relatively high dissolved oxygen concentrations near the surface throughout the estuary. Further down the water column, lowest values occur near the nose of the saline wedge when the estuary is stratified: this is reflected in a nadir in the 5-percentile value 30+ km from the sea. The 95-percentile values at the bottom in this area of the estuary are higher because the saline wedge is not permanent and can be completely displaced during periods of high river flow.

DO Predictions without Dredging

(1 November to 30 December 2005)

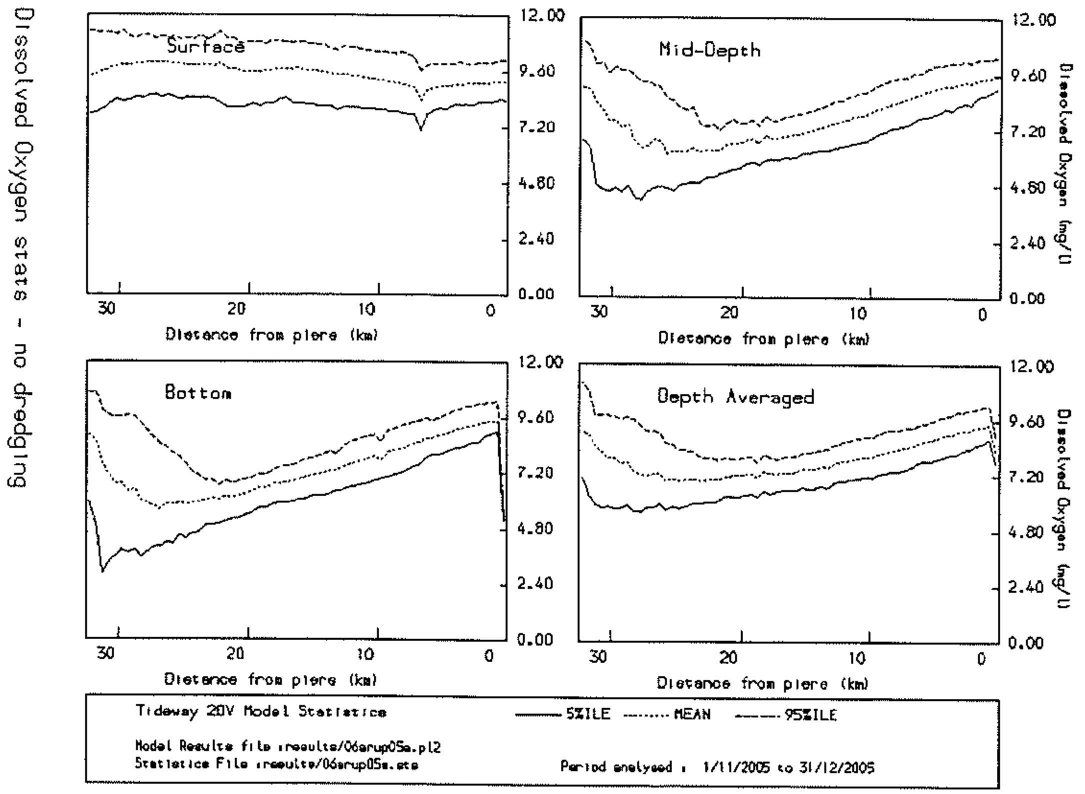


Figure 7.1

DO Predictions with Dredging

(1 November to 30 December 2005)

