Report No: 3040

Port of Tyne

Sea Disposal Trials of Contaminated Tyne Estuary Sediment:

Required Cap Thickness

February 2007

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Status : **DRAFT**

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1. INTRODUCTION

The need to remove 60,000m^3 of contaminated sediments from the Port of Tyne Estuary has resulted in a unique trial involving the deposition of the dredged material at sea followed by capping with silt and sand. The trial disposal was approved by DEFRA and licensed (licence number 31995/04/1 dated 5 October 2004).

The rationale and design of the sediment disposal trial was founded on the US Army Corps of Engineers (USACE, 1998) manual 'Guidance for sub-aqueous dredged material capping'. The design of the trial allowed for approximately 60,000m^3 of contaminated material to be disposed and capped by a 1m silt sediment cap, followed by a 0.5m sand cap to isolate material from the environment and protect against erosion.

At the design stage, the agreed cap thickness was based on what was assumed to provide a safe protective thickness to the marine environment from the contaminated materials with a substantial 'factor of safety' incorporated. Empirical techniques were used to provide a scientific basis for the proposed cap design. Following completion of the sediment disposal, cap thicknesses had not met the original design criteria; however monitoring data revealed that there was no significant risk to the marine environment. It was agreed with DEFRA/CEFAS that further monitoring would be undertaken (as agreed in the monitoring program) to aid in determination of the longer term risk. CEFAS, in parallel, also undertook a risk assessment of the cap integrity. They considered that the greatest risk to the cap was a series of moderate storms exposing contaminated dredge material beneath. Following twelve months of monitoring data it was revealed that the cap remained intact and that benthic life was returning in good numbers and that there were no elevated concentrations of contaminants noted in the capping area. It has subsequently been agreed at a meeting with CEFAS in September 2006 that the optimum cap thickness to provide a minimal risk to the environment could be revised to 0.6m from the original license.

However, assessing the exact cap thickness is problematical in 45 metres depth of open sea. Measurement of the cap thickness is not possible (see Section 3 for discussion) even with the advanced surveying techniques utilised. Interpreting the data obtained it is estimated that 0.65m of cap was present following the initial disposal event. Additional sand cap material was placed on the disposal area in May 2006 further increasing the cap thickness at the site and has been estimated to further exceed the agreed thickness providing 0.85m on average over the significant CDM deposits.

Using the *real* data for the system made available through observation and monitoring of the trial site over the last year the opportunity exists for redesign of the optimum cap thickness. For example, the CEFAS risk assessment highlighted that the primary concern for erosion of the cap would be from a series of moderate storms events. Over the period between the annual monitoring rounds three moderate storm events occurred and it has been shown that the cap thickness has not changed. Adjustment of the risk assessment in light of conditions at the disposal ground since the material was deposited is required.

In order to further monitor the cap thickness to ensure that the CDM is safe from exposure a satisfactory thickness of cap must be determined. This thickness should be such that it is suitable as a 'trigger' thickness, i.e. if the cap thickness was shown to become less than this level then replenishment works would be initiated.

Defining the adopted technique for measurement of cap thickness is an essential aspect of the design process. This is a complicated issue given the inherent difficulty of measuring the thickness of a marine sediment layer underneath 45m of seawater.

The following report documents the information currently available for cap design for seabed disposal sites both in general and specific to the trial site. Section 2 then goes on through the design process to a final cap design. The final section of the report discusses the complicated issue of measurement of cap thickness and presents the adopted future monitoring approach.

2. CAP DESIGN REASSESSMENT

2.1 Generic design requirements

The cap must be designed to adequately isolate the contaminated material from the benthic environment over the required time frame. The design components are the composition and the dimensions (area and thickness) of the cap. USACE (1998) consider that the composition of the cap is likely to compromise a single layer of sediments and they therefore focus on design of the cap thickness.

Determination of the required cap thickness is dependent on

- the physical and chemical properties of the contaminated and capping sediments;
- the hydrodynamic conditions such as currents and waves;
- the potential for bioturbation of the cap by aquatic organisms;
- the potential for consolidation and the resultant expulsion of pore water from the contaminated sediment;
- the potential for consolidation and erosion of the cap material; and
- operational considerations.

The minimum required cap thickness is considered to be that required for physical isolation plus any thickness needed for control of contaminant flux, erosion, consolidation and operational losses.

The integrity of the cap with respect to physical changes can be evaluated once the overall size and configuration of the capped mound or deposit and resulting water depth over the cap are determined.

2.2 Site Specific Cap Design

The USACE approach for cap design has been adapted to the requirements and context of the Souter Point Outer disposal site. Experience to date at the trial site has been incorporated into the design process.

2.2.1 Cap composition

The composition of cap replenishments should be of a single layer of sand material as defined by USACE. It was shown during the capping works at the trial site that the sand material fell to the disposal ground as required, whereas the finer silt material spread more widely and thinly than suitable.

