

Crymlyn Tip Coed Darcy

Stability Assessment

St Modwen Developments Ltd
R1870/23/5287 - Rev 0B

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eNGLOBE

St Modwen Developments Ltd

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Prepared by:



PP

Sladen Associates

Consultant

Englobe Regeneration UK

Reviewed by:



Ian Wright

Project Manager

Englobe Regeneration UK

Approved by:



Martin Holmes

Operations Director

Englobe Regeneration UK

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1 Introduction

This report presents an assessment of the long-term geotechnical stability of the Crymlyn Tip following restoration. Post restoration, the Tip is to be landscaped and suitable for a public open space end use. The only significant slope area is along the northern boundary of the tip, where a steep sided 'ash' bund was originally constructed to contain the wastes. The tip is to be re-profiled as part of the restoration programme, which will generally result in flattening of the northern side slopes to an angle of 4H:1V. To the south of the bund, the re-profiled tip will generally have a gradual slope to the south at significantly lower gradients - ie 10H:1V or flatter. The report also addresses potential settlements within the tip area in response to changes in final ground level during restoration.



2 Initial Conceptual Ground Model

2.1 Topographical Setting

The tip site lies on the eastern edge of the Crymlyn Bog and has been constructed by placement of fill and waste materials over part of the former bog area. In particular, a bund was formed along the northern edge of the tip and wastes placed to the south. Ground levels rise to the east and south to an area that was formerly a large BP Refinery. The bog area to the north and west is typically at about 8 mAOD. Ground levels on the overall site area drop from about 20 mAOD in the north east to about 10 mAOD in the west.

Cross sections through the northern tip area are included in Addendum K1 together with a plan showing section locations.

2.2 Site History

2.2.1 Pre-Controlled Landfill History

Prior to the Llandarcy refinery opening, the area of the Tip formed part of Crymlyn Bog and consisted of a series of natural ponds and marshland. The area forming the Tip was enclosed with an external bund comprising largely of ash, built out into the Crymlyn Bog. The bund, which still defines the northern extent of the Tip stands circa 10 m above the bog at its eastern end and reduces to approximately bog level in the west. The bund formed a boundary structure but has also been used as a primary access haul road into the Tip.

The base of the Tip is understood to be unlined and is likely to have accepted wastes straight onto natural bog strata. This is generally supported by data from boreholes which have penetrated the base of the waste and generally encounter natural peat.

Waste disposal is understood to have commenced in the Tip in the early 1920s and continued until the 1970s when relevant regulations for waste disposal were introduced, including the Deposit of Poisonous Wastes Act 1972 and the Control of Pollution Act 1974.

A photograph from 1947 shows the eastern end of the Tip looking towards the south east across the southern tank farm, see Figure 1, below. The ash bund is clearly visible along the northern boundary of the Tip at the bottom of the photograph - this feature is reported to have been constructed in the late 1930s with the intention to act as a containment feature in the event of bombing of the southern tank farm during the second world war which could have resulted in uncontrolled releases of free phase hydrocarbons.

It appears that disposal of waste is active in the eastern part of the Tip. Waste is being spread from an access road in the north, and it appears that waste material is potentially being informally deposited from the railhead adjacent to the eastern Tip boundary. Tracks across the centre of the Tip suggest that waste disposal may have taken place in the west by this date. It is understood that at this time, the Tip was used for disposal of a range of refinery wastes including demolition waste, refractory waste and asbestos.

Figure 1: 1947 Photograph



A photograph from 1951 shows the entire area of the Tip looking to the west across the railhead. More extensive waste disposal appears to have taken place in the north eastern corner of the Tip, over the earlier waste deposits and to the same height as the ash bund. The western end of the Tip is flooded, and appears to be natural, marshy ground.

There are no formal records of waste deposited in the early operational phases of the refinery. The depth, volume, type and location of these wastes is largely unknown.

2.2.2 Licenced History Pre-Closure

The disposal areas/sites referenced numerically below which relate to controlled waste disposal in the Tip are shown on Atkins Ltd (Atkins) Drawing 5041216-RAP-DWG-1906, (see Appendix A). Note that this Drawing shows the original, larger permit boundary which included the Coed Darcy Wetlands, and is based on available records and anecdotal information obtained by URS Corporation Ltd (URS) on behalf of BP.

Under the Deposit of Poisonous Wastes Act 1972, waste disposal at the Tip is reported to have been controlled by an annual 'season ticket' issued by Neath Rural District Council for disposal of the waste streams summarised in Table 1.

Table 2: Understanding of controlled waste deposition from 1970s

Disposal Area/Site	Type of waste
1	Non- notifiable Waste
2	Oil Contaminated Waste
3	Oily Sludge
4	Pyrophoric Material
5	Asbestos
6	Sanitary Waste (excluding septic tanks)
7	Asbestos (1984)
8	Asbestos (1988)

In 1977, Neath Borough Council granted BP Oil Llandarcy Refinery a new waste disposal licence to operate the Tip. This licence incorporated the requirements of the Control of Pollution Act 1974 and covered the disposal of asbestos, boiler cleanings, oil sludges, bitumens and waxes, ion exchange resin, spent clay, pyrophoric material and contaminated debris. Additional sites for the disposal of asbestos were introduced in 1984 (Site 7) and 1988 (Current site). The URS Tip Strategy 2006¹ outlines the boundaries of these areas.

Around 1984, the sludge pits extending eastwards from the remaining sludge pit were refilled and consolidated.

In 1985, BP Oil Llandarcy was rationalised from a main fuels refinery to a lube oil and special product refinery. In the short term there was an increase in waste disposal due to demolition works, following this refinery operations significantly reduced resulting in a reduction in waste disposal. Waste disposal in Site 1 (non-notifiable wastes) ceased in 1985. Site 2 was then used for the disposal of substantially oil free general waste.

In 1990, BP Oil Llandarcy handed management of the bog over to the Countryside Council for Wales (CCW) who developed it as a Nature Reserve.

In 1993, the Crymlyn Bog was designated as a National Nature Reserve and it is also designated as a RAMSAR site (wetland of international importance).

Modifications were made to the licence by Neath Borough Council on 25th March 1994 to include new legislation relating to classification of special waste. The modified licence was issued as a new consolidated version under reference number NBWD 5. The waste disposal licence was converted to a waste Management Licence under the Waste Management Licensing Regulations 1994.

In 1998, the Environment Agency issued a notice of modification to the licence, Appendix 1 of this licence replaced the modifications prepared by Neath Borough Council in 1994. The licence made provision for an aggregate of 1,500 tonnes for industrial waste, plastic, timber, paper, ion exchange resins and scrap metal, a total of 100 tonnes of asbestos and asbestos product was also included. Waste from powder sludges and liquid waste was prohibited. A landform survey and recording of inspections and maintenance of the plywood interceptor system around the perimeter of the Tip was also required under the new licence¹.

Use of Site 2 for the disposal of substantially oil free general waste was discontinued in November 1999, no waste has been disposed of since 1999, with the site declared non-operational in 2001. The aerial photograph from circa 1999 coincides with the cessation of waste deposition at the Tip. The Tip is well vegetated with grass and scrub vegetation throughout, and dense patches of woodland in the north, east and west. A series of material windrows are located directly to the west of the road which passes through the centre of the permit area aligned north to south. To the east of the road there appears to be a large stockpile of loosely tipped material. Two lagoons are present in the east of the Tip which are understood to correspond with the reported locations of sludge pits.

Figure 2: 1999 Aerial Photograph



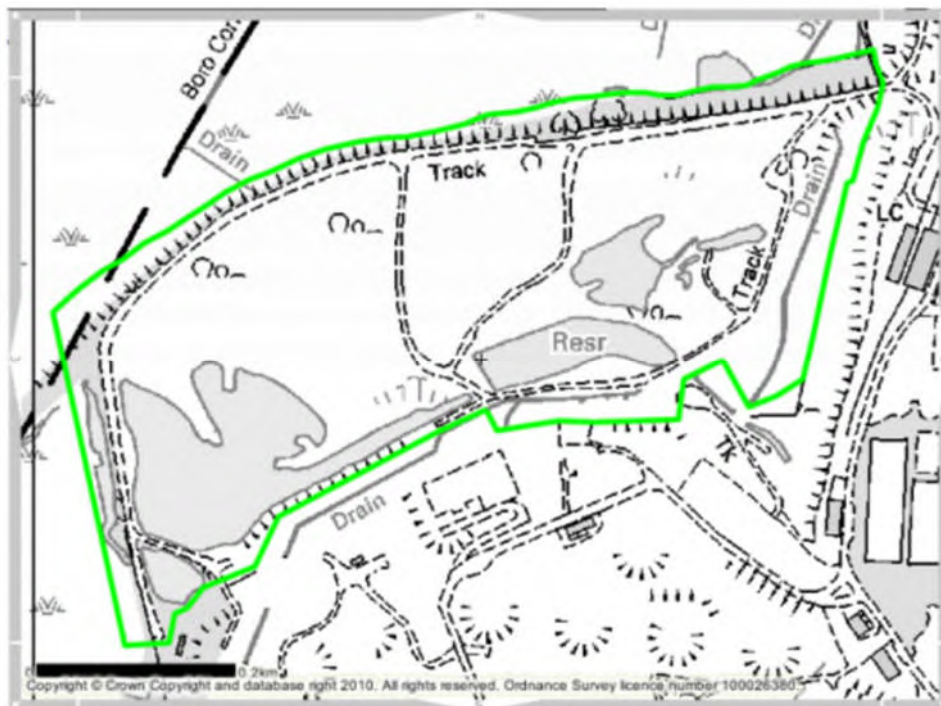
On 4th of June 2001, the Environment Agency wrote to BP Llandarcy Refinery Ltd (BPLR) informing them that a condition plan must be completed or alternatively that the site must cease to accept waste before 16 July 2001. BPLR's response confirmed that the site had not accepted waste since 1999 and it was BPLR's intention to close the site. Accordingly, the Tip was then classed by the Environment Agency as a closed or closing landfill site¹.

2.2.3 Licence History Post-Closure

St. Modwen took over the Crymlyn Tip Waste Management Licence EAWML 34003 (formerly Waste Disposal Licence NBWD5) in 2008. This was updated to a new and consolidated Environmental Permit reference EPR/AP3990LR in December 2010. The permitted area at that time covered 120,784 m² of land

and was defined by the red line boundary shown in Schedule 7 of the permit, (Figure 3 - using Schedule 7 of original permit).

Figure 3: Site Plan (from Schedule 7 of Original Permit)



The current operations, regulated by NRW, that are allowable at the Tip, following the 2010 variation, are detailed within the permit's Table S1.1, which is re-produced within Table 3.

Table 3 - S1.1 Activities - Closed In-house Landfill

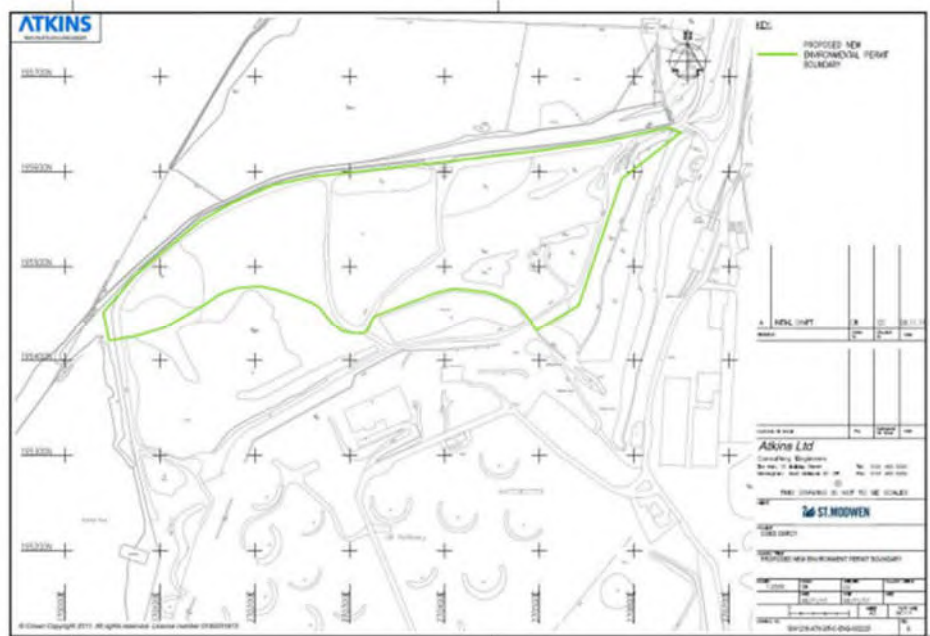
	Description of activities for waste operations	Limits of activities
A07 - In-house landfill (closed)	R03 - Recycling/reclamation of organic substances which are not used as solvents (including composting and other biological transformation processes) R05 - Recycling/reclamation of other inorganic materials	No waste is to be accepted for disposal at the site. Treatment operations shall be limited to the use of waste for the purpose of restoration. Waste used for restoration shall be limited to inert waste as agreed in writing with NRW.

In May 2012, a SCR was prepared for St. Modwen by Atkins Ltd for partial surrender of the Permit and in September 2017, an application was made, with a final SCR, to surrender approximately one third of the permitted area known as the 'Coed Darcy Wetlands', covering approximately 49,000 m² and largely comprising the lagoons and bays described in the previous section, and associated access tracks.

The wetland area was never used for waste disposal and historically formed part of the site wide drainage system with a direct outflow into the Crymlyn Bog to the west and north of the site.

As a result of this partial surrender, the permit boundaries were re-drawn and agreed with NRW. This was confirmed by the part surrender notice of 15th November 2017, which provided the new permit boundaries in an updated Schedule 7 (as shown in Figure 4 below and Drawing D1870/23/5289/02 in Appendix A).

Figure 4: Site Plan (from Schedule 7 of Updated Permit)



Section 3 of this report contains details of Improvement Programme assessments and reports completed to date under the Permit, and Section 4 contains details of remedial actions since closure of the landfill.

2.3 Ground Conditions

Various phases of ground investigation have been undertaken on site and recently Englobe Regeneration UK Ltd (Englobe) have undertaken some additional investigation works, including installation of further boreholes and wells and groundwater monitoring.

Mapping published by the British Geological Survey (BGS) shows the site to be underlain by solid strata of the Pennant Sandstone Formation of Carboniferous Age. The bedrock is overlain by glacial deposits that include clay till and granular fluvioglacial strata, which are generally represented by gravels in the area of the northern tip boundary. The glacial strata are overlain by the bog sediments that generally comprise soft clays overlain by peat.

Figure K1a shows an extract from the published geological map of the areas surrounding the site and Figure K1b shows a detail for the site area. Although mapped across most of the lower site area, intrusive investigation has indicated that peat is locally absent from some parts of the site area.

Made Ground, comprising tipped material from the refinery operations and some excavated peat, appears to have been placed straight over the original ground profile, with no attempt to remove the existing peat, soft clays, or vegetation.

Although no pre-construction topographic information is available, it is assumed that the ground surface under the main tip area that lies over the bog was relatively flat prior to construction of the tip,

which would be consistent with the remaining un-tipped bog areas to the west and north of the tip. Intrusive investigation has shown that the ash bund material extends to a depth significantly lower than the level of the bog surface. There is no reason to consider that bog sediments were removed prior to placement of the ash bund so that it is inferred that the deeper ash bund material is the result of some combination of settlement due to compression primarily of the bog sequence deposits and lateral displacement of the bog sediments. Analysis of the apparent magnitude of settlement in relation to peat compressibility suggests that compression rather than displacement could be responsible for the majority of the settlement.

2.4 Groundwater Conditions

Based on the site's topographic setting, the direction of near surface groundwater flow below the site could be expected to be to the west in the eastern site area and to the north in the south. Within the central northern site area, the predominant flow direction would be expected to be to the north west, becoming more westerly in the western area, with discharge into the adjoining bog area and eventual discharge to a series of streams and drainage ditches within the bog, including the Tennant Canal. Previous experience from studies for sites adjoining other areas of the Crymlyn Bog have suggested that the canal water level is generally in continuity with the groundwater and that groundwater usually discharges to the canal.

Data on groundwater levels within the site area are available from monitoring undertaken during two main periods; firstly from 1998 to 2003 and reported by URS and more recently from 2020 to 2022 and reported by PJA.

Figures K2 shows a snapshot of typical inferred contours of groundwater level based on the monitoring data.

The available data show reasonably consistent conditions. Where sufficient data are available, they show relatively high groundwater levels in the east with a generally westerly flow direction. This becomes more northerly in the central site area and then more westerly in the extreme west. This is generally consistent with the anticipated directions of near surface groundwater flow that would be inferred from the site's topographic location.

Superimposed on this general pattern are local groundwater highs within the north central site area that are thought most likely to be related to the heterogeneity of the wastes in this area but could also potentially be partly due to changes in character of the bog sequence strata underlying the relevant areas. The local high levels imply that locally the vertical conductivity of the wastes is so low that infiltration is being restricted from migrating vertically downwards through the unsaturated zone. This could be due to locally higher clay content in the wastes or LNAPL presence reducing the effective hydraulic conductivity. There are also occasional areas of locally apparent low groundwater level. Some of the local highs and lows on some monitoring visits could be the result of product recovery activities that may have been ongoing at the time.

For some monitoring well locations shallow and deep response zones were installed. Levels in the two are generally similar. Near the bog, deeper data generally show slightly higher levels than shallow whereas within the tip area the reverse is the case. This general pattern could be explained by an upward flow within the deeper bedrock and glacial strata as groundwater discharges to the bog and a downward flow within the tip area, where recharge is occurring. It also suggests that, although the deeper and shallow groundwater levels are similar, the bog sediment clays are acting as at least a partial aquiclude.

2.5 Conceptual Model

Figure K3 shows the initial conceptual model of ground conditions. It is evident from the ground model that the stability of the bund is likely to be dominated by the geotechnical properties of the ash bund and the bog sediments, the underlying natural superficial material and bedrock being relatively much more competent than the bog sediments.



3 Modelling Software

Numerical modelling undertaken as part of the present study has made use of the SLOPE/W program developed by Geo-Slope International Ltd. This was chosen as it allows rapid parametric studies to be undertaken and the implications of various assumptions to be graphically displayed. The program is based on the well-established limit-equilibrium method for slope stability analysis. The 'Morgenstern-Price' method of analysis was adopted. This method, which considers both force and moment equilibrium, is considered to be the most rigorous of the commonly used method of analysis. Because both force and moment equilibrium are considered, the computed factor of safety is not sensitive to the assumed centre of rotation, obviating the need for consideration of grid of assumed centres.

4

4 Previous Stability Assessments

URS Corporation Ltd (2008) undertook a geotechnical investigation of the tip area. This included a number of geotechnical boreholes put down on or near the northern slope area that included in-situ testing and subsequent laboratory testing of samples recovered. However, testing of the ash bund material was very limited due to hydrocarbon contamination. Selected summary plots from the URS Report are included in Addendum K2 for ease of reference. The report did not include detailed stability assessments but made the following generalised recommendations:

Based upon standard earthwork practice, it is proposed that the final finished landform should not have slopes in excess of the angles given below.

Granular - Well-Graded Class 1A	32°
Granular - Uniformly-Graded Class 1B	30°
Cohesive (Class 2)	24°

The final slope angles of the proposed landform shall be confirmed by slope stability analysis.

It would seem that these recommendations were intended to relate to local slopes formed in the made ground as they are very high for full height permanent slopes.

Subsequently Atkins (2013) included an assessment of the stability of the proposed landform in their Construction Quality Assurance Plan. This included some geotechnical testing, including shear box testing, of samples recovered from trial pits. Their work included slope stability analysis and concluded that restoration slopes at or flatter than 3H:1V would have an acceptable factor of safety. However, potential deep failure modes into the bog sediments were not considered.



5 Geotechnical Parameters

5.1 General

Data relating to shear strength, density and compressibility of the site soils are available from the following:

In-situ Testing	URS 2008 Study and Recent Englobe Investigation
Laboratory Testing	URS 2008, Atkins (2013) and Recent Englobe Investigation
Back Analysis of Existing Conditions	Present Report

5.2 In-Situ Testing

Figure K4a shows a plot of SPT values vs depth from the URS and Englobe investigations for data near the northern site boundary. The same data are shown at a somewhat greater scale for the Englobe and URS data, respectively in Figures K4b and K4c. These show the ash bund material to be generally in a very loose state. The recent data show somewhat higher values, possibly because tests undertaken below the groundwater level were delayed until water conditions had come into equilibrium.

5.3 Laboratory Testing

5.3.1 Ash Bund Material

The recent Englobe investigation allowed geotechnical testing of samples from the ash bund, which had not been possible during the URS study due to contamination levels. Figure K5 shows the results of grading tests on this material, which fall within a surprisingly narrow range. The material is predominantly sand and gravel sized with fines content ranging from 2 to 16 %.

Shear box testing was undertaken on two samples, one a combined sample. Figure K6 shows the results of this testing in which Peak Shear Stress is plotted against vertical stress. Use of residual strength parameters is not appropriate for consideration of first-time failures and generally granular materials do not show high brittleness under drained loading conditions. Also shown on this plot are the results of the Atkins testing on waste material ('Batch 1', 'Batch 2' and 'Waste'). The lower bounds from the two datasets are as follows:

Table 1 Lower Bound Strength Parameters for Ash Bund and Waste

Material	Drained Angle of Internal Friction (ϕ') (degrees)	Drained Apparent Cohesion Intercept (c') (kPa)
Ash Bund	32	9.5
Waste	34	10.2

The second ash bund sample showed a very high apparent friction angle (47 degrees) and cohesion intercept (59 kPa). In the recent testing the samples were prepared in a loose state. The apparent relatively high cohesion intercept suggests that even in a loose state the material is somewhat dilatant when sheared. This is most likely due to the angular nature of the gravel, which includes ash, clinker and slag.

It is not possible to directly measure the in-situ bulk density of granular materials. Maximum dry densities were determined in the range 1.53 to 1.78, average 1.65 Mg/m³, suggesting that bulk densities of the material in a very loose state is likely relatively low.

5.3.2 Bog Sediments

Geotechnical test results for the bog sediments from the URS study are summarised in Addendum K2.

Index test data from the recent Englobe investigation are summarised in Figure K7. Peat samples show high moisture contents, typically in the range 250 to 450 %. The bog clays have moisture contents typically in the range 15 to 150 %. Plasticity index is relatively low, generally less than 15 % with an upper limit of about 30 %. Liquidity Indices are very variable, probably reflecting the effect on organic content on the applicability of the test method for this type of material, but generally high, averaging about 0.5, suggesting that the material would be generally contractive in shear.

Below the ash bund, the material typically comprises layers of firm fibrous peat and soft or very soft organic clay. Although sometimes interbedded, generally the peat overlies the clay units.

No effective stress testing was undertaken on the bog sediments during previous studies but two consolidated undrained triaxial tests with pore pressure measurement on clay were undertaken during the recent Englobe study on samples re-compacted at natural moisture content. As such they may be taken to give an indication of failure criteria at critical state conditions. Figure K7 summarises failure conditions. Assuming zero effective cohesion intercept, values of M (q'/p' at failure) are 1.18 and 1.47, corresponding to effective friction angles of friction of 29.5 and 36.2 degrees. These are relatively high for clay and likely reflect the organic inclusions.