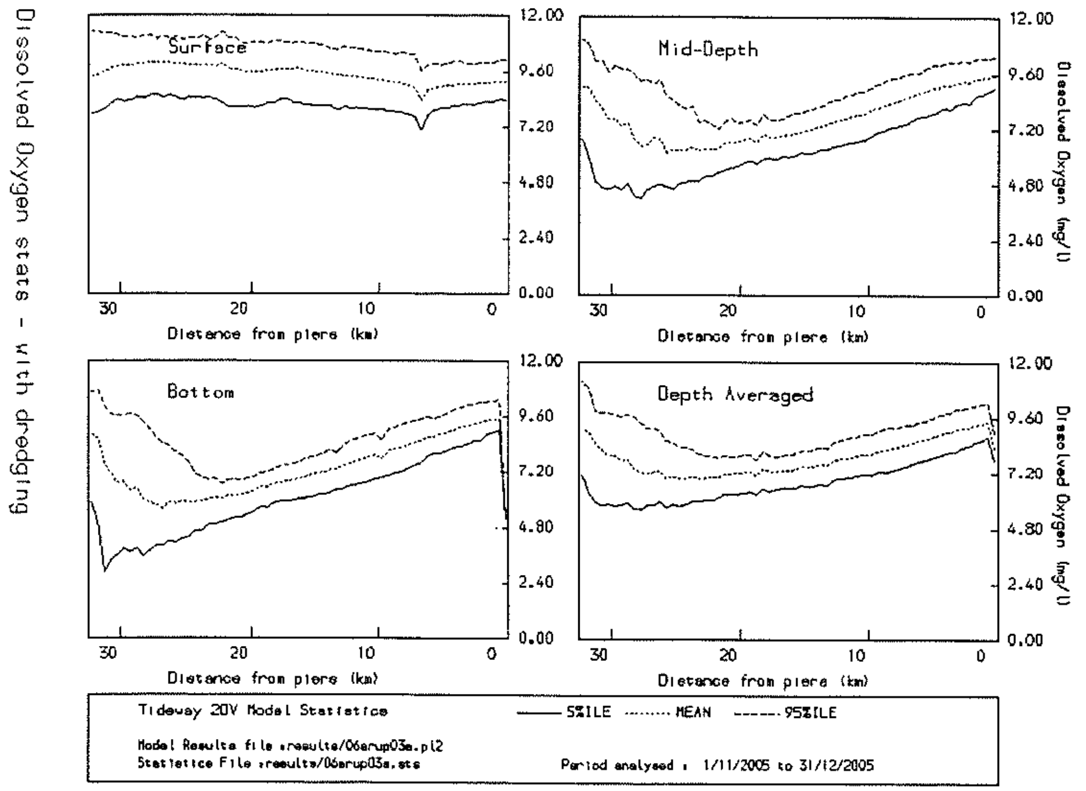


Figure 7.2

DO Predictions without Dredging

(1 June to 30 July 2006)

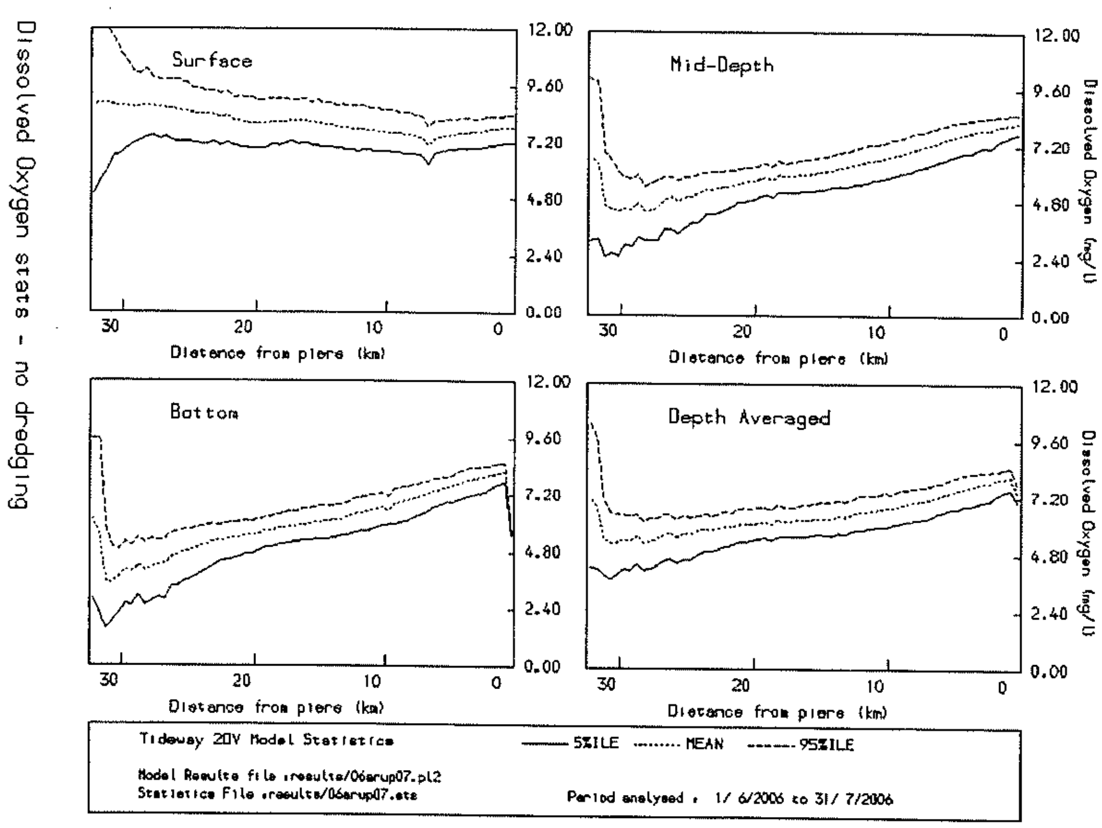


Figure 7.3

DO Predictions with Dredging

(1 June to 30 July 2006)

