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Godre'r Graig Primary School, Godre'r Graig

Preliminary Investigation and Additional Assessment

Report Reference: ESP.7234e.02.3302

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Godre'r Graig Primary School
Preliminary Investigation and Additional Assessment

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Report Reference: **ESP.7234e.02.3302**

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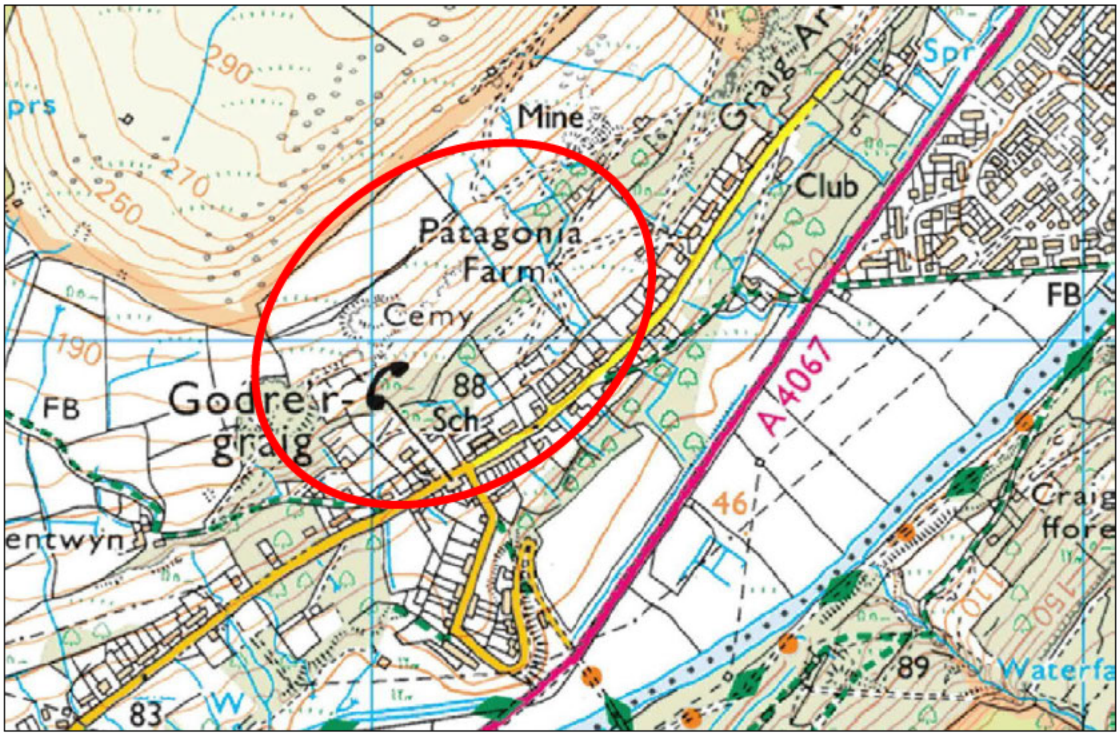
1 Introduction

1.1 Background

Neath Port Talbot County Borough Council (NPTCBC), hereafter known as the Client, have instructed Earth Science Partnership Ltd (ESP) to undertake a preliminary investigation and additional assessment of a Spoil Tip on the slopes above Godre'r Graig Primary School (the School), located in the Tawe Valley.

The general location of the study area is shown on Insert 1 below.



Insert 1: Wider Study Area 1:10,000 (Ordnance Survey License No.: AL100015788).

The Wider Study Area is located on the eastern flank of Mynydd Allt-y-grug, between Pontardawe and Ystalyfera. The approximate National Grid Reference for the school is (SN) 275155 206870 and the postcode is SA9 2NY.

This report follows on from a Preliminary Landslide Hazard and Risk Assessment undertaken by ESP in August 2019. The preliminary report assessed the risk of natural landslides and man-made hazards across in the Wider Study Area on the slopes above the school, the Wider Study Area is generally defined in Insert 1 above. The full report is displayed in Appendix A and salient information is included in the following sections.

The previous assessment examined the Wider Study Area for evidence of shallow slips and any other landslides hazards that may impact upon the school. The assessment concluded that the risks to the school from natural hazards were considered to be very low, or implausible. However, there was considered to be a moderate risk to the school from the Quarry Spoil Tip upslope of the school.

As part of the previous assessment, The Coal Authority visited the site and some of their pertinent recommendations for this assessment included:

- Consider clearing vegetation to allow inspection of drainage routes at the Quarry Spoil Tip (their Site 2 – see Section 2.2);
- Ensure drainage infrastructure to the rear of Godre'r Graig Primary School is regularly inspected and maintained;
- Consider undertaking a slope stability analysis for the Quarry Spoil Tip (their Site 2) based on available information supplemented by ground investigation; and
- Undertake an inspection during winter, when vegetation has died back to allow a more detailed viewing of the site with less vegetation constraints. The requirement for further inspection should be determined following the winter inspection.

Information from the previous report is included in this assessment where necessary to reduce the need to reference our previous report, however, it would be prudent for the reader to have knowledge of our initial report as an introduction.

1.2 Objective and Scope of Works

The aim of this assessment is to develop further understanding of the historical and existing ground conditions of the Quarry Spoil Tip above the school and assess the hazards and risks that the Quarry Spoil poses to the school.

The scope of works for the investigation was mutually developed with the Client and ESP within an agreed budget, and comprised:

- A detailed geological and historical desk study;
- Obtaining aerial photograph and subsequent interpretation, including stereographical analysis;
- Vegetation clearance to provide access for site investigation works and visual assessment;
- Generation of a morphological map with the assistance of a topographic survey;
- Geophysical survey of the quarry spoil to help delineate the extents and depth of the tip;
- Site investigation to include trial pitting, cable percussion and rotary boreholes, geotechnical testing, installation and monitoring of slope and groundwater monitoring equipment;
- Generation of a conceptual engineering geological model; and
- A slope stability assessment of the quarry spoil tip alongside recommendations for next steps.

The exploratory hole density and coverage does not meet standard development requirements (e.g. Eurocode 7 or BS:5930) due to land access restrictions and costs. However, the scope of works has been designed to provide an indication of the ground conditions at key locations and to provide suitable detail for our assessment.

The contract was awarded based on a competitive tender quotation. The terms of reference for the assessment are as laid down in the Earth Science Partnership proposal of 14th May 2019 (via email). The assessment, including a brief period of monitoring was undertaken in May 2019 to January 2020.

1.3 Report Format

This report includes a summary of the previous investigation, detailed geological and historical desk study including the findings of aerial photography interpretation and detailed geomorphological mapping. Details of the site investigation, monitoring and a detailed ground conceptual model are discussed in Sections 4 and 5 alongside a preliminary slope stability assessment. This report is issued in a digital format only.

1.4 Limitations of Report

This report represents the findings of the brief as detailed in Section 1.1. It should be appreciated that only a limited intrusive investigation has been undertaken to date. Should an alternative current land use or structure be considered, the findings of the assessment should be re-examined relating to the new proposals or land uses. Where preventative, ameliorative or remediation works are required, professional judgement will be used to make recommendations that satisfy the site-specific requirements in accordance with good practice guidance.

Consultation with regulatory authorities will be required with respect to proposed works as there may be overriding regional or policy requirements which demand additional work to be undertaken. It should be noted that both regulations and their interpretation by statutory authorities are continually changing.

This report represents the findings and opinions of experienced geo-environmental and geotechnical specialists. Earth Science Partnership does not provide legal advice and the advice of lawyers may also be required.

As discussed in Section 1.1, this report encompasses the study area previously referred to as 'Site 2' (ESP, Aug 2019) comprising the quarry spoil tip upslope from Godre'r Graig Primary School, the quarry above and the immediate surrounding vicinity.

Given the nature of the site, a number of limitations were imposed on the investigation. Limited access to the site was primarily due to constraints posed by dense vegetation and steeply sloping ground. Works were only carried out where safe access and working areas could be achieved. Vegetation clearance was undertaken to gain access to previously inaccessible areas however, a large proportion of the study area remains covered with vegetation and, limited, to no investigation was undertaken in these areas. Intrusive investigation (e.g. trial pits and boreholes) could only be undertaken in areas of cleared vegetation and were it was safe to do so. All of the vegetation clearance was undertaken by hand due to the steepness and inaccessibility of the site for plant. Therefore, it was not possible to clear the entire site by hand in the timeframe of the investigation.

Due to the private land ownership of access routes to the investigation area, extensive and careful planning was required at every stage which resulted in an extended time frame for the investigation. Given the difficult nature of the site, a number of investigation options were reviewed extensively taking into consideration many factors including but not limited to, Health and Safety, the effectiveness of the method and the reasonability of costs.

Our assessment was required in a relatively short period time and this placed some limitations on the amount of monitoring time available to feed into the ground model and assessment. At the time of writing, on a short period of monitoring has been undertaken and this may have missed some seasonal variations in the groundwater regime, or perhaps seasonal movement of the tip has not been identified. The monitoring should be continued, and the assessment should be updated accordingly.

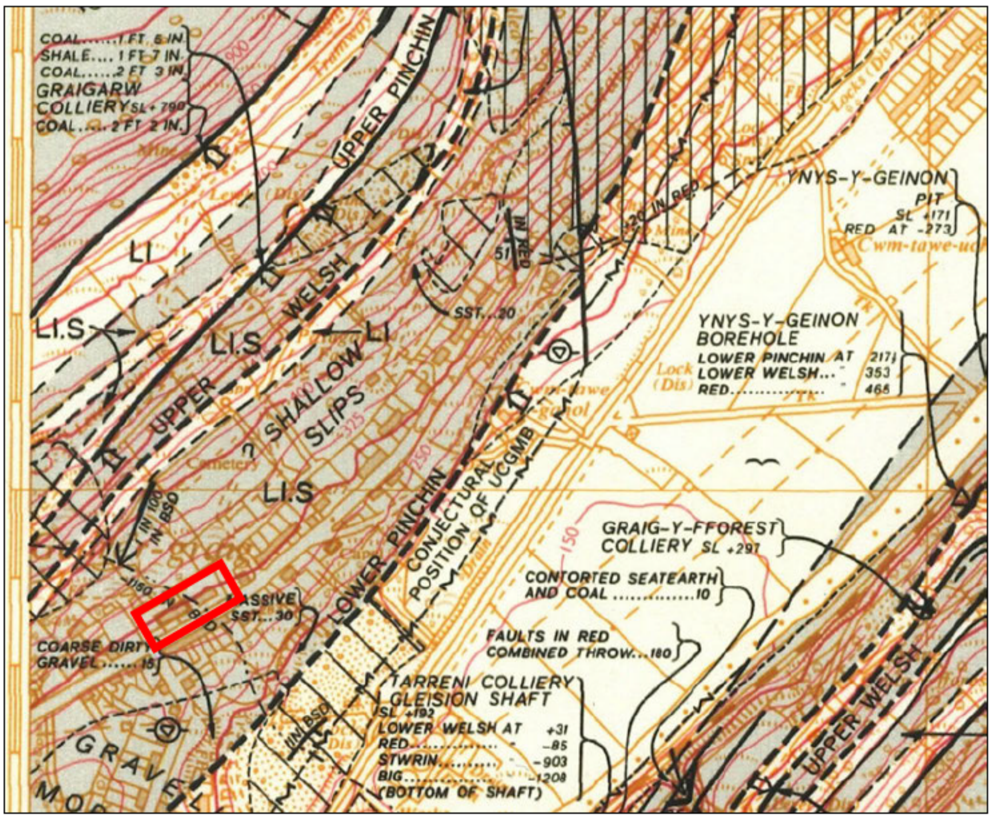
2 Previous Investigation and Assessment

2.1 Earth Science Partnership, August 2019

This report follows a Preliminary Landslide Hazard and Risk Assessment undertaken by ESP in August 2019. The preliminary report assessed the risk of natural landslides and man-made hazards across the wider area on the slopes above the school. The full report is displayed in Appendix A and salient information is included in the following sections.

The study area for the preliminary assessment was determined following a review of geological mapping of the area (SN 70 NE) which indicates an area of 'shallow slips' some 250m northeast of the school. The location of the shallow slips in relation to the school is shown in Insert 2, which is an extract of the geological map for the area. The area of the shallow slips is not defined, there is a '?' prefix to the shallow slips, suggesting some uncertainty to the location, or perhaps the presence of such features.

There is no record of these shallow slips in the South Wales Landslip Survey by Conway et al in 1980.



Insert 2: Geological Map extract. Red rectangle shows school location. (BGS licence number: C15/05 CSL) Not to scale

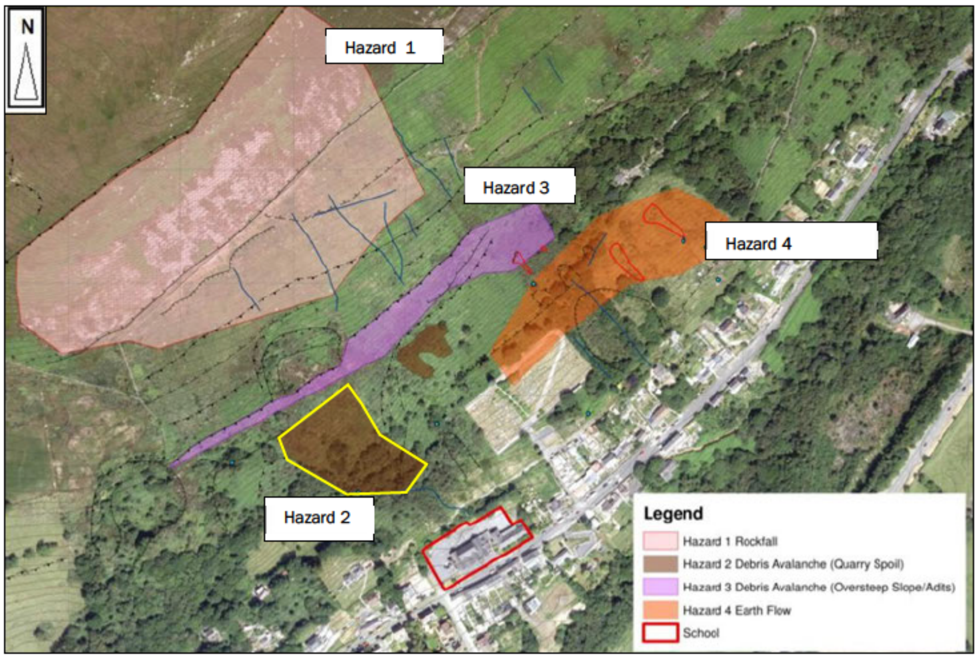
2.2 Desk Study

The assessment included a preliminary desk study alongside review of aerial photography and preliminary morphological mapping. The salient information from the desk study is discussed further throughout this report.

2.3 Hazard Identification and Risk Assessment

A Landslide Hazard and Risk Assessment for the terrain above the school was undertaken primarily to identify risks from potential landslides. The assessment identified four types of landslide hazards in the study area, two of which are natural and two are man-made. The hazards are outlined below, and their locations shown on Insert 3:

- Hazard Type 1: Rock fall initiating from outcrops of the Rhondda Sandstone
- Hazard Type 2: Impact from debris avalanche initiating from quarry spoil.
- Hazard Type 3: Impacts from debris avalanches originating from the over steep slope associated with the working of the Upper Pinchin seam.
- Hazard Type 4: Shallow earth slides.



Insert 3: Extract from Hazard Location Map taken from previous report ESP, 2019. Site 2 is highlighted in yellow.

2.4 Site Investigation

An exploratory site investigation was undertaken comprising trial pits and windowless sampling boreholes and the installation of groundwater monitoring wells. The preliminary investigation was limited to the area between the spoil tip and school due to access restraints. The investigation therefore only provided meaningful information for Hazard 4, however, the information from the assessment has been used to populate our Ground Model.

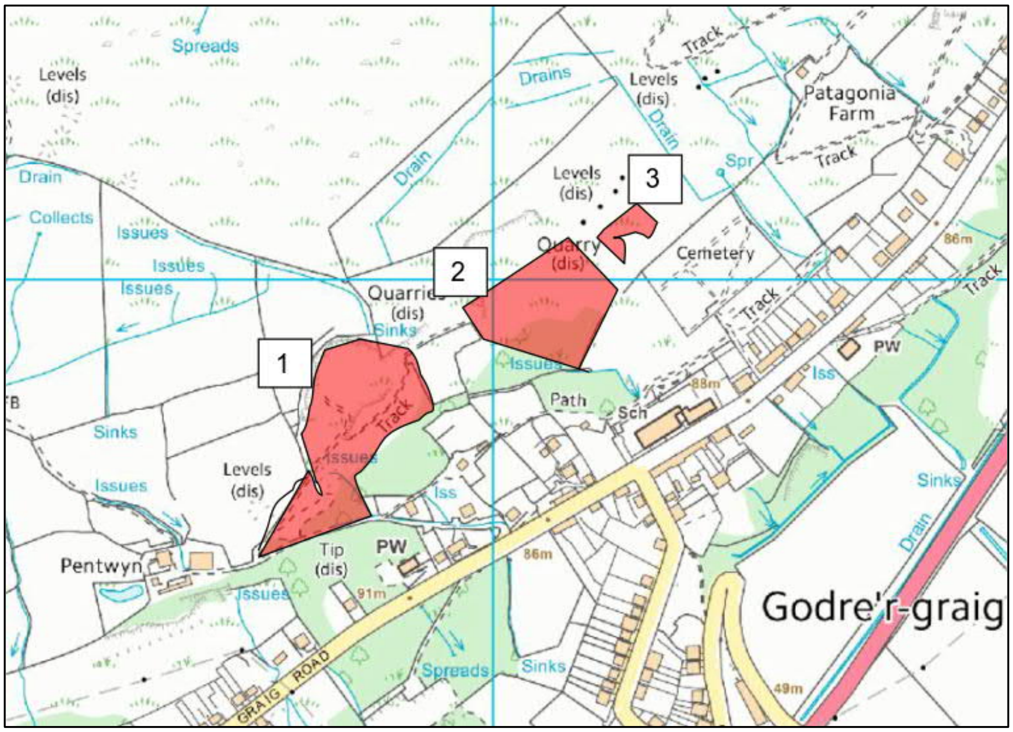
The investigation identified topsoil over Diamicton with pockets of Made Ground. During the works and subsequent groundwater monitoring identified an inconsistent groundwater body within the Diamicton, the main groundwater body is anticipated within the underlying bedrock.