There are problems with the effective stress testing of peat due to high compressibility but peat generally exhibits very high effective angles of friction (typically > 40 degrees) but low undrained shear strength such that undrained failure is generally the critical mode of failure in field conditions.

Bulk densities of the peat are low, typically less than 1.1 Mg/ m³. Based on natural moisture content the bulk density of the bog clays would be expected to be in the range 13 to 21 kN/ m³.

5.4 Back Analysis of Existing Conditions

The existing north slope of the tip is relatively steep and has remained stable for a considerable period of time. As no significant failure has occurred, it is not possible to directly estimate actual mobilised strength conditions from back analysis. Rather back analysis can provide an estimate of the average lower bound strength by parametrically determining the minimum strength necessary to provide a low factor of safety. Generally, for slopes with a factor of safety less than about 1.1, some indication of potential failure, such as crest tension cracks or toe bulging. No such features are evident in the accessible areas of the existing embankment but heavy vegetation obscures much of the toe area. No significant slope failures in the past have been reported.

From the conceptual ground model, two main potential failure modes would need to be considered in an assessment of the stability of the existing condition: firstly a relatively shallow failure within the Ash Bund and secondly a deeper failure extending into the foundation bog sediments.

The procedure adopted was to undertake a series of analyses considering each mode for Sections EE and FF, refer to Addendum K1, as these are representative of the highest and steepest sections of the existing embankment where soft clay and peat are present in the foundation soils. Figures K9 and K10 show typical critical failure surfaces for this condition.

Figure K11 and K12 summarise the results of this analysis for Sections EE and FF, respectively, for shallow failures in the bund, the computed factor of safety is plotted against assumed effective cohesion intercept for various values of effective friction angle.

Figure K13 summarises the results for deep failures in which factor of safety is plotted against assumed average undrained shear strength of the bog sediments. For this plot it is necessary to assume strength parameters for the ash bund material but for this mode of failure the results are not particularly sensitive to the assumed strength parameters for the ash bund.

Based on this work the following lower bound strength parameters are consistent with the existing slope conditions:

Table 2 Derived Lower Bound Strength Parameters

Material	Average Lower Bound Strength Parameters		
	Effective Friction Angle - ϕ' (degrees)	Effective Cohesion Intercept - c' (kPa)	Undrained Shear Strength - C_u (kPa)
Ash Bund Fill	38	2.5	-
	36	3.0	-
	34	3.5	-
	32	4.0	-
Bog Sediments	-	-	15

In reality the bog sediments are likely stronger below the ash bund than in the main bog area and the above estimate is essentially an inferred minimum average value along potential failure planes.

6

6 Stability Analysis of Proposed Restoration Slopes

6.1 Design Assumptions

Based on the previous section's considerations, the following table summarises proposed design assumptions:

Table 3 Design Strength Parameters

Material	Proposed Design Values		
	Reasonable Design Assumption	Worst Credible Lower Bound Assumption	Bulk Density
Ash Bund Fill	$\phi' = 32$ degrees, $c' = 9$ kPa	$\phi' = 32$ degrees, $c' = 4$ kPa	17 kN/ m ³
Bog Sediments	$C_u = 20$	$C_u = 15$	12 kN/ m ³

Computed factors of safety are not highly sensitive to assumed value of bulk density and reasonable values based on material classification have been adopted.

A factor of safety in excess of 1.1 is considered reasonable where 'worst credible' conditions have been assumed and 1.4 in relation to reasonable design assumptions.

It is intended to introduce a cement-bentonite slurry wall within the restored slope. As this is not expected to penetrate to the base of the bog sediments it would have little impact on computed factors of safety for deep potential failures through the bog sediments. The anticipated lower bound shear strength of the set slurry would, in any case, exceed the shear strength of the surrounding soils.

6.2 Analysis of Proposed Post-Reclamation Slope Profiles

The overall slope angle of the existing bund slopes are typically in the range 3H:1V to 2H:1V and they have remained stable for a considerable period of time. The existing factor of safety is clearly above unity and likely not less than about 1.1 but is not known with certainty. Generally, the slope profiles comprise a relatively flat lower section, typically at about 4H:1V and steep upper section. The proposed restoration profile comprises generally making the ash bund profile no steeper than 4H:1V with levels then typically grading off to the south at significantly lower gradients - i.e., 10H:1V or flatter. As the proposed restoration profile will require cutting back of the upper portion of the slope to achieve an overall slope angle of about 4H:1V, it follows that a significant improvement in the overall factor of safety and in the factor of safety of the steeper upper slope portion would be anticipated and this has been confirmed by analysis of the proposed profiles. Figures K14 and K15 show the derived critical failure conditions for Sections EE and FF, respectively. Computed factors of safety are as follows:

Table 4 Post-Reclamation Factors of Safety

Location	Factor of Safety	
	Reasonable Design Assumption	Worst Credible Lower Bound Assumption
Section EE	1.66	1.31
Section FF	1.64	1.35

These margins of safety are considered acceptable for the permanent condition.

It is assumed that the finished surface of the tip will be vegetated with grasses and other low-lying vegetation. It is assumed that the landscaping will be maintained in the future and that there will be no significant deterioration of the restoration layer across the tip. For the proposed slope angles it is considered that vegetation would be sufficient to prevent erosion due to storm run-off but a system of surface drains would be included in the final design to accommodate surface water flows during severe storm events.

6.3 Cover Veneer Stability

As no impermeable cap is being proposed, the cover soils will be unsaturated and no separate analysis of the stability of the cover soils is warranted.

6.4 Potential for Liquefaction Flow Sliding

Where loose granular soils exist in soil slopes, in addition to conventional stability analysis, consideration should be given to the potential for flow sliding or liquefaction leading to instability. For flow liquefaction to occur a number of conditions must be met, including:

1. The soils must be loose enough to be entirely contractive in shear. That is the void ratio must be well above the critical state line.
2. The material must be sufficiently impermeable to the pore fluid to allow high excess pore pressures to be maintained at least temporarily. This generally means that the material must either be saturated or potentially become saturated and that coarse grained materials are rarely susceptible to flow sliding.
3. The ratio of shear stress to effective average stress must be sufficiently high.

Given the difficulty in determining the actual in-situ void ratio and critical state conditions of granular materials, various correlations with in-situ test results have been proposed.

In relation to point one above, Figure K16 shows a plot of normalised SPT N value vs depth for tests undertaken below the groundwater table, which has often been used in correlations with liquefaction potential. The boundary between liquefiable and non-liquefiable material is material specific but values of less than about 10 would generally be considered potentially liquefiable, for fine sand, based on most published criteria. However, based on the available laboratory testing and the steepness of slopes that are present in the bund, it would appear that the material is dilatant during shear. That is likely due to the angular nature of the material.

In relation to Point 2, much of the ash bund material is above the water table and there is no obvious mechanism by which it could become saturated. The grading of the material shows it to comprise more than 30 percent gravel size and less than 20 percent fine sand or smaller. It is unlikely therefore that the hydraulic conductivity would be low enough to sustain high excess pore pressures for any significant period of time.

In relation to Point 3, in the absence of some dynamic loading, slopes flatter than about 3.5H:1V are unlikely to exhibit shear stresses sufficient to trigger static liquefaction.

Based on the above discussion, the risk of flow sliding in the ash bund material following restoration at slopes flatter than 4H:1V is considered to be very low.

6.5 Temporary Slopes

Temporary slopes adopted during construction should be such that no increase in gradient of the overall slope occurs, i.e., there should be no increase in slope loading. Subject to that qualification, temporary slopes could be relatively steep, and the indicative values suggested by URS (Section 4 above) should be acceptable.



7 Post Restoration Settlement

Cut and fill regrading of the tip during restoration will be associated with some areas away from the northern slopes where ground levels will rise above pre-existing levels. A plan showing the currently anticipated changes in surface level is included in Addendum K3. This will result in settlement due to compression of the wastes and underlying natural sediments. Much of that settlement will occur during earthworks. The anticipated phases of construction and approximate minimum time frames are as follows:

Cut and fill to form cap subgrade: 2 to 3 months

Vertical Barrier Construction: 3 months

Capping Placement: 2 to 3 months

Given the heterogeneous nature of both the made ground on site and natural underlying materials, it is not feasible to make accurate predictions of absolute magnitude, time frame and distribution of resulting settlements. However, the period during vertical barrier construction will allow some monitoring of actual settlements and rates prior to final capping, which will allow final design of fill levels to compensate for long term settlement.

The most compressible materials present are the natural peat and any peat inclusions with the made ground and to a lesser extent any soft clay units in the made ground and bog sediments. While primary consolidation of the peat would be expected to occur relatively rapidly, secondary compression will be ongoing. Peat materials generally exhibit the highest ratios of secondary to primary consolidation. Primary and secondary consolidation of the clay could continue after completion of the earthworks, but the secondary component would be relatively low compared to peat. Potential post-construction settlement will therefore be dominated by distribution of peat. Figure K17 shows inferred contours of peat thickness based on all boreholes that proved the full thickness of the bog sediments below the tip area. Figure K18 shows inferred contours of the overall thickness of bog sediments (mainly clay and peat). The distribution of these materials is complex and in some areas

neither peat nor bog clay is present. It follows that potential post construction differential settlements will be affected not only by the distribution of cut and fill areas (refer Addendum K3) but also the varying thickness of compressible soils.

There are five areas where ground levels will be raised as a result of the reclamation works, as summarised in Figure K20. The following table summarises conditions in these areas:

Table 5 Conditions in Land Raising Areas

Area	Increase in Ground Level	Peat Thickness	Bog Sediment Thickness	Existing Depth to Top of Bog Sediments
	(m)	(m)	(m)	(m)
1	Up to 6.5	Less than 0.5 in south, Up to 2.0 in north	0 to 3.5	5 to 8
2	Up to 3.5	0 to 0.75	0 to 2.5	10 to 12.5
3	Up to 5.5	0 to 1.0	0 to 1.0	4 to 10
4	Up to 2.5	0 to 1.5	1 to 2	2.5 to 6.5
5	Up to 2.5	0 to 2.0	2.5 to 5.0	5 to 7.5

However, for Area 1 (known as the 'Santander Ditch') ground levels were previously higher than at present by of the order of up to 2.0 m. Reloading to previous levels would not be expected to be associated with any significant compression of the pre-loaded materials but once that level is exceeded significant settlement is likely to occur where soft sediments are present.

Assuming a period of secondary compression of 1 to 100 years, average compressibility values for the peat and clay based on the URS testing, reasonable assumptions concerning the proportion of primary consolidation that will be complete during construction and literature data concerning the typical ratio of secondary to primary consolidation, the following estimates of likely post construction settlement may be derived:

Table 6 Predicted Long Term Settlement

Area	Likely Upper Limit of Post Construction Settlement
	(m)
1	Up to 0.5
2	Up to 0.3
3	Up to 0.2
4	Up to 0.3
5	Up to 0.6

Monitoring of performance between general regrading and cap placement will allow these estimates to be refined.

The principal risk of the settlement is that the planned slopes of the regraded tip would be reversed resulting in ponding of water. The shallowest slope proposed in the five areas of maximum fill/settlement is 20H:1V. In consideration of the maximum settlements in Table 6, it is not considered likely that the slopes planned in the five areas of greatest potential settlement will reverse based on the estimated likely upper limit of post construction settlement. The estimated post construction settlement is therefore not considered to be an issue. The above are estimates of post construction settlement. Some settlement will occur after regrading of the site to base of capping levels. That settlement will then either be negated by further regrading prior to actual placement of capping or in increased capping thickness.



8 Summary Conclusions

The northern slope of the tip area comprises an artificial predominantly granular bund ('ash bund') overlying bog sediments that generally comprise peat over soft clay and which in turn overlie more competent strata. The ash bund materials extend significantly below the surface level of the bog areas to the north and west, primarily due to compression of the soft sediments by bund loading.

Information concerning the geotechnical properties of these materials is available from in-situ and laboratory testing undertaken during various stages of ground investigation. Although loose the ash bund materials exhibit relatively high shear strength, which can be attributed to the angular nature of the materials present. Back analysis of existing slope conditions has allowed estimates to be made of 'worst credible' strength parameters for the existing site soils that are consistent with limit equilibrium.

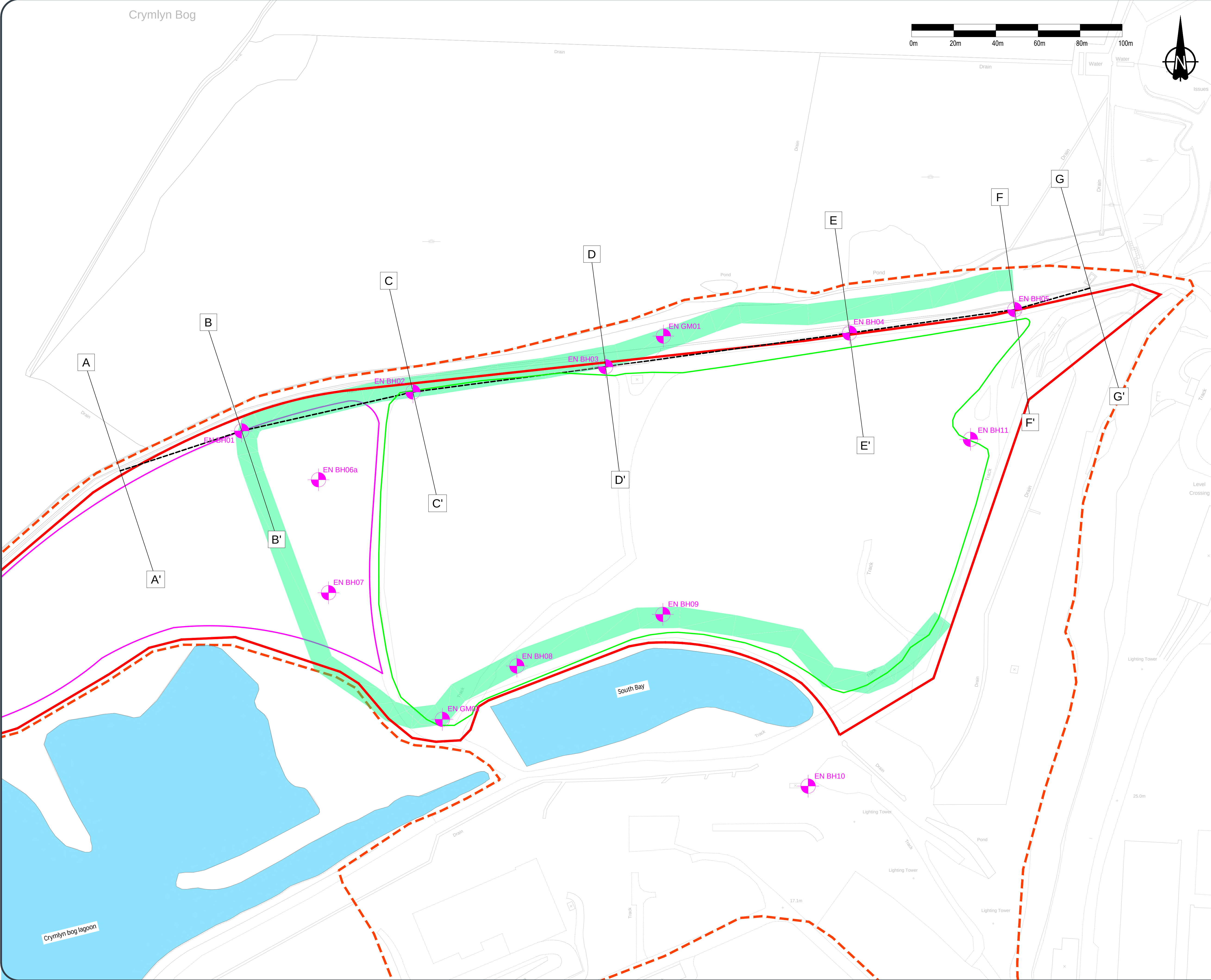
The proposed re-profiling of the tip will result in reduced slope gradients along the northern slope, which will act to increase the existing factor of safety. Even if 'worst credible' soil strength parameters are adopted the proposed final profile will have an acceptable margin of safety.

Long term post-construction settlements of the remainder of the tip area will be non-uniform and controlled by variations in proposed final levels and distribution of soft sediments but are unlikely to exceed about 0.6 m. Monitoring during the construction should allow these estimates to be refined. In consideration of the gradients of the proposed reprofiled tip, the estimated post construction settlement is not considered to be an issue.

Addendum K1



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Legend

- Site Boundary
- NRW Permit Boundary
- Long Section Location Line
- EN BH
Englobe Borehole Location
- Proposed Bentonite Slurry Wall and 10m Wide Platform Location for Construction
- Upper Tip
- Lower Tip

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RG7 4AB
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Columbus House
Greenmeadow Springs
Tongwynlais
Cardiff
CF15 7NE
02920 368636

enquiries@englobecorp.com
www.englobecorp.com

Client

St Modwen Homes

Project

Coed Darcy Tip

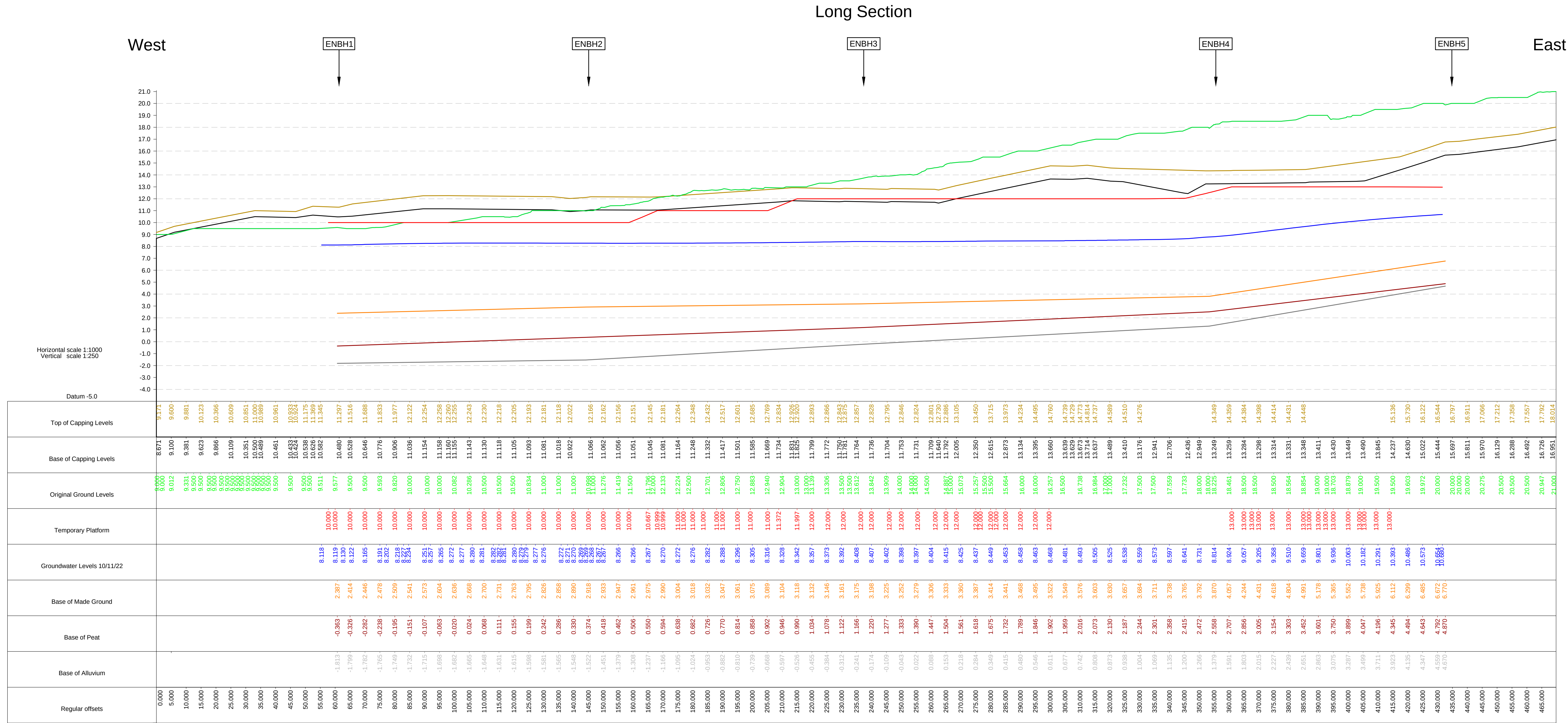
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Cross Section Location Plan

Drawn by JA	Checked AB	Date 13.03.23	Authorised MH	Date 13.03.23
Original Scale NTS	Date 24.02.23	Rev 0	Paper A1	

Drawing Number

D1870/23/5289/09



Legend

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Project Coed Darcy

Title
Long Section Through Ash Bund

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Original Scale N/A	Date 24.02.23	Rev 0	Paper A1

Drawing Number
D1870/23/5289/10

A

A'

Datum 5.0	
Top of Capping Levels	
Base of Capping Levels	
Original Ground Levels	
Temporary Platform	
Groundwater Levels 10/11/22	
Base of Made Ground	
Base of Peat	
Regular offsets	

Chainage 0.0m (270154.5E 195557.7N)

B

B'

Datum -5.0	
Top of Capping Levels	
Base of Capping Levels	
Original Ground Levels	
Temporary Platform	
Groundwater Levels 10/11/22	
Base of Made Ground	
Base of Peat	
Regular offsets	

Chainage 60.725m (270212.2E 195576.7N)

C

C'

Datum -5.0	
Top of Capping Levels	
Base of Capping Levels	
Original Ground Levels	
Temporary Platform	
Groundwater Levels 10/11/22	
Base of Made Ground	
Base of Alluvium	
Regular offsets	

Chainage 144.136m (270293.5E 195595.2N)

D

D'

Datum -3.0	
Top of Capping Levels	
Base of Capping Levels	
Original Ground Levels	
Temporary Platform	
Groundwater Levels 10/11/22	
Base of Made Ground	
Base of Peat	
Base of Alluvium	
Regular offsets	

Chainage 236.428m (270385.1E 195607.2N)