2.2.2 Cap dimensions

The thickness of cap required to meet the design requirements is discussed by component below:

- Bioturbation potential

During initial design considerations infauna typical of the Souter Point area in the North Sea were considered to bioturbate to depths of 30cm. The evidence from the infauna survey would suggest that no organisms have been identified that are likely to burrow deeper than this. Furthermore there is no evidence from the SPI camera images of creatures burrowing to even 25cm depth. Whilst recognised that this is likely to change over a greater time period the maximum bioturbation depth is considered to be a maximum of 40cm.

- Consideration of deposit geometry, site conditions and evaluation of potential erosion

Consideration of the deposit geometry and gently sloping seabed at Souter Point envisaged a spreading of the CDM in a relatively even pattern in the direction of the predominant currents. Whilst this happened, there was perhaps a more 'blocky' element to the deposited material as noted from the SPI camera work ultimately resulting in more consolidation of the material than was initially considered. This revealed itself in the difficulties there are in interpreting the bathymetric data once the CDM was capped.

CEFAS undertook a risk assessment in early 2006. This considered that the greatest risk to the erosion of the cap was a series of moderate storms likely to remove up to 45cm of capping material in 1 year. The results of the monitoring highlight that whilst there have been a number of moderate storms in the year since the CDM was deposited there has not been any significant decrease in the cap thickness. A review of this risk assessment may allow the amount of material considered to erode to be reduced.

- Evaluation of operational considerations and addition of a cap thickness component

This is considered to have a minimal influence on the cap thickness

- Assessment of cap thickness component required for control of contamination flux

It is considered that the cap thickness required by the other components of the design (bioturbation, erosion, operational) will provide a sufficient thickness to prevent the upward migration of contamination the zone where it could be exposed to the benthos.

2.3 Derivation of replenishment trigger conditions

Using the above considerations and through the risk assessment process and discussion with CEFAS it is considered that a cap thickness of 0.6m will provide suitable protection to the marine environment from contaminated dredge material deposited at Souter Point. A full definition of cap thickness is outlined below.

There should be an average of 0.6m of cap present across the significant deposits of CDM at the disposal site. This will be determined by subtracting the 'Modelled CDM Surface' (methodology to determine this is outlined in Section 3 of this report, EnviroCentre Report 3040) from the bathymetric survey data for the relevant monitoring period. Significant deposits are defined as 'CDM greater than 1cm thick' from April 2005. A histogram of cap thickness points across the significant deposits will be plotted. The average cap thickness shown on this histogram is to be greater than or equal to 0.6m.

It is recommended that this is incorporated into a revised license.

3. DETERMINING THE CAP THICKNESS

Measurement of the thickness of the cap present at the trial site is a complicated task given the inherent difficulties of measuring a layer of sediment underneath 45m of seawater in the middle of the North Sea. The experience of this trial has allowed various state-of-the-art techniques to be tested in a practical situation. The value of each technique and the limitations are discussed below, before moving towards determination of the preferred combination of techniques to be adopted for future measurement of cap thickness. Detailed explanations of each technique have been presented in the monitoring reports for the trial and the reader is referred to these documents for supporting information.

3.1 Previous measurement of cap thickness

- Bathymetric surveying

A bathymetric plot of the trial site provides the depth to the current surface of the seabed. The major benefit of this technique is that it covers the whole trial site, as opposed to other techniques which provide only spot point data. The limitations of using bathymetric plots to determine cap thickness are the margins of the error, and more significantly the effect of consolidation.

The margin of error of the bathymetric survey is +/- 0.2m. Therefore when comparing the change in seafloor height, by calculating the difference between two bathymetric plots the margin of error is +/-0.4m. This is a very significant portion of the target measurement of cap thickness (0.6m).

More importantly however is the effect of consolidation. The process of consolidation has occurred at the trial as the material, disposed in 'blocky' cohesive dredge loads has settled, and then been further compressed by weight of the overlying cap. This prevents the use of bathymetry to determine cap thickness in the following way. Each new bathymetry plot only provides one of the two measurements required to know cap thickness - the upper cap surface. It cannot provide any information on the current depth of the base of the cap. If using bathymetry to calculate cap thickness we are reliant on the earlier measurements of former surfaces to provide the other half of the calculation. The surface that represented the base of the cap when it was first placed, i.e. the top of the CDM, was measured immediately following the placement of the CDM and it is tempting to use this data to calculate the current cap thickness. This would not be correct as consolidation means that this surface no longer exists (see Figure 1); the base of the cap has moved downwards over time. The current location of the base of the cap is not known. The cap thickness can be roughly estimated in this way, but the distance of consolidation must be added to this measurement to get *actual* cap thickness (see Figure 1).