The full report is displayed in Appendix A and salient summarised below in the following sections.

2.5 Coal Authority Recommendations

As part of the Preliminary Landslide Hazard and Risk Assessment (ESP, Aug 2019), the Coal Authority were instructed to undertake an inspection of the quarries and tips in the study area. The purpose of their inspection was to provide an assessment of stability and relevant safety issues.

The Coal Authority visited the Wider Assessment Area (Insert 1) and suggested that there were three coal tips, or sites as shown in insert 4 below.



Insert 4: Extract from Coal Authority Report. Site Locations shown by red polygons.

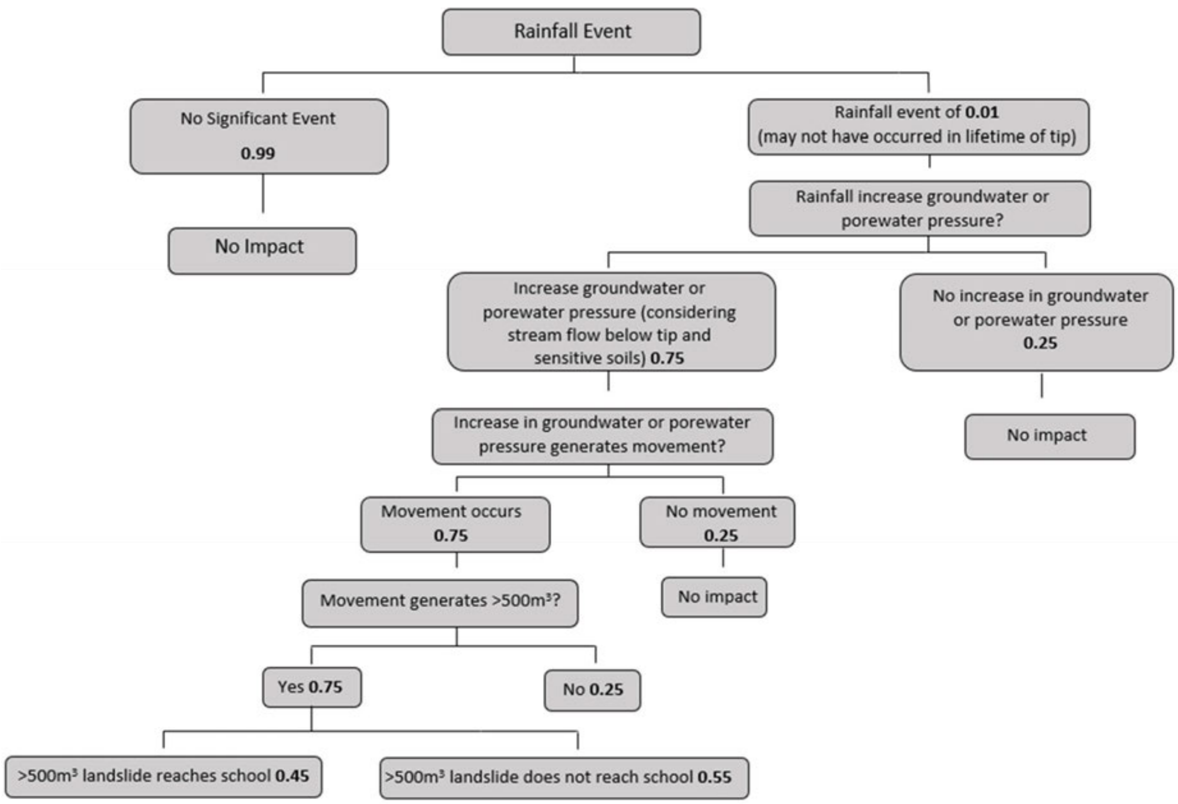
The Coal Authority provided recommendations, considerations and actions for all three sites, however, pertinent recommendations for their site 2, which is the Spoil Tip above the school are replicated below:

- Although they suggest it unlikely, they speculated that a major failure of the spoil tip would be able to reach Godre'r Graig School;
- Consider clearing vegetation to allow inspection of drainage routes at Site 2;
- Consider undertaking a slope stability analysis for Site 2 based on available information supplemented by ground investigation; and
- Undertake an inspection during winter, when vegetation has died back to allow a more detailed viewing of the site with less vegetation constraints. The requirement for further inspection should be determined following the winter inspection.

2.6 Preliminary Conclusions

It was concluded that Hazards 1, 3 and 4 posed no or very low to low risk to the school.

In order to assess the risk from Hazard 2, "impact from debris avalanche initiating from quarry spoil", an event tree was produced to provide a qualitative, indicative value of approximate annual probability for such an event occurring. Based on the event tree and the qualitative risk analysis matrix detailed in the previous report (ESP, 2019 -Section 7), a medium risk was identified.



Using the probabilities assigned in the event tree, for a 1 in 100 year rainfall event (which is equivalent to 0.01), it suggests that the estimated annual probability of a landslide hitting the school is 0.0019, or $1.9x10^{-3}$.

This annual probability correlates to a 'possible' likelihood i.e. the event could occur under adverse conditions over the design life. Using a consequence of 'moderate', for a >500m^3 landslide hitting the school, the qualitative risk assessment is of medium risk.

The AGS guidelines state that a medium risk may be tolerated in certain circumstances (subject to regulatory approval) but requires investigation, planning and implementation of treatment options to reduce the risk to low.

3 Site Overview

3.1 General Topographic Setting

The Quarry Spoil Tip is located in the Tawe Valley, on the eastern flank of Mynydd Allt-y-grug, between Pontardawe and Ystalyfera. From the River Tawe at the bottom of the valley the slopes are initially steep becoming shallower uphill towards the village of Godre'r Graig. Beyond Graig Road going uphill the slopes become increasingly steep.

The topography of the area slopes downward toward the southeast from the relatively steeply sloping, eastern flank of Mynydd Allt-y-grug to the west. The Tawe Valley generally forms a typical U-shape valley, however, there appears to be a gently stepped nature to the valley side, and this is likely to represent the harder and softer layers of bedrock (sandstone and mudstone) weathering at different rates.

The topography has been altered by man with two large quarries noticeable in the vicinity of the site, and numerous other mining features which has generated steeper slopes and spoil mounds.

The site description is largely based a number of field reconnaissance and site inspection visits made throughout the duration of the investigation during variable weather conditions. General views of the site are included as a series of photographs within the Plates section of this report, the location of each photograph is displayed on Figure 1a.

The Wider Study Area comprises the land downslope of an old quarry on the lower slopes of Mynydd Allt-y-grug. The slopes underlying layered bedrock of the Lynfi Beds comprising sandstone and mudstone has results in a gently stepped topography which has since been anthropogenically modified and over-steepened as a result of quarry spoil tipping. General views from the upper slopes area displayed as Plates 1 to 3 in the Plates section of the report. A cemetery, with an associated small car park is located some 50m north of the school and to the east of the Quarry Spoil Tip. The cemetery has a stone wall boundary and a concrete track providing access to the higher portions of the cemetery.

The land immediately to the rear of Godre'r Graig Primary School for approximately 40m generally comprises an access track with grazing land beyond which is separated into several fields by post and wire fences, see Plate 4.

Beyond the grazing land behind the school, the area is wooded for some 100m as you ascend the valley side. The slopes of the quarry spoil tip and the base of the quarry is generally covered by bracken, brambles and gorse and is generally overgrown. North of the quarry, further grazing is noted near to the base of a scree, or talus slope on the upper parts of Mynydd Allt-y-grug, and this is separated by a dry stone wall.

3.2 Quarry Spoil Tip Extents

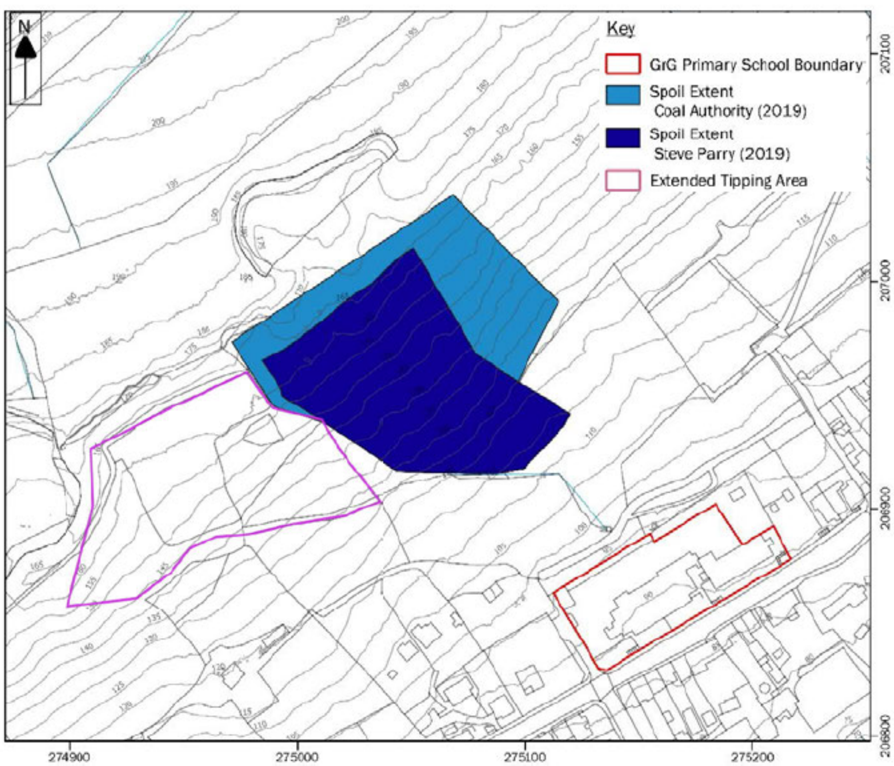
Preliminary boundaries of the spoil tip were identified as part of the preliminary hazard assessment (ESP, 2019). The spoil tip extents have been updated throughout the investigation, these are summarised in Table 1 below and displayed in as inserts in the following sections. The preliminary extents identified as part of the previous investigation (Section 2.1) are shown below in Insert .

An Extended Tipping Area was identified during the detailed review of historical maps, aerial images and on site observations following the vegetation clearance works, the approximate extent of the extended area is displayed on Insert 5 below. At this stage the area has been visually inspected only and no intrusive investigation has been undertaken.

Table 1: Summary of Preliminary Spoil Extent boundaries.

Source	Figure/Insert No.	ESP Comment
ESP/PEGS (2019)	Insert	Spoil extents as displayed in report by ESP/PEGS (2019).
Coal Authority (2019)	Insert	Spoil extents as displayed in report by Coal Authority (2019)
Historical Mapping	Insert	Spoil extents predominantly based on 1:2,500 map dated 1877.
Aerial Photography	Insert	Spoil extents based on aerial photographs dated 27th May 1952

Notes on Table 1:
1. Spoil extents as identified in reports by ESP/PEGS and Coal Authority (2019), are detailed in the appendices of the ESP 2019 report (Appendix A).



Insert 5: Preliminary Spoil Extent Boundaries identified by the Coal Authority and ESP/PEGS (2019).

3.3 Quarry Tip Spoil Area Description

Following vegetation clearance, detailed geomorphological mapping and site investigation, a more comprehensive boundary of the quarry spoil was delineated and is displayed on Figure 2. To aid the following descriptions, items of interest (quarries, mine adits and springs) have been labelled/itemised to help reference individual features and show their change throughout time as this ties into the historical review in following Sections. For ease of reference, Figures 3 and 4 labels the quarries (Q), mine entries (M), and spring (S) locations.

The key site observations identified throughout the field mapping are outlined below.

- Generally, across the Quarry Spoil Tip there are no obvious terraces which is indicative of the man-made conditions under which the material was placed in an organised manner. In the lower portions of the tip, the ground surface generally appears hummocky whilst in the area beyond the Quarry Spoil Tip to the south, the site surface is smoother or with clear terraces (Figure 2).
- Quarry spoil is visible across the site surface and generally comprises interlocking, angular and tabular boulders and cobbles of weak to medium strong sandstone. In the lower portions of the slopes, there is evidence on the site surface of groups of loose angular sandstone cobbles and boulders (Plate 13).
- A distinct mound of material adjacent to the western stream (S3) was identified as potentially being anthropogenically modified, possibly in relation to the drainage in the area (Plate 14).
- A number of streams previously identified on historical mapping have been observed on site with smaller tributaries also observed issuing from the base of the spoil tip. Areas of saturated ground were also noted at the base of the tip as shown on Figure 2 and Plates 15 and 16.
- Streams S2 and S3 (Figures 2 and 3) were identified on site on the eastern and western boundaries of the quarry spoil tip respectively. The extents of the streams do not fully correlate with that identified in the historical mapping. Both streams are shown on historical mapping (~1877, Figure 3) to emanate significantly higher upslope. Stream S2 was observed on site to appear approximately halfway down slope from its previously mapped position. Similarly Stream S3 was identified intermittently in the upper portions of the slope until approximately halfway upslope where a distinct stream was observed on site.
- Stream S3 likely relates with the stream detailed by the Coal Authority in their report (2019). On-site observations by ESP generally correlate with those of the Coal Authority, the stream is intermittently present in the upper portions and is noted to emanate approximately halfway downslope as a defined stream. Vegetation clearance works allowed for the defined stream to be mapped significantly further upstream by ESP. The initial spring source was previously identified by the Coal Authority in the location of a mine adit (M1), on-site observations by ESP differs slightly with source located approximately 40m to the west. In keeping with the Coal Authority, the stream was observed to enter the Quarry Spoil Tip in the upper portions of the slope and could not be fully traced.

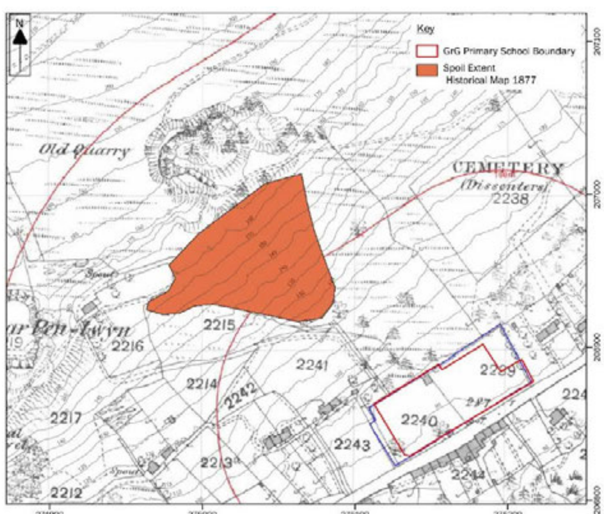
- A 1 to 2m high vertical break in slope was noted immediately west of the spoil tip and is considered to be related to the historic route of stream S3.
- Coal was present at ground surface immediately northwest of the boundary in the location of a former quarry/mine entry (M1) (Plate 17 and Figure 2).
- The angle of the slope surface was measured using both a Range Finder and compass clinometer. The slopes of the spoil material ranged between 20 to 35° with steeper angles recorded at the base/toe of the slope, between 35 to 40°. The land downslope of the spoil material typically had a slope angle between 14 to 20°.
- The northern extent of the spoil material was less defined due to the presence of historic adits and presumed associated spoil material (Figure 2).
- During the trial pitting, a land drain was encountered in TP104 at a depth of 1.2m. The trial pit (TP104) was located at the base of the Quarry Spoil Tip, as shown on Figure 5.

3.4 Site History

The site history has been assessed from a review of available historical Ordnance Survey County Series and National Grid maps alongside an Aerial Photograph Interpretation (API). Throughout the historical review, items of interest (mining and springs) have been labelled/itemised to help reference individual features and their change throughout time. For ease of reference, the streams (S) and mining (M) features are highlighted on Figures 3 and 4 respectively.

3.4.1 Historical Mapping

The site history has been assessed from a review of available historical Ordnance Survey County Series and National Grid maps. The historical maps are presented in Appendix B and the salient features since the First Edition of the County Series maps are summarised below in Table 2. An extract of the 1877 historical map is displayed below in Insert .