Legend

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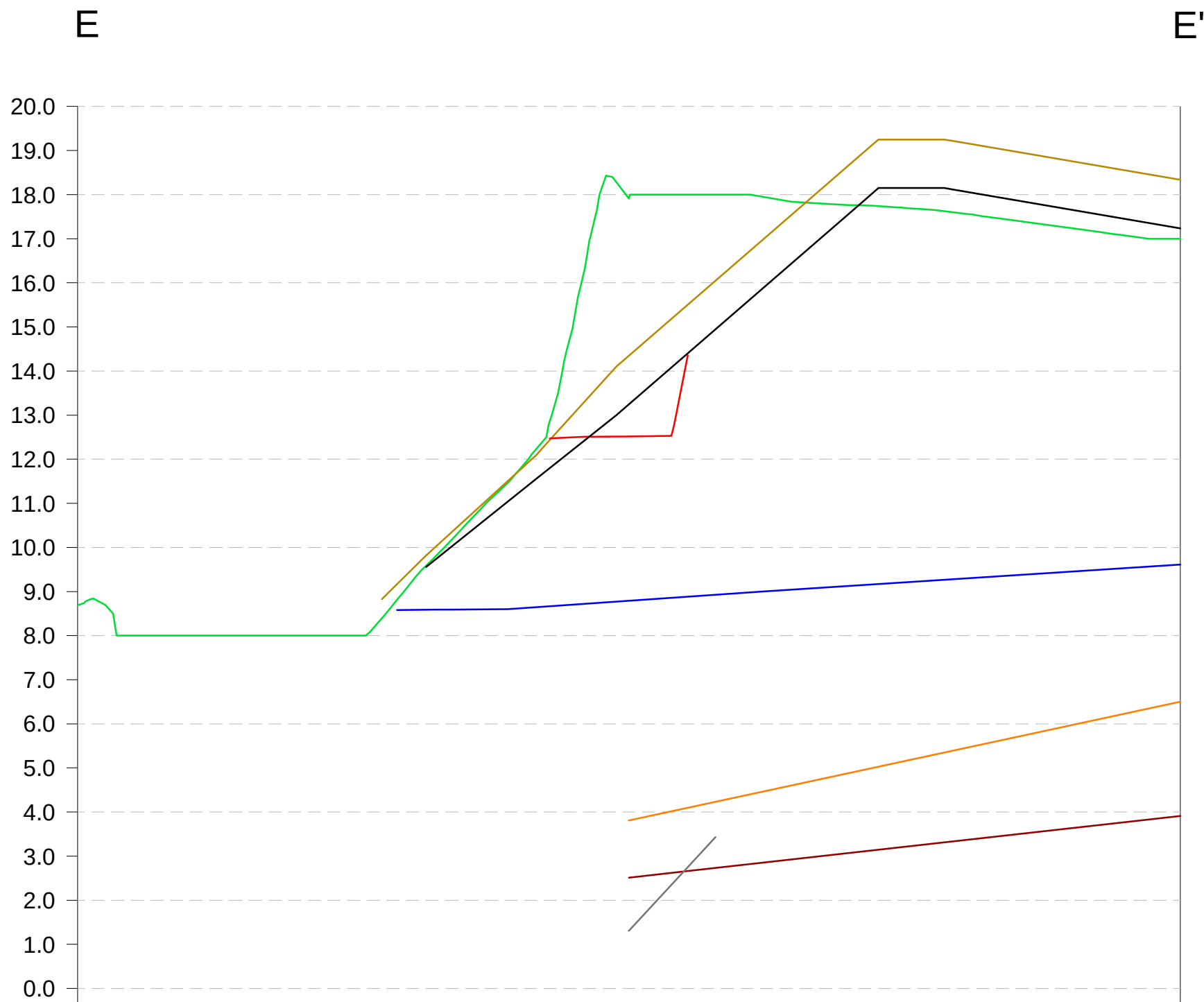
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Title
Cross Sections - Page 1 of 2

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		Paper A1

Drawing Number
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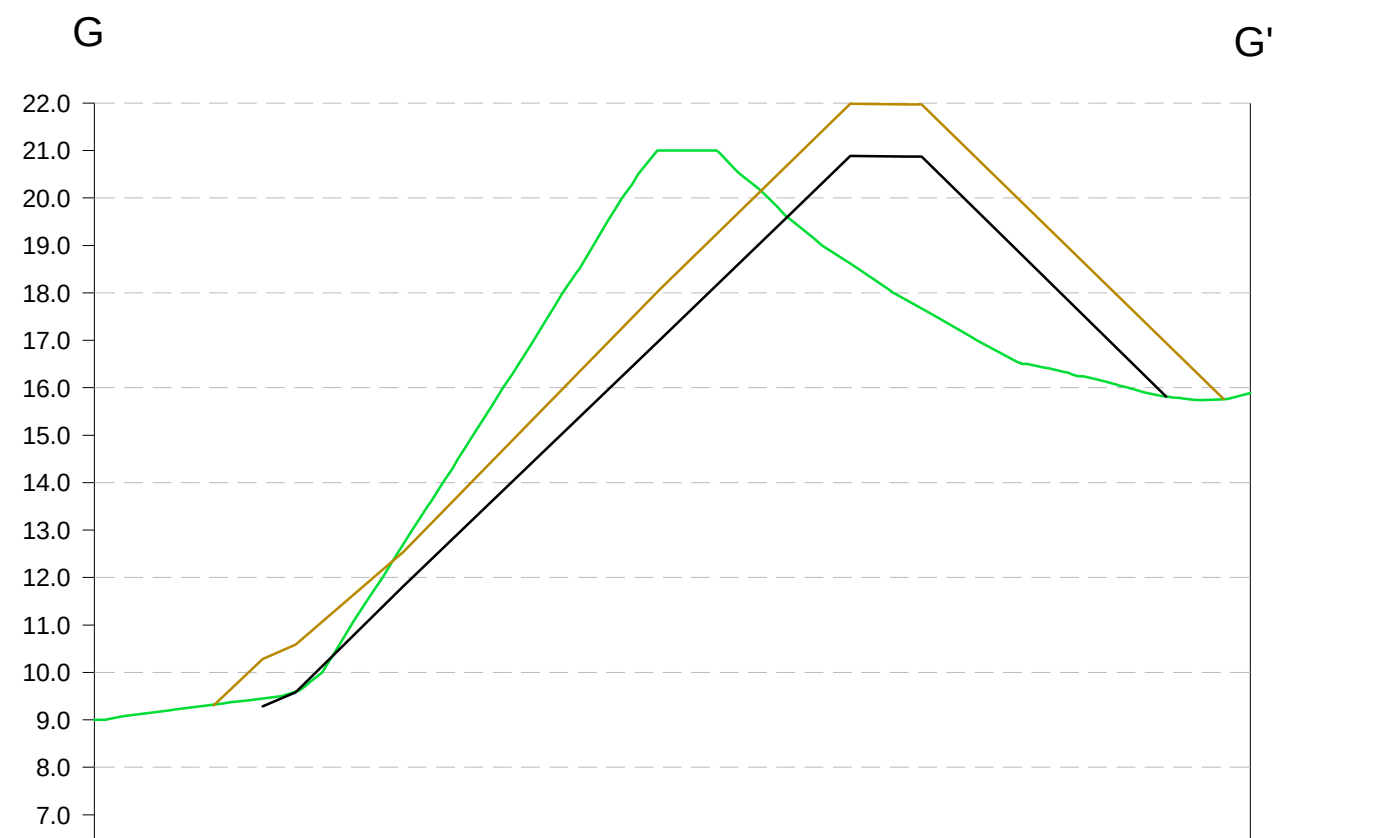
Datum -1.0	
Top of Capping Levels	8 828 9 420 9 820 10 590 11 728 13 032 14 100 15 430 16 513 17 596 18 680 19 250 19 250 18 978 18 763 18 549 18 334
Base of Capping Levels	9 554 10 232 11 235 12 232 13 000 14 330 15 413 16 496 17 580 18 150 18 150 18 150 17 878 17 663 17 449 17 234
Original Ground Levels	8 692 8 700 8 800 8 000 8 000 8 000 8 000 8 000 8 000 10 000 10 500 11 500 12 500 15 000 16 000 18 000 18 000 18 000 18 000 17 837 17 763 17 701 17 580 17 500 17 412 17 244 17 072 17 000 17 000
Temporary Platform	12 469 12 511 12 516 12 527 12 537
Groundwater Levels 10/11/22	8 579 8 592 8 601 8 704 8 790 8 876 8 961 9 044 9 126 9 207 9 288 9 370 9 451 9 532 9 613
Base of Made Ground	3 810 4 079 4 348 4 617 4 886 5 155 5 424 5 693 5 962 6 231 6 500
Base of Peat	2 510 2 650 2 791 2 931 3 071 3 212 3 352 3 492 3 633 3 773 3 913
Base of Alluvium	1 310 2 659 3 431
Regular offsets	-50 000 -45 000 -40 000 -35 000 -30 000 -25 000 -20 000 -15 000 -10 000 -5 000 0 000 5 000 10 000 15 000 20 000 25 000 30 000 35 000 40 000 45 000 50 000

Chainage 353.382m (270500.9E 195623.2N)



Datum 1.0	
Top of Capping Levels	9 390 10 398 11 293 12 318 13 335 14 100 15 571 16 766 17 875 18 983 20 091 20 951 20 929 19 193 17 451 15 723 14 365
Base of Capping Levels	9 398 10 269 11 266 12 256 13 000 14 471 15 666 16 775 17 883 18 991 19 851 19 829 18 083 16 351 14 623 14 365
Original Ground Levels	8 500 8 500 8 500 8 709 9 000 9 000 10 000 10 500 11 000 11 500 12 000 13 000 14 000 15 000 16 000 17 000 18 000 19 000 20 000 20 000 20 000 20 000 19 500 19 000 18 500 18 000 17 500 16 500 16 000 15 500 15 000 14 500 14 000 13 678
Temporary Platform	13 000 13 000 13 999 13 999
Groundwater Levels 10/11/22	10 500 10 506 10 524 10 560 10 628 10 667
Base of Made Ground	6 770 7 001 7 232 7 462 7 693 7 924 8 155 8 386 8 616 8 847 9 078
Regular offsets	-50 000 -45 000 -40 000 -35 000 -30 000 -25 000 -20 000 -15 000 -10 000 -5 000 0 000 5 000 10 000 15 000 20 000 25 000 30 000 35 000 40 000 45 000 50 000

Chainage 432.616m (270579.4E 195634.3N)



Datum 6.0	
Top of Capping Levels	9 305 9 868 10 282 10 686 11 765 12 901 14 179 15 457 16 736 18 014 19 235 20 453
Base of Capping Levels	9 282 9 700 10 932 12 154 13 353 14 553 15 752 16 951 18 158 19 366
Original Ground Levels	9 000 9 076 9 235 9 394 9 500 9 647 10 000 10 000 12 000 14 000 15 500 17 000 18 000 19 000 20 000 21 000 21 000 20 500 20 000 19 000 18 500 17 500 17 000 16 500 16 282 16 000 15 728 15 885
Regular offsets	-45 000 -40 000 -35 000 -30 000 -25 000 -20 000 -15 000 -10 000 -5 000 0 000 5 000 10 000 15 000 20 000 25 000 30 000 35 000 40 000 45 000 50 000

Chainage 469.795m (270615.1E 195644.5N)



Legend

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Title
Cross Sections - Page 2

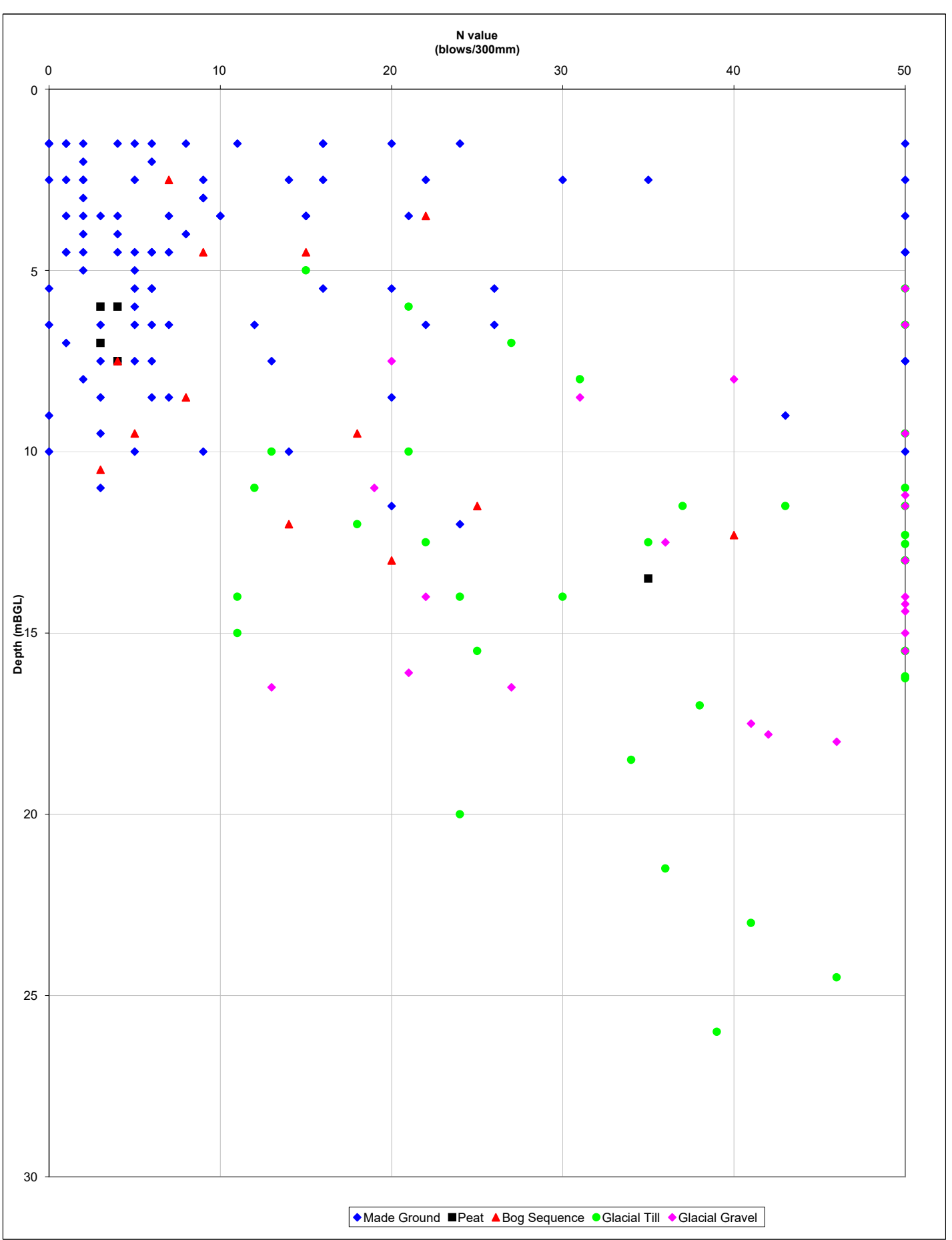
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Addendum K2

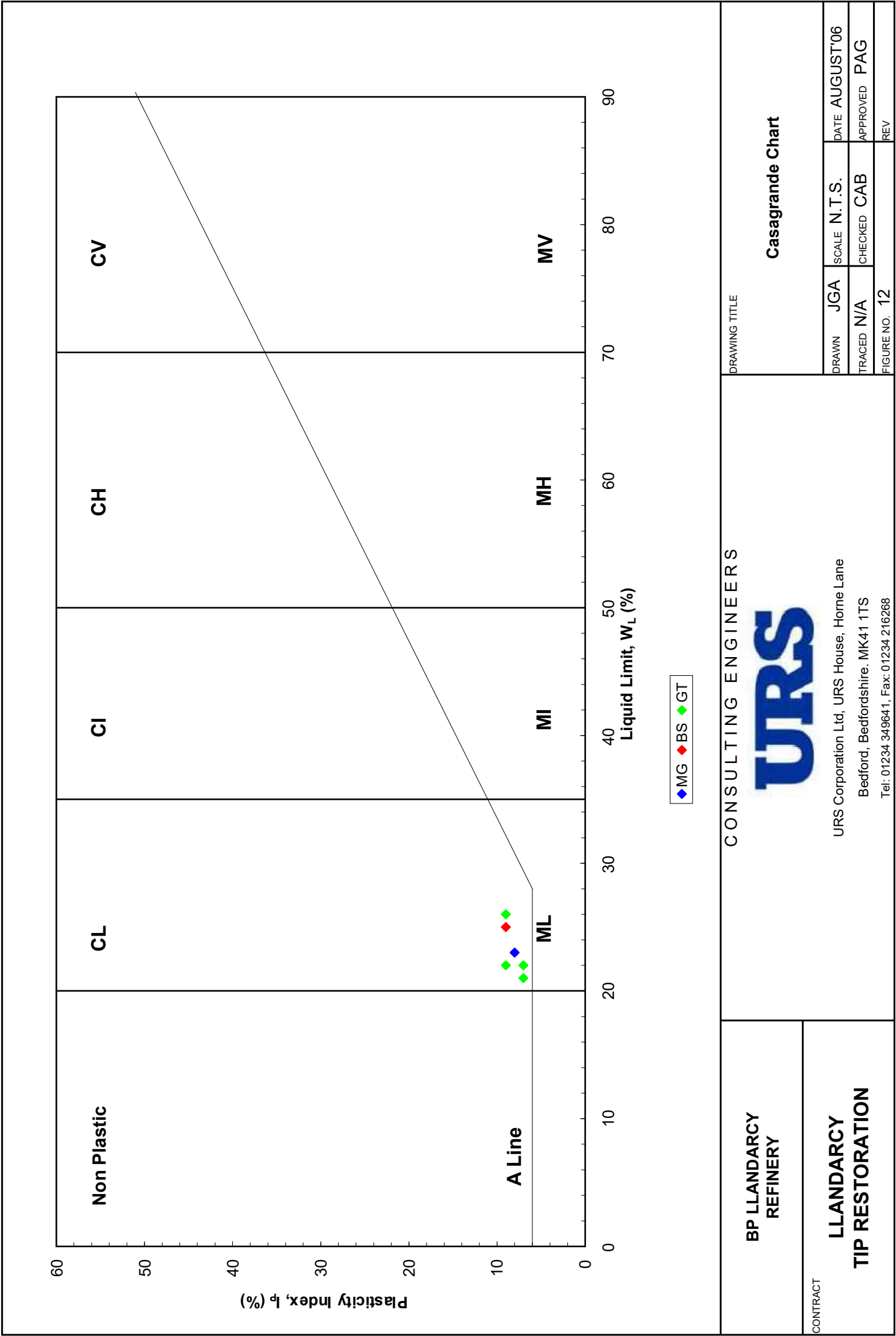


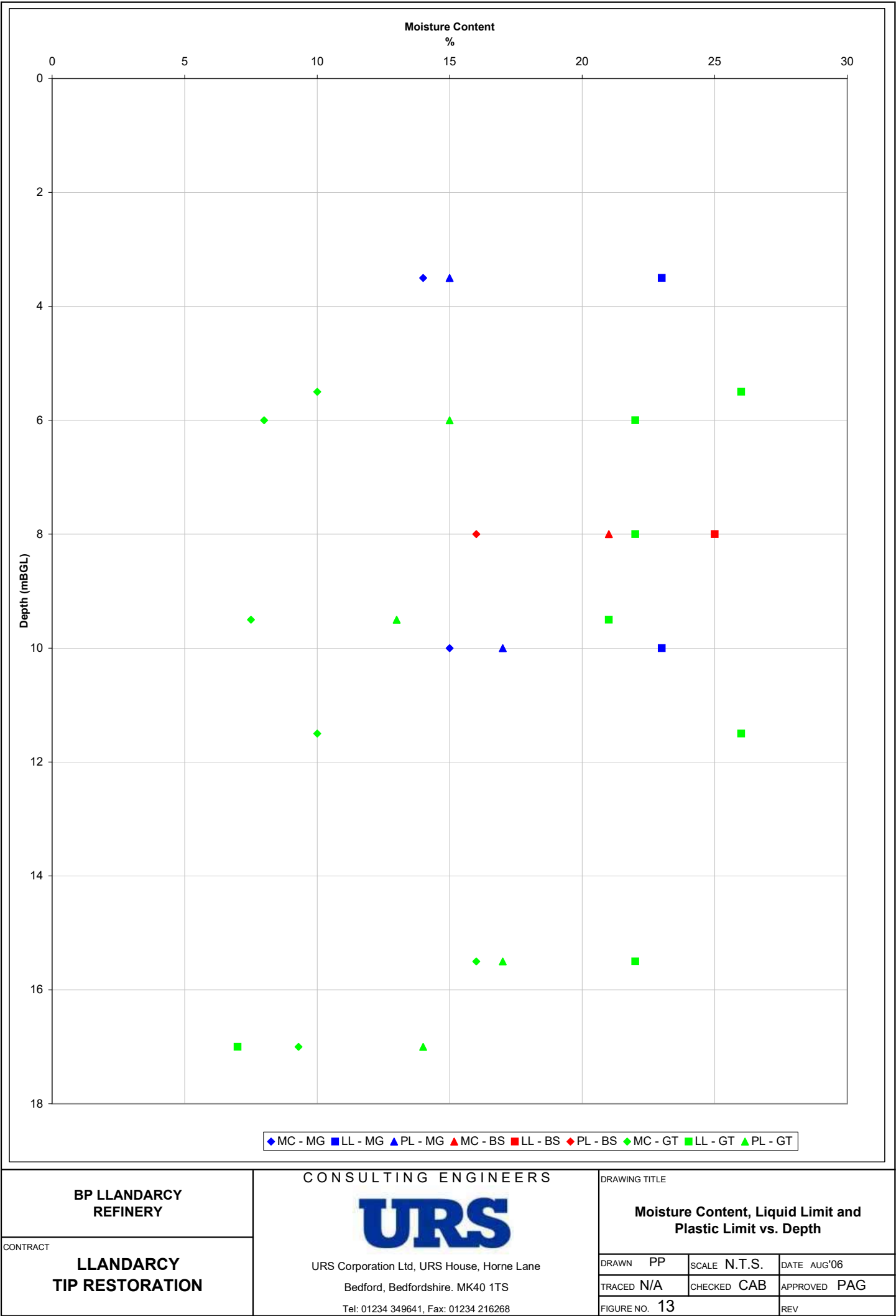
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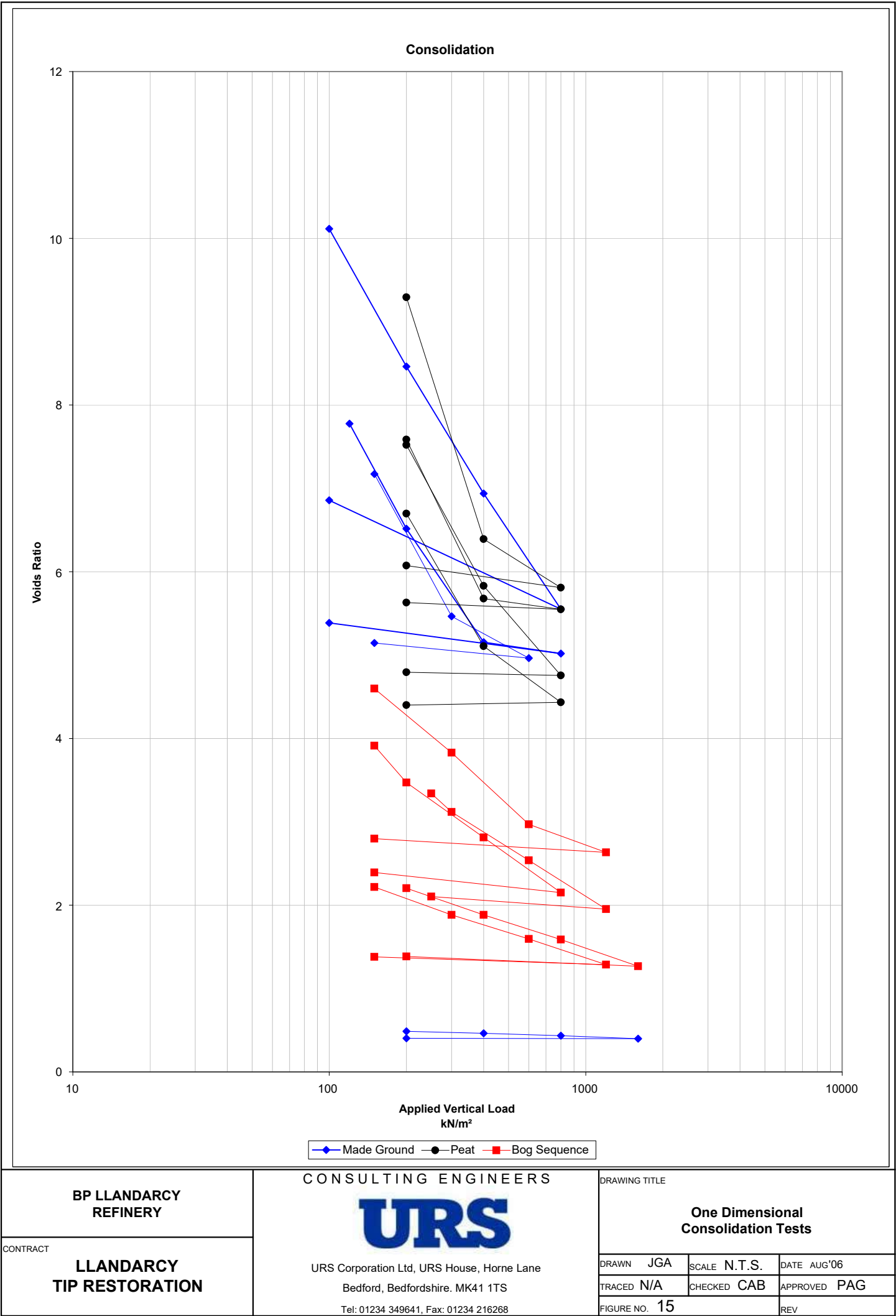