- Geophysical measurement of cap thickness

Attempts have been made to determine the depth of the upper CDM surface via geophysical means (sub-bottom profiling). This technique relies on the physical differences in the sediment types of the CDM and the cap to be reflected in the geophysical profile. The benefit of this technique, compared to bathymetry, is that the base of the cap is shown as well as the surface. Experience at the trial site have shown the disadvantages SBP to be:

a) only cross-sections of the trial site are provided and the areas in-between must be inferred;
b) again, there is the issue of error margins, in this case being +/- 0.5m. This prevents the use of SPB for thin layer definition, and severely limits its use for measuring cap thickness in this situation; and
c) because the surface of the CDM was blocky and rough, it was infilled with the sand cap material. This created an indistinct line between the CDM and the cap which cannot be measured clearly using geophysical means.

- Physical measurement of cap thickness

Physical techniques to measure the cap thickness have also been applied to the trial site; sediment profile imagery (SPI) and sediment coring. SPI uses a prism with an internal camera. The prism is driven into the cap and a photograph taken of the sediment profile. Sediment coring involves drilling through the cap and measuring the thickness of the cap in the recovered core. The advantages and disadvantages of each technique specific to measuring cap thickness are discussed below.

Sediment Profile Imagery (SPI)

The major advantage of SPI is that the sediment is visible in the photographs and the cap thickness can be directly measured with small margins of error. The limitations are that:

a) SPI provides spot point data; cap thickness across the remainder of the site must be inferred.
b) The maximum thickness of cap that the SPI camera can penetrate is 0.17m, so in locations where the cap is thicker than this the total cap thickness cannot be determined.

Sediment coring

Like SPI, the major advantage of this monitoring technique is that the actual thickness of the cap can be measured directly from the recovered core. The limitations of sediment coring when used at the trial site have been:

a) Coring provides spot point data; cap thickness across the remainder of the site must be inferred.
b) Specific to the trial site, it has been shown that where the cap thickness is greater than 0.35m the sand washes out and is lost. In comparison, where the cap is thinner than 0.35m the sand is penetrated and the underlying cohesive sediments are captured blocking the corer and allowing recovery of the sediment. Coring cannot therefore determine if the cap thickness is at or near 0.6m, but is limited to showing only that it is greater than 0.35m thick.

3.2 Measurement of cap thickness in the future

The use of the various available techniques to measure cap thickness have shown that each has significant limitations. So significant in fact, that to date total cap thickness across the whole site has not been able to be measured directly. It has only been able to be inferred, or measured in the peripheral areas where the cap is thinner. It should be borne in mind that sampling on the surface of the cap has not indicated any exposure of CDM.

As the bathymetric surveying provides coverage of the whole trial site (continuous rather than spot data) and is the most simple to commission at short notice, it is recommended that further monitoring of the cap thickness is based on this technique. The problem with using bathymetric surveying to define the cap thickness is that the base of the cap is not known as it has moved by consolidation since it was measured immediately following placement (refer to section above). To get around this problem it is recommended that a 'Modelled CDM Surface' be derived to replace this unknown surface. This surface will represent the 'base' of the cap and thus ensure that there is a semi-fixed baseline that can be subtracted from future bathymetry plots to allow a more accurate cap thickness to be determined.

The 'Modelled CDM Surface' can be calculated by bringing together all the information collated on cap thickness as part of an annual monitoring round. Isopachs of cap thickness can be derived from the SPI cross sections, coring spot points and supported by the bathymetry and geophysical assessment. These isopachs can then be utilised to infer a zone of a specific cap thickness which when subtracted from the relevant bathymetric surface data points creates the modelled surface of the current CDM surface.

Unfortunately this process cannot be completed from the 2006 annual monitoring round because the bathymetric survey was of poor quality (due to adverse weather conditions) and covered only 9ha of the central part of the disposal ground. While the isopachs of cap thickness can be developed, there is no corresponding bathymetric survey to create the 'Modelled CDM Surface'. A worked example of how this process will proceed when a full data set is available (physical data and bathymetric data) is presented in the following section.

3.2.1 Worked Example

To show how the 'Modelled CDM Surface' will be derived when the full data requirements are available (physical data and bathymetric data) the 2006 isopachs (from the physical data) have been subtracted from the *2005* bathymetric data.

The 2005 bathymetric survey was the last survey to cover the whole area of the site, needed to create the 'Modelled CDM Surface'. The problem with using this survey is that shows the disposal ground surface *before* consolidation has occurred; i.e. it shows a higher surface. Therefore when the cap thickness isopach surfaces are subtracted from the bathymetric data a *higher* 'Modelled CDM Surface' will be produced. This is overly conservative. It is conservative because when this surface is then used to calculate the current (following the May 2006 replenishment works), or any future cap thickness the higher cap basal surface derives a thinner cap. If full bathymetric data was available from 2006, following the consolidation phase, and was applied to the isopachs defined from the 2006 physical data then a lower 'Modelled CDM Surface' would be produced which would then show that actually a thicker cap is present.

Despite the lack of matching data currently available this process has been worked through to show how the process will work, and to give a conservative indication of the cap thickness present at the site.