Insert 6: Preliminary Spoil Extent Boundaries identified from historical mapping (1:2,500 scale map, published 1877)

Table 2: Summary of historical maps

Map Date	ESP Comment
1877	Graig road in its current day position with houses either side. The school has not been constructed. The cemetery is shown some 50m north of the school, an Old Quarry (Q1) is shown some 200m northwest of the school and another quarry labelled as Cwar Pen-tywn Quarry is sown some 220m west of the school. The Old Quarry (Q1) some 200m northwest of the school is shown to have an access track trending east/west along the base of the quarry. The map indicates that the area of the spoil heap comprises woodland with boulders. A stream (S2) originating near spoil mounds of the quarry some 200m to the northwest flows towards the southeast and intersects with the northern boundary of the school. A second stream (S3) originates from a spring located near the western quarry (Q2), some 250m northwest, which flows toward the east and also intersects the northern boundary of the school. A spout is shown downstream at 200m northwest. A number of other springs and streams are indicated within 500m north, northwest and west which typical trend northwest to southeast.
1897 - 1918	By 1897, coal levels to the north, northwest and west were common with the majority shown within 500m of the school. The school was constructed between maps dated 1899 and 1913. The 1899 map indicates that the springs northwest and west of the school (S2 and S3) now originate from positions further downslope of the Old Quarry. The track at the base of the quarry is no longer shown. The area of the spoil heap is shown to be trees and heath land. The spout associated with stream S3 is no longer shown. In 1918, a previously labelled old coal level (M1) between Cwar Pen-twyn Quarry (Q2) and the Old Quarry (Q1), is shown as a quarry (Q3). There are several mounds or spoil heaps shown in relation to the quarry to the west (Q3) and Cwar Pentwyn quarry (Q2) to the northwest.
1960 - 1993	The 1960, 1:2,500 historical map provides good detail on the mining entries from the north to the west of the school, some six mine adits (M2 – M7) are shown approximately 190m west of the school boundary, the coal levels are shown as disused. The 1960 map shows streams S2 and S3 originating from issues some 80m north and northwest of the site. In 1993, the issues and stream (S2) is no longer shown. Cwar Pentwyn quarry (Q2) to the west of is labelled as disused on the 1964 map, so became disused between 1948 and 1964.
2002 - present	No significant change shown.
Notes to Table 2: 1. Extracts from historical maps presented in Appendix B. 2. Features may have been present on site between the dates of the individual mapping, and it should be appreciated that these cannot be identified from the map review. 3. Surface water features indicated on Figure 3 and mining features shown on Figure 4.	

The historical maps shown that the Old Quarry (Q1) north of the school was worked prior to 1877 (earliest map) when it is labelled as an 'Old Quarry'. Quarrying of Cwar Pentwyn Quarry (Q2) is shown as early as 1877 and continues until at least 1964 when the quarry is labelled as disused. The quarry to the northwest (Q3) is shown to be active from 1918, the quarry is not labelled from 1960 onwards and is likely disused. Coal levels (M2 – M7) northeast of the school are shown in detail as disused in 1960 suggesting mining occurred between 1948 and 1960.

3.4.2 Aerial Photography Interpretation

An Aerial Photograph Interpretation (API) of historical aerial photographs supplied by ESP has been undertaken. The photographs evaluated are documented in Table 3.

All the aerial photographs were reviewed to evaluate any changes through time, as well as anthropogenic modification that could induce instability. A selection of the photographs were stereographical pairs, others were single images, and both have been used in this assessment, the below lists the aerial photographs studied in this assessment.

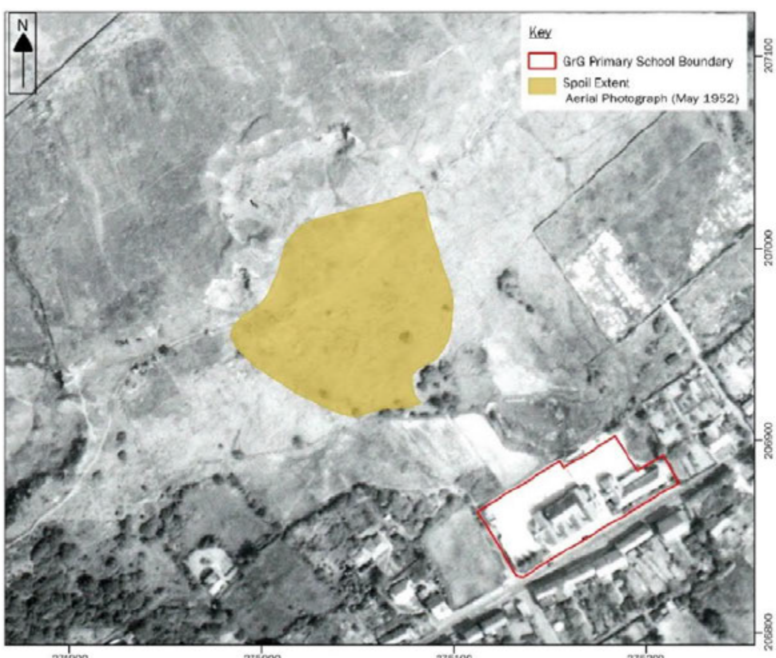
The photographs were reviewed upon a comparison of shape, colour, tone, size and pattern and stereographical analysis was done using a Geoscope stereoscope with 1.2 and 4 times magnification eye piece attachments.

A summary of the salient features identified on the aerial photographs is provided below in Table 4 with an extract from the May 1952 photograph shown below as Insert .

Table 3: Summary of aerial photographs studied

Date	Sortie No.	Type of Photograph and Frame Number	Comments
3 August 1945	3G TUD T19PtII	Stereo Pair (5075, 5076)	Enlarged photographs, good detail although 5076 marginally out of focus.
22 May 1948	541 RAF 41	Stereo Pair (4173, 4174)	Low detail
27 May 1952	540 RAF 758	Stereo Pair (5032, 5033)	Good detail
14 April 1955	58 RAF 1715	Stereo Pair (302, 303)	Low detail
21 April 1960	58 RAF 3506	Aerial Photo	Low detail
14 April 1962	OS 62 014	Stereo Pair (37, 38)	Low detail
16 May 1973	OS 73 175	Stereo Pair (26, 27)	Low detail
24 April 1975	OS 75 037	Stereo Pair (106, 107)	Low detail
9 June 1975	OS 75 211	Stereo Pair (149, 150)	Low detail
7 April 1978	OS 78 009	Stereo Pair (23, 24)	Low detail
30 May 1982	OS 82 136	Stereo Pair (108, 109)	
30 August 1983	MAFF 218/83	Stereo Pair (71, 72)	Good detail
8 June 1984	MAFF 76/8	Stereo Pair (408, 409)	
14 June 1989	OS 89 279	Stereo Pair (034, 035)	
7 Sept 1989	OS 89 408	Stereo Pair (61, 62)	
11 April 1994	13 94	Stereo Pair (197, 198)	Low detail
9 April 1997	OS 97 090	Stereo Pair (57, 58)	Good detail

Notes on Table 3:
1. A selection of the above aerial photographs are provided in Appendix D.
2. The photographs and stereo images are generally black and white until the mid-1990s when colour photographs become widely used.



Insert 7: Preliminary Spoil Extent Boundaries identified from aerial photography (27th May 1952, Stereo Pair -5032, 5033).

Table 4 :Review of Aerial Photographs

Date	Comments
3/8/1945	The arc of the quarry (Q1) highwall northwest of the school is clearly visible with a dark area in the centre of the quarry. A lighter area south of the quarry looks to define the spoil heap as darker tones possibly representing natural undisturbed ground are present downhill and to the west and east edges of the quarry. The stereo photographs show no definition (breaks of slope for example) to the tip. Lighter tones probably associated with workings in mine adits (M2 – M7) to the east of the quarry (Q1) are evident. (Note. Image 5076 is out of focus for stereo analysis).
22/5/1948	Photo quality is poor. No obvious changes observed.
27/5/1952	The images provide relatively good detail, although tone changes are slight as the range in tone is small. The boundary of the tip is not easily observable through differences in tone; however, stereo analysis shows a slight break in slope at a similar extent of the previously identified tip boundary (1945 image), suggesting it not to have moved. The quarry walls (Q1) are grey (rather than light/high reflectance) possibly suggesting that they have not been worked recently. The whole tip has a mottled appearance with some possible breaks of slopes indicated on the area of the spoil heap trending east/west. In the north western corner of the tip, there is a roughly circular area of high reflectance suggesting recently placed soil or possible some form of instability, however, there are no obvious morphological features are identifiable (such as a small scarp). Streams look to be well developed including streams S3 and S2, darker tones of ground noted around these. The fields above the school are darker in tone and there is some evidence of anthropogenic modification between the school and cemetery.
14/4/1955	The photographs are generally of poor quality. Differences in tone generally confirm the outline of the Quarry Spoil Tip and no significant changes to the spoil mound identified.
21/4/1960	Generally poor detail and no obvious signs of movement. Photographs shows the quarry and spoil heap with no significant changes.
14/4/1962	Poor detail. No significant changes to the spoil mound identified.
16/5/1973	Poor detail. No significant changes to the spoil mound identified.
24/4/1975	Poor detail. No significant changes to the spoil mound identified.
9/6/1975	Poor detail. No significant changes to the spoil mound identified.
7/4/1978	Poor detail. No significant changes to the spoil mound identified.
30/5/1982	Poor detail. No significant changes to the spoil mound identified.

30/8/1983	The photos provide good detail in comparison to other images. Extents of the quarry high wall are clear, and a mound is evident within the quarry (Q1). The different tones from the vegetation clearly defines the quarry spoil downslope of the quarry, the extents of the tip look to be similar as previously noted in previous images. There are tone changes within the tip which look to be associated with different vegetation coverage. The lighter areas appear to be 'bare', suggesting poor vegetation growth on the tip, these could be signs of movement inhibiting vegetation growth. The tips associated with the mine adits to the east of the Quarry Spoil Tip are visible, and whilst lighter in tone than the surrounding undisturbed ground, they are darker than the possible 'bare' soil on the tip. Streams look to be well developed including streams S3 and S2, darker tones of ground noted around these. An area of darker tones is shown at the base of the hill and is likely related to undisturbed vegetation.
8/6/1984	Poor detail. No significant changes to the spoil mound identified.
14/6/1989	The images provide good detail and shows an increase in vegetation cover over the spoil heap downslope from the quarry. The stereo photographs show a hummocky nature to the spoil heap but no sign of obvious movement.
7/9/1989	Good detail on photographs however poor 3D appearance in stereopair. The tip boundary remains the same, but the vegetation again appears mottled, the upper portions of the slopes appear light in tone suggesting less vegetation growth as a result of movement or modification. These areas of lighter tone do not correspond with areas previously noted in the 1983 aerial photo. Again, it may be that the tonal changes are due to bare soil exposed by movement, or it is simply that vegetation is not able to grow regularly across the variable tip material, probably containing little organic matter.
11/4/1994	Colour photograph and poor detail. The area of the quarry is green with the mound downslope slightly brown with dark vegetation.
9/06/1997	Good detail. No significant changes to the spoil mound identified.

Overall the API shows a good boundary of the Quarry Spoil Tip through time however lacked detail in the areas known to be associated with historic adits.

The API identified areas of lighter tones possibly indicating areas of bare soil on the tip, particularly in the upper portions. This may be result of generally poor vegetation cover although it could be sign of instability. The API shows no signs of obvious movement however, tonal changes possibly show variations in vegetation growth or could possibly be a sign of small scale movement within the tip.

The aerial photographs look to shown that there are no large scale anthropogenic changes to the tip.

As discussed in section 3.4.1, there is no evidence of water storage tanks northeast of the school on the aerial photographs.

3.5 Preliminary Ground Model

3.5.1 Introduction

The study area comprises the spoil heap associated with an old quarry on the lower slopes of Mynydd Allt-y-grug. The slopes underlying layered bedrock of the Lynfi Beds comprising sandstone and mudstone has results in a gently stepped topography which has since been anthropogenically modified and over-steepened as a result of quarry spoil tipping.

As discussed in Section 4.1.1 below, vegetation clearance works were carried out in order to enable better access to the quarry spoil tip. Following the clearance works, a topographic survey was undertaken alongside detailed geomorphological mapping of the study area, these are discussed in further in the following sections.

3.5.2 Topographic Survey

As part of the assessment, a topographic survey of the study area was carried out by John Vincent Surveys Ltd on behalf of ESP between 3rd and 4th October 2019. The purpose of the survey was to gain a more detailed understanding of the topography of the study area, including the slope steepness as well as providing a detailed plan of the streams within the study area. The survey was limited due to dense tree cover and vegetation and was only undertaken in areas where vegetation had been cleared, however the survey provided useful and meaningful information for our assessment at this stage. The topographic survey is displayed in Appendix D.

The topographic survey indicates the site slopes from northwest to southeast from the top of the quarry wall to the school wall in the south eastern corner. The levels along the top of the quarry wall in the north western portion vary between 176m OD on the side walls and 194m OD in the most central point; the quarry wall is approximately 17m in height.

The survey indicates that the top of quarry spoil tip is at around 176m OD at its maximum, falling in elevation to about 108m OD at the base of the tip. At the base of the slope (i.e. off the tip) the levels are generally more consistent with the southern fence boundary at 97m OD and the school wall at 95m OD.

Due to dense vegetation, limited information is available for the spoil present in the plateau of the quarry however, based on the information available, the quarry floor is at approximately 170m OD with a central mound approximately 7m in height (177m OD in elevation).

The profile based on the topographic survey (Appendix D) shows a stepped profile from the edge of the quarry plateau to assumed base of the quarry spoil tip. The profile indicates that from beyond the base of the quarry spoil, the slope gradient is marginally shallower with a smoother profile.

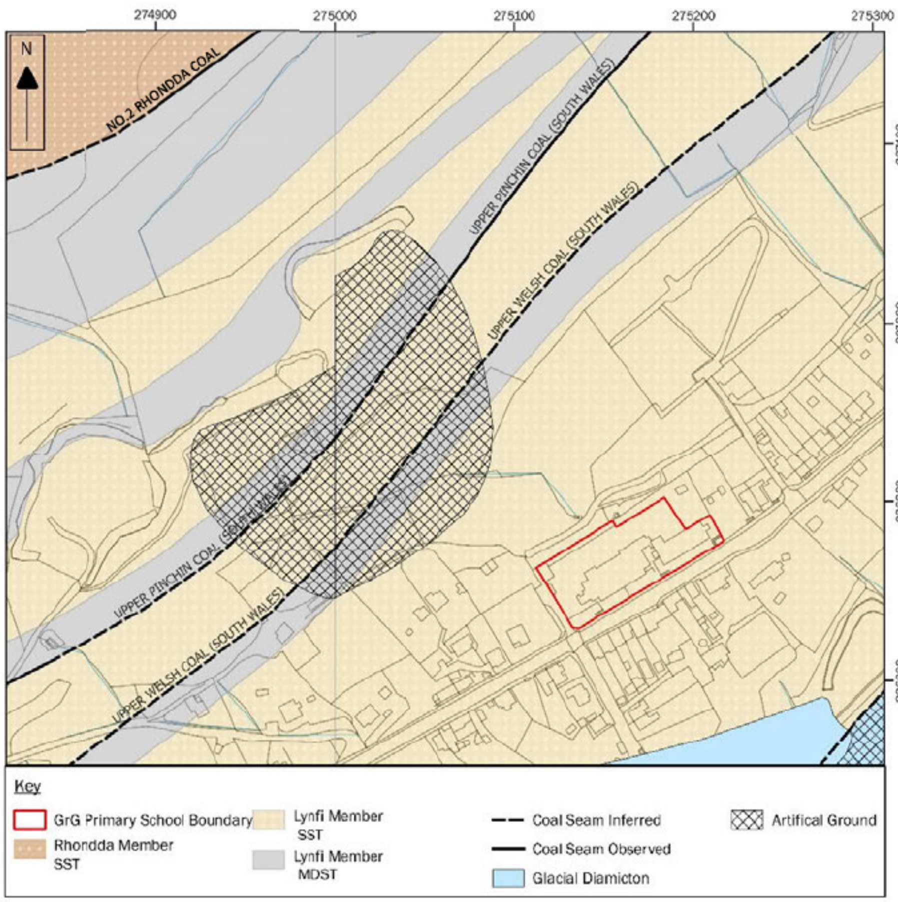
3.5.3 Geomorphological Mapping

Field mapping was undertaken by ESP on 18th November 2019 during sunny and dry conditions with the final engineering geomorphological map displayed on Figure 2.

During the site visit, items of interest identified in the desk study and preliminary assessment were inspected and all areas of the site were inspected for relatively recent, or old movement. The field mapping was generally limited to areas where vegetation clearance had previously been undertaken or where vegetation had died back. The site observations identified during the field mapping are discussed in Section 3.3 above.

3.5.4 Geology

The published 1:10,560 scale geological map for the area (Insert 2, Sheet SN 70 NE) indicates that the hillside is predominantly made up of the Upper Coal Measures (now formally known as the South Wales Upper Coal Measures Formation) which underlie a sandstone outcrop at the top of Mynydd Allt-y-grug of the Rhondda Member, which is part of the Pennant Sandstone Formation. The geology detailed in the 1:10,000 and 1:50,000 maps is shown below in Insert 8.



Insert 8: Geological setting of the site area interpolated from 1:10,000 (SN 70 NE) and 1:50,000 (BGS, 2019) scale geological maps.

The No. 2 Rhondda coal seam outcrops at the base of the Pennant Sandstone Formation and forms the boundary between the (older) Upper Coal Measures which underlie the school and the Quarry Spoil Tip, and the overlying (younger) Rhondda Beds which comprise sandstone.

The Upper Coal Measures comprises a series of units formally known as the Llynfi Beds, these are now referred to as the Llynfi Member and according to the Geological Memoir for the area, the Llynfi Member is essentially argillaceous, and contains sandstones bands within it that are generally thin and in-persistent.

The strata above the No. 2 Rhondda or roof rock in the overlying Rhondda Member is understood to be a Conglomerate.