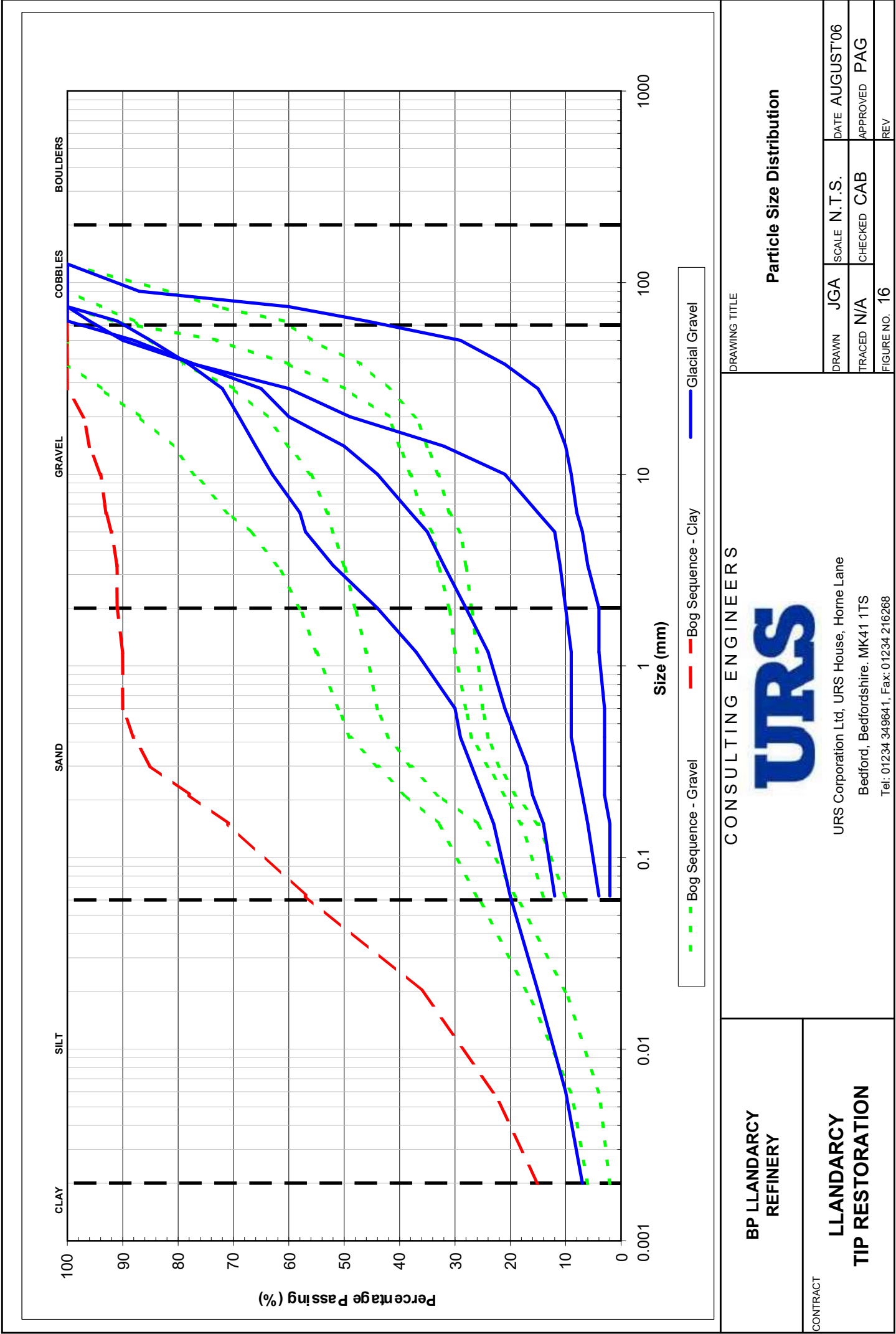
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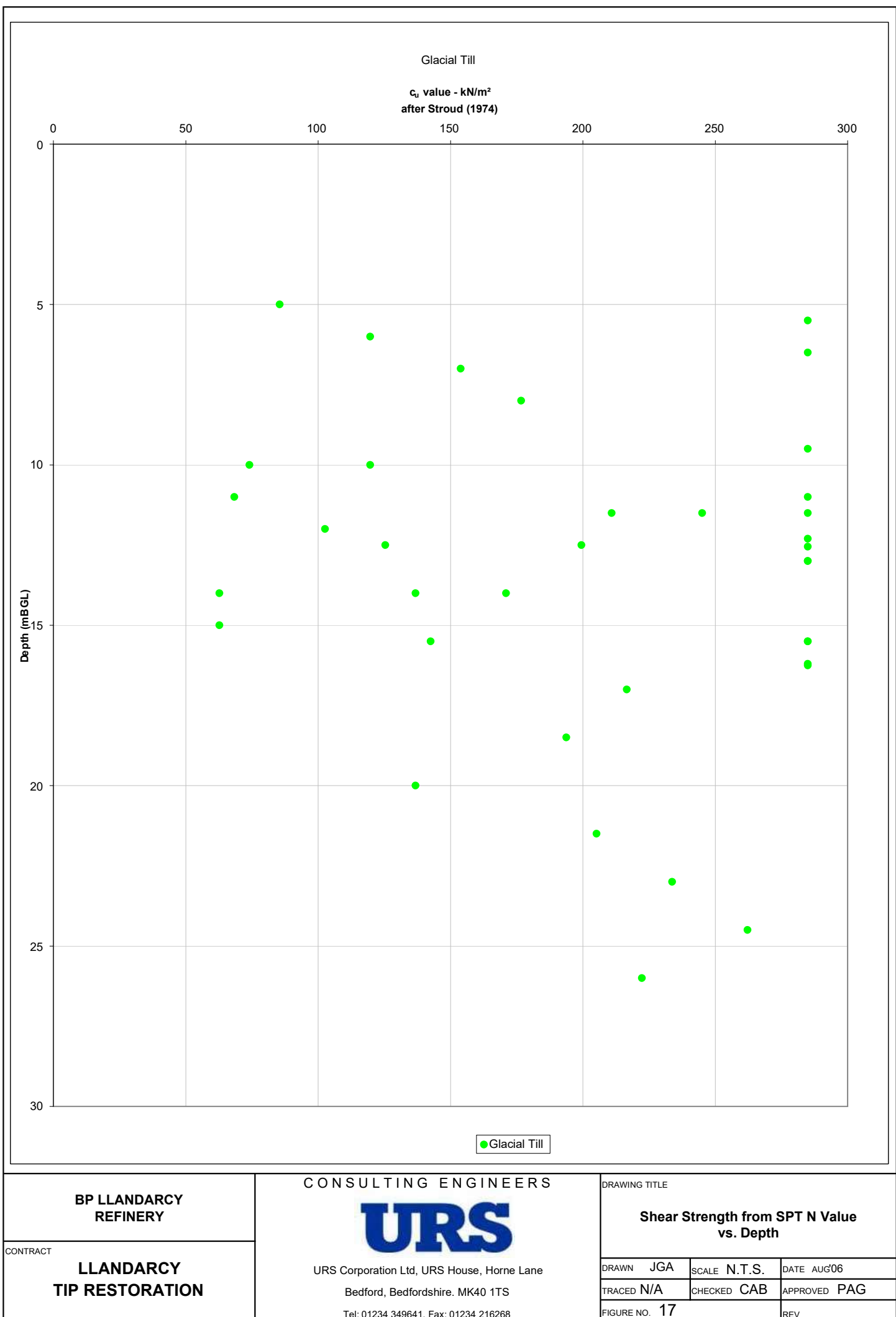
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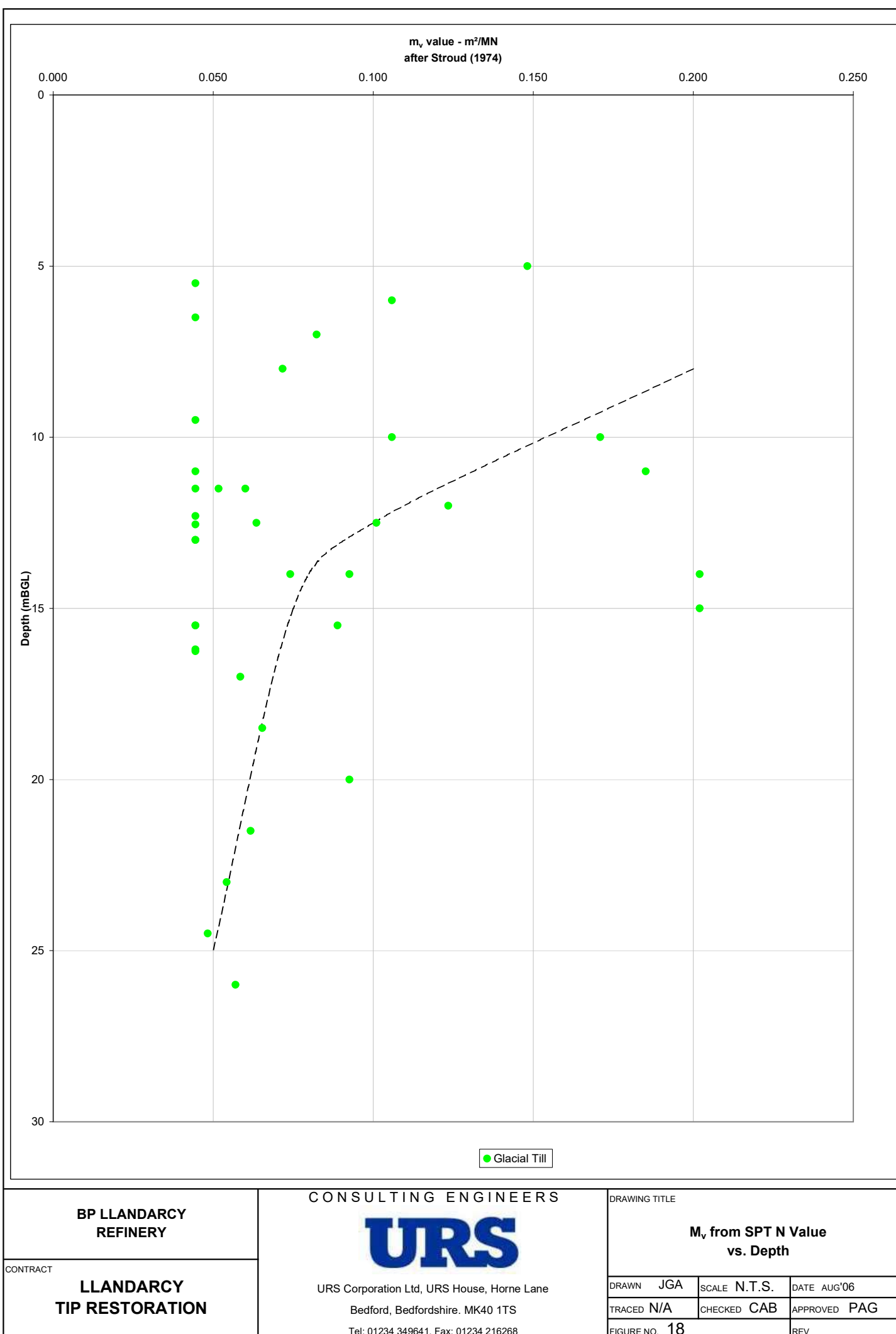










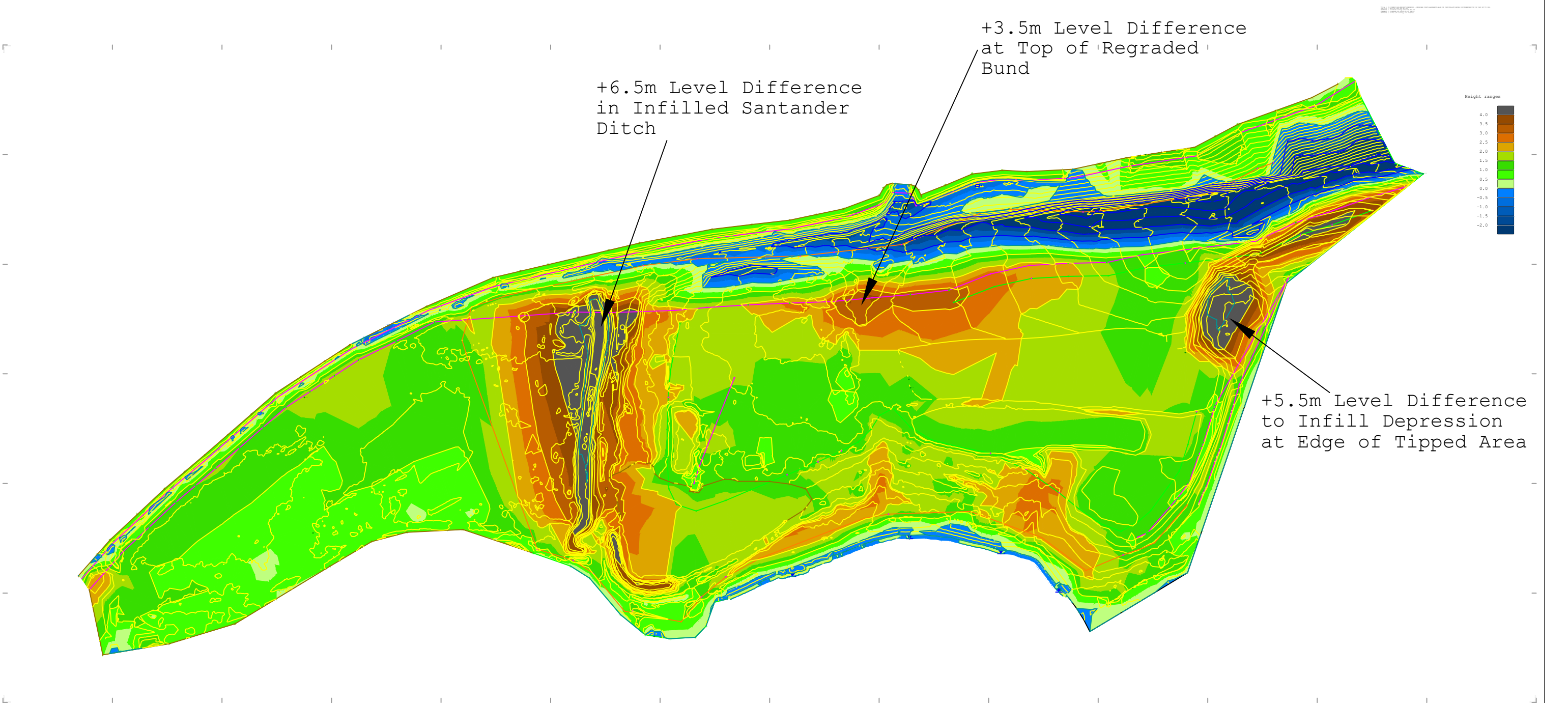


Addendum K3



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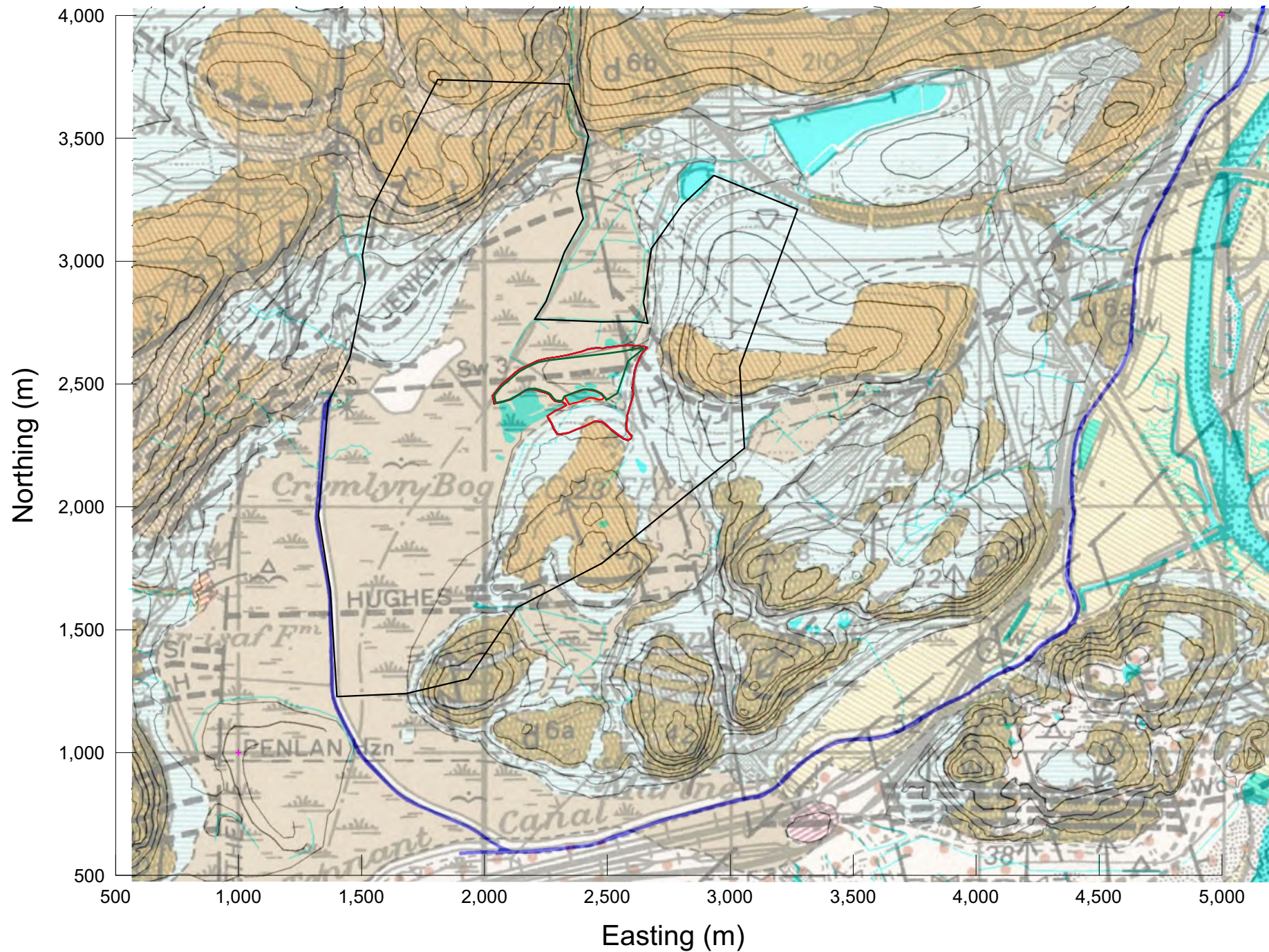
Coed Darcy - Level Differences - Top of Capping R5 Compared
to Original Ground Level 20/02/23