An explanation of how the cap thickness isopachs from the 2006 data, shown in Figure 2, were derived is detailed below:

<table>
<tr><td>1cm</td><td rowspan="4">SPI data; refer to Figure 19 – Annual monitoring report (October 2006)</td></tr>
<tr><td>2cm</td></tr>
<tr><td>5cm</td></tr>
<tr><td>17cm</td></tr>
<tr><td>35cm</td><td>Coring; refer to Figure 24 – Annual monitoring report (October 2006)</td></tr>
<tr><td>60cm</td><td rowspan="2">Assessment of change in bathymetry</td></tr>
<tr><td>80cm</td></tr>
</table>

This modelled cap surface using the isopachs from April 2006, converted to zones of cap thickness, was then subtracted from the *2005* bathymetric survey to create a worked example of the 'Modelled CDM Surface'. This surface is shown on Figure 3.

This plot shows a CDM surface with a general maximum height in the centre of the disposal ground of -45.5m to -46.0m below sea level. Comparing this modelled surface to the surface of the CDM surveyed when it was first placed in 2005 (refer to Figure 8; EnviroCentre report 2045 July 2005) shows the consolidation that has occurred since the capping materials were placed on the CDM.

3.3 Provision assessment of current cap thickness (using the worked example)

Cap replenishment works were undertaken in May 2006 just after the April 2006 annual monitoring round. The 'Modelled CDM Surface – Worked Example' was used to calculate the current thickness of the cap at the disposal site from the bathymetric survey conducted following the replenishment works. This was done by subtracting the 'Modelled CDM Surface – Worked Example' from the most recent survey (May 2006). The cap thickness is plotted in Figure 4. A histogram of the cap thickness (Figure 5) shows that a median cap thickness of 0.7m is present across the surveyed area.

4. CONCLUSIONS AND RECOMMENDATIONS

The above worked example is unsatisfactory primarily because of the incomplete data set that exists for the bathymetry. However the method is considered to represent the best method for assessing cap thickness.

To ensure that a more accurate ‘Modelled CDM Surface’ is created it is recommended that a further detailed technical meeting with EnviroCentre and CEFAS is arranged following the next survey to agree the process and details of creating the ‘Modelled CDM Surface’.

All cap thickness determination is aimed at ensuring that the concept of capping manages the risks adequately and is licensable, and informs when replenishment is necessary. It is stressed that the primary risk is exposure of CDM. The best way of assessing this remains routine sampling of the surface sediments to determine if CDM is exposed.

5. REFERENCES

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EnviroCentre, 2005 (d). *Sea Disposal Trials of Contaminated Tyne Estuary Sediments – Post Placement Monitoring – Short Term,* Report No 2045.

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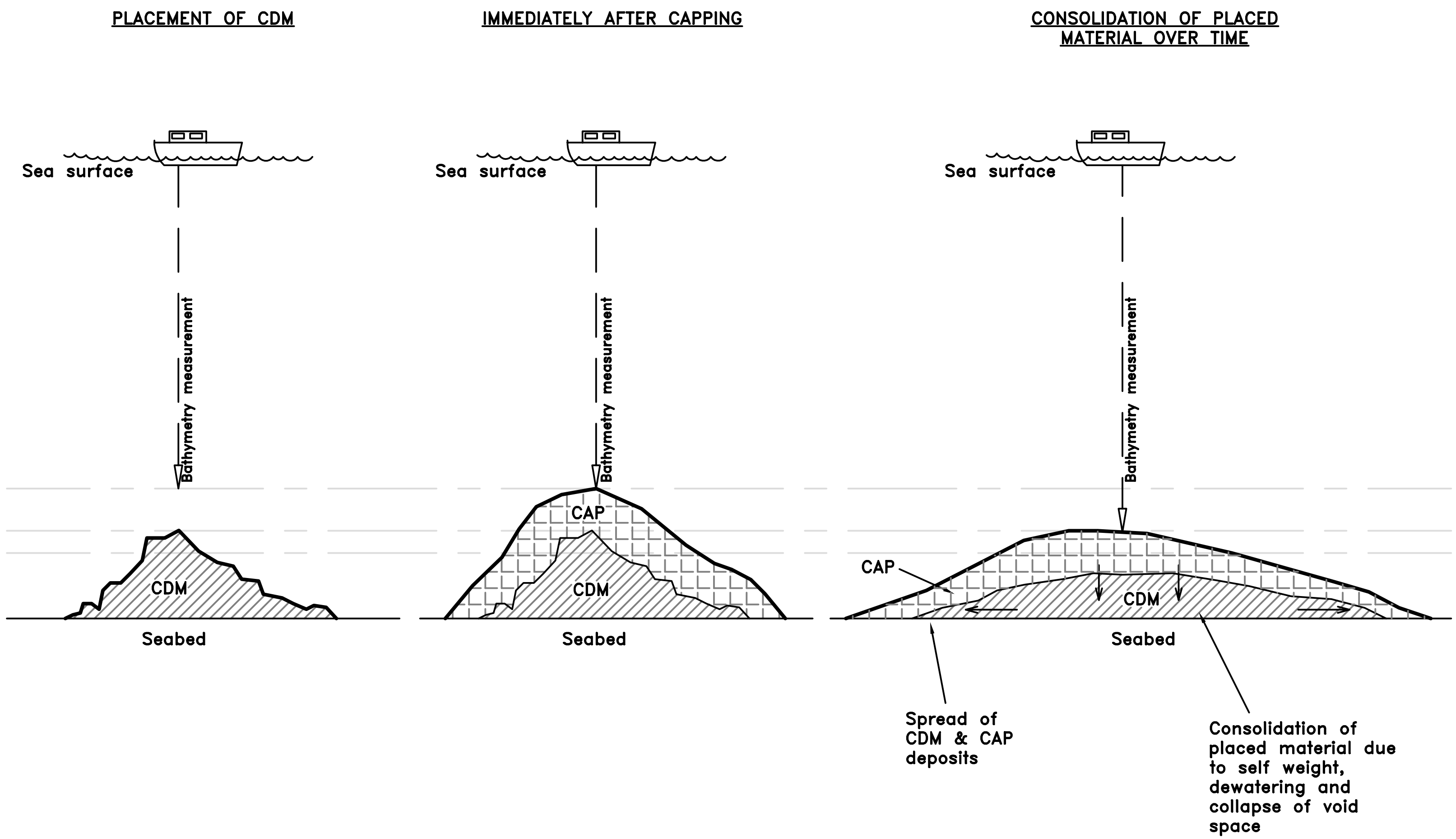
USACE, 1998. Guidance for Sub-aqueous Dredged Material Capping, Technical Report DOER-1.