The published 1:50,000 scale geological map for the study area (Sheet 230, available on the website of the British Geological Survey, 2020) generally confirms that above stratigraphy and shows the beds to be dipping toward the south at angles of between 3° and 5°.

As mentioned above the No. 2 Rhondda coal seam is situated high above the school, however there are other coal seams that outcrop in the hill side, which include the Upper Pinchin and the Upper Welsh. Another seam, the Lower Pinchin coal seam is likely to underlie the school at depth within the Llynfi Member. All these seams are widely worked in the area, noticeable in the location of the Upper Pinchin above the school. Study of the geological map and adjacent sheets has shown the potential for several other seams, between the No. 2 Rhondda and Lower Pinchin, which include the Paynes and the Pant Rhyd Y Dwr, however these are not mapped in the study area, they occur in the same sequence in nearby areas and they may or may not be present.

Both the 1:10,560 and 1:50,000 scaled maps of the area show no glacial or superficial deposits on the hill side above the school, however, Diamicton and Fluvioglacial deposits are shown in the Tawe valley. Recent workings by ESP in the Tawe valley has shown Glacial Diamicton further upslope than mapped and some covering of glacial deposits is likely.

3.5.5 Past Coal Mining

A detailed assessment of the coal mining risk in the area was undertaken as part of the Preliminary Landslide Hazard and Risk Assessment (ESP, 2019). A summary of the findings are outlined below.

As discussed in Section 2.1, the site is underlain by bedrock of the South Wales Upper Coal Measures, which contains several seams of coal (and bands of ironstone).

The Upper Pinchin and Upper Welsh coal seams are indicated to outcrop within the boundaries of the Quarry Spoil Tip. The published geological maps suggests that the Upper Pinchin seam is 2ft to 4ft (0.6 to 1.2m) thick and the Upper Welsh seam is 1ft to 2 ft (0.3 to 0.6m) thick.

The information obtained to date indicates a large amount of coal mining in the study area, it is likely that most of the mining concentrated upon the No. 2 Rhondda and Upper Pinchin, but other seams exist above and below the school which would also have likely been worked. The workings in the No.2 Rhondda and Upper Pinchin are most noticeable when considering the historical maps and mining data, spoil from quarries and adits accessing these coal seams have been placed on the landscape above the school, see Figure 4. Although no evidence of quarries or adits relating to the Upper Welsh coal seam was identified, it cannot be discounted that the seam has been worked in the past.

It should be noted that no evidence of coal seams or workings were identified during the trial pitting or drilling works.

A series of adits are shown on Figure 4 (M2 – M7) which have been collated from the geological sheet and historical mapping. The adits are linked to the out crop of the Upper Pinchin Seam in the upper portion of the quarry spoil material. As discussed in Section 3.3, coal was present at ground surface immediately northwest of the boundary in the location of a former quarry (Q3) and mine entry (M1) identified on the historical maps.

3.5.6 Hydrology

A review of the historical maps have showed a series of springs that emanate in the hillside above the school. They all flow downhill, toward the east or southeast. The descriptions, locations and changes of the streams discussed below are also shown in Figure 3; the reader is recommended to view this drawing in conjunction with this section.

The historical maps show that the tip was essential situated between two streams; stream S2 is located on the eastern side of the tip and stream S3 is located on the western side of the tip.

The historical maps show stream S2 to flow from the eastern extend of the quarry (Q1) located upslope of the school, and to flow downhill in a south-easterly direction. This stream is not shown on recent OS mapping. S2 was not observed along most of the eastern boundary of the spoil tip, as it may be covered by the tip. It was found to emerge near the base of the tip by an area of waterlogged ground and a series of small streams that go on to flow into a relatively well developed ditch that flows to the eastern end of the school, as shown on Figure 3.

Stream S3 is generally located along the western side of the spoil tip. The historical maps show it to originate near to Cwar Pentwyn Quarry (Q2) and to initially flow to the east, when it reaches the spoil tip it is shown to flow toward the southeast. The Coal Authority report (2019) suggested that this stream disappeared and reappeared in several locations. ESP site observations since the vegetation clearance was able to trace the stream along much of the western boundary of the tip, but it was not traceable near the northwestern corner of the tip, as shown on Figure 3. The lower portions of the stream S3 was located within a well incised ditch and as discussed in Section 3.3. Recent OS mapping also suggests that the stream now emerges further down slope than the 1877 historical mapping.

No water features or areas of wet ground were identified within the boundaries of the Quarry Spoil Tip.

Several small streams and areas of waterlogged ground were evident at the base of the tip, as shown in Figure 3. These smaller streams form, what look to be relatively young streams that join streams S2 and S3 downslope.

Recent OS mapping and information from the Coal Authority report (2019) suggest the presence of water issuing from old mine adits, such as Stream S8, see Figure 3.

It is possible that debris/spoil from the quarries has been placed on top of the springs and their streams masking them. An alternative reason for their change in emergence is mining, and mine drainage may have altered their pathway.

3.5.7 Hydrogeology

The combination of the geological setting and topography of the study area will dictate the hydrogeology. Generally, as discussed in Section 3.1, the wider study area is situated on the eastern flank on Mynydd Allt-y-grug in the Tawe Valley and water will most likely drain to the river which lies at the base of the valley.

Simplistically, Mynydd Allt-y-Grug is formed by sandstone (Rhondda Member) that overlies a series of mudstones, siltstones and sandstone beds of the South Wales Upper Coal Measures.

The sandstone units will be relatively more permeable (secondary porosity) than the underlying relatively argillaceous rocks and to a certain extent, the argillaceous rocks will limit downward migration of groundwater. The bedding planes of these strata all dip gently about 3° to 5° toward the south.

Whilst groundwater will percolate downward, due to gravity and primarily via fracture flow; some groundwater could also flow along bedding planes and near horizontal fractures and thus there may be a small component of groundwater flowing out of the eastern side of Mynydd Allt-y-Grug, into the study area. Spring lines will likely form where more permeable strata overlie less permeable strata and several springs within the study area are noted to mirror the outcrop pattern.

Spring lines may also occur in relation to coal seams, work ESP have carried out in the Tawe valley has indicated groundwater bodies associated with coal seams. In addition, any worked coal seams will likely provide a preferential pathway for groundwater to drain, and water will discharge through adits, which will form preferential pathways. Flow rates of water bodies associates with mine workings are likely to higher than natural springs. Given the presence of two coal seams that are likely to subcrop beneath the Spoil Tip, there is likely possibly two groundwater bodies that will be feeding into the tip, as the water is effectively 'trapped' by the tip to form a groundwater body within the tip.

The presence of several streams, and areas of standing water, or waterlogged ground at the base of the tip suggest that there is a body of water in the Spoil Tip. Visual observations made over various visits have shown water to flow out constantly, suggesting that it may be groundwater fed, rather than a flow in response to rain/infiltration alone.

4 Exploratory Investigation

4.1 Enabling Works

Due to the topography of the land and the dense vegetation covering, enabling works were required to clear vegetation and provide access for a detailed investigation. These are discussed further in the sections below.

4.1.1 Vegetation Clearance

Vegetation clearance works were carried out by a Arborum Ltd. on behalf of ESP between 30th August and 7th October 2019 with primary aim of providing access for site works and to allow for more detailed assessment and mapping of the area. The extent of the vegetation clearance is displayed on Figure 1.

Areas of vegetation were removed in order to provide a track upslope from the rear of the school to gain access to the low portions of the quarry spoil. Further clearance was carried out on the slopes of the spoil primarily focussed on providing access for the geophysical survey and intrusive ground investigation works i.e. trial pits and boreholes. An overview of the vegetation clearance is displayed within the Plates section of this report (Plates 5 to 8).

It Is understood that further vegetation clearance was undertaken by Neath Port Talbot County Borough Council primarily along the stream routes.

4.1.2 Access Track

In order to gain vehicular access to the study area for the site investigation, works were required to construct an access track.

An already existing track crossing to the rear of the primary school was initially utilised and following vegetation clearance, access for a machined excavator was gained to the lower portions of the slope, the lower access track is shown on Figure 1. The Quarry Spoil Tip was assessed as being too steep and unstable to safely track equipment to the required investigation area upslope and as such, a second track thought necessary.

In order to provide machine access to the upper portion of the slopes, a number of options were investigated. The upper access track was constructed through the former Cwar Pen-twyn Quarry (Q2), accessed off a private lane north of Graig Road. Vegetation clearance and excavation works were undertaken between 10th and 14th October 2019 by the Client to construct a track to the site investigation area allowing access for an excavator and drilling equipment.

4.1.3 Ecology

The vegetation clearance works were carried out in accordance with a methodology agreed by Neath Port Talbot County Borough Council ecology department.

4.2 Investigation Points

4.2.1 Introduction

Further intrusive investigation was undertaken between 15th October and 27th November 2019 in accordance with BS5930:2015 (method only) and was designed to identify the ground conditions of the study area and identify the extents of the quarry spoil tip.

Given previous walkover to the site, the investigation was designed so it could be reactive to emerging conditions and flexible to the available access. The below details the final approach to the site investigation but this occurred through several iterations after careful consideration to access, health and safety and information benefits/value.

The investigation comprised trial pitting, light cable percussive boreholes, dynamic sampling with rotary cored following on and the installation of monitoring wells including vibrating wire piezometers and inclinometers. A geophysical survey of the study area was undertaken by Terradat Ltd. and is discussed further in Section 4.6.

The exploratory holes were supervised and logged by an engineering geologist in general accordance with BS5930:2015. Descriptions and depths of the strata encountered are presented on the trial pit and borehole records in Appendix E and Appendix F respectively. The investigation point positions are shown on Figure 5.

The ground levels indicated on the investigation point records are approximate only and have been interpolated from the topographical survey (Appendix D).

4.2.2 Investigation Limitations

The investigation points were limited due to the steeply sloping nature of the site as well as dense vegetation and poor ground conditions. The trial pits and boreholes were carried out in areas where vegetation clearance had previously been undertaken and sufficient level ground was present enabling works to be carried out safely.

3no. boreholes (BH01 to BH03) and 2no. trial pits (TP101 to TP102) were undertaken in the upper portion of the spoil tip, along the upper line of vegetation clearance. 1no. borehole (BH04) was undertaken downslope along the middle line of vegetation clearance.

A cut-down cable percussion drill rig was used to carry out the boreholes on site which allows for the rig to be man-handled to a position. In order to access the middle portion of the slope (BH04), a tracked excavator and winch were required to lower the cut-down rig and tools to a level platform identified during vegetation clearance. Due to the steeply sloping and uneven nature of the ground surface in this area, only 1no. borehole could safely be carried out, see Plate 8.

Due to the steep slopes and loose nature of tip surface, the rotary rig was only able to access the site via the upper track and carry out boreholes along this track, where sufficient working area was available to undertake the works safely.

We consider that the number of investigation points in conjunction with the geophysical survey, is sufficient to provide the basis of a more detailed ground model.

4.2.3 Trial Pits

5no. trial pits (TP1 to TP5) were excavated on 21st June 2019 using a wheeled, backacting hydraulic excavator. The trial pits were excavated to depths of between 1.8m and 2.9m. The trial pit records are presented as Appendix E, and their positions are shown on Figure 5.

Disturbed samples were collected from the trial pits for laboratory testing as shown on the trial pit records.

On completion, the trial pits were backfilled with arisings in layers compacted with the excavator bucket, and the Topsoil reinstated on the surface. The arisings were left slightly proud of the adjacent surface to allow for future settlement.

4.2.4 Cable Percussion Boreholes

4no. 250mm diameter cable percussion boreholes (BH01 to BH04) were constructed to depths between 3.1m and 7.2m between 29th October and 5th November 2019. The borehole records are presented as Appendix F, and their positions are shown on Figure 5.

Small and large plastic tub and bag disturbed samples were obtained throughout the boreholes for identification and laboratory testing purposes, as shown on the borehole records.

Standard Penetration Tests (SPT) were carried out using a split spoon and solid cone (within coarse material) in the boreholes in accordance with BS EN ISO 22476-3 (2005) and BS5930 (2015) to assess the relative density of the coarse-grained soils encountered in the borehole and to provide a correlated assessment of the likely undrained shear strength of fine-grained soils using relationships published by Stroud (1975).

On completion, monitoring instrumentation was installed in the boreholes as detailed in Section 4.2.

4.2.5 Rotary Cored Boreholes

A single rotary cored borehole was constructed (BH05) to a depth of 11.1m between 25th and 27th November 2019. The borehole record is presented as Appendix F, and the position is shown on Figure 5.

The ODEX 115 system of simultaneous drilling and casing was used in the Made Ground and superficial deposits, and the depth of casing in each borehole is shown on the borehole records.

The soils within the borehole were recovered using windowless sampling techniques, whereby the soil was collected within plastic lined sampling tubes, which were then split to allow sampling and logging. Disturbed samples were obtained throughout the borehole for identification purposes, as shown on the borehole record. The windowless sampling provided generally good recovery to the depth of refusal.

Standard Penetration Tests (SPT) were carried out using a solid cone in the boreholes in accordance with BS EN ISO 22476-3 (2005) and BS5930 (2015) to assess the relative density of the coarse-grained soils encountered in the borehole. As required in BS5930:2015, the SPT N-values shown on the borehole records are the direct, uncorrected results obtained in the field.

Cores of nominal 72mm diameter were recovered in plastic liners using a triple tube barrel system, over runs of nominal 1.5m length. The recovered cores were sealed in the plastic liners and placed in solid core boxes to prevent disturbance and swelling before logging. The plastic liners were only cut immediately prior to logging. In addition to the nature of the rock material, the identified fractures within the rock mass were also logged in accordance with BS5930:2015 and BS EN ISO 14689:2:2018. The Rock Quality Designation (RQD) recorded was for rock core 100mm or greater in length, unless otherwise stated. The fracture state of the recovered cores (in terms of number of fractures per metre run) is presented on the borehole records.

Compressed air was used as a flushing medium during drilling to keep the drill bits cool.

On completion, instrumentation was installed in boreholes as detailed in Section 4.3.

4.2.6 Non-intrusive Geophysical Survey

Prior to the commencement of the light cable percussions boreholes, a geophysical survey was undertaken along 3no. profiles (parallel and perpendicular to the quarry wall) across the study area by TerraDat Ltd between 21st and 25th October 2019. This involved an integrated survey approach comprising the following techniques:

- Electrical Resistivity Tomography (ERT)
- Compressional (P) Wave Seismic Refraction
- Shear (S) Wave Seismic Refraction
- Multichannel Analysis of Surface Waves (MASW)

The results of this survey are discussed in Section 5.5 and the full report is presented in Appendix K.

4.3 Installations and Monitoring

4.3.1 Groundwater Monitoring Wells

4.3.1.1 Trial Pits

2no. 50mm diameter HDPE monitoring wells were installed in trial pits TP102 and TP104 to provide an indication of longer term groundwater levels in the trial pit locations. The wells, comprising slotted plastic pipe were installed within trial pits where significant groundwater had entered the excavation. The plastic pipe was lowered into the excavation and arisings placed around the pipe during backfilling. Further details of the installations are provided in the trial pits records in Appendix E.

4.3.1.2 Boreholes

2no. 19mm piezometer monitoring wells were installed in boreholes BH02 and BH03 to allow monitoring of groundwater levels in general accordance with BS ISO 5667-22 (2010). The wells, comprising slotted plastic pipe with a gravel surround (the response zone), bentonite seals above the response zone, and a lockable vandal proof cover, were installed as detailed on the borehole records (Appendix F).

To date the installations have been monitored on 6no. occasions between 11th November 2019 and 17th January 2020. The standpipe, piezometer and 50mm wells are monitored on a 'spot' basis, i.e. periodic visits to monitor groundwater levels at the time of the visit).

4.3.2 Inclinometer

3no. inclinometers were installed to a maximum depth of 7.2m using 70mm easy-connect inclinometer casing. A summary of the installs is shown below in Table 5.

Table 5: Summary of Inclinometer installations

Borehole ID	***Depth (m)***	***Summary of Response Zone***
BH01	5.3	Quarry spoil to 4.0m, over bedrock of Upper Coal Measures.
BH04	7.2	Quarry spoil to 6.0m, over bedrock of Upper Coal Measures.
BH05	11.1	Quarry spoil to 5.25m, over bedrock of Upper Coal Measures.

Notes on Table 5:
1. Details of each inclinometer and the ground conditions are presented on the individual borehole logs (Appendix F)

The inclinometer casing has been monitored using a digital biaxial inclinometer system, with the results of each monitoring visit to date presented in Appendix G.

Due to access limitations, borehole BH01 and BH04 were drilled using a dismantlable cable percussion rig. This method of investigation can have poor penetration into rock but was considered the only method of drilling boreholes mid-slope due to access limitations (which could not be overcome with more specialist slope climbing equipment).

It is common practice to install the base of the inclinometer casing into rock, or a material that is known to be stable, such that monitoring can be carried out with reduced error. However, due to the limitations of the cable tool rig and what is expected to be a shallow weathering profile of the bedrock, it was not possible to ensure deeper vertical penetration for the base of the inclinometer. This should be considered when reviewing the monitoring results.

4.3.3 Vibrating Wire Piezometers

Vibrating Wire Piezometers were installed in boreholes BH04 and BH05 upon completion. The details of the installations are displayed in the borehole records in Appendix F. The vibrating wire piezometers are connected to a datalogger which has been set to monitor every 3 hours. The interpreted data collected to date from the data loggers is shown in a series of graphs in Appendix H.