Figures - K1 - K20



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LEGEND

- Assessment Area
- Permit Boundary

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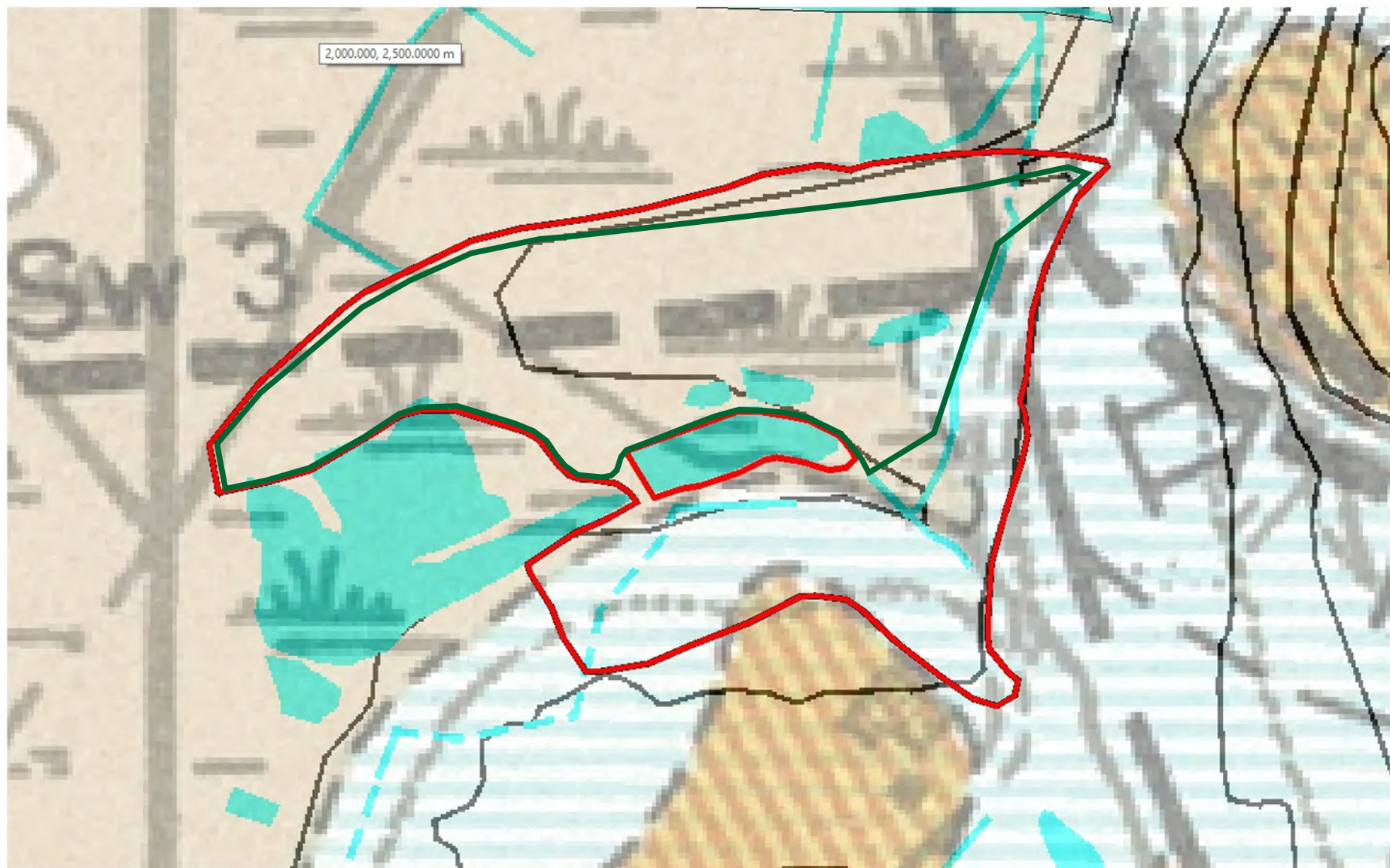
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Original Scale	Date	Rev	Paper
	Feb. 2023	0	A4

Contract Number C1870	Drawing Number K1a
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-  Assessment Area
-  Permit Boundary

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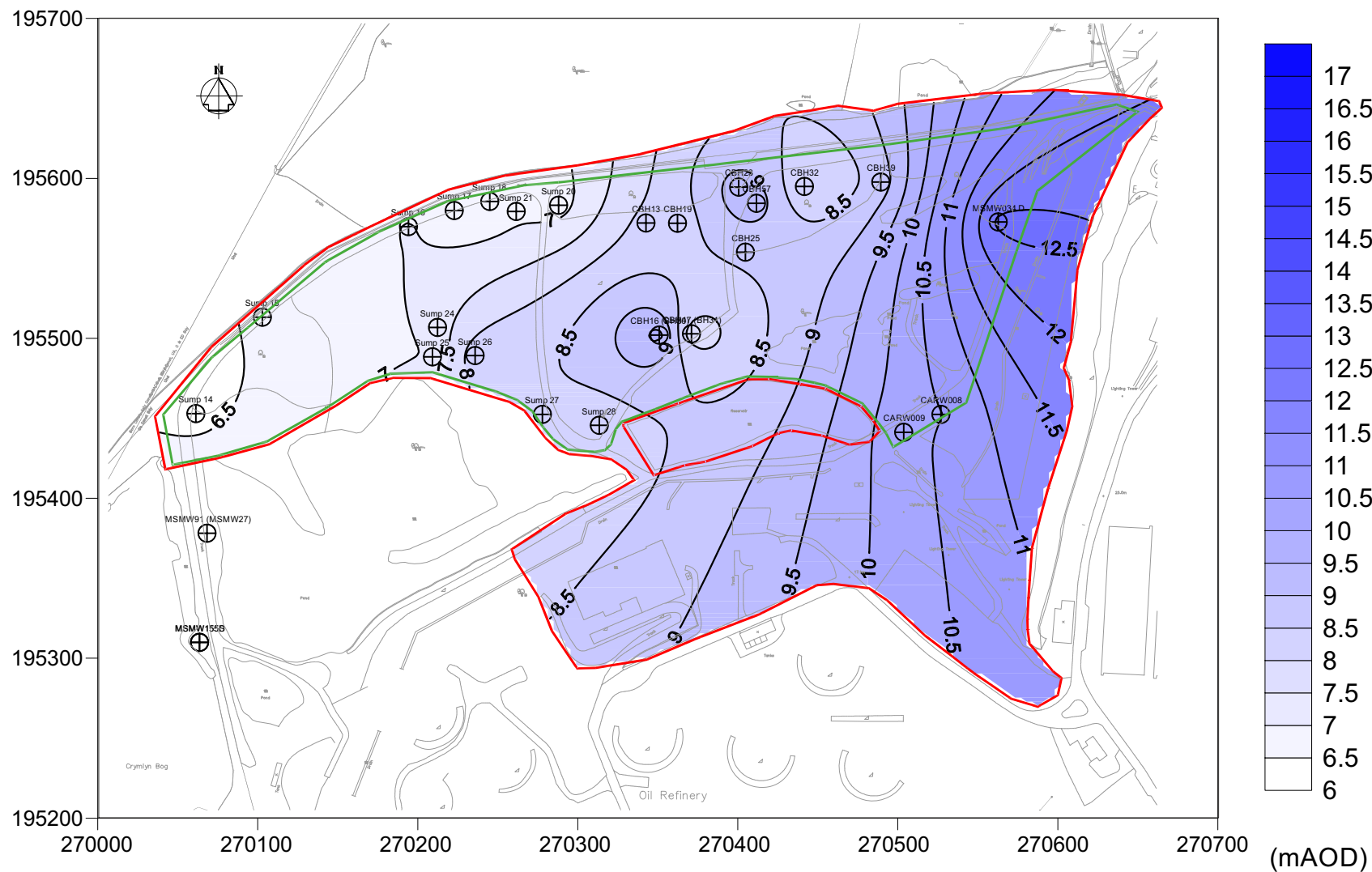
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C1870	K1b			

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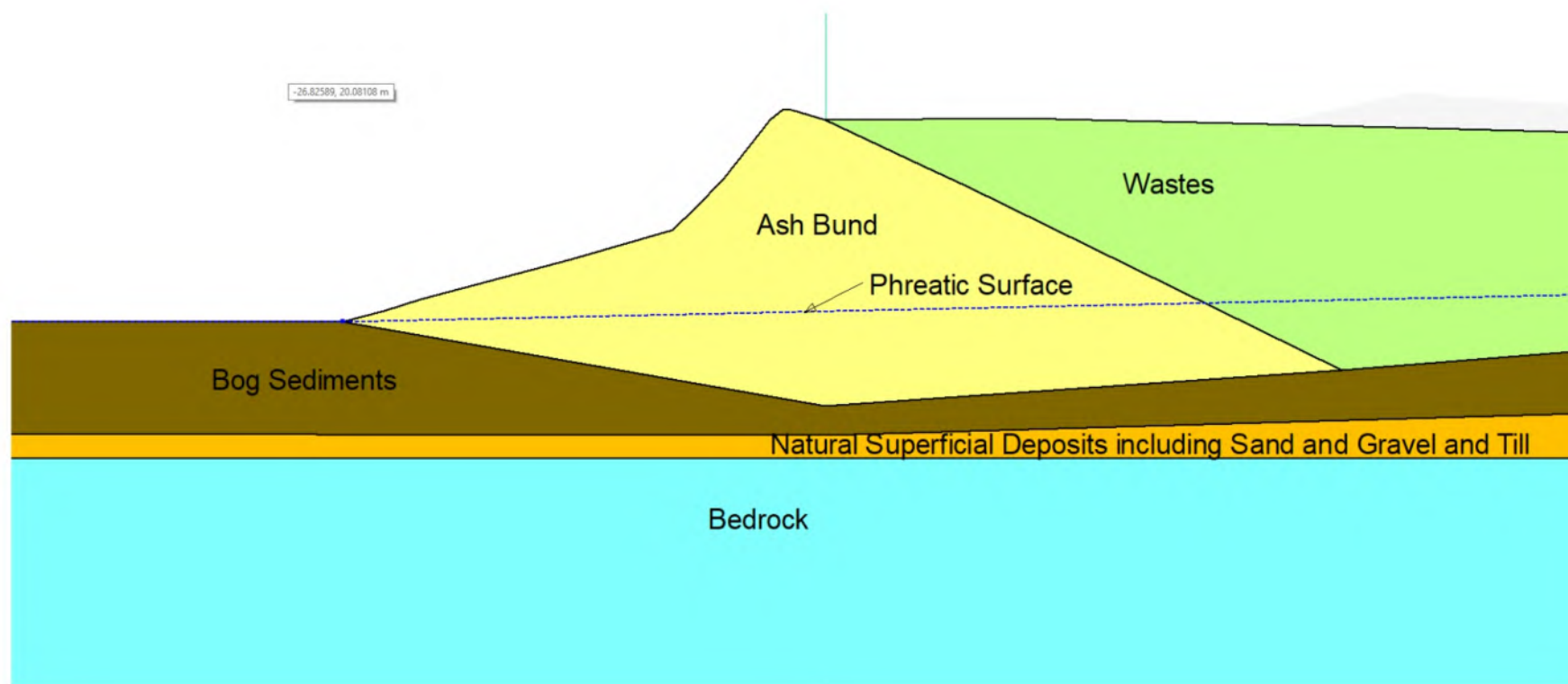
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Title		
Typical Inferred Contours of Groundwater Level		
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Original Scale	Date	Rev
Contract Number	Drawing Number	Paper
C1870	K2	A4



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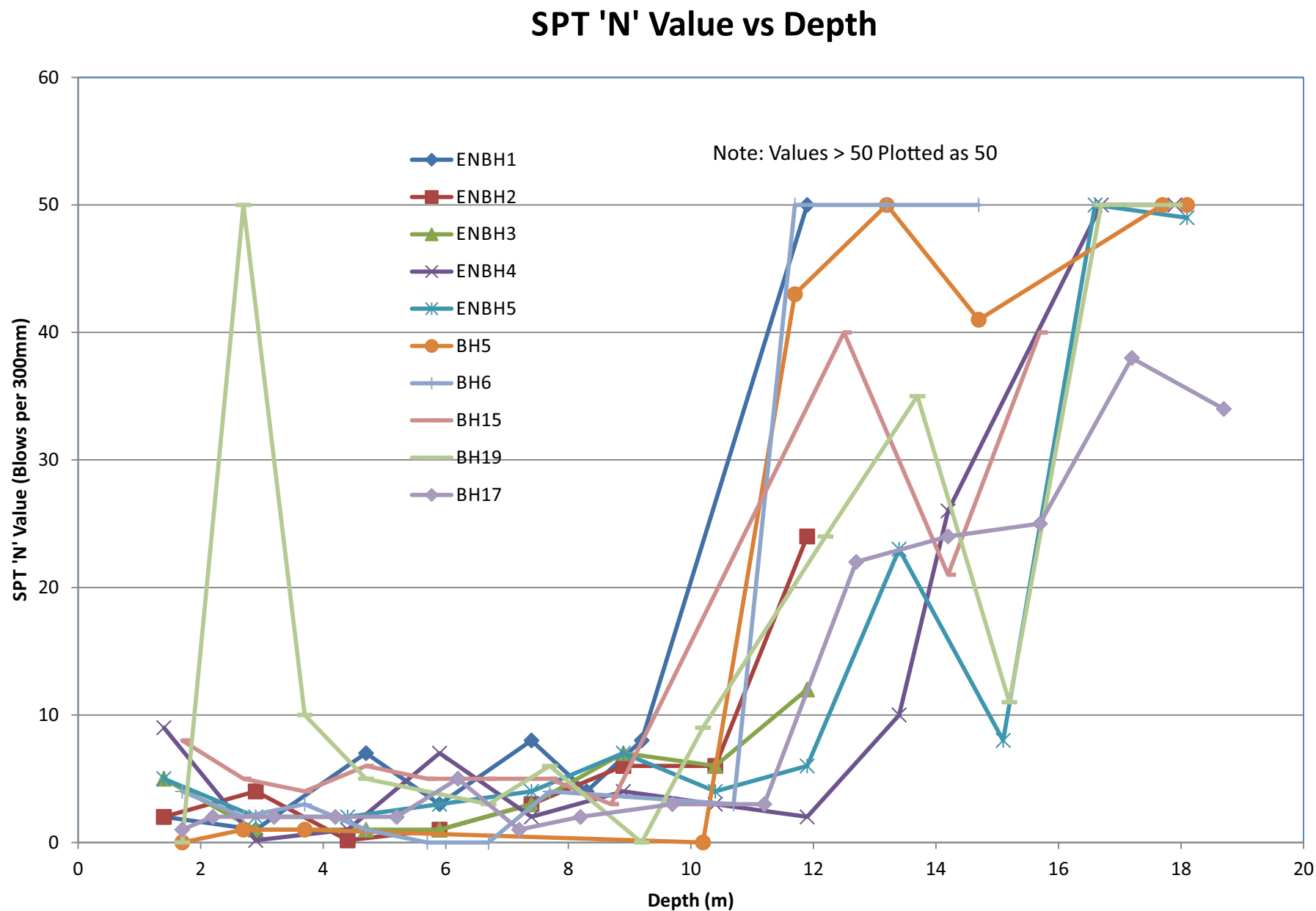
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Title
Conceptual Ground Model

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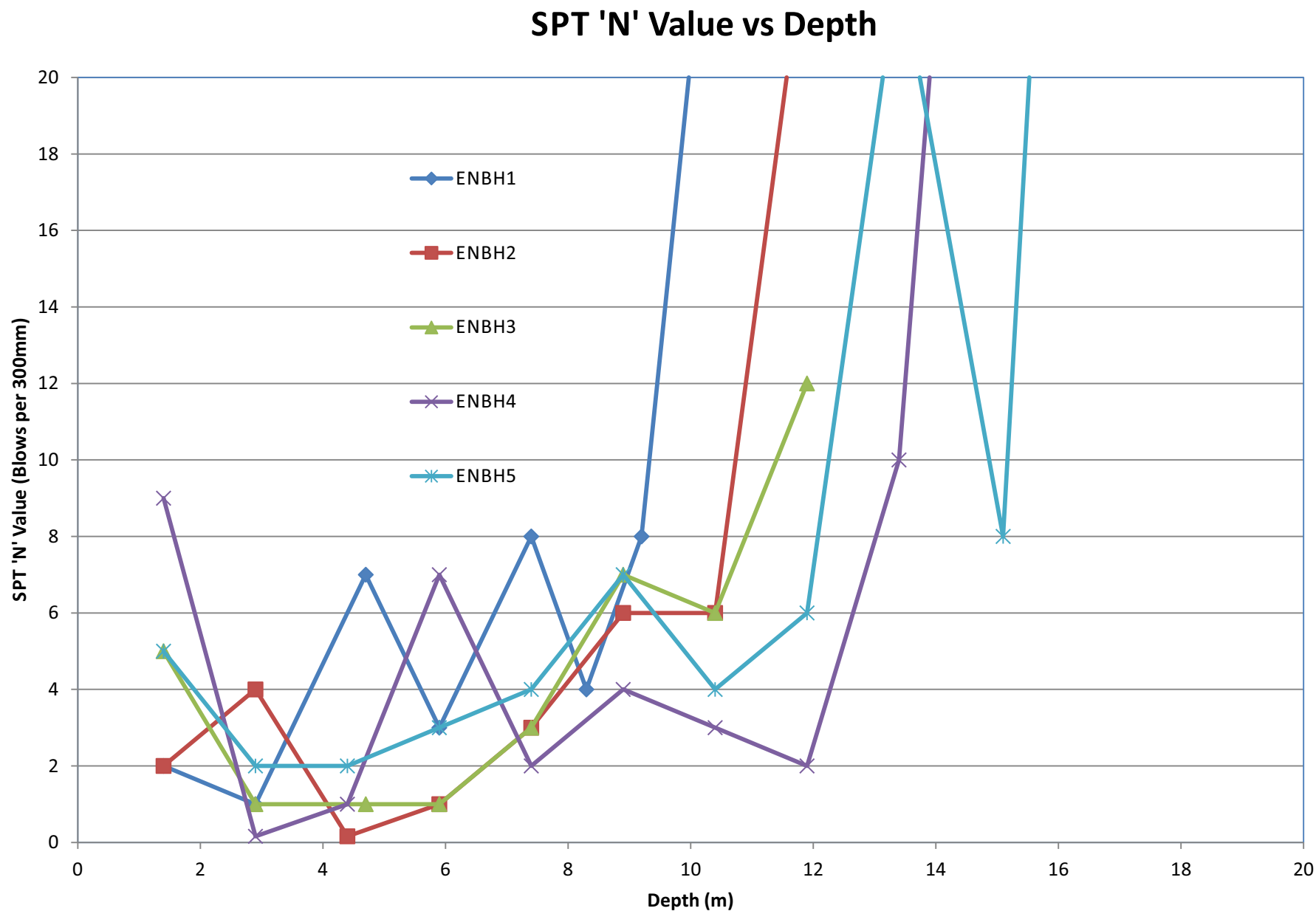
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Original Scale Date Feb. 2023 Rev 0 Paper A4

Contract Number C1870 Drawing Number K4a

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Title
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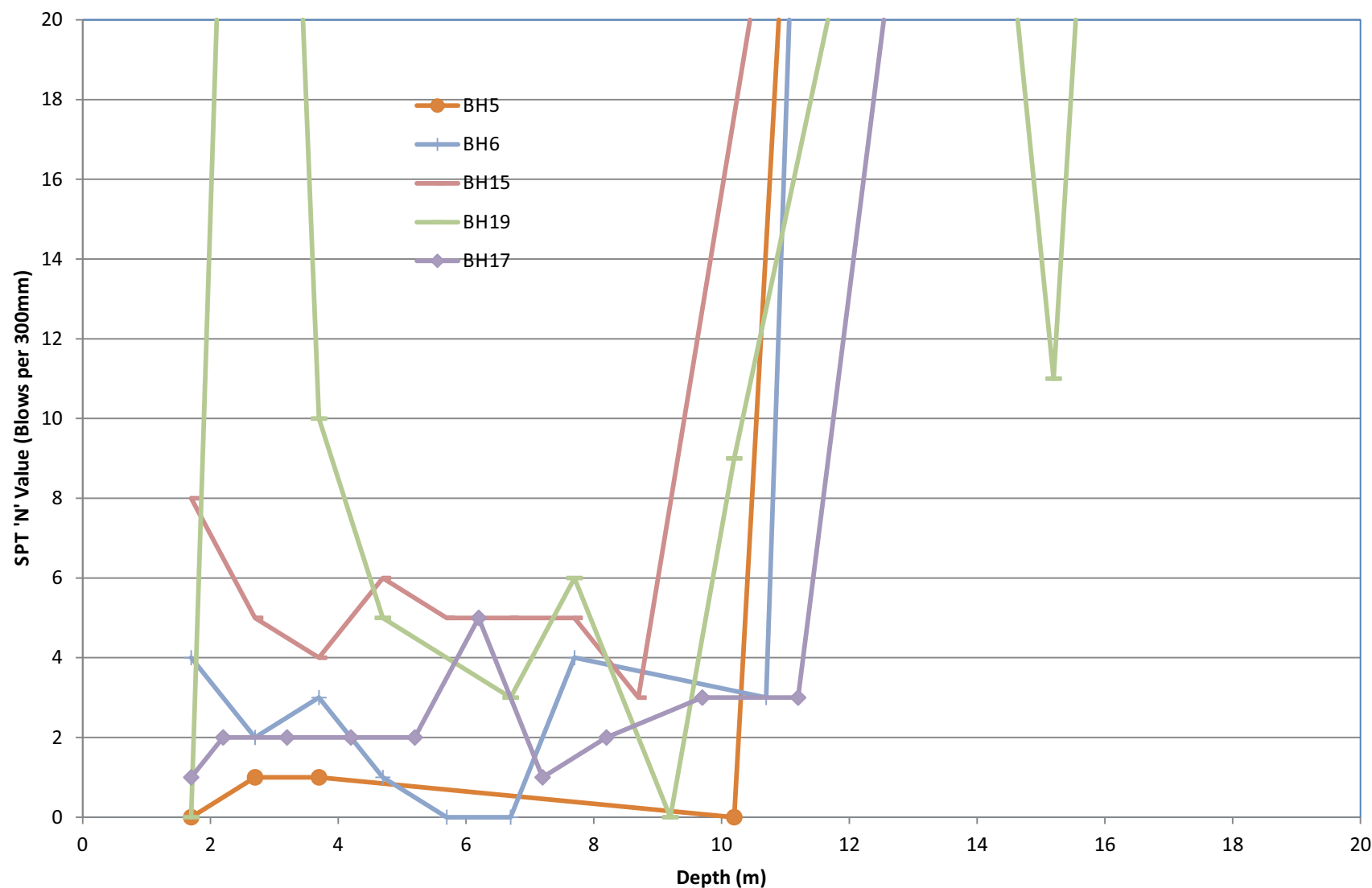
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Original Scale	Date	Rev	Paper
	Feb. 2023	0	A4