Notes

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Rev	Date	Amendment	Initial

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Project	Annual Monitoring 2006
Title	**Schematic Presentation of Consolidation of Placed Sediments Over Time and Effect on Bathymetric Measurements**
Drawing No.	11549j/Fig E1
Revision	
Scale	N.T.S.
Date	16/02/07
Drawn	FM
Checked	LKH
Approved	JAW

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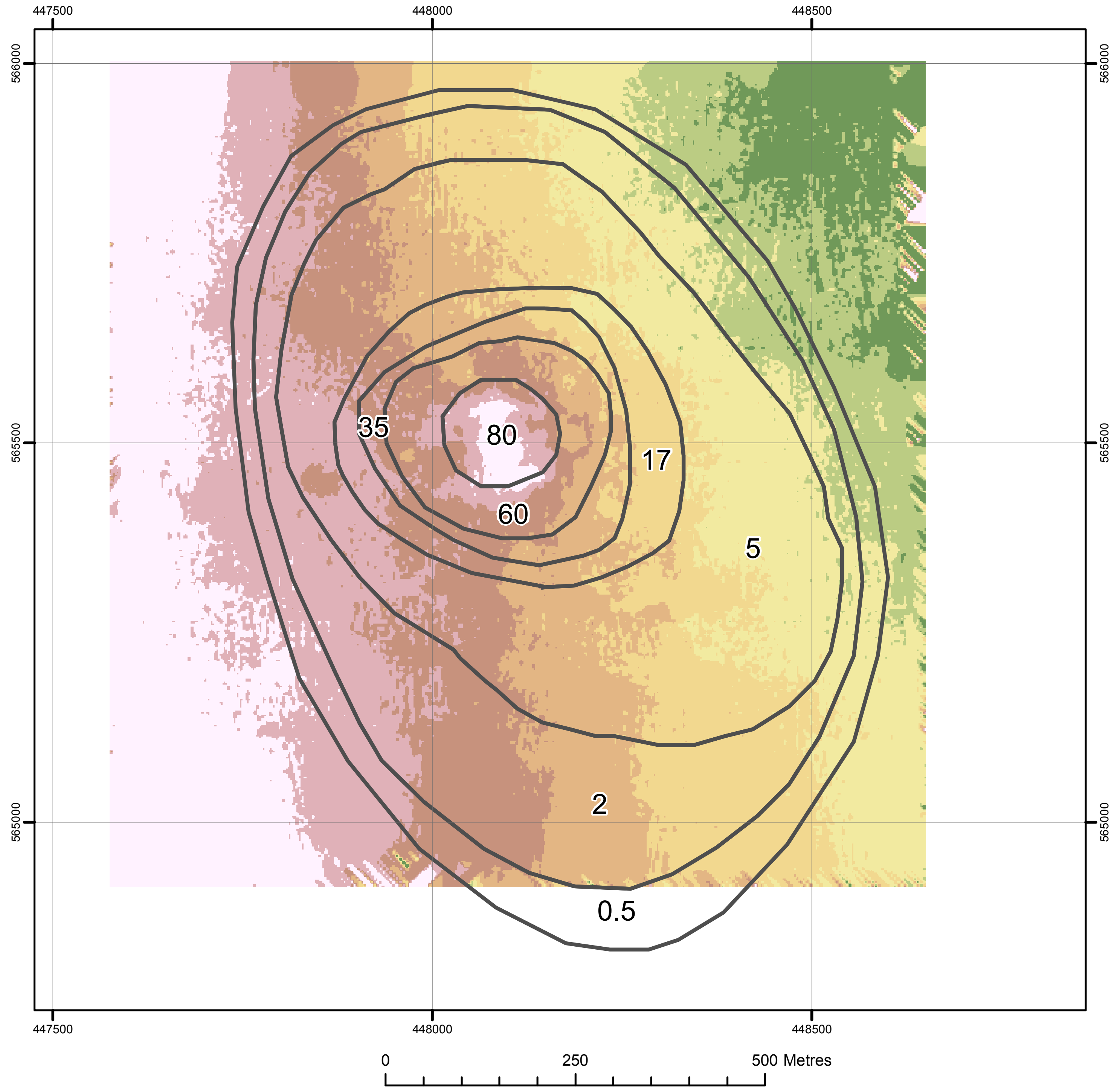
File path: K:\Drawings and Figures\Cad\Working\Annual Monitoring (2006)