4.4 Sampling Strategy

4.4.1 Soil Sampling

Samples for logging and geotechnical laboratory testing purposes were collected at regular intervals within the exploratory holes.

4.4.2 Soil Sample Quality

Samples of soil recovered from investigations are classified as Classes 1 to 5 in terms of quality and depend on the investigation and sampling method, the particle size of the strata sampled, and the presence of groundwater. Class 1 and 2 samples are those in which there has been no or only slight disturbance of the soil structure, with moisture contents and void ratios being similar to the in-situ soil. Class 3 and 4 samples contain all the constituents of the in-situ soil in their original proportions, and the soil has retained its original moisture content, but the structure of the soil has been disturbed. In Class 5 samples, the soil structure and original layering cannot be identified, and the water content may have changed from that in-situ. The category and class of samples are discussed further in BS EN ISO 22476:2006, EN 1997-2:2007 and BS5930:2015.

In general terms, disturbed samples recovered from trial pits (bulk bags and small tubs) are classed as Class 3 (if dry), Class 4 (fine soil below the water table), or Class 5 (coarse soils from beneath the water table).

The split spoon sample from a Standard Penetration Test (SPT) is usually considered a Class 5 sample however, it can be deemed Class 4 in homogeneous fine-grained soils. Disturbed sampling (bulk bags and small tubs) from boreholes is considered Class 3 (if dry), Class 4 (fine soil below the water table) or Class 5 (coarse soils from beneath the water table).

4.5 Geotechnical Laboratory Testing

Geotechnical laboratory testing was undertaken on samples from the suitable quality classes recovered from the exploratory holes in order to obtain information on the geotechnical properties on the soils beneath the site.

The following tests were undertaken by a UKAS accredited laboratory on samples selected by ESP in accordance with the methodologies presented in BS1377:1990. The results are presented in Appendix J.

- Natural moisture content.
- Atterberg limits.
- Particle size analysis inc. wet sieve method and pipette analysis.
- Large shear box (300mm), peak and residual shear.

5 Ground Model

5.1 Geology

The exploratory holes have identified the site to be generally underlain by Made Ground comprising spoil tip material, possible Glacial Diamicton, and Coal Measures bedrock. These strata are discussed in more detail in the following sections.

Overall the ground conditions were variable across the Quarry Spoil Tip area especially with regards to the Quarry Spoil Made Ground which has been subdivided into two separate strata primarily based on the particle size of the material and the clay content. Furthermore, Glacial Diamicton was only encountered in the lower portions of the slope, the precise extent of the Glacial Till uphill was not identified within the intrusive investigation and has been modelled based on the geophysical data.

5.1.1 Made Ground – Quarry Spoil

Made Ground comprising quarry spoil was consistently identified in the exploratory holes below vegetation and topsoil.

Made Ground – Topsoil: encountered below vegetation to a maximum depth of 0.20m across the site and generally comprising a greyish black sandy gravel with abundant rootlets. Occasional angular sandstone cobbles and boulders were noted across the site surface below vegetation. This is unlikely to have been placed across the Spoil Tip and probably originates from decomposed, predominantly wind-blown or old organic debris.

Made Ground – Coarse Discard: encountered to a maximum depth of 4.0m in the upper portions of the spoil tip and 2.3m depth on the lower portions of the spoil tip. In BH04 in the middle portion of the slope, coarse material was identified to 3.0m depth and between 5.0 to 6.0m depth.

The material generally comprised clayey sandy gravel with medium to high cobble content. Boulders up to 700mm diameter were noted throughout the upper portions of the strata. Gravels were fine to coarse, predominantly coarse, angular to subrounded sandstone. Cobbles and boulders were angular to subangular, interlocking medium strong to strong sandstone. Typically, the cobbles and boulders were fresh dark grey and purple sandstone with occasional orange/brown surface weathering recorded.

In TP101 the cobbles are noted to be generally horizontal in orientation with rare vertical orientated cobbles and in TP104, the cobbles are noted to be both horizontal and vertical in orientation.

Field SPT N-values within the coarse quarry spoil ranged between 11 and 28 indicating medium dense gravels.

Particle size analyses within the laboratory have indicated the coarse-grained spoil tip material to comprise between 31 and 91% gravel, predominantly medium/coarse, between 5 and 21% sand, predominantly fine/medium, and with 0 - 42% cobbles. Based on our observations on site, these proportions would appear representative of the in-situ soils.

Poor stability was recorded within the trial pits through the coarse strata, with TP101 terminated at 2.90m due to trial pit collapse.

Made Ground – Coarse Discard (finer): encountered to a maximum depth of 5.25m in the upper portions of the slope in boreholes BH01 to BH03 and BH05 and in BH04 in the middle portion of the slope between 3.0 and 5.0m depth. Fine grained quarry spoil material was not encountered in the trial pits at the base of the slope.

The material generally comprised soft to firm brownish grey and grey brown sandy very gravelly clay with low cobble content. The gravel is typically fine to coarse, angular to subrounded grey sandstone with occasional fine coal fragments. In boreholes BH01 and BH04, a soft, brown saturated clay layer was identified at between 3.00 to 4.00m and 4.00 to 5.00m depth respectively. In BH05, a silty gravelly clay layer was encountered between 4.30 and 5.25m depth.

Field SPT N-values within the fine made ground suggested a generally soft to firm consistency. Where higher values are recorded (28 to >50), the results are attributed to possible boulder obstructions.

5.1.2 Probable Glacial Diamicton

Probable Glacial Diamicton was encountered beneath quarry spoil to a maximum depth of 3.4m in the trial pits in the lower portions of the slope. The material generally comprised a soft to firm orange-brown mottled grey silty sandy slightly gravelly clay with low to medium cobble content. A coarser band was encountered in TP103 comprising a medium dense very silty/clayey sandy gravel with medium cobble content. Gravel within both units was recorded as fine to coarse, predominantly angular to subangular with occasional subrounded sandstone gravels. Cobbles and boulders was angular to subangular sandstone.

Laboratory testing within the fine-grained Diamicton indicated liquid limits of 49%, a plasticity index of 26% and natural moisture content of 32%. The modified plasticity indices (after the coarse-grained particles have been removed) suggest that the soils are generally of medium shrinkage potential and high swelling potential and would be generally classified as clays of intermediate plasticity.

Particle size analyses within the laboratory have indicated the probable Glacial Diamicton to comprise between 10 to 59% gravel, predominantly fine to coarse, between 20 and 21% sand, predominantly fine to coarse, and with between 0 to 15% cobbles. Typically, the results correlate with the site observations however, results for TP103 indicate a lower clay content than identified on site.

5.1.3 South Wales Upper Coal Measures Bedrock

5.1.3.1 Possible South Wales Upper Coal Measures Bedrock

Encountered beneath quarry spoil and Diamicton to a maximum depth of 7.2m in BH04. Possible weathered bedrock was encountered to a maximum depth of 5.3m in the upper portions of the slope and to a depth of 5.5m in the trial pits at the base of the slope.

The material generally comprised a stiff to very stiff dark grey silty sandy gravelly clay and very silty/clayey sandy gravel with varying proportions of cobbles and boulders. The gravels, cobbles and boulders were angular sandstone. Pockets of stiff dark grey clay with traces of coal was noted in TP103. Boreholes BH01, BH03 and BH04 refused on very stiff, friable dark grey sandy gravelly clay with angular sandstone gravels which has been interpreted as weathered Upper Coal Measures (Grade D).

Field SPT N-values within the possible weathered bedrock ranged between 24 and greater than 50 indicating a stiff to very stiff consistency.

Particle size analyses within the laboratory have indicated the coarse-grained spoil tip material to comprise between 39 and 53% gravel, predominantly fine to coarse, between 11 and 15% sand, predominantly fine to coarse, and with zero to 20% cobbles. Based on our observations on site, these proportions would appear representative of the in-situ soils.

5.1.3.2 South Wales Upper Coal Measures Bedrock

Upper Coal Measures was identified in BH05 below quarry spoil at a depth of 5.6m and proven to 11.1m depth. The upper strata were encountered as weak thinly laminated friable mudstone becoming medium strong and strong siltstone and sandstone. The strata are considered to be of weathering grades, Grade C and Grade B respectively. Generally bedding fractures are horizontal and sub horizontal (<5°), clean and with occasional iron oxide staining and occasional fossilised plant remains are noted throughout.

Below a depth of 7.7m, the bedrock comprised grey strong to very strong micaceous sandstone interpreted as Grade A, unweathered bedrock. Rare patches of iron oxide staining was noted, and recovery of this strata was good and intact.

5.2 Excavation Stability

During the excavation of the trial pits, some spalling of the pit walls was experienced, particularly within the coarse-grained Spoil Tip material. In TP101, significant instability was experienced below 1.50m with the trial pit terminated at 2.9m due to trial pit collapse.

5.3 Hydrogeology and Groundwater Monitoring

5.3.1 Groundwater Strikes, Monitoring and Groundwater Bodies

The groundwater conditions identified in the investigation are summarised in Table 6 below.

Table 6: Summary of Groundwater Ingress in the Investigation

Hole ID	Stratum	Comment on groundwater encountered
TP101	Coarse Quarry Spoil	Groundwater not encountered to a depth of 2.9m– soils saturated below 2.5m depth
TP102	Coarse Quarry Spoil	Soils becoming saturated below 2.4m depth. Groundwater struck at 3.0m with moderate ingress recorded.
TP103	Fine and Coarse Quarry Spoil	Minor seepage recorded between 1.0m and 2.3m depth. Soils saturated below 2.8m depth. Groundwater strike at 3.6m depth with slow ingress recorded.
TP104	Possible Weathered UCM Bedrock	Minor seepage recorded at 2.3m depth below large boulder. Pockets of saturated material recorded below 3.45m depth.
BH01	Fine Quarry Spoil	Groundwater not encountered. Saturated material encountered between 3.0 to 4.0m depth.
BH02 & BH03	-	Groundwater not encountered.
BH04	Fine Quarry Spoil	Groundwater not encountered. Saturated material encountered between 4.0 to 5.0m depth
BH05	Base of Quarry Spoil & top of UCM	Groundwater encountered between 5.0 and 5.3m depth. Groundwater level standing at 5.3m depth at the beginning of following day.

Notes to Table 6:
1. Full details of groundwater ingress presented on exploratory hole records in Appendix E and F.
2. UCM – South Wales Upper Coal Measures

The results of the monitoring are presented in Table 7 and Table 8 below.

Table 7: Monitoring Data from groundwater monitoring standpipes.

Well ID	Response Zone depth	Visit 1 11/11/19	Visit 2 19/11/19	Visit 3 29/11/19	Visit 4 9/12/19	Visit 5 20/12/19	Visit 6 17/1/20
		Depth to water (m)					
TP102	2.0 – 5.0m	4.7	4.95	4.7	4	4.7	4.66
TP104	3.5 – 5.5m	2.0	2.1	1.9	1.9	1.8	1.81
BH02	2.0 – 3.0m	2.6	2.82	2.9	2.6	2.6	2.6
BH03	3.2 – 4.2m	2.6	2.75	2.9	2.6	2.9	2.6
Comments on weather preceding monitoring visit		Following period of heavy rainfall	During period of heavy rainfall	-	Following period of heavy rainfall	-	-

Notes to Table 7:
Full details of groundwater ingress presented on exploratory hole records in Appendix E and F.

Table 8: Monitoring data interpolated form VWP installations

Well ID	VWP Depth (m)	Strata	Recorded water depth range (m)	
			Min	Max
BH04	6.95m	Weathered Llynfi Member Bedrock	4.70m	7.02m
BH05	5.70m	Llynfi Member Bedrock	5.27m	5.87m

Notes to Table 8:
1. Full details of groundwater ingress presented on exploratory hole records in Appendix E and F.

Based on the above findings and the Conceptual Ground Model, we consider that there is a body of water within the Quarry Spoil Tip.

Monitoring points at the top of the Spoil Tip (TP102, BH01, BH02) showed water at depths of between 2.6m and 4m, the Quarry Spoil in this area is approximately 5m thick (based on BH05). Monitoring of the vibrating wire piezometer in BH05 has shown a water body near the base of the Spoil Tip and bedrock, suggesting that the groundwater level varies along the same contour – possible as a results of natural variations in the underlying junction of the tip base and former topography.

BH04 is situated mid-slope of the Quarry Spoil Tip and this has shown a changeable head of water that is situated that looks to be with the Quarry Spoil Tip, although the depth varies, however the monitoring period to date, it has shown a body of water some 1.3m from the base of the tip material.

Seepages of water have been visually identified in numerous places in the toe of the Spoil Tip, a monitoring well within TP104 has shown a head of water correlating to the tip material.

5.3.2 Summary

The monitoring data has shown that there is a body of water within the Quarry Spoil Tip, the vibrating wire piezometers suggest that the head of water changes over time, likely to be as a result of rainfall or increased groundwater inflows from rainfall on Mynydd Alt-y-grug.

The highest variation in head measured by the two vibrating wire piezometers is in BH04, which is positioned mid-slope. The higher variation might be due to the fact that groundwater in this area is connected to a larger body of water, perhaps associated with the main groundwater body in bedrock below Mynydd Allt-y-grug, a plausible path is through the (worked) coal seams in the valley.

Visual evidence of water emanating at points at the base of the tip, rather than all the way along, coupled with the possibility of a variable head of water in the tip suggests that the groundwater body varies in thickness under the tip, perhaps due to water following former hollows or depressions in former ground surface.

Investigation to date has not included monitoring of groundwater conditions outside of the tip and it is not possible to determine where the 'water table' is within the bedrock of Mynydd Alt-y-Grug.

5.4 Ground Movement Monitoring

5.4.1 Introduction

Inclinometers were installed in three boreholes (BH01, BH04 and BH05). To date, the inclinometers have been monitored on four occasions. The details of the installation are outlined in Section 4.3.2 and displayed in the borehole logs in Appendix F.

5.4.2 BH01

The inclinometer was installed to a depth of 5.3m and although some movement, in the region of 3mm has been recorded, it is not at present considered to be representative of any downslope, or significant movement occurring and is within the accuracy of the instrumentation.

5.4.3 BH04

The inclinometer was installed to a depth of 7.2m and the monitoring showed the inclinometer to move some 20mm downslope on its further return visit. Three subsequent visits have shown that the inclinometer has gradually 'moved back' and it is possible this initial 20mm of movement was some settling of the inclinometer installation which is common. Further monitoring is recommended to ensure downward movement is not identified.

5.4.4 BH05

The inclinometer was installed to a depth of 11.2m, show no significant signs of movement with displacements recorded generally less than 2mm, which is within the realms of the accuracy of the inclinometer.

5.4.5 Summary

Monitoring of the inclinometers has only been carried out over a relatively short period of time and therefore continued monitoring is needed over a longer time period.

Movement in BH04 is currently thought to be attributed to some settlement of the inclinometer casing, as subsequent monitoring has shown no further downslope movement. The two other inclinometers show no significant movement of the tip; however, monitoring should be continued.

5.5 Geophysics Data

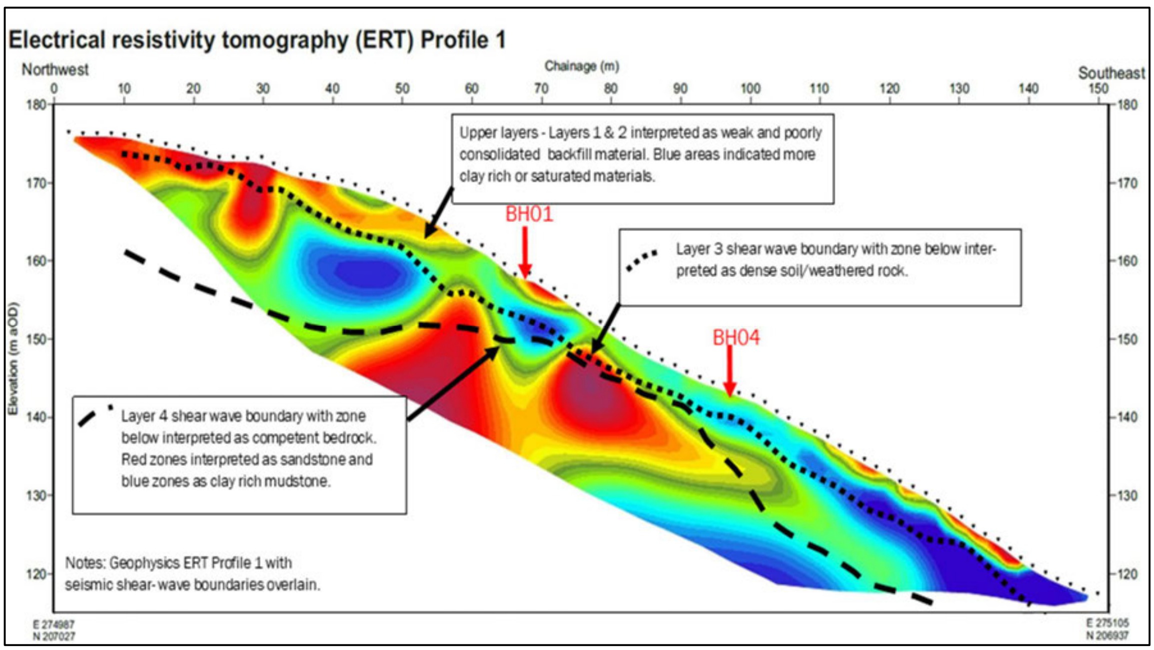
As discussed previously in Section 4.6, geophysical survey of the area consisting 3no. resistivity, seismic refraction and multichannel analysis of surface waves (MASW) profiles has been undertaken. The geophysical report is presented as Appendix K and a summary plan is displayed as Insert 9.