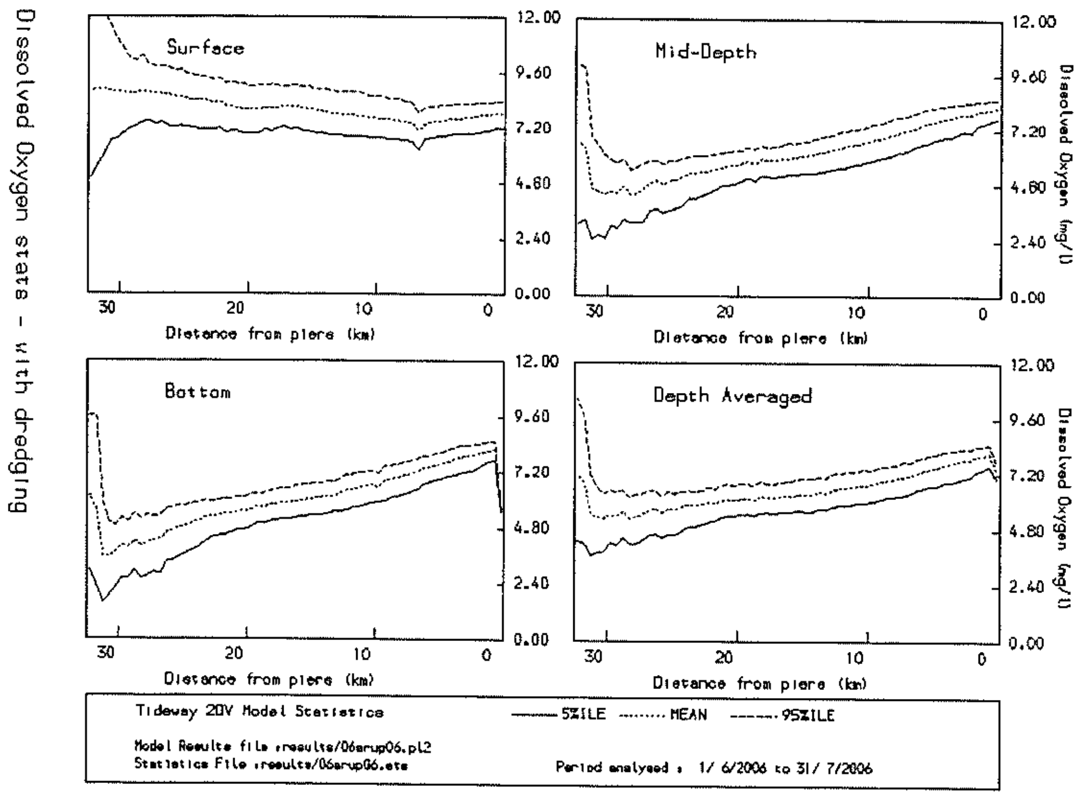


Figure 7.4

8.0 Conclusions

From visual inspection of the plotted data it is difficult to determine any change in the dissolved oxygen profile either in winter or summer conditions. Inspection of the tabulated results showing the reduction of dissolved DO concentrations below baseline levels indicates a 5 percentile difference of 0.082 mg/l and a difference in the minimum values of 0.093 mg/l for winter conditions. These values were found in the surface segments close to the dredging zone.

The differences in DO concentrations under summer conditions were slightly more pronounced and occurred over a wider spatial range in length and depth in the estuary surrounding the dredging zone. The largest differences were 0.092 mg/l for the 5 percentile in the bottom layers and 0.045 mg/l for the minimum values in the surface layers. The largest difference of 0.092mg/l represents an increase in oxygen deficit of approximately 1 % of the saturated dissolved oxygen value.

These small differences indicate minimal impact of dredging for the new Tyne Tunnel on the general distribution of dissolved oxygen concentration in the Tyne estuary. There is no evidence from the modelling work that the dissolved oxygen sag in the upper reaches of the estuary will be significantly increased due to the dredging activity. The sag in the upper reaches is primarily due to the existing benthal demand in that area and to the existing fresh water BOD and suspended BOD in the tidal water. The redistribution of particulate BOD from the dredging activity does not change the upstream rate benthal demand and is not of sufficient magnitude in suspended form to provide a significant change in DO in the upper reaches. However, it may be argued that the deposition of material in the upper reaches will affect the length of time over which the demand is exerted.

This paragraph provides an estimate of the order of magnitude of the long term effect of sediment redistribution on DO in the upper estuary due to works at the New Tyne Crossing. It has been estimated (Posford Duvivier, 2001) that 540 tonnes of silt released into the water body will pass upstream of Low Walker which is approximately 10 km from the mouth of the estuary. This material will be carried upstream near the bed by the densimetric flow and be deposited over a wide area of the estuary between Low Walker and Lemington, a distance of approximately 15 kilometres. Tracer study experiments (James, 1996) have demonstrated that suspended organic material can be transported long distances to the upper reaches of the estuary. Previous benthal respiration studies have indicated that substantial organic deposits, resulting mainly from land based discharges along the full length of the estuary, occur over a 5 km stretch of estuary between the Tyne Bridges and Blaydon. Assuming that the 540 tonnes is distributed over this area with a density of 1.5 tonnes /m^2 then the depth of the new deposit is of the order of 0.0007m or 0.7 mm. This is approximately 0.1% of the depth of the existing mud. Assuming a linear rate of depth reduction, the extra material will increase the time taken for the organic deposits to degrade by 0.1 %. It is difficult to estimate the time taken for the deposits to be removed by natural degradation however the time will be of the order of tens of years. Assuming that it takes 20 years to decay then the extra time period required by the new deposits will be of the order of 7 days.

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