Notes

Legend

April 2005 Bathymetric Survey

- -48.5 and greater
- -48 - -48.5
- -47.5 - -48
- -47 - -47.5
- -46.5 - -47
- -46 - -46.5
- -45.5 - -46
- -45- -45.5
- Cap thickness from 2006 physical data

Note: Bathymetry in metres below O.D.

Status

Client: Port of Tyne Authority

Project: Sea Disposal Trial

Title: Derivation of Modelled CDM Surfaces - Worked Example

Drawing No.	Figure 2	Revision	
Scale at A4	1:7,500	Date	14/02/07
Drawn	SBW	Checked	Approved

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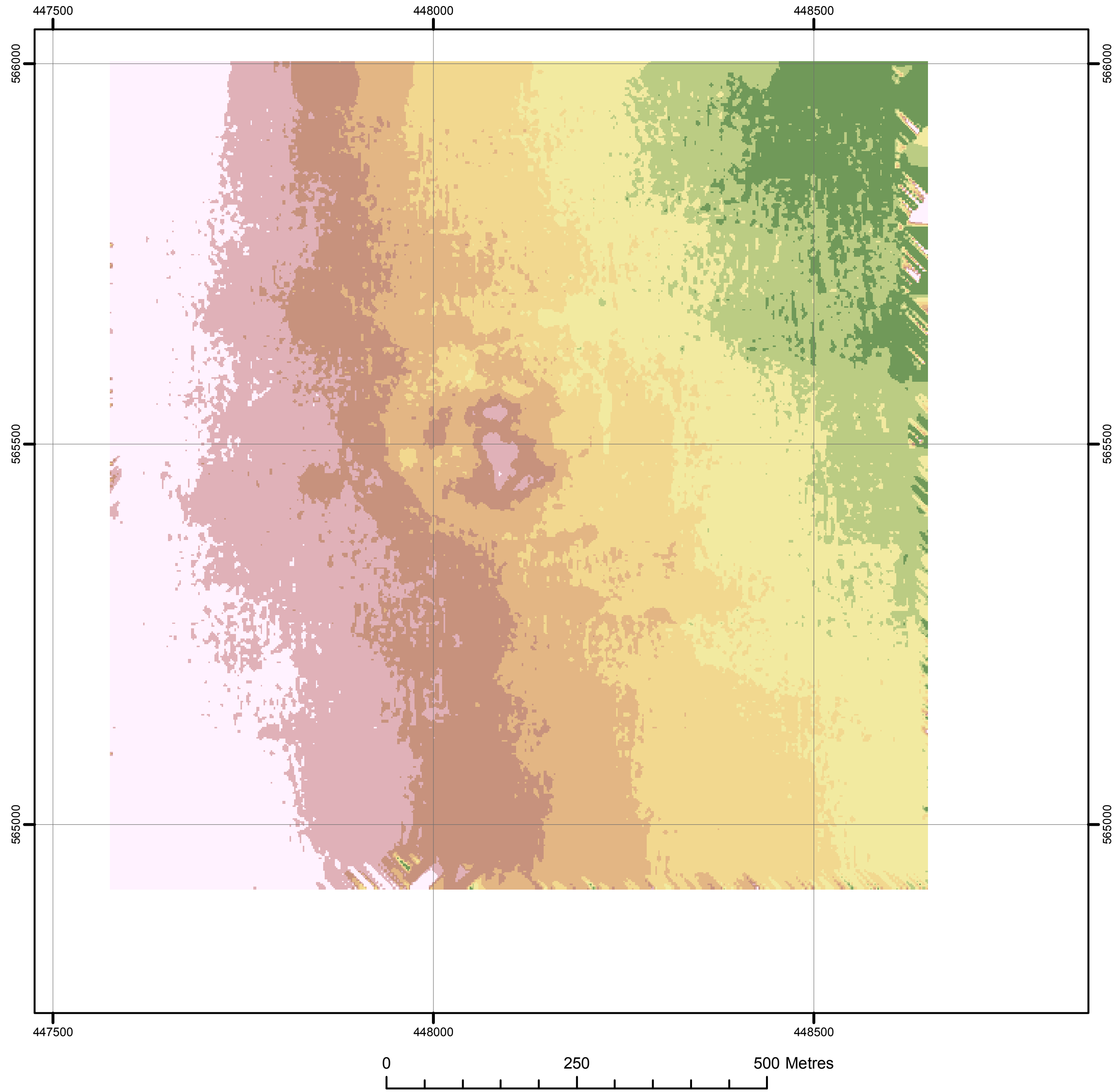