The resistivity survey identified two layers interpreted as backfill material consisting of an upper high to intermediate resistive dry granular material between 1 to 10m depth typically overlying a layer of lower resistivity results from increased moisture or clay content at between 4 to 18m depth. The interpretation largely correlates with the findings of the trial pits and boreholes which identified a dry granular layer occasionally becoming more clay rich and/or saturated with depth.

The survey identified two zones of deeper backfill material, the first within the extents of the old quarry and indicated bedrock to be at a depth of around 20m. The second zone is further downslope and shown to be deeper at the horizon of the Upper Pinchin coal seam. The deeper zone may be related to coal seam excavation or as a result of higher weathering rates.

In the lower portions of the slope, the more conductive material is present at shallower depths and becomes indistinguishable from the unit interpreted as mudstone bedrock. Trial pitting in the area indicates this portion of the layer may represent clay rich Glacial Diamicton.

Laterally across the area, the resistivity survey indicates a deeper portion of dry backfill material to the west with a pinching out of the conductive backfill layer. This coincides with a marked drop in the S-wave refraction boundary and is indicative of deeper rockhead. The more conductive backfill is consistently present to the east which may be representative of the excavation related to the Upper Pinchin coal seam. On the lower portions of the slope, the Profile 2 indicates a possible shallowing out of the backfill material to the east and may represent the western extent at this level. Profile 2 corresponds with the location of former adits identified by the Coal Authority and in the historical mapping.



Insert 9: Summary of geophysical data (ERT and Seismic data) interpolated from Terradat report (2019). Full report displayed in Appendix K.

The seismic survey generally shows good correlation between the P and S-wave boundaries of layer 3 (dense soil/weak rock) and termination of the cable percussive boreholes on presumed weathered Upper Coal Measures. Comparison of BH05 shows good correlation between the P and S-wave Layer 4 (competent rock).

The seismic survey shows the bedrock to be roughly subparallel to the ground surface, with rockhead at around 5 to 19m below the surface.

Alongside the borehole and trial pitting information, the survey concluded that the Quarry Spoil material ranges in thickness of between approximately 4 and 18m thick. A more conductive layer of Quarry Spoil material was identified which indicates that the material is more clay rich and/or saturated. No definitive groundwater table was identified in the survey. The survey generally correlates with the information obtained within the boreholes and trial pits and allowed for modelling of the ground conditions in areas inaccessible for intrusive investigation techniques.

6 Preliminary Slope Stability Assessment

6.1 Assessment Methodology

A slope stability assessment has been undertaken utilising the GeoStudio SlopeW package, in order to assess the Adequacy Factor (AF)/Factor of Safety (FoS) within the slope. The FoS is being adopted as it simply considers the ratio of disturbing forces against restoring forces and gives a simple indication to stability.

The assessment has been done to understand if the tip is, stable or marginally stable. No active instability was noted during the works or site walkovers and as such it is not considered to be actively unstable.

For the purposes of this assessment, the slope profile adopted is that if the tip above the school, in that, the modelled line has been drawn perpendicular to the contour lines and this has been taken through where nearby borehole information has been obtained, BH01 to BH05 and TP101 to TP104. In addition, this slope profile has been surveyed in and as such the slope geometry is considered to be accurate.

Visual observations and slope measurements made during the geomorphological mapping showed that this profile is generally the steepest section of the tip.

The line of section is shown on Figure 1.

6.2 Slope Stability Ground Model

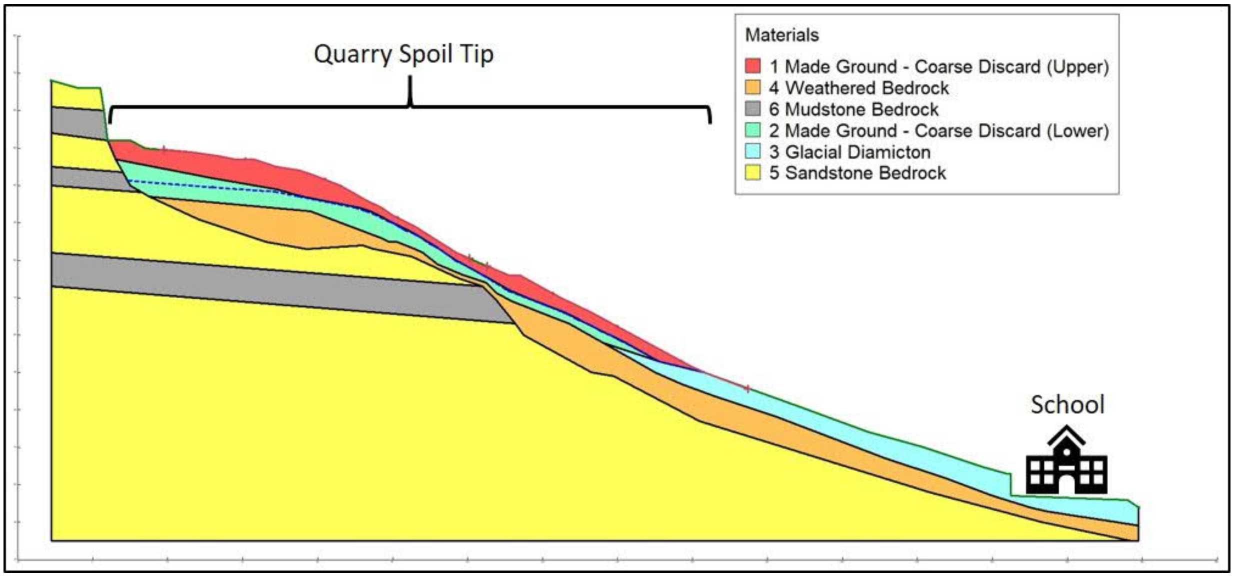
As discussed above, the slope profile has been generated using the topographic survey information (Section 3.5.1) and the geophysical survey information (Section 4.6).

Geological information from the boreholes and trial pits, along with visual observations has been used to populate the Ground Model which is shown as Figure 6.

The geophysical information has also been used to provide the general boundaries of the Glacial Diamicton, base of the Quarry Spoil (Coarse Discard), between boreholes, and help delineate groundwater and variations on the Coarse Discard material, as well as the boundary to 'bedrock'.

Initial groundwater monitoring data, along with visual observations has been used to draw an anticipated piezometric line (Water Table) in the Ground Model.

The slope stability ground model can be seen in Insert 10 below.



Insert 10: SlopeW digital Ground Model

6.2.1 Assumptions

As discussed above, the Ground Model, material parameters and groundwater conditions have primarily been determined from the investigation findings, along with some based on established correlations from other soil characteristics and information. These and other assumptions for the model to be run are listed below:

- Lateral extent of Quarry Spoil, up and downslope slope assumed;
- Excluded modelling any global stability issues of the wider Tawe Valley area;
- Excluded modelling any seismic events that may trigger instability;
- We have not modelled any loads from structures or temporary/dynamic loads from possible vehicle movements;
- Assumed no leaking drains/sewers/services in slope;
- With the exception to the monitoring information we have at a several discrete points in the slope and visual observations on site, the precise location of the groundwater is not fully known. In order to provide a likely location of the groundwater, our judgement has been used to define the groundwater profile on the Ground Model.
- Assuming a constant groundwater level – as shown;
- We've assumed the groundwater level based upon the information and monitoring to date, monitoring should be continued to determine if worst case groundwater conditions modelled;
- Topsoil, and any positive or negative impacts from trees or vegetation (i.e. root action) has not been modelled in the assessment;
- Smaller individual/inpersistent layers of finer Made Ground within Spoil Tip ignored, lower phi angle adopted to allow for some variation; and
- Movement information from inclinometers (at present) not representative of large-scale instability.

6.3 Reasonable Case Material Parameters

Considering the reduced availability of information on ground parameters, the values used in the model have been adopted from a combination of in-situ testing and laboratory testing from the site, or established correlations from other soil characteristics and information to specific materials is discussed below individually. We consider that this approach has provided a realistic indication of the soil and water conditions at the site, however, further evidence will be required.

A summary of the parameters used in the analysis in provided in Table 9 below. Along with justification for their adoption.

Table 9: Reasonable Case Material Parameters for Slope Stability Assessment

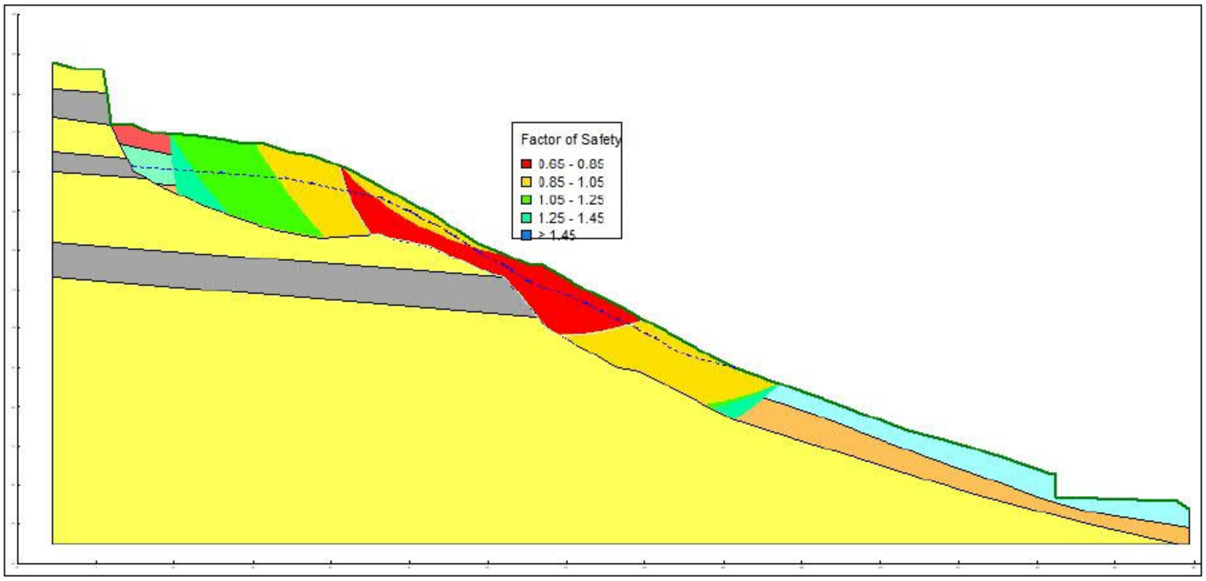
Strata Unit	Soil Type	Bulk Density	Effective Cohesion (c')	Angle of Friction (ø')
Made Ground – Coarse Discard - coarse	Variable	1.9 Mg/m^3	0kPa	28°[4]
Made Ground – Coarse Discard – finer[3]	Variable	1.9 Mg/m^3	0kPa	28°[4]
Glacial Diamicton	Variable	1.9 Mg/m^3	1kPa	30°[4]
Possible Weathered Rock Grade E / D	Mainly clay/gravel	1.8 Mg/m^3	1kPa	32°
Bedrock[2]	Mudstone, Siltstone, Sandstone[5, 8]	Modelled as impenetrable		

Notes on Table 9:
1. For full details of strata see Section 5.1.
2. Assume impermeable and hard boundary for assessment.
3. Material contains higher proportions of fine-grained material, modelled as cohesive strata. Ref. BS:8004.
4. In-situ testing used to guide parameter - value is considered conservative and allows for some variability/uncertainty.
5. Possible impact of coal seam/seat earth providing possible weak horizon ignored.
6. Bulk Densities in accordance with values within BS:8004.

6.3.1 Results of the Assessment – Reasonable Case Material Parameters

Analyses of the section has shown that for the strength parameters outlined in Table 9 and on the assumed piezometric surfaces shown, a minimum factor of safety of around 0.6 can be assumed when considering the current slope geometries. The model shows numerous potential failures below a Factor of Safety of 1, suggesting that the Quarry Spoil Tip is unstable.

The outcomes of the slope stability assessment can be seen below, in Insert 11.



Insert 11: Contoured failure planes in Quarry Spoil Tip using Reasonable Case Parameters.

The site walkover, historical mapping and aerial photographic review show no sign of instability predicted by the modelling. It is therefore likely that the Reasonable Case Material Parameters adopted are too low as signs of movement would likely be visible at the Quarry Spoil Tip.

6.4 Upper Range Parameters

The material parameters were reviewed, and the parameters set out in Table 10 are considered the Upper Range of parameters when considering the visual observations made on site, in-situ and geotechnical testing. Justification for the individual parameters is proved in the table notes.

Table 10: Upper Range Parameters for Slope Stability Assessment

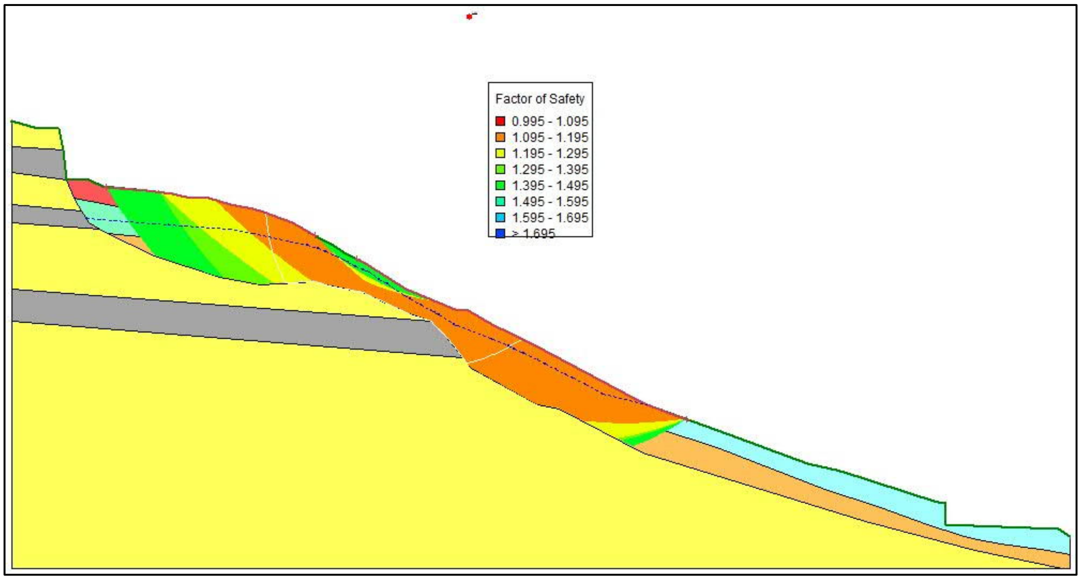
Strata Unit	Soil Type	Bulk Density	Effective Cohesion (c')	Angle of Friction (ø')
Made Ground – Coarse Discard - coarse	Variable	2.0 Mg/m³	0kPa	40°[4]
Made Ground – Coarse Discard – finer[3]	Variable	2.0 Mg/m³	2kPa[7]	33°[4]
Glacial Diamicton	Variable	2.0 Mg/m³	2kPa[7]	35°[6]
Possible Weathered Rock Grade E / D	Mainly clay/gravel	1.9 Mg/m³	3kPa[7]	36°
Bedrock[2]	Mudstone, Siltstone, Sandstone[5, 8]	Modelled as impenetrable		

Notes on Table 10:

1. For full details of strata see Section 5.1.
2. Assume impermeable and hard boundary for assessment.
3. Material contains higher proportions of fine-grained material, modelled as cohesive strata. Ref. BS:8004.
4. Laboratory test data used to guide parameter whilst considering in-situ tests results.
5. Possible impact of coal seam/seat earth providing possible weak horizon ignored.
6. CIRIA C504 used to estimate angle of friction.
7. Some soil suction assumed and modelled through cohesion.

6.4.1 Results of the Assessment – Upper Range Parameters

Analyses of the section has shown that for the Upper Range Parameters outlined in Table 10 and on the assumed piezometric surfaces shown, a minimum factor of safety of around 0.95 can be assumed when considering the current slope geometries. Much of the possible failure planes are however above unity, i.e. have a factor of safety of 1 or above, as can be seen on Insert 12 below.



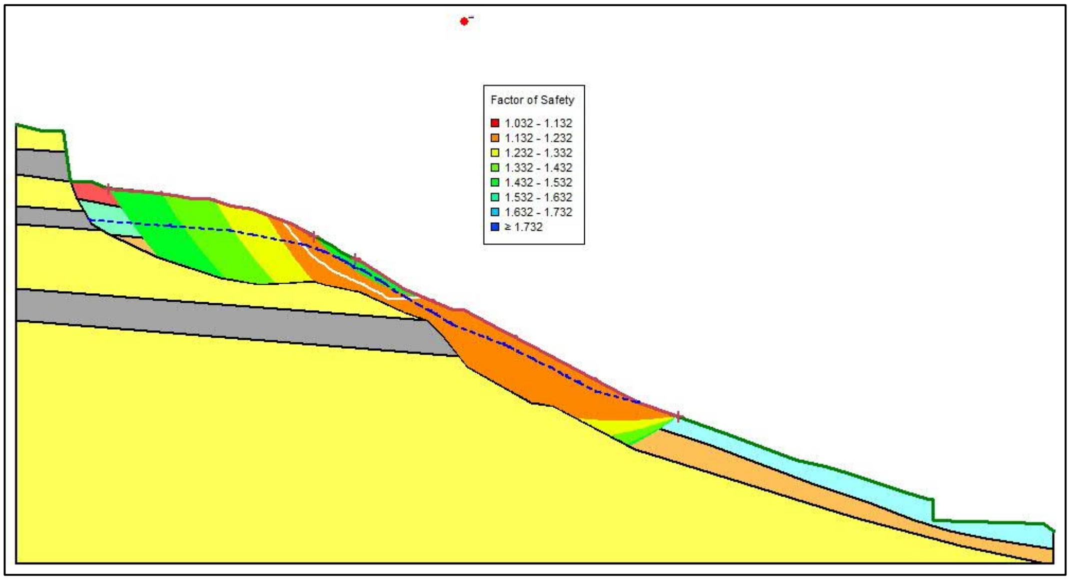
Insert 12: Contoured failure planes in Quarry Spoil Tip using Upper Range Parameters.

The modelling shows that the Quarry Spoil Tip could be considered marginally stable, which is likely to represent the current condition, as the material would have been 'end tipped' and reached a state of stability on the hillside. Based upon the above, it is likely that the Upper Range Parameters are reasonable for modelling of the slope.

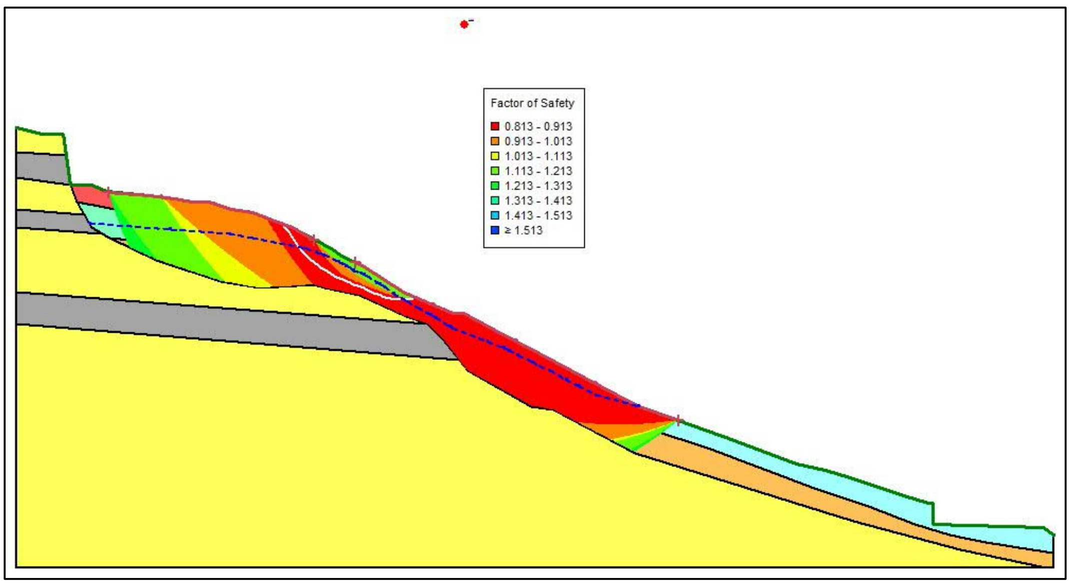
It would be prudent to undertake further geotechnical testing to provide confidence in the material parameters used, ideally, a large quantity of testing should be carried out such that robust statistical testing could be carried out on the results such that the variability could be understood.

In order to understand the tip stability in modern day design situations, the model has been run adopting partial factors for Design Approach (DA) 1, Combination 1 (C1) and Combination 2 (C2).

Insert 13 below shows the model run using partial parameters for DA1, C1 and Insert 14 shows the model when run against DA1, C2 partial parameters.



Insert 13: Contoured failure planes in Quarry Spoil Tip using Upper Range Parameters – DA1 C1.



Insert 14: Contoured failure planes in Quarry Spoil Tip using Upper Range Parameters – DA1 C2

The above inserts show that the worst-case design situation would be DA1, C2, with significantly lower FoS, or AFs being realised.

The above modelling suggests that if the quarry Spoil were to be constructed, it would not satisfy current requirements for construction.

6.5 Preliminary Groundwater Sensitivity Analysis

The slope stability analysis has been run using a groundwater level approximately 1m and 2m higher than our ground model shows to understand the possible stability of the Quarry Spoil Tip in an adverse weather event.

It should be noted that due to the short range of monitoring, that these increases of groundwater heights are simply arbitrary, and the assessment should be re-run once more data is available on the groundwater regime.

The differing Factors of Safety or Adequacy Factors are summaries in Table 11 below.

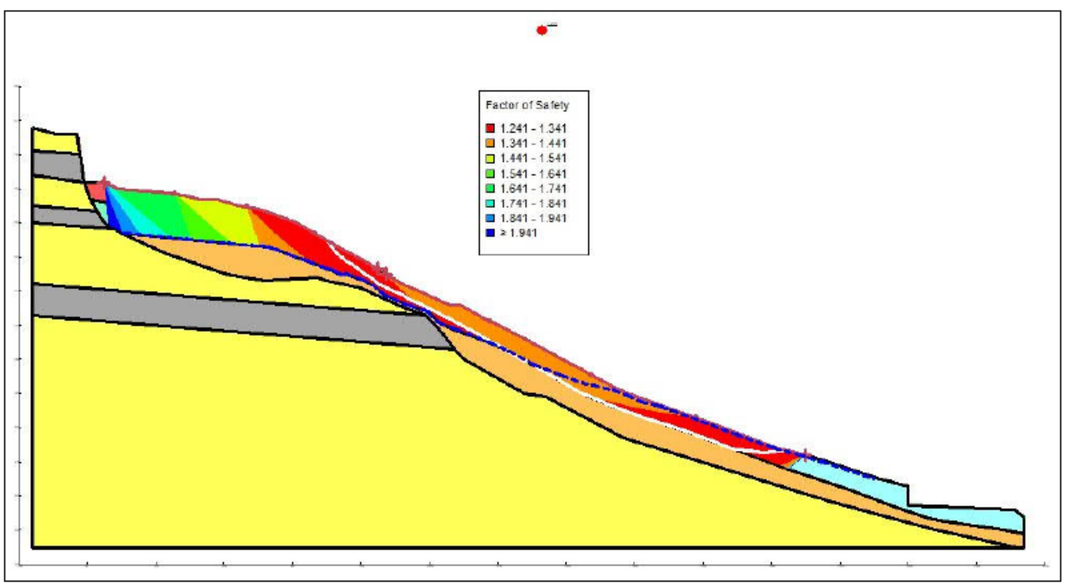
Table 11: FoS or AF for different groundwater levels

	Groundwater level				
	Groundwater based upon Ground Model	Groundwater level increased by approximately 1m	Groundwater level increased by approximately 2m[4]	Groundwater at base of Quarry Tip	Groundwater 2m below Quarry Tip base
Unfactored, Global Parameter	0.995 (2)*	0.923 (3)*	0.77 (12)*	1.24 (none)*	1.299 (none)*
DA1 C1	1.032 (none)*	0.954 (1)*	0.837 (4)*	1.28 (none)*	1.300 (none)*
DA1 C2	0.813 (20)*	0.763 (33)*	0.616 (51)*	0.993 (1)*	1.053 (none)*

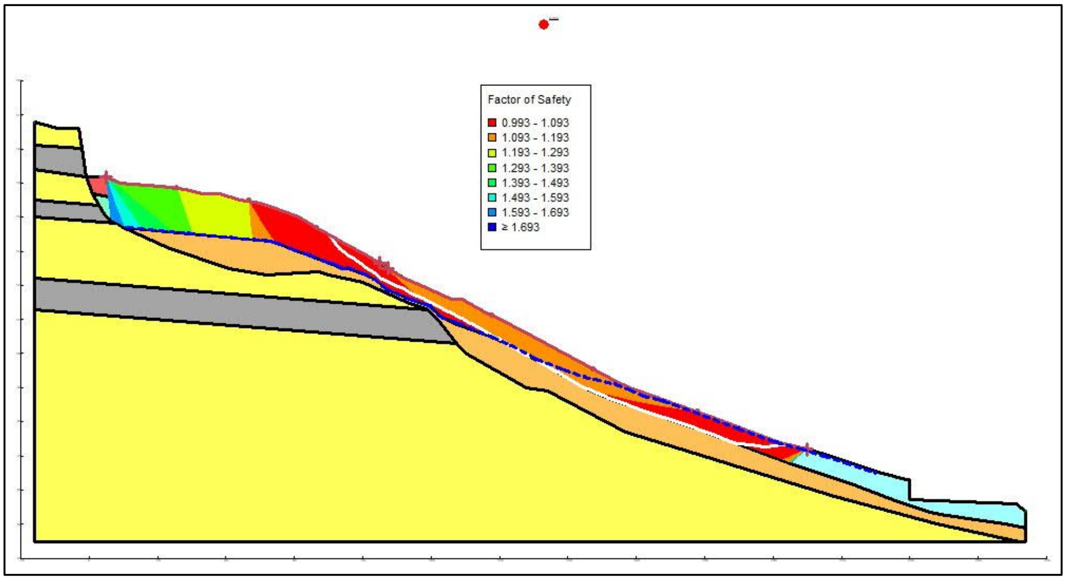
Notes on Table 11:
1, Model run using Upper Range Parameters
2, DA1 = design approach, C1 = combination 1, C2 = combination 2
3, Critical, or lowest FoS or AF shown.
4, Where it was not possible to raise groundwater by 2m, it was plotted just below ground level.
* Number in brackets indicates how many possible slip surfaces calculated below unity.

The above shows that an increase in groundwater height decreased the quarry Spoil Tip stability and reducing the groundwater level to 2m below the expected base of the tip increased stability.

The stability analysis modelling groundwater at the base of the tip is shown in Inserts 15 to (global stability), Insert 16 (DA1 C2), below.

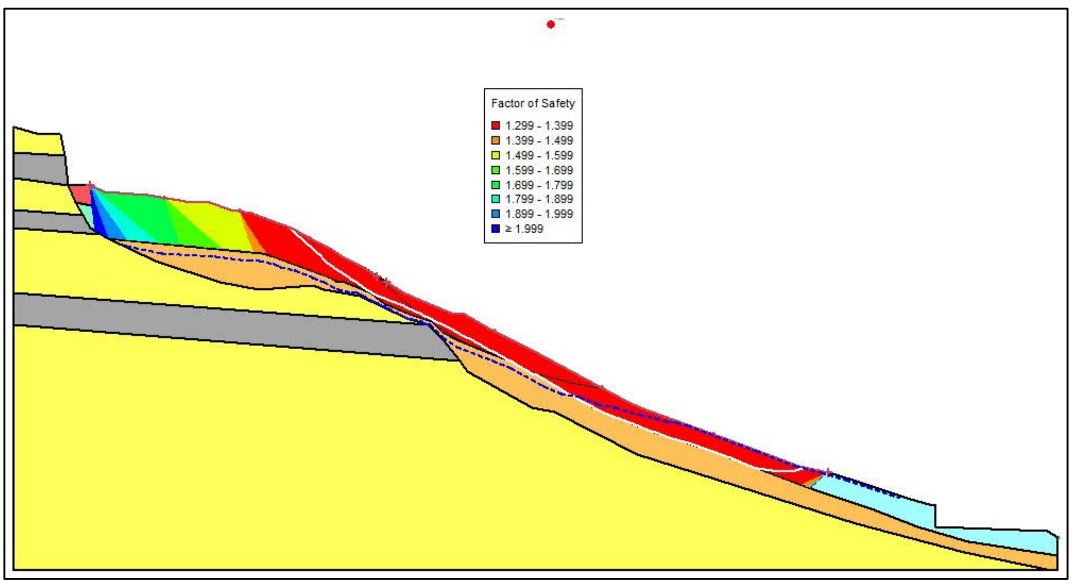


Insert 15: Contoured failure planes in Quarry Spoil Tip using Upper Range Parameters and groundwater at the tip base – global stability.

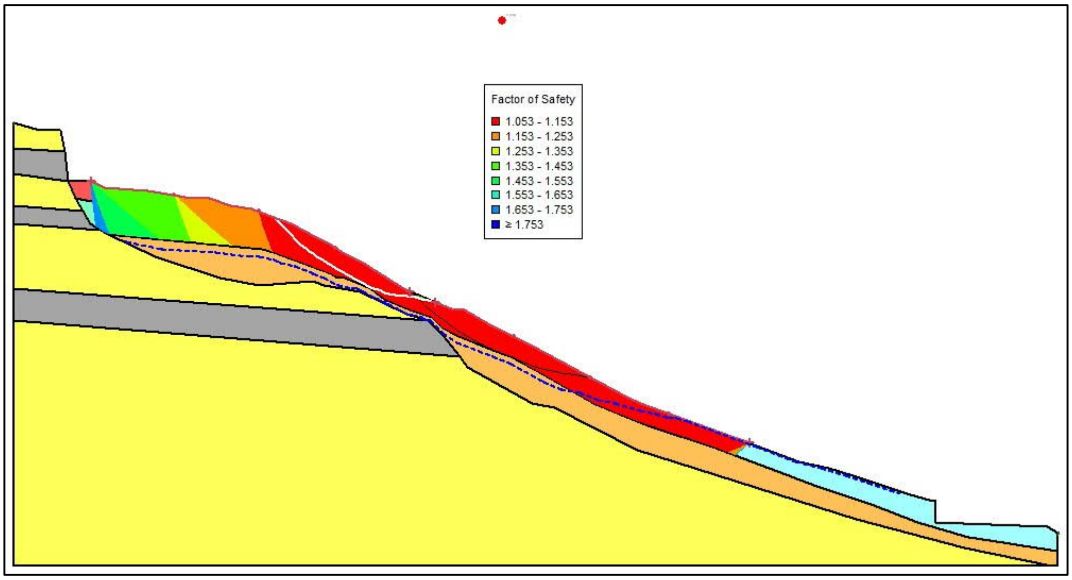


Insert 16: Contoured failure planes in Quarry Spoil Tip using Upper Range Parameters and groundwater at the tip base – DA1 C2.

The stability analysis modelling groundwater about 2m below the base of the tip is shown in Inserts 17 to (global stability), Insert 18 (DA1 C2), below.



Insert 17: Contoured failure planes in Quarry Spoil Tip using Upper Range Parameters and groundwater 2m below tip – global stability.



Insert 18: Contoured failure planes in Quarry Spoil Tip using Upper Range Parameters and groundwater 2m below tip – DA1 C2.

6.6 Reprofiling or Reduction in Material

Consideration could be given to reprofiling the Quarry Spoil Tip to reduce slope angles, however, difficulties at this site may be encountered due to the already steeply sloping nature of the surrounding valley and reprofiling is unlikely to be successful without significant earthworks to compact the material to a method compaction.

Analysis has shown that if the top 1m of Quarry Spoil Material was removed then little to no significant improvement would be measured in global stability of the Quarry Spoil Tip.

6.7 Slope Stability Conclusions

Broad definitions to describe a slopes stability are described below (after Popescu, M., A suggested method for reporting landslide causes. Bull IAEG, No. 50, Oct. 1994, pp 71-74.):

- **Stable** – the margin of stability is sufficiently high to withstand all destabilising forces;
- **Marginally Stable** – likely to fail at some time in response to destabilising forces reaching a certain level of activity;
- **Actively unstable** – slopes where destabilising forces produce continuous or intermittent movements.

Preliminary slope stability analysis has shown that the Quarry Spoil Tip is likely to be in a marginally stable state. This assessment broadly aligns with the medium risk assigned to the Quarry Spoil Tip on our previous report (ESP 2019).

Although the assessment has shown that the quarry Spoil Tip is marginally stable, this is below what would be expected for a slope if it were to be constructed to modern day engineering standards given the high risk to life if failure were to occur. Thus, some betterment could be considered to increase the stability of the Quarry Spoil Tip.

In general, the assessment has shown that an increase in groundwater levels will reduce stability of the tip and the control/lowering of groundwater will increase stability. Reprofiling of the slope may have smaller betterments but in combination with controlling surface and groundwater, stability of the tip could be increased, i.e. a degree of betterment can be achieved.

The material parameters used are considered favourable and there are likely to be areas of the manmade Quarry Spoil Tip where lower soil parameters will govern decisions, and some instability could occur in these, perhaps localised areas.

7 Discussion of Remedial Options

7.1 Introduction

The slope stability and preliminary sensitivity analysis has shown that the Quarry Spoil Tip is likely to be marginally stable, but likely to be unstable as a result of a significant weather event increasing groundwater pore pressures in the tip (or increasing the groundwater table).

If the Quarry Spoil Tip were to be scrutinised to modern safety criteria, it would need significant alteration or betterment to increase its stability or remedial options would be needed to reduce the risk it poses to elements at risk to low.

7.2 Management Options

The risk management/mitigation options below are outlined in AGS Guidance (2007). These provide a summary of management strategies/options.