Contract Number	Drawing Number
C1870	K4b

LEGEND

SPT 'N' Value vs Depth



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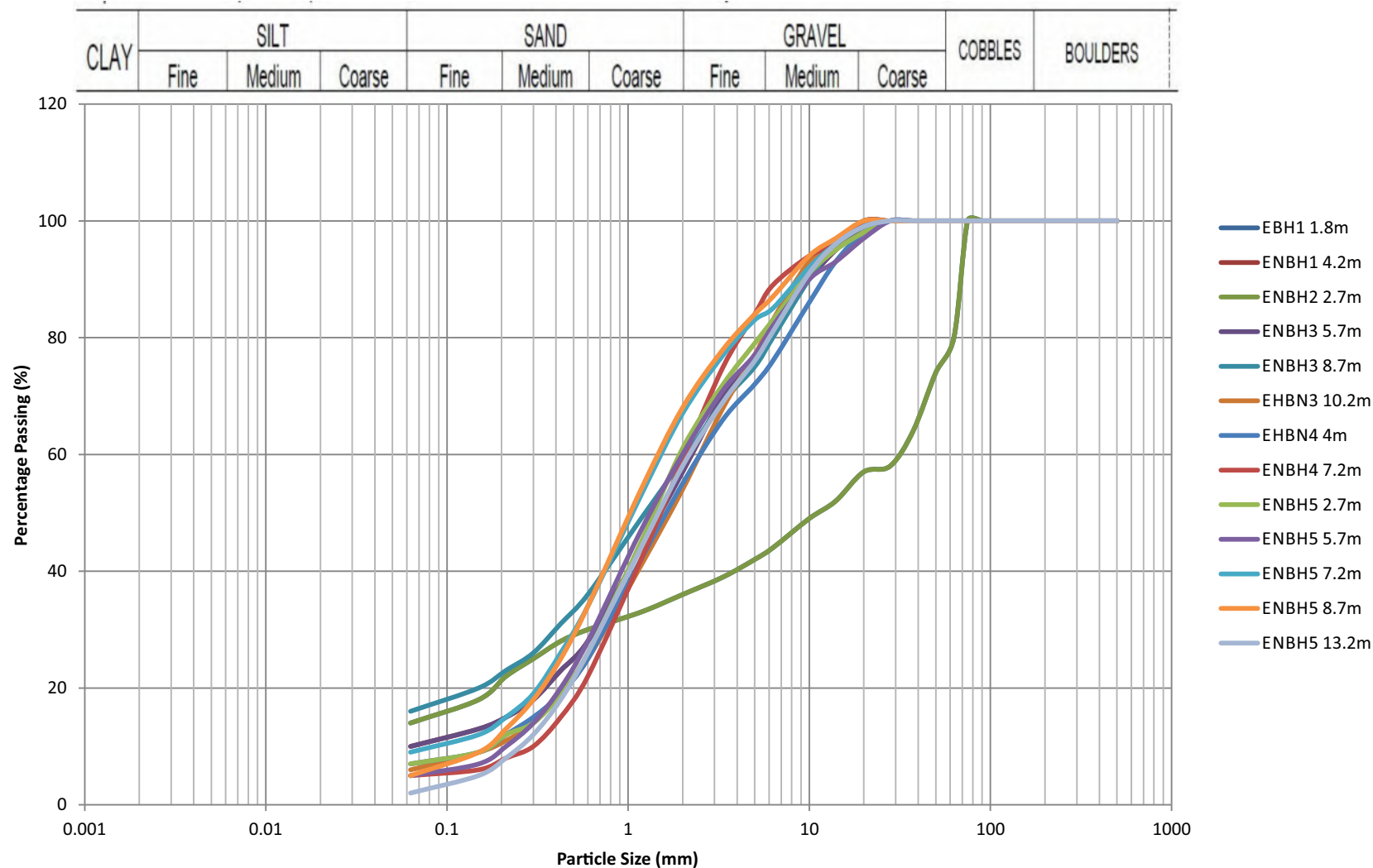
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Title
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Original Scale	Date	Rev	Paper	A4
Contract Number	C1870	Drawing Number	K4c	



LEGEND



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Title
Grading Analysis for Ash Bund Samples

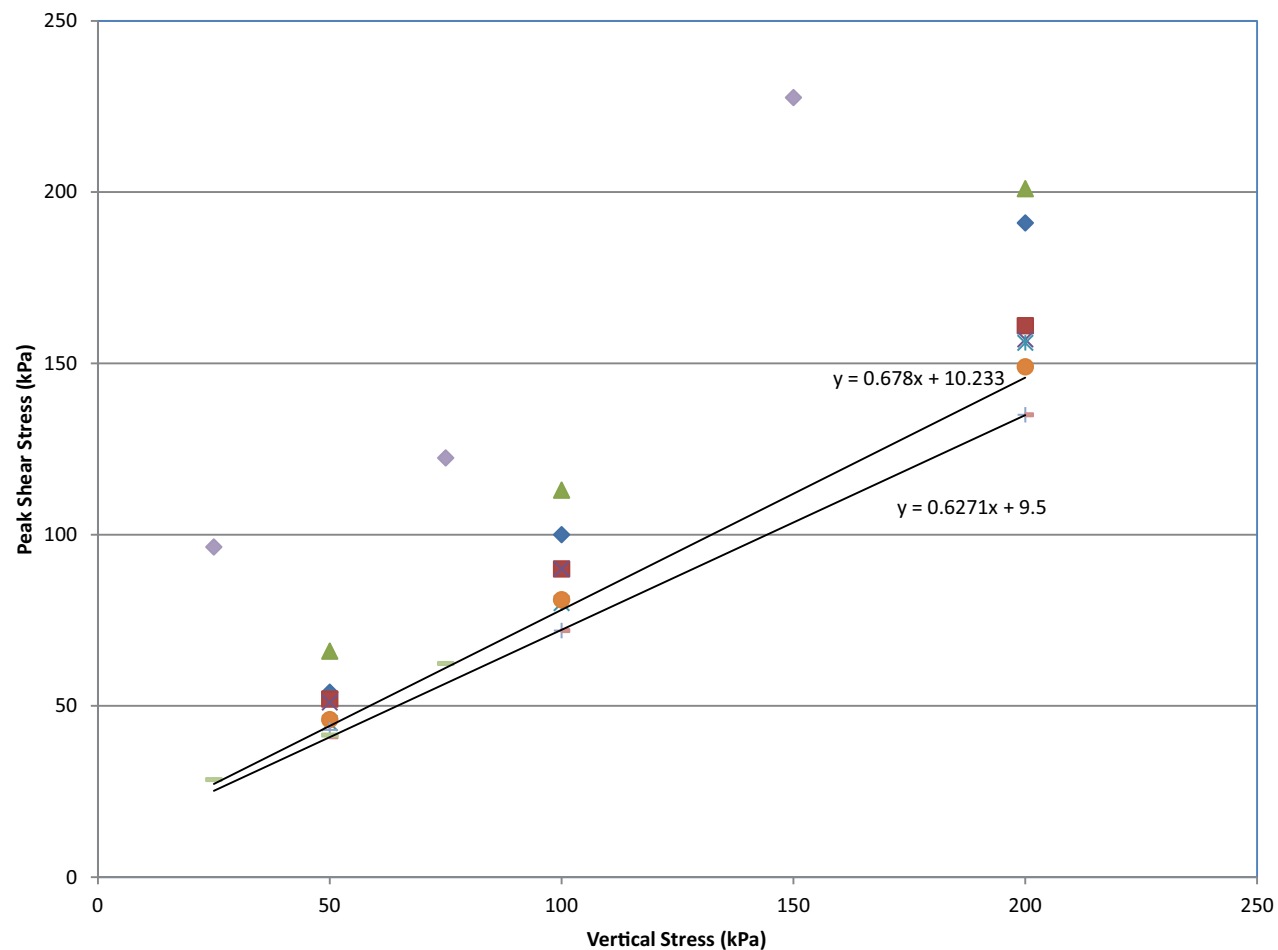
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Original Scale	Date	Rev	Paper
	Feb. 2023	0	A4

Contract Number	Drawing Number
C1870	K5

LEGEND

Summary of Shear Box Testing - Ash Bund and Wastes



- ◆ Batch 1 Sample 1
- Batch 1 Sample 2
- ▲ Batch 1 Sample 3
- ✕ Batch 2 Sample 6
- ✕ Batch 2 Sample 7
- Batch 2 Sample 8
- + Waste Sample 4
- Waste Sample 5
- Ash Bund 1
- Ash Bund 2
- Linear (Ash Bund 1)
- Linear (Waste Sample 5)

0	First Draft	DATE
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REV	COMMENT	DATE
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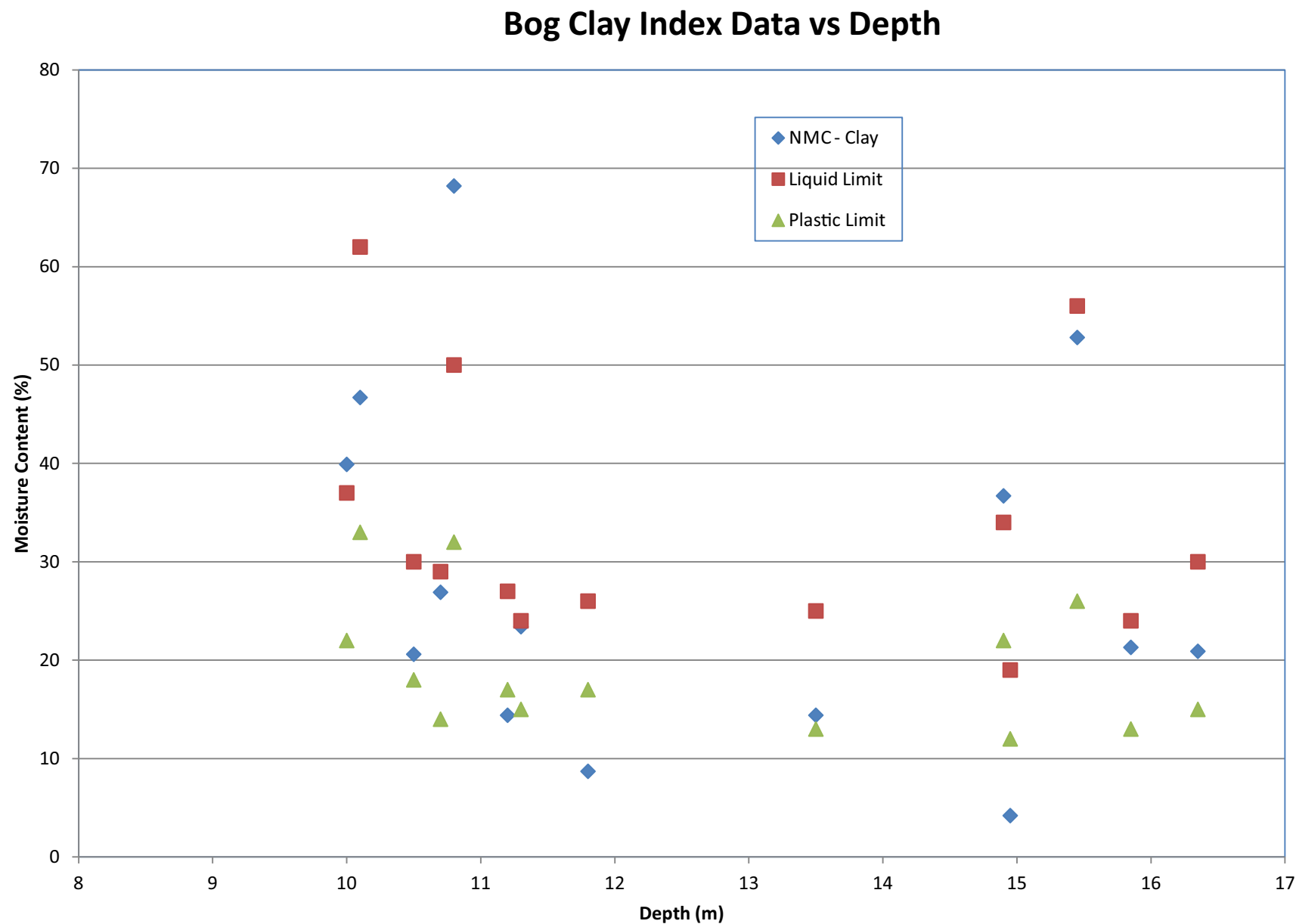
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Original Scale	Date	Rev	Paper
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Contract Number	Drawing Number
C1870	K6

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Title
Bog Clay Index Data vs Depth

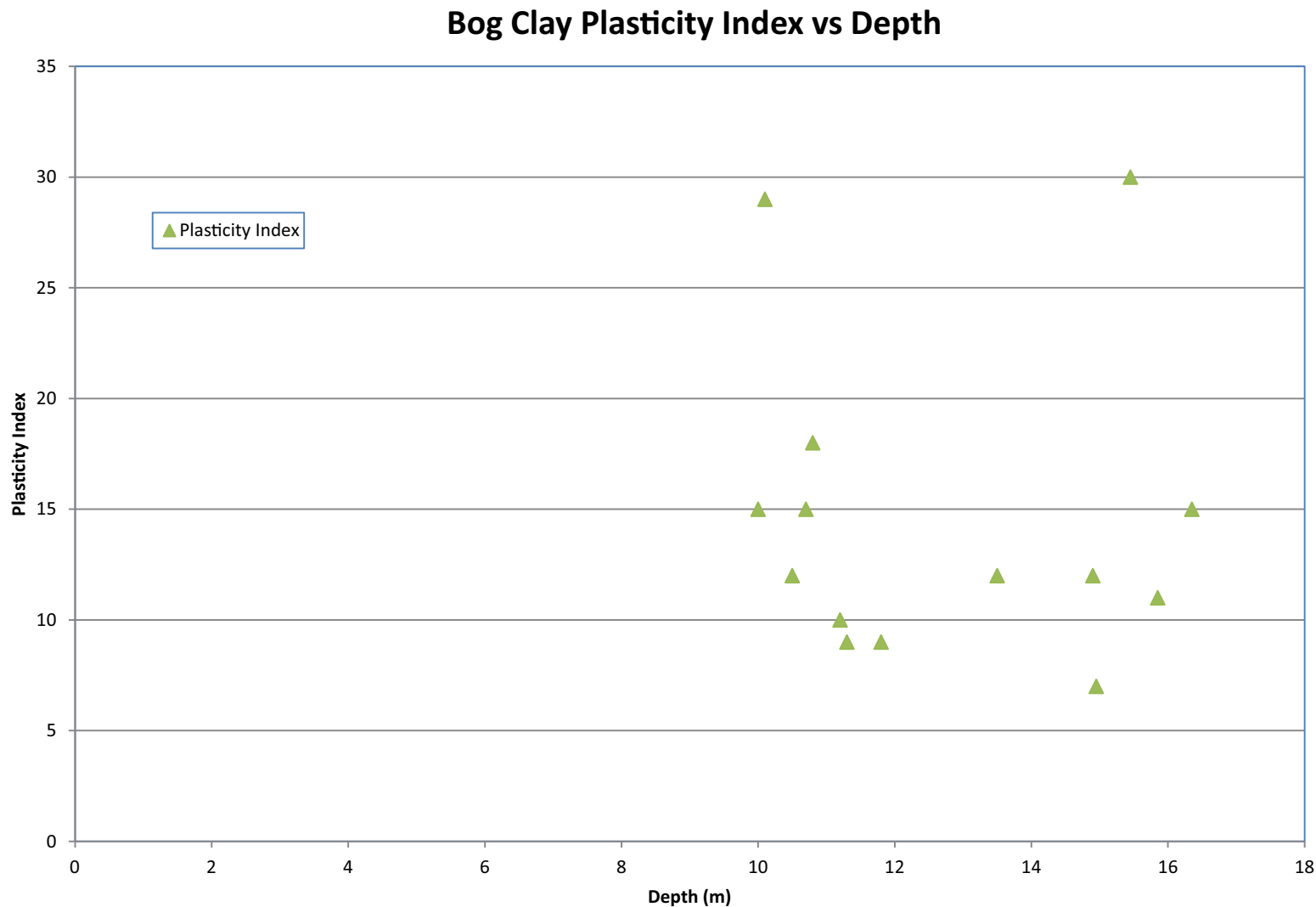
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Original Scale	Date	Rev	Paper
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Contract Number	Drawing Number
C1870	K7b



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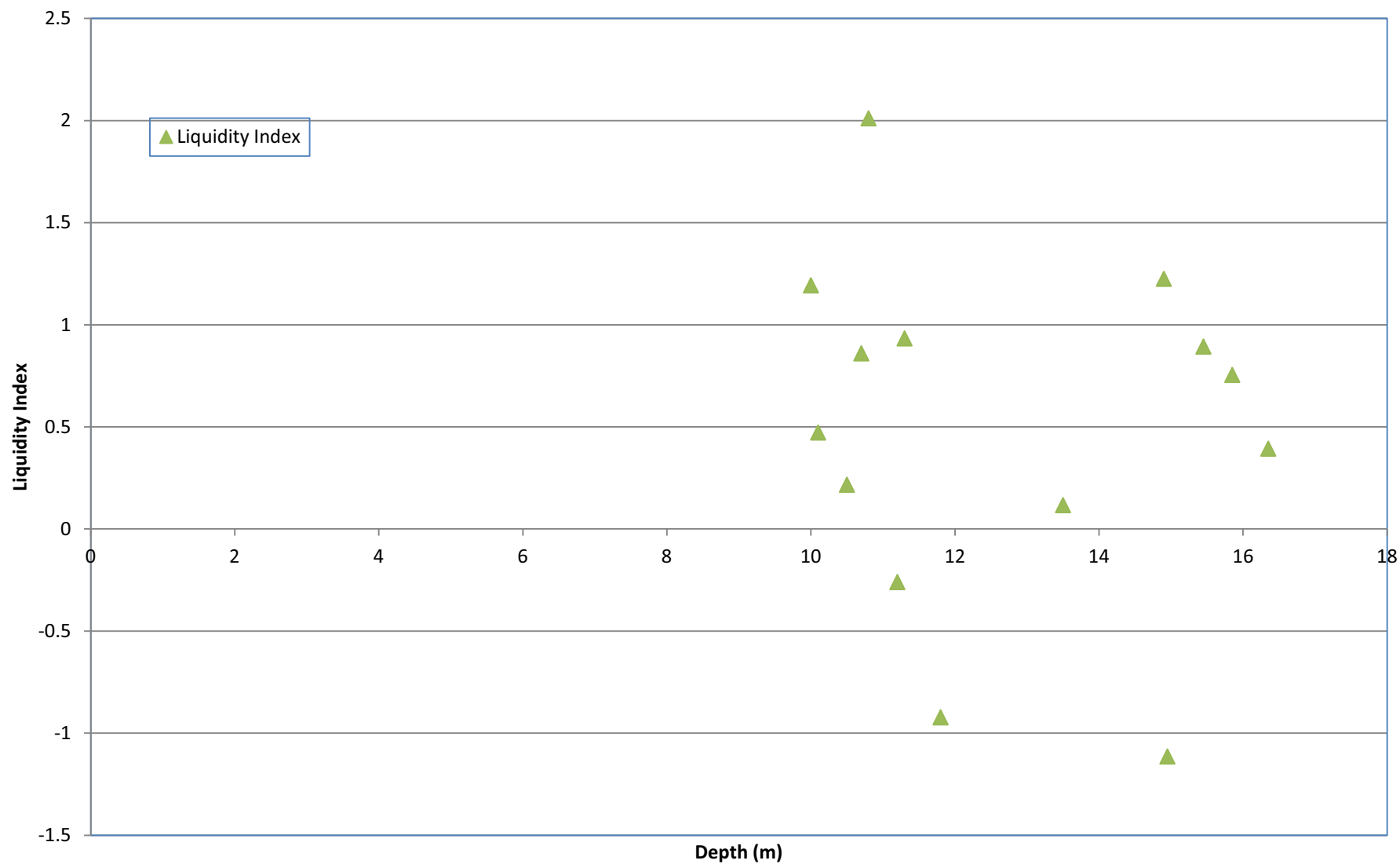
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Bog Clay Plasticity Index vs Depth

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C1870			Drawing Number	K7c



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Bog Clay Liquidity Index vs Depth



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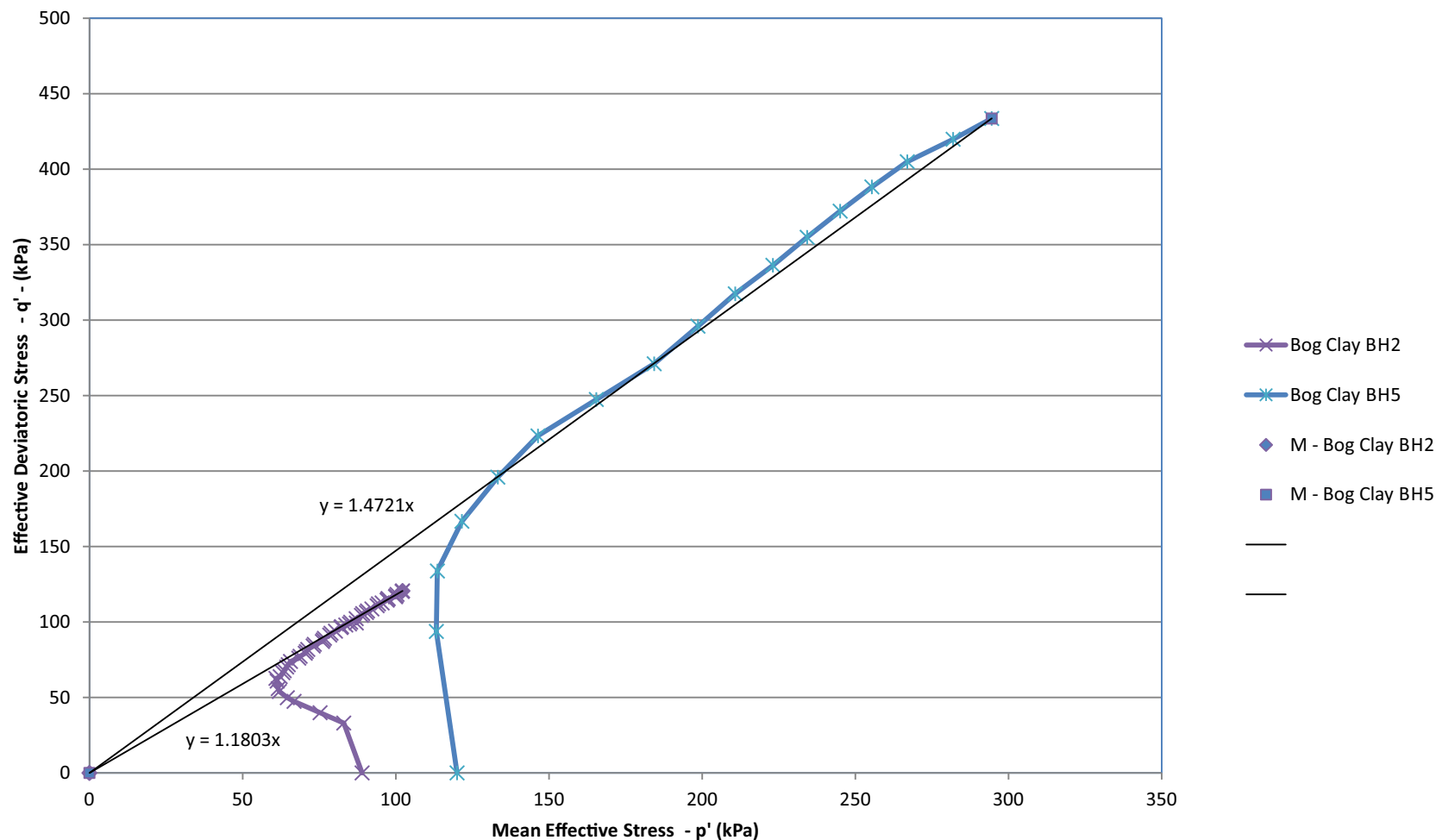
Project
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Title
Bog Clay Liquidity Index vs Depth

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Contract Number	C1870	Drawing Number	K7d	A4

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Summary of Effective Stress Paths to Peak from Undrained Triaxial Tests with Pore Pressure Measurement on Bog Clay Samples



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Title
Summary of Effective Stress Paths to Peak from Undrained Triaxial Tests with Pore Pressure Measurement on Bog Clay Samples

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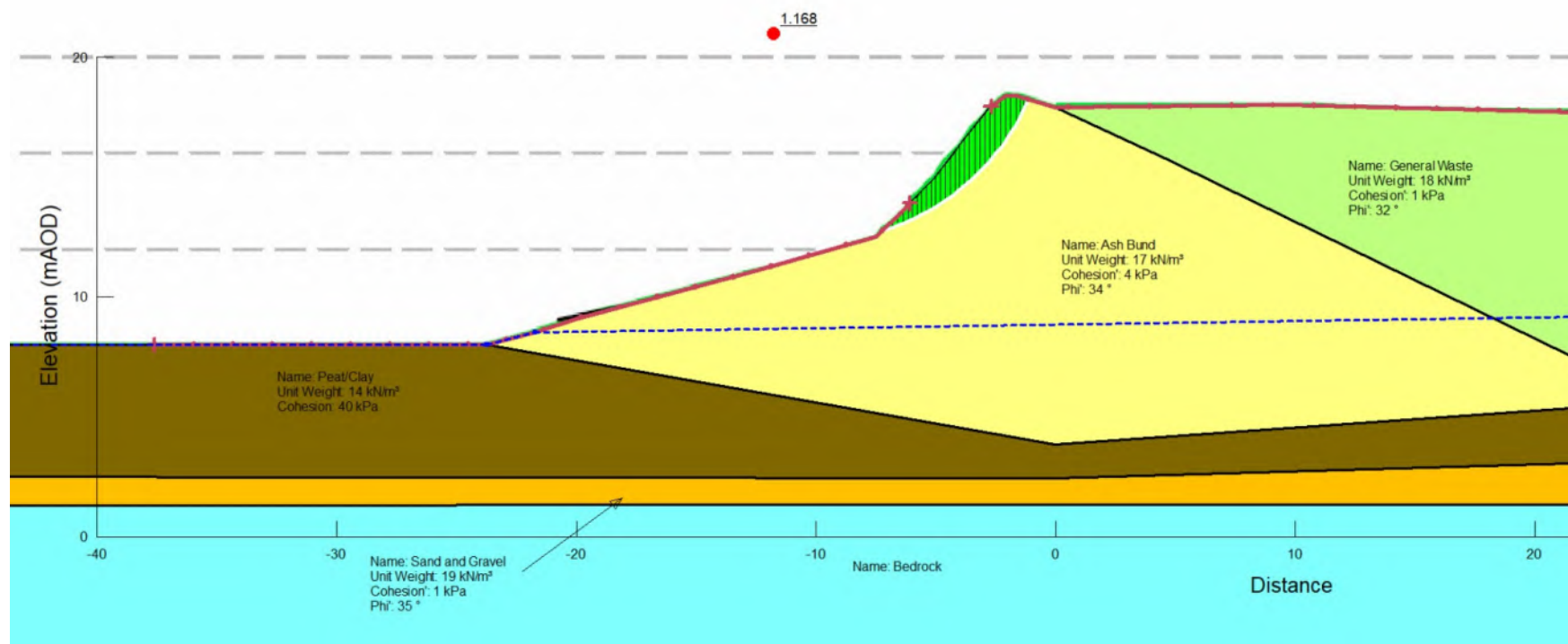
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Contract Number C1870 Drawing Number K8



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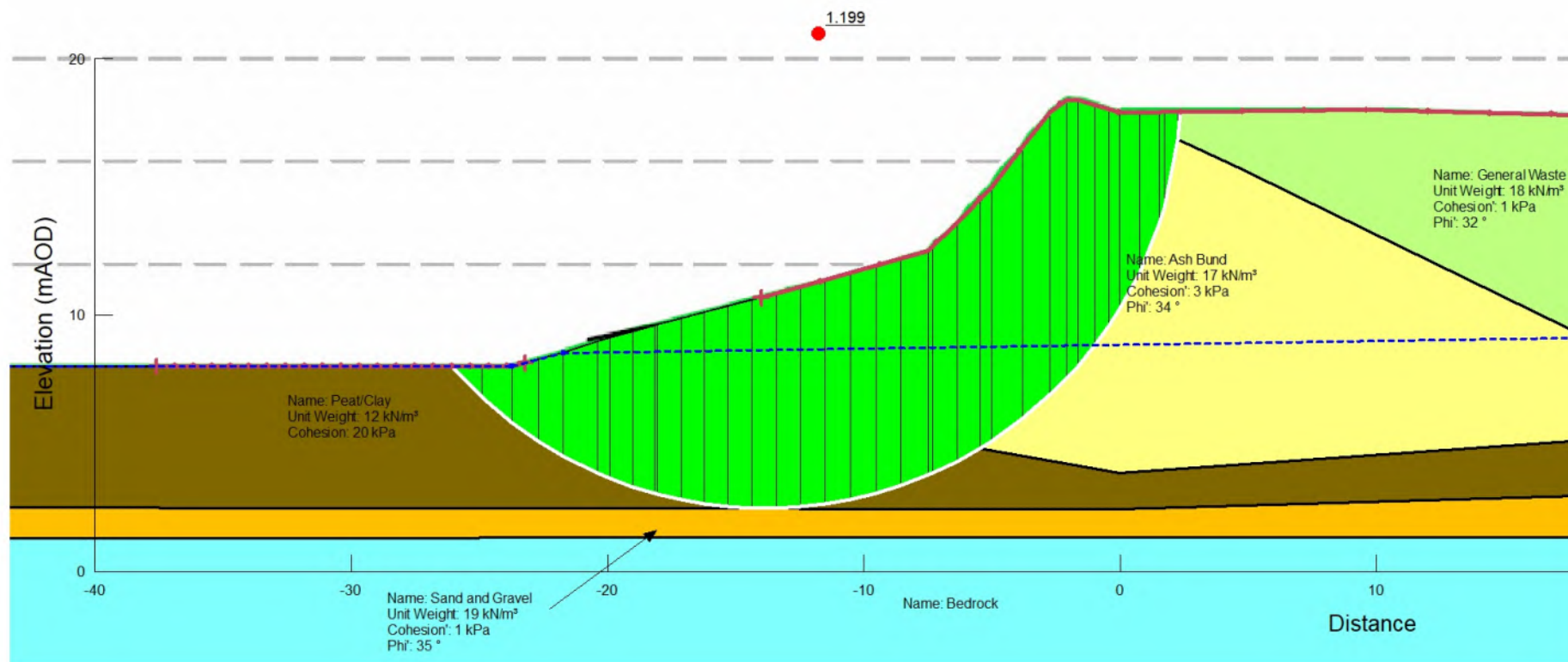
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Typical Critical Failure Surface in Ash Bund

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Title
Typical Critical Failure Surface in Bog
Sediments

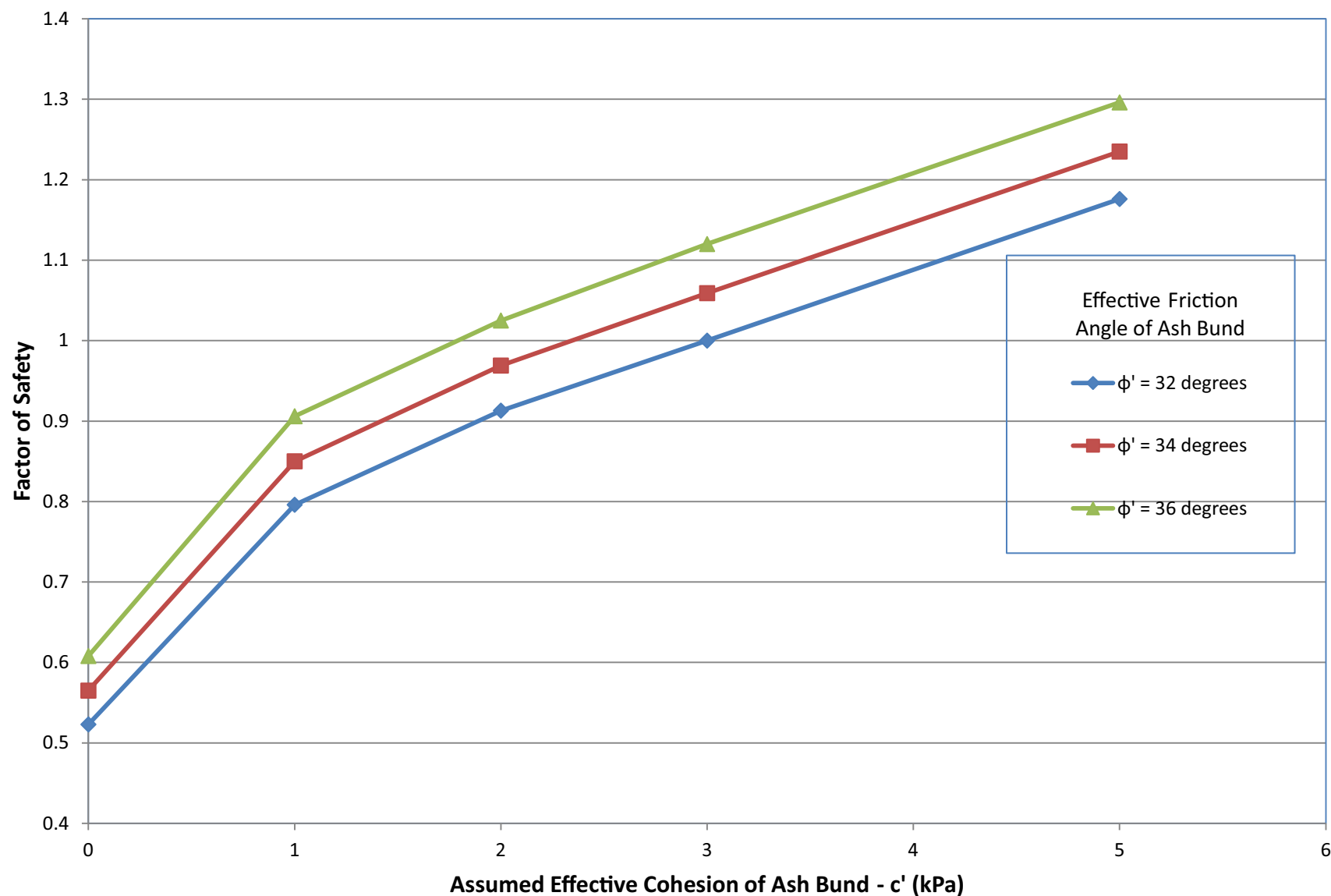
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Contract Number C1870 Drawing Number K10

LEGEND

Section EE - Back Analysis of Existing Slope - Failures in Ash Bund



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Title
Section EE - Back Analysis of Existing Slope
- Failure in Ash Bund

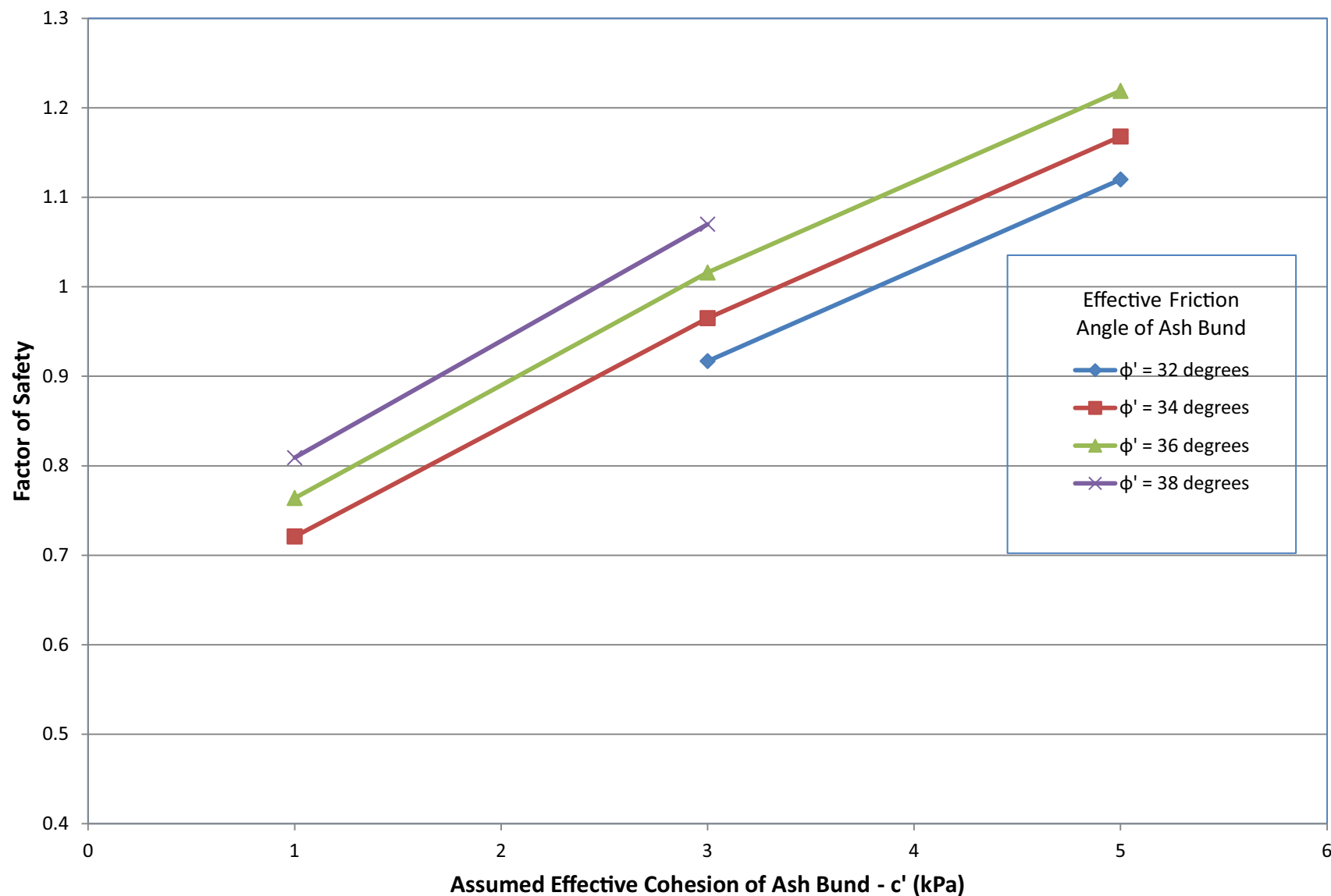
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Contract Number C1870 Drawing Number K11

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Section FF - Back Analysis of Existing Slope - Failures in Ash Bund



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Title
Section FF - Back Analysis of Existing Slope
- Failure in Ash Bund

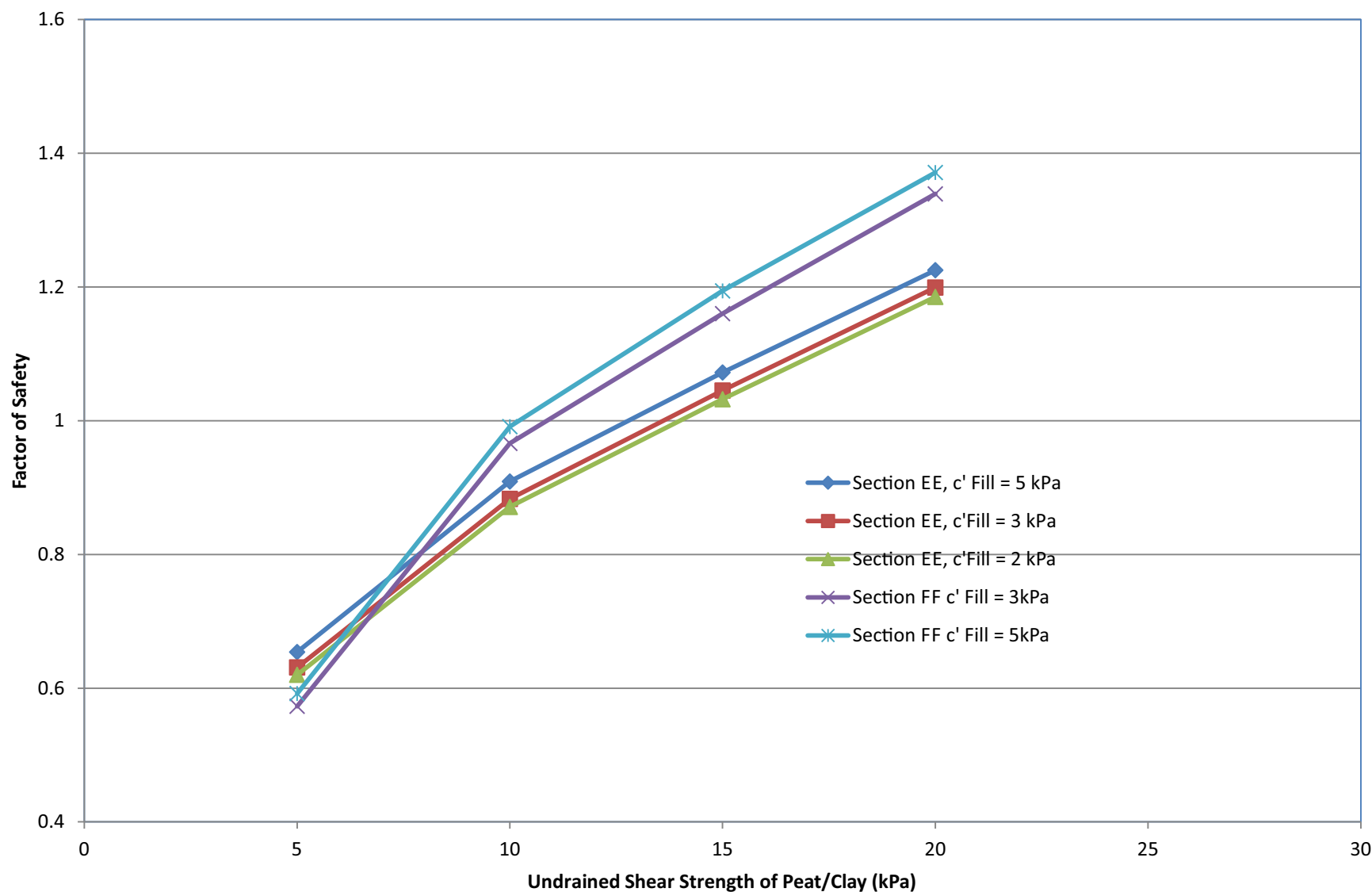
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LEGEND

Back Analysis of Existing Slope - Deep Failure in Peat/Clay



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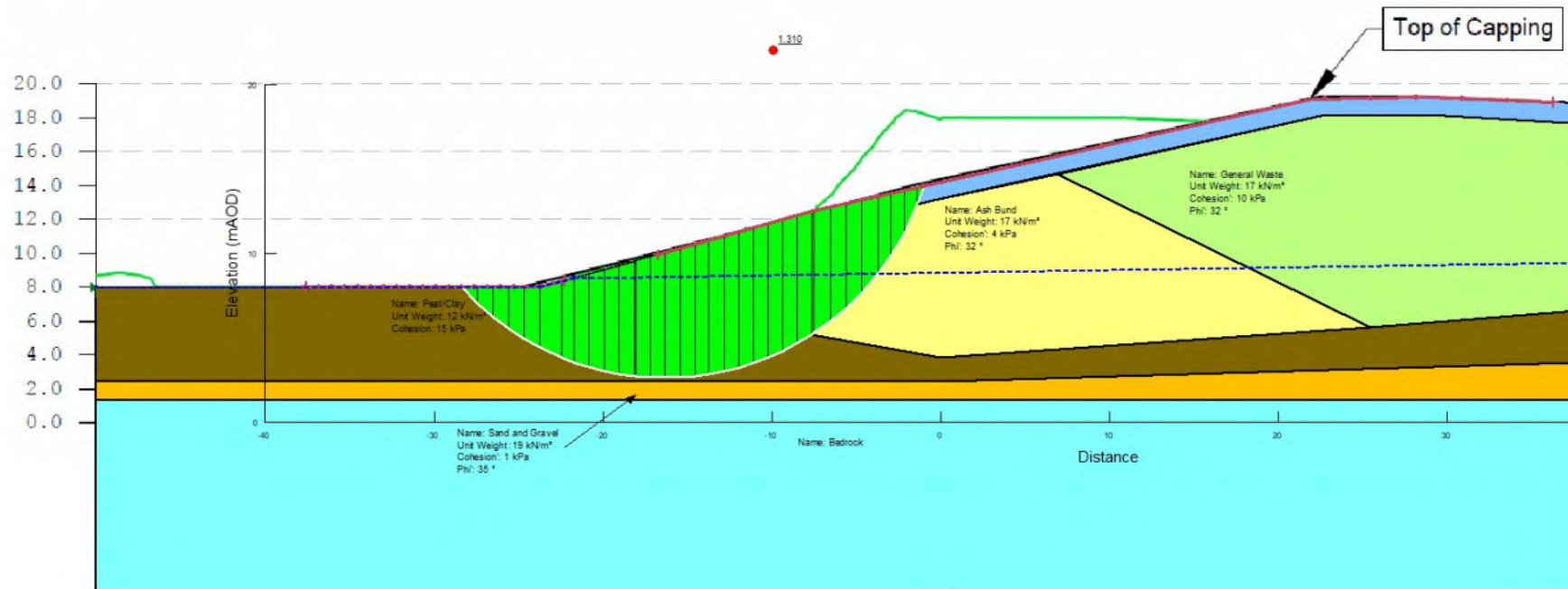
Title
Back Analysis of Existing Slope
- Deep Failure in Peat/Clay

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E



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Project
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Title
Critical Failure Mode for Proposed
Reclamation Section EE - Worst Credible
Condition

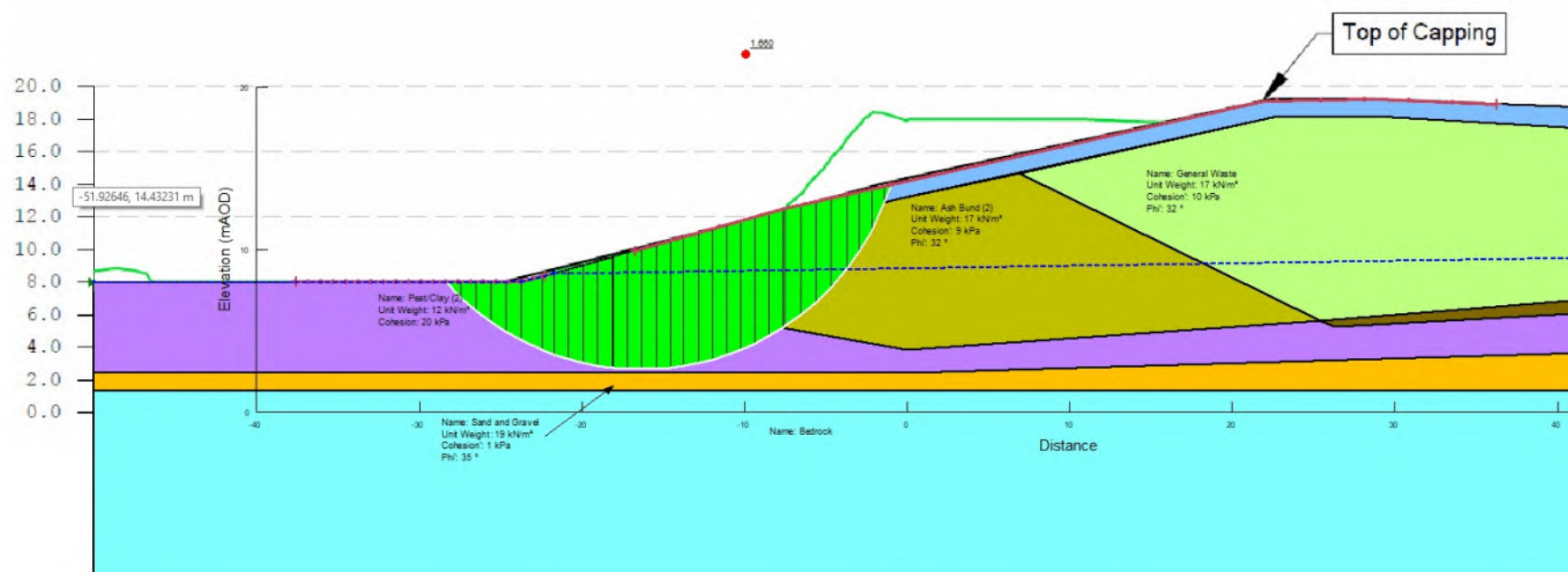
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Contract Number	Drawing Number
C1870	K14a

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E



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Title
Critical Failure Mode for Proposed
Reclamation Section EE - Reasonable
Design Condition

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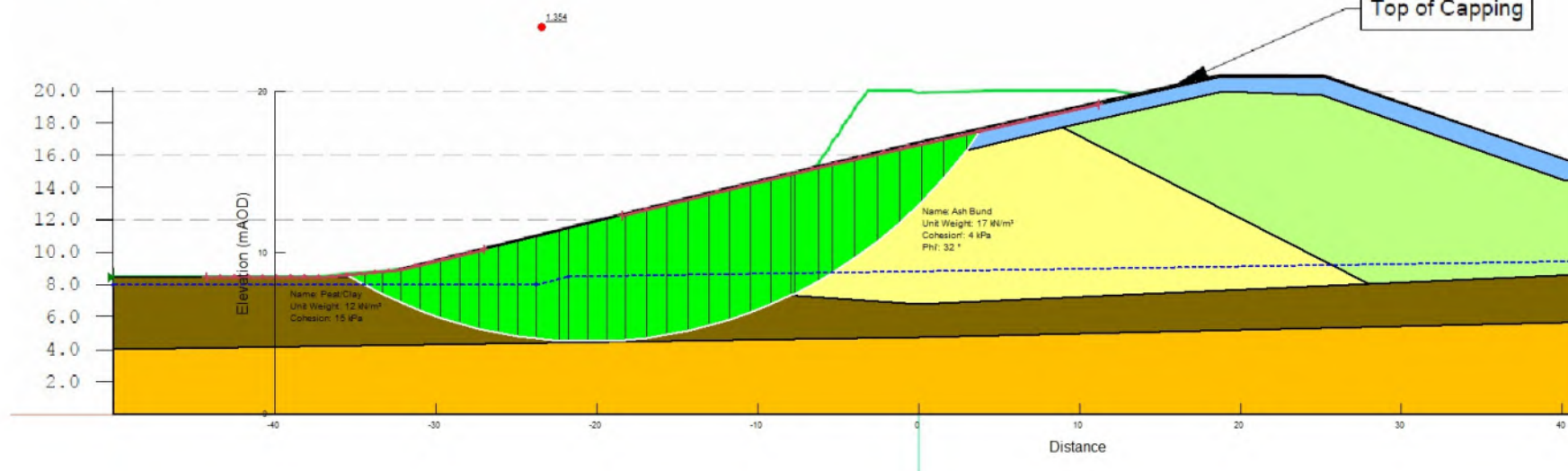
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Contract Number	Drawing Number
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F



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Title
Critical Failure Mode for Proposed
Reclamation Section FF - Worst Credible
Condition

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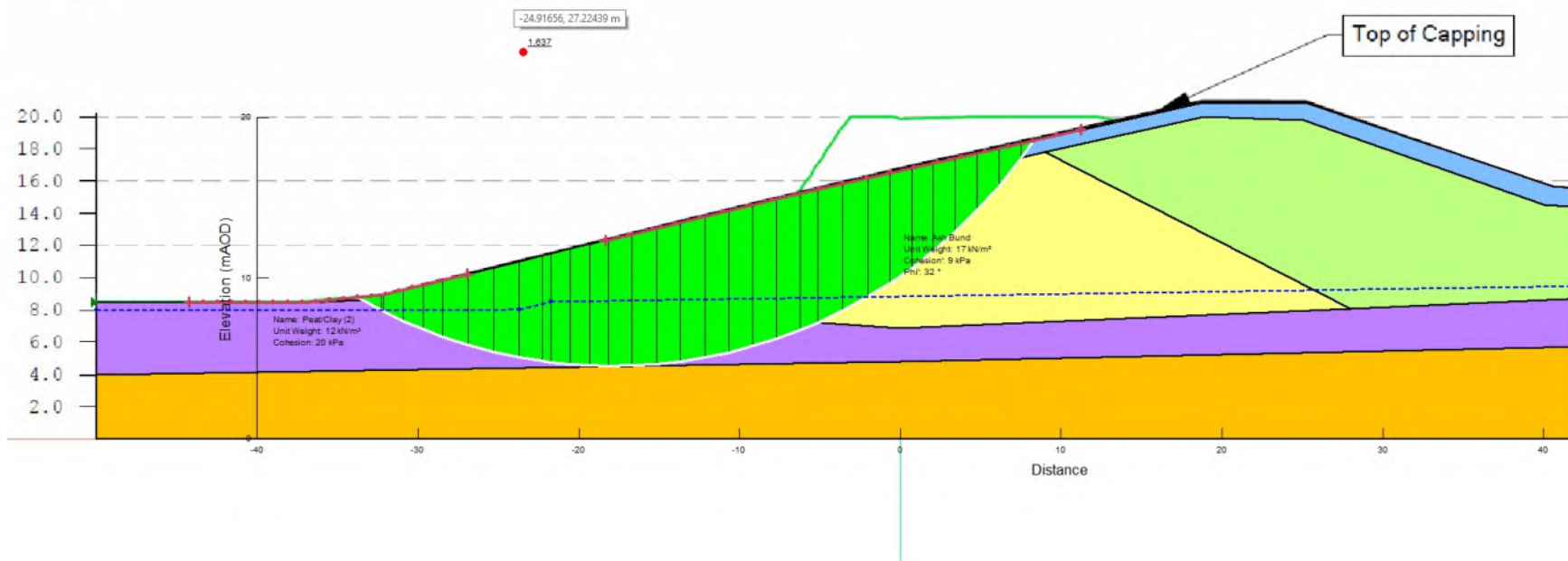
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Contract Number C1870 Drawing Number K15a



LEGEND

F



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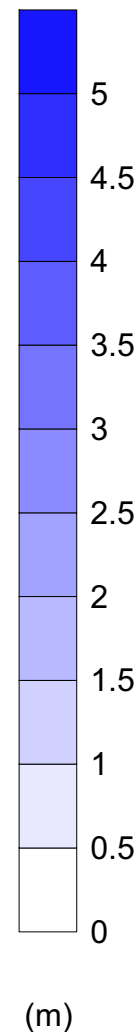
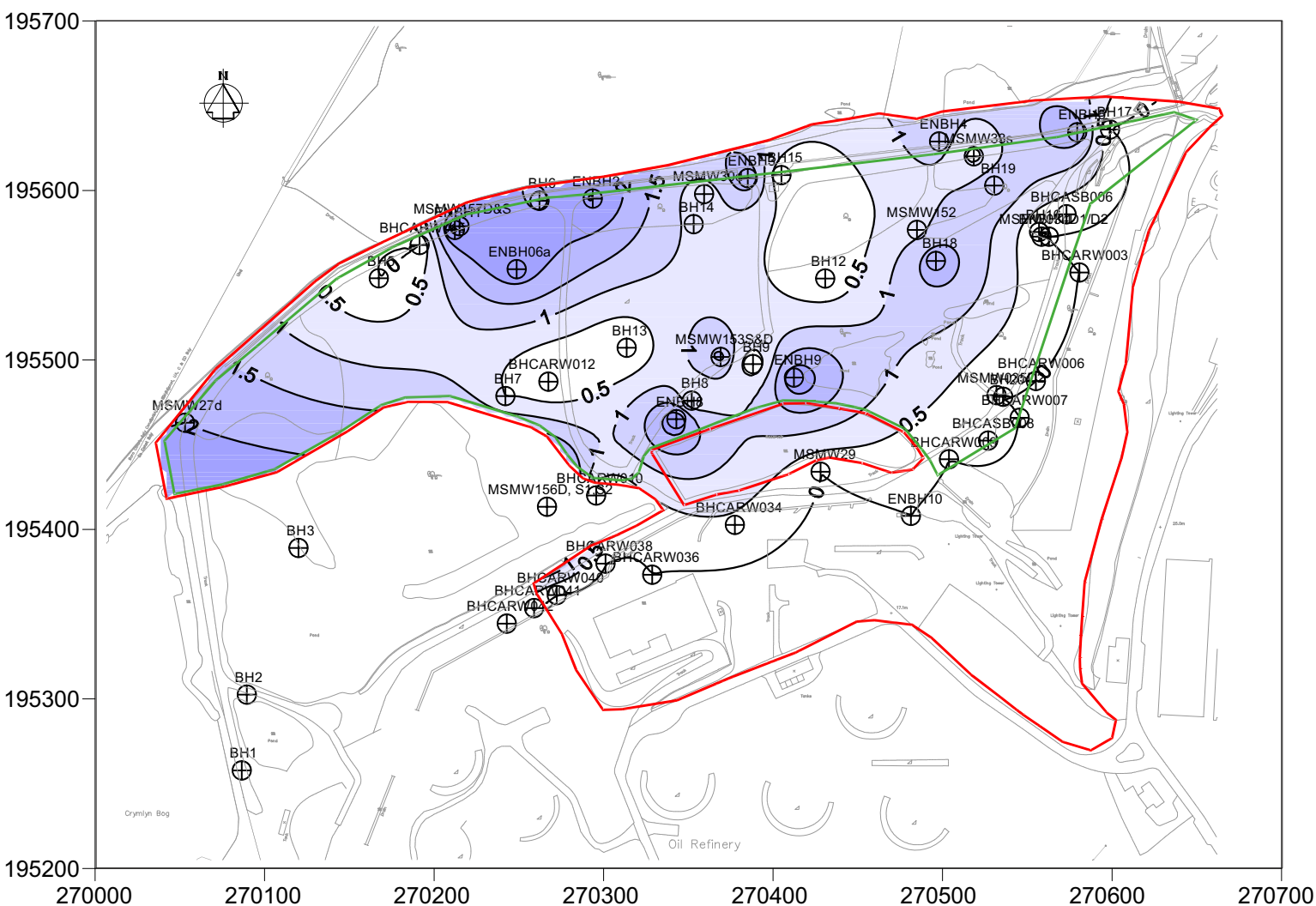
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Project
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Title
Critical Failure Mode for Proposed
Reclamation Section FF - Reasonable
Design Condition

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Original Scale	Date	Rev	Paper	A4
Contract Number	Drawing Number			
C1870	K15b			

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Title

Inferred Contours of Peat Thickness

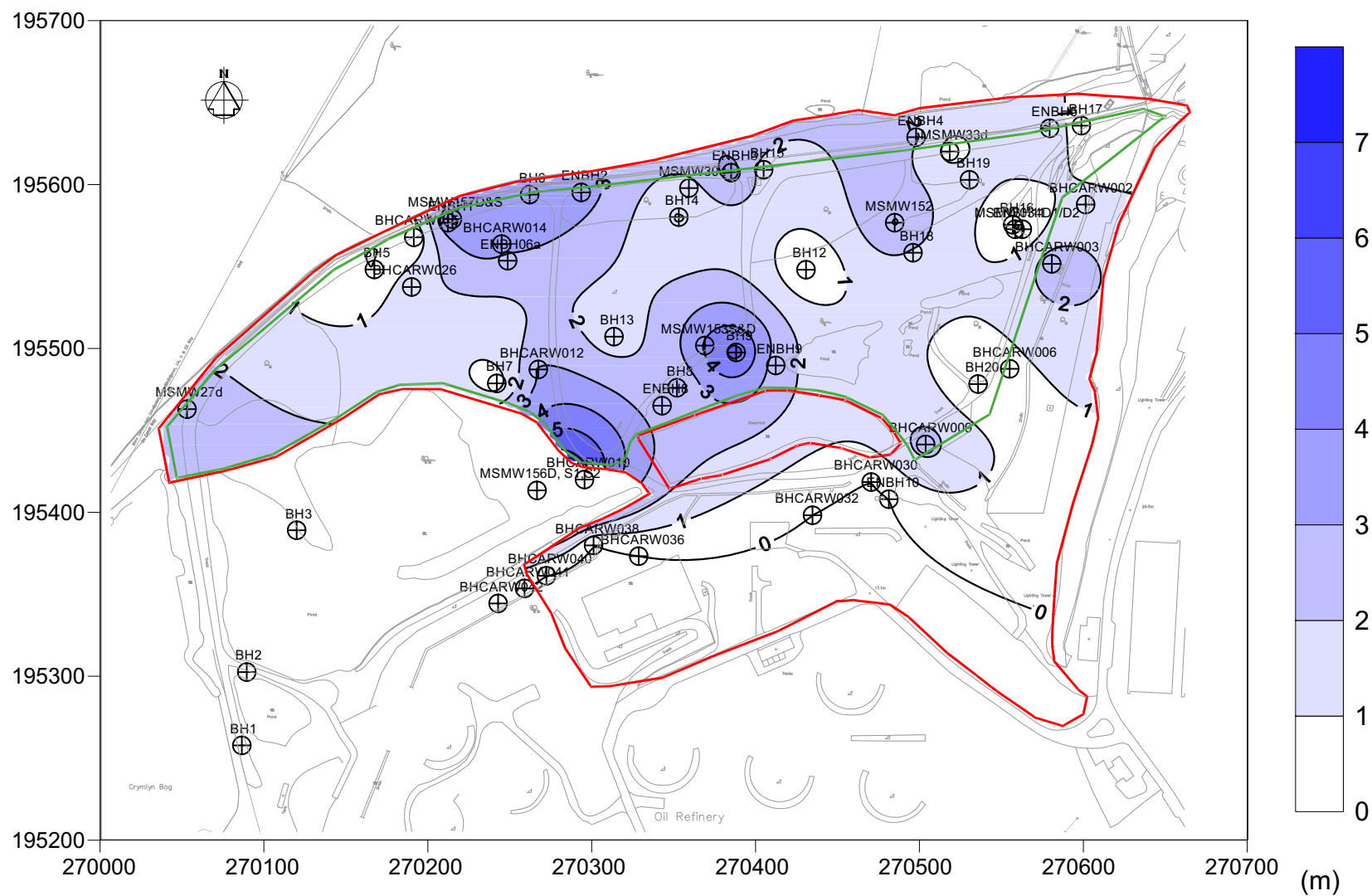
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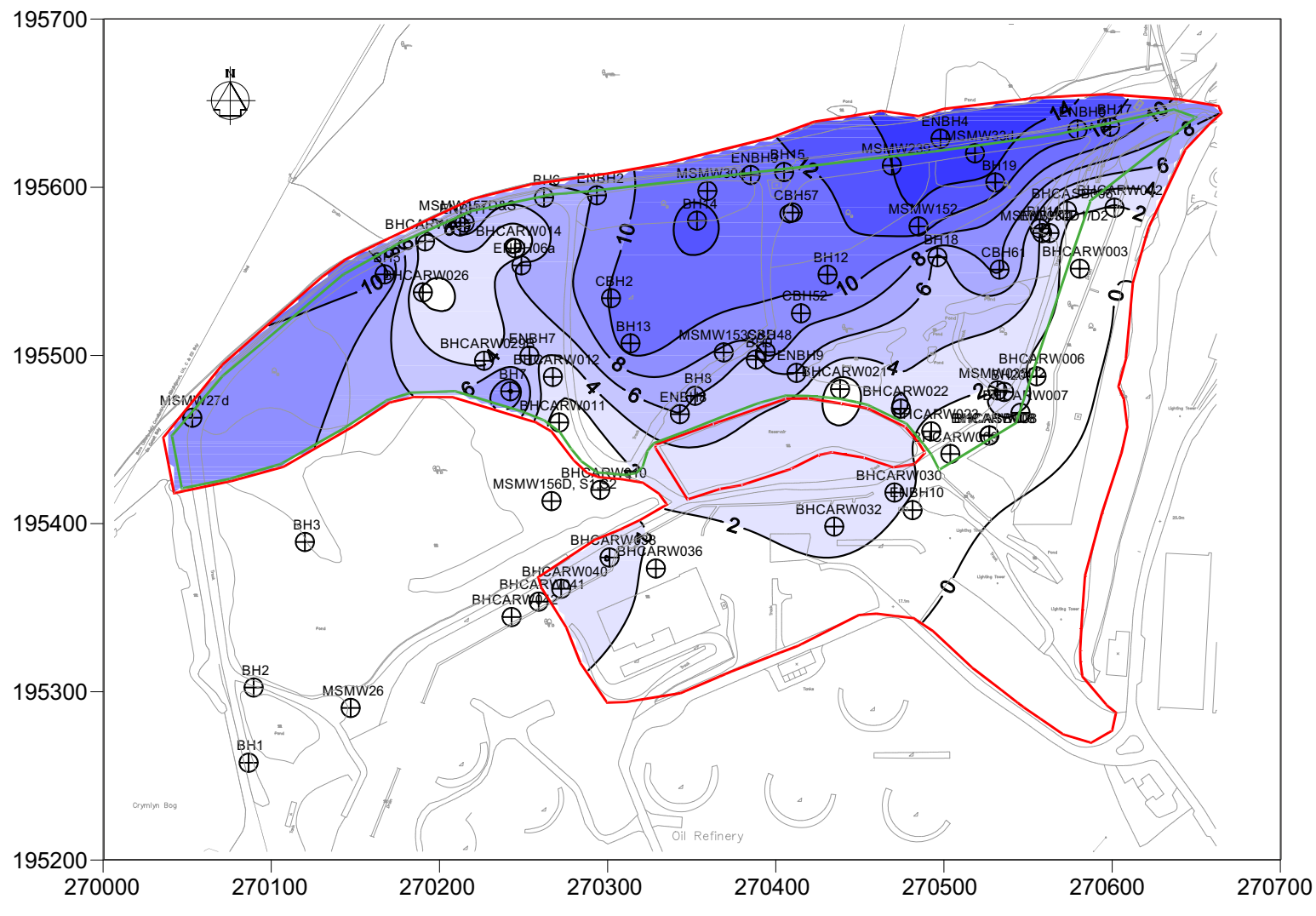
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Project			
Crymlyn Tip Coed Darcy			
Title			
Inferred Contours of Thickness of Bog Sediments			
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		Feb. 2023	0
Contract Number		Drawing Number	
C1870		K18	



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Title
Inferred Contours of Existing Made Ground

Thickness

Drawn by Checked Date Authorised Date

Original Scale Date Feb. 2023 Rev 0 Paper A4

Contract Number Drawing Number

C1870 K19



LEGEND

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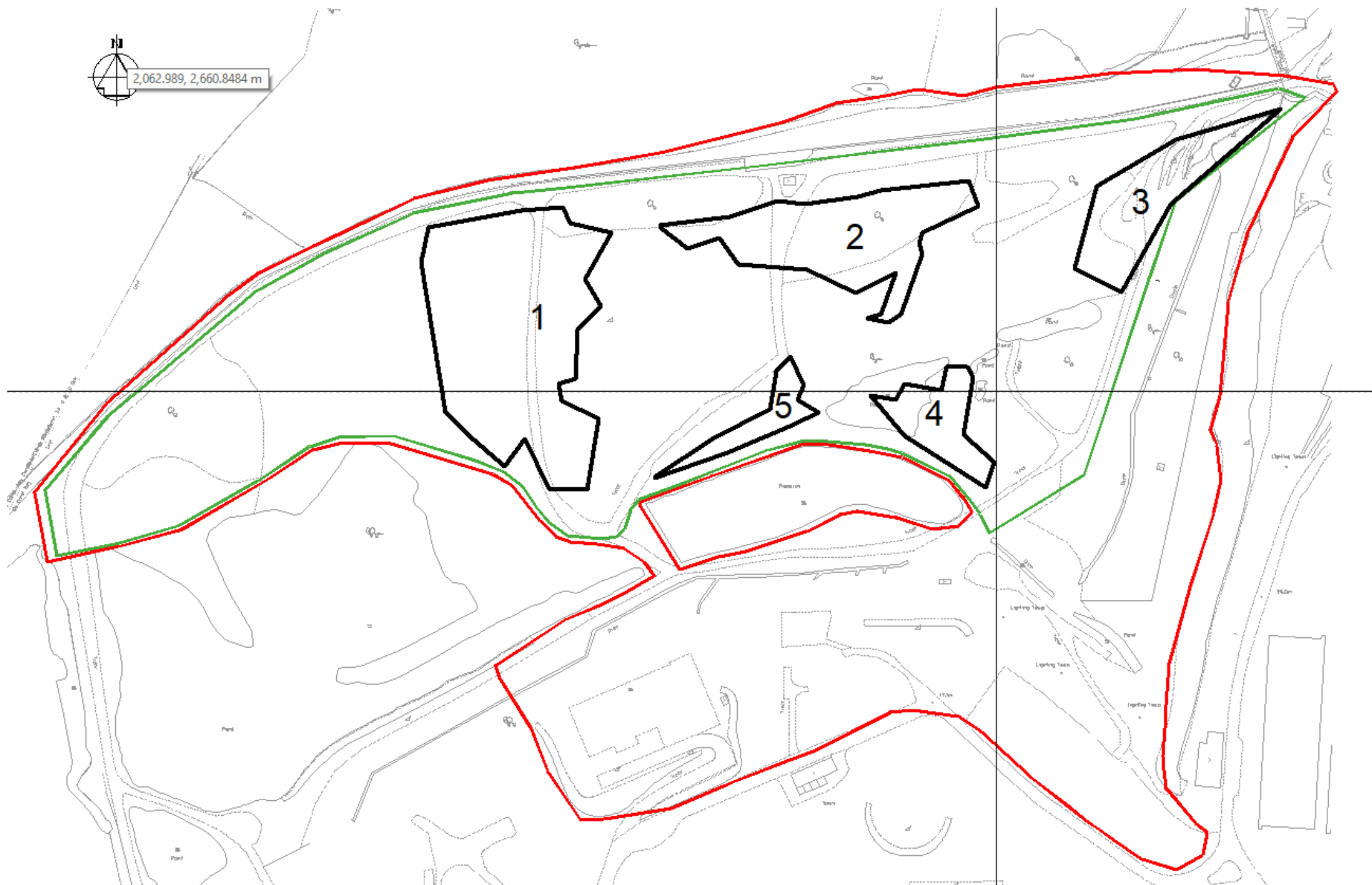
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Title
Zones of Proposed Increased Ground Levels

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