Notes

Legend

Modeled CDM Surface (2005 Bathymetry)

- -48.5 and less
- -48 - -48.5
- -47.5 - -48
- -47 - -47.5
- -46.5 - -47
- -46 - -46.5
- -45.5 - -46
- -45- -45.5

Note: Bathymetry in metres below O.D.

Status

Client: Port of Tyne Authority

Project: Sea Disposal Trial

Title: Modelled CDM Surface - Worked Example

Drawing No.: Figure 3 | Revision:

Scale at A4: 1:7,500 | Date: 14/02/07

Drawn: SBW | Checked: | Approved:

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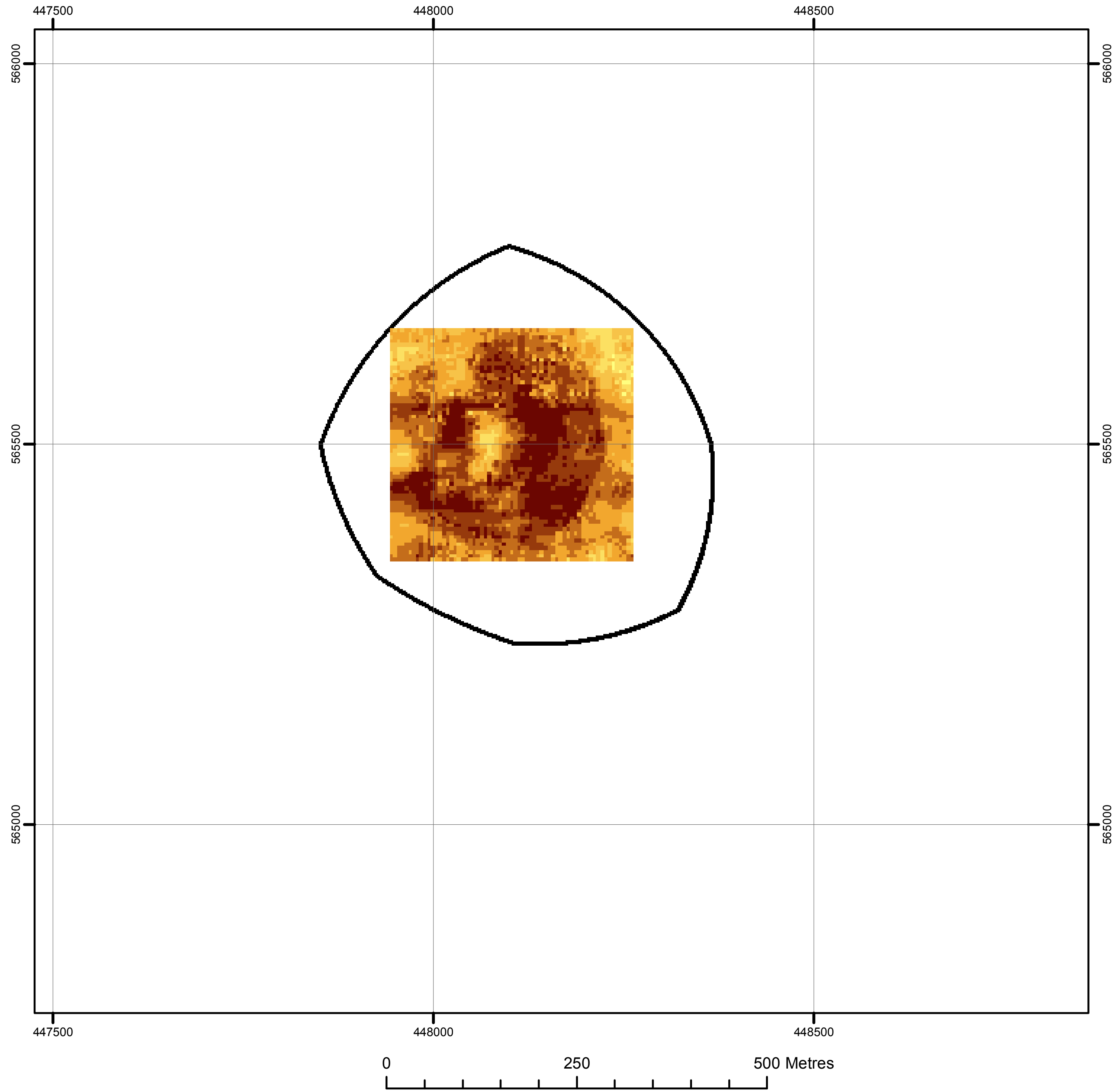