1. **Accept the risk**, which is only an option subject to the criteria set by the regulator. Where the risk is not tolerable then risk mitigation measures are required.
2. **Avoid the risk**, such as relocation of the site of proposed development, or revise the form of the development, or abandon the development (though this may still require some risks to be controlled due to possible effect on third parties adjacent or nearby).
3. **Reduce the frequency of landsliding**, by stabilisation measures to control the initiating circumstances, such as by re-profiling the surface geometry where existing slopes are 'over steep', by provision of improved surface water drainage measures, by provision of subsurface drainage scheme, by provision of retaining structures such as retaining walls, anchored walls or ground anchors.
4. **Reduce the consequences**, by provision of defensive stabilisation measures or protective measures such as a boulder catch fence, or amelioration of the behaviour of the landslide, or by relocation of the development to a more favourable location.
5. **Manage the risk by establishing monitoring and warning systems**, such as by regular site visits, or by survey, which enable the risks to be managed as an interim measure in the short term or as a permanent measure for the long term by alerting persons potentially affected to a change in the landslide condition. Such systems may be regarded as a method of reducing the consequences provided it is feasible for sufficient time to be available between the alert being raised and appropriate action being implemented.
6. **Transfer the risk**, such as by requiring another authority to accept the risk (possibly via a court appraisal) or by provision of insurance to cover potential property damage.
7. **Postpone the decision**, where there is sufficient uncertainty resulting from the available data, provided that additional investigations or monitoring are likely to enable a better risk assessment to be completed. Postponement is only a temporary measure and implies the risks are being temporarily accepted, even though they may not be acceptable or tolerable.

We understand that NPTCBC are unlikely to accept the risk (1), as the outcome is similar to our previous assessment (ESP, 2019). Nor will it be possible to transfer the risk (6) and postpone the decision (7). Consideration to the other options is discussed separately below.

In addition to the above, the remediation or betterment at the site will largely be governed by the available access.

In proposing and assessing some of the remedial options described below, consideration has also been given to:

- Access to the tip and land ownership;
- Constructability (any temporary works have not been considered in detail);
- Available space; and
- General costs.

Whilst some commentary on the relative costs of each solution is given it is offered in only the broadest terms. More detailed costing is beyond the scope of this report; as the likely costs will be significantly influenced by framework arrangements already put in place by the council.

The options considered herein are not exhaustive, proprietary methods and methods likely to be impractical are not discussed.

7.2.1 Avoid the Risk

Consideration could be given to relocating the school, by removing the elements at risk, the Quarry Spoil Tip no longer represents a risk to school users.

The option to do this would need to be decided through a cost benefit analysis and that analysis should also strongly consider social economic impacts of relocating the school. If the school was relocated, a review would be needed to determine if the Quarry Spoil Tip represented a risk to residents in Godre'r Graig as they will then become the elements of risk and may drive some betterment of the Quarry Spoil Tip.

If this option was not to be chosen, then other options discussed below should be considered and implemented.

7.2.2 Reduce the Frequency of Potential Landslides

The sensitivity analysis has shown that betterment, or increased stability could be achieved by dewatering or adding drainage to remove water from the Quarry Spoil Tip. In addition, some reprofiling may also be beneficial which should be carried out in conjunction with the installation of drainage.

7.2.2.1 Dewatering or Drainage

The most practical solution for betterment, or to increase the stability of the tip would be to incorporate some form of drainage into the Quarry Spoil Tip and also improve the efficiency of the existing systems. Slope stability analysis modelling groundwater about 2m below the anticipated tip base is provided in Insert 11. The global factor of safety is in the region of 1.3 and the DA1 C2 AF (worst case situation) is 1.05 in this situation, which may be tolerable subject to stakeholder agreement.

Water is likely to be entering the Quarry Spoil Tip from various sources:

- Directly from infiltration;

- Overland flow;
- Water may be issuing out of nearby adits and into the tip;
- Water flowing into the tip from streams S2 and S3;
- Unmapped springs below the tip; and
- Possibly from groundwater in coal mine workings and the general groundwater body with the bedrock of Mynydd Allt-y-grug.

In order to prevent and reduce water/groundwater entering the Quarry Spoil Tip, the following broad recommendations will need to be implemented:

- Reinstate all streams (S2 and S3) so that they are channelised and do not enter the tip;
- Install surface water drainage channels at regular points to divert water off the tip;
- Install drainage above the tip to limit shallow groundwater and overland flow entering the tip;
- Install drains into the tip to remove water at regular points, this is to decrease groundwater entering the tip from possible mine workings;
- Consider groundwater pumping via boreholes at specific points to reduce the groundwater level;
- Consider directional drilling to install subsurface drainage below the tip to provide a preferential flow; and
- All the above drainage should link into a managed outflow system.

The above drainage should be designed by a specialist and the effectiveness should be monitored by a series of monitoring wells or site inspections. Significant temporary works would be required to achieve the above and some removal, or relocation of material would also likely be required.

7.2.2.2 Reprofiling

Slope stability modelling has shown that a simple reduction of say 1m across the entire Quarry Spoil Tip would not make a significant difference to stability. The Spoil Tip is situated on the side of a valley and reducing the slope angles significantly will be hampered by the surround valley sides, i.e. there are no flat areas to spread the material and parts of the valley side are already relatively steeply sloping.

Due to this, reprofiling alone is unlikely to provide significant betterment and consideration should be given to other remedial options.

7.2.2.3 Removal of Quarry Spoil Tip

Removal of the Quarry Spoil Tip altogether will remove the hazard and there would thus be no risk.

There would be some significant cost implications to remove the spoil tip to landfill, on the basis of our current ground model, the tip comprises approximately 90,000–110,000m^3 of material. It may be possible to transfer the material to a sorting plant such that it could be graded or sorted into a useable aggregate and sold. Based upon our visual observations on site, the material would have to go through some sort of processing.

There would be waste management licences, exemptions to consider and further testing (contamination) required to ensure suitability but this could be explored if this option were to be chosen.

Following removal of the tip material, all streams would need to be reinstated and it may also be prudent to undertake an ecological assessment. Once all the material is removed, the site could be reinstated to an ecological specification to ensure betterment in this regard.

Undertaking the work in a safe and controlled manor would require detailed temporary work designs and the valley side will need to be left in such a condition that there are no landslide hazards. NPTCBC would likely be responsible for the residual condition of the valley side and the degree of stability that would need to be achieved could limit the cost effectiveness of this option; engineering systems may be required.

7.2.3 Reduce the Consequences

Consideration could be given to some form of hard engineering solution, such as a retaining structure at the toe of the spoil tip, a barrier near the school or some combination of netting, bolting and anchoring of the Quarry Spoil Tip.

All options would require significant further ground investigation and detailed design.

Whilst these options could be adopted, they may take a significant amount of time to design and construct and a combination of these features would be recommended in line with the drainage improvements/measure discussed above.

7.2.4 Monitoring and Warning System

It would be possible to employ a monitoring strategy and warning system; however, we would recommend that this be carried out in conjunction with some site betterment discussed above, rather than a stand-alone option for ongoing management.

In most of the site betterment options discussed above, improved access will be required to provide access to most of the tip. This access could be used to install a robust set of boreholes across the tip with groundwater and ground movement monitoring systems that could either be designed to be monitoring on weekly or have wireless systems such that monitoring could be carried out in real time.

In addition to installing monitoring equipment, boreholes could be installed to detect movement, and trigger an alarm for school users and residents. The precise amount of monitoring equipment and warning system could be tailored to the site and on the specific management strategy.

In addition to instrumentations, regular visual assessments should be made to look for signs of instability, or changes in the water discharge for example. Depending upon the monitoring programme chosen, an emergency procedure will need to be drafted for the school to adopt, much like a fire alarm procedure.

7.3 Balanced Recommendation for Betterment

On the basis that the school is to remain, adopting a combination of the above mitigation strategies may provide an overall betterment of the slope stability for the Quarry Spoil Tip. It would be prudent to consider various options for remediation at the site and the final solution may be governed by the acceptance of risk and available budgets.

7.3.1 Drainage Solution

Modelling has shown that the stability increases if there is less water within the tip material. Site drainage offers a single solution but would need to be designed to ensure control of surface water and groundwater as discussed in Section 7.3.1.

In order to install the drainage required, access will need to be improved such that tracked vehicles can access the tip. This process will allow access to areas not previously accessible by vehicles, and once complete it would be necessary to install a greater density of boreholes to facilitate groundwater and ground movement monitoring. The boreholes will help ensure that the dewatering process is successful, and the monitoring points could be set up in such a way as to from part of an ongoing monitoring regime, and possibly eventually form part of an warning system.

Depending upon the temporary works and access some reprofiling, along with netting and ground anchors could be installed.

Whilst the access is made, it would be necessary to collect a larger number of samples for geotechnical testing such that increased confidence in the material parameters could be gained, or to at least understand the wider variability of the tip such that the slope stability modelling can be confirmed.

Whilst the above will provide significant betterment, it still may not result in a slope that would be classified as stable in accordance with modern design standards, but it could increase the stability of the Quarry Spoil Tip such that the landslide risks are considered acceptable by the various stakeholders.

7.3.2 Risk Estimation Discussion

As discussed in Section 2.6, our previous report (ESP 2019) suggested that the Quarry Spoil Tip represented a medium risk, when using the risk AGS risk assessment methodology from the (AGS, 2007).

Our preliminary intrusive investigation has provided information for the ground model and enabled a preliminary slope stability assessment. This assessment generally indicates that the slope is marginally stable, which is considered comparable with a medium risk.

Recommendations discussed above will result in overall betterment of the slope stability. The classification of the ongoing risk could potentially be downgraded if it can be demonstrated and accepted that:

- A robust drainage system designed for a defined rainfall event (e.g., a 1 in 100-year storm event) can effectively drain the spoil tip such that groundwater levels do not increase within the tip soil mass;

- Further geotechnical testing provides confidence in the soil parameters used in the slope stability monitoring; and
- Monitoring and ongoing visual inspections confirm no ground movement.

Betterment may not result in a slope that is compliant with modern day engineering design criteria but will improve the stability of the Quarry Spoil Tip. Whilst these work items could enable the risk to be reduced, it is unlikely the categorisation could be reduced to very low unless an active monitoring and warning system could also be incorporated; this is discussed in Table 13.

7.4 Remedial Options Comparison

To allow a simple comparison between options, a semi-quantitative scoring system has been used below, to summarise their overall benefit, relative to each other. The table also summarises advantages and disadvantages for each option and provides comments on other things to consider for each approach.

Each option has been scored for:

- Effectiveness – does it mitigate the risk;
- Durability – will it provide a robust solution over design life;
- Practicability – is the strategy achievable within site/social constraints;
- Sustainability – review of overall environmental impact;
- Cost – estimate of total financial implications.

The scoring system is summarised as follows:

- +1: a positive impact (a clear advantage against most other options).
- 0: balanced with most other options.
- -1: negative impact (a clear disadvantage against most other options).

The scoring and the limitations/advantages for each option, along with some comments are presented in Tables 12 and 13.

7.4.1 Notes on Assessment

It should be noted that we are a company of engineers and geologists, therefore elements of the below assessment are best undertaken in collaboration with NPTCBC technical staff and other professionals as there are other issues, including but not limited to economic and social economic impacts, that we may not be aware of. The following is intended to be a live document that will evolve with input from others.

The assessment is therefore focussed at reducing risk to the school and considers ease of construction, costs of construction, effectiveness of each option. It may be prudent to, if wanted, to incorporate a human weighting, or other consideration to the assessment as considered necessary.

ESP have not considered any Local Development Plans or any other strategic development options as we are not privy to this information. The assessment is given as a guide only and should be amended by NPTCBC accordingly.

Table 12: Comparison of Remediation Options

<table>
<tr><th>Remediation Option</th><th>Advantages/Disadvantages to Mitigate Risk</th><th>Assessment Criteria</th><th>Suggested Score*</th><th>Total Score*</th></tr>
<tr><td rowspan="6">Avoid the Risk -
Close the School</td><td rowspan="5">Advantages:
There would be no risk to school users from the Quarry Spoil Tip.
No cost for tip mitigation.
No ongoing investigation, inspections or monitoring.
Can be implemented immediately.
Disadvantages:
Costs of creating new school.
Significant 'human' impact on residents, children having to travel to another school.
Potentially impact village socially/society.</td><td>Effectiveness</td><td>1</td><td rowspan="5">1</td></tr>
<tr><td>Durability</td><td>1</td></tr>
<tr><td>Practicability</td><td>0</td></tr>
<tr><td>Sustainability</td><td>0</td></tr>
<tr><td>Cost</td><td>-1</td></tr>
<tr><td colspan="4">Comments:
The only likely method to ensure no risk to school users.
Cost positive when considering likely long-term condition.
Approximate cost of £5/6 million for a new primary school (to be confirmed).
Hard to assess social economic cost/impacts – rated as neutral.</td></tr>
<tr><td rowspan="6">Avoid the Risk -
Remove the Tip to Landfill</td><td rowspan="5">Advantages:
Removes risk to school.
Disadvantages:
Access to tip would need to be improved
Significant earthworks required - Excavation operations will need to be very carefully controlled and implemented to avoid health and safety risks. Temporary work designs required, some risk whilst works carried out.
Disposal costs would be substantially high.
Remaining slope would need to be reprofiled and ecology, stability items all to be ensured.
Not environmentally friendly.
Not cost effective.</td><td>Effectiveness</td><td>1</td><td rowspan="5">-1</td></tr>
<tr><td>Durability</td><td>1</td></tr>
<tr><td>Practicability</td><td>-1</td></tr>
<tr><td>Sustainability</td><td>-1</td></tr>
<tr><td>Cost</td><td>-1</td></tr>
<tr><td colspan="4">Comments:
Option unlikely to be feasible.
Recycling/reusing the material may change the scored outcomes.</td></tr>
<tr><td rowspan="5">Reduce Frequency/Improve Stability –
Incorporate Drainage to agreed design objectives (e.g. Factor of Safety/Degree of Stability approach)</td><td rowspan="5">Advantages:
School can remain open if works are successful.
Disadvantages:
Some residual risk (probably low) will remain.
Access to tip would need to be improved.
Significant earthworks required - excavation operations will need to be very carefully controlled and implemented to avoid health and safety risks. Temporary work designs required, some risk whilst works carried out.
Cost to install drainage/materials.
Ongoing maintenance, visits and responsibility.
Ground Model not completely known for groundwater recharge and dewatering options not easily designed at this stage.
Several types of dewatering may be needed (borehole pumping, surface water drainage, directional drilling).</td><td>Effectiveness</td><td>0</td><td rowspan="5">-2</td></tr>
<tr><td>Durability</td><td>-1</td></tr>
<tr><td>Practicability</td><td>-1</td></tr>
<tr><td>Sustainability</td><td>1</td></tr>
<tr><td>Cost</td><td>-1</td></tr>
</table>

<table>
<tr><th>Remediation Option</th><th>Advantages/Disadvantages to Mitigate Risk</th><th>Assessment Criteria</th><th>Suggested Score*</th><th>Total Score*</th></tr>
<tr><td rowspan="2"></td><td>Monitoring would be needed after drainage works are complete to ensure effectiveness and this cannot be guaranteed at this stage due to the relatively low site investigation resolution.</td><td></td><td></td><td></td></tr>
<tr><td colspan="4">Comments
The drainage works would need to be designed based upon emerging conditions, unless further investigation is carried out in advance (time impacts).
It is likely that extensive groundwater monitoring would be required to confirm that works have been successful.</td></tr>
<tr><td rowspan="6">Reduce Consequence - Retaining Wall, Barrier, netting (hard engineering solution)</td><td rowspan="5">Advantages:
Will allow the school to remain open.
Disadvantages:
Some residual risk (probably low) will remain.
Access to tip would need to be improved in several areas.
Will need to place structures on third party land.
Significant earthworks required – works will need to be very carefully controlled and implemented to avoid health and safety risks. Temporary work designs required, some risk whilst works carried out.
Cost of additional investigation, designing and constructing significant structures. This will also take time to go through proposer processes.
Further investigation may show numerous structures needed, along with drainage, this may not be the most economic or quickest solution.
Ongoing maintenance, visits and responsibility.
Some dewatering needed to build structures, ensure temporary stability.
May look visually obtuse.
Monitoring would be needed after drainage works are complete to ensure of its effectiveness and this cannot be guaranteed at this stage.</td><td>Effectiveness</td><td>0</td><td rowspan="5">-4</td></tr>
<tr><td>Durability</td><td>-1</td></tr>
<tr><td>Practicability</td><td>-1</td></tr>
<tr><td>Sustainability</td><td>-1</td></tr>
<tr><td>Cost</td><td>-1</td></tr>
<tr><td colspan="4">Comments:
Exact scope of hard engineering solution not known and significant additional site investigation would be required to enable a suitable design.
By the time access has been made for the required level of investigation, which will present significant difficulties, this time and money could have been spent on other methods more suited and for this reason it is unlikely to be economical.</td></tr>
<tr><td colspan="5">Notes to Table 12:
* The suggested score, and thus the total score is based upon our opinions and should be reviewed, amended as necessary based upon knowledge held by Neath Port Talbot County Borough Council as required.
1. Reprofiling on its own is not considered to be a plausible mitigation measure and is not discussed separately.</td></tr>
</table>

Consideration could be given to a monitoring programme and possibly a warning system, however, given the proved sub-optimal drainage identified and anticipated risk to the school, this on its own is unlikely to reduce the risk to acceptable levels.

Table 13 below uses the same approach as above, however, a hybrid strategy comprising drainage betterment, monitoring and a warning system has been considered.

Table 13: Review of hybrid strategy

Hybrid Approach	Advantages/Disadvantages to Mitigate Risks	Assessment Criteria	Suggested Score*	Total Score*
Drainage Betterment and Warning System – Install drainage to create betterment only, install monitoring points and produce warning system	*Advantages:* • Following the works (or during, if it can be demonstrated to be safe), the school can be used/remain open. • Ongoing monitoring will be able to determine groundwater levels and allow a continued assessment, i.e. the risk level can effectively be monitored. • Works to install drainage can also be designed to allow access for equipment to install monitoring wells