Notes

Legend

Cap thickness (m)

- -0.362998962 - 0
- 0 - 0.2
- 0.2 - 0.4
- 0.4 - 0.6
- 0.6 - 0.8
- 0.8 - 1
- >1
- CDM 1cm thickness (2005)

Status

Client
Port of Tyne Authority

Project
Sea Disposal Trial

Title
Plot of May 2005 Cap Thickness using Worked Example of Modeled CDM Surface

Drawing No. Figure 4		Revision
Scale at A4 1:7,500	Date 14/02/07	
Drawn SBW	Checked	Approved

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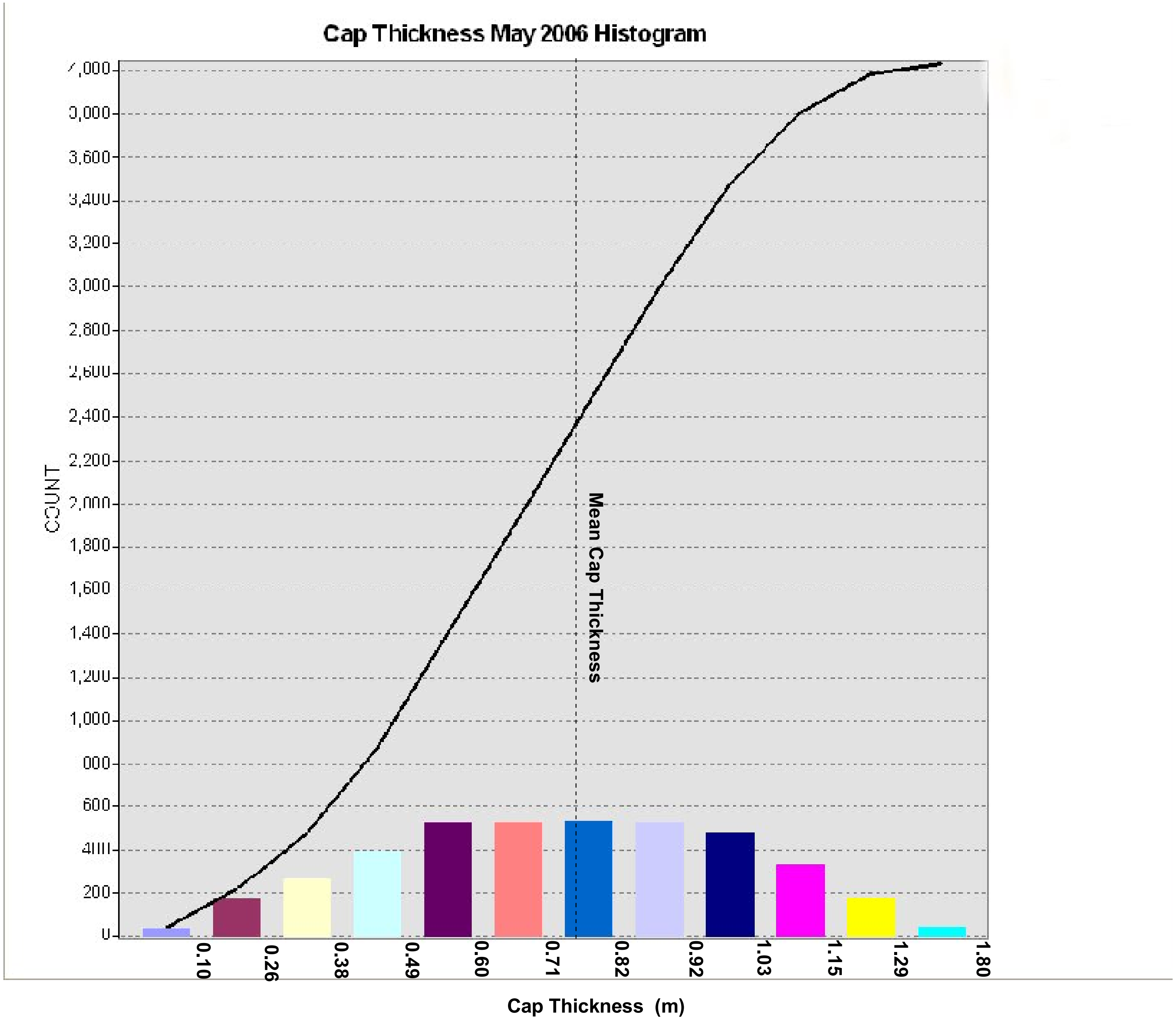

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Rev	Date	Amendment	Initial

Status

Client: Port of Tyne Authority

Project: Sea Disposal Trial

Title: Cap Thickness Histogram

Drawing No.: **Figure 5**

Revision

Scale at A4

Date: 15/02/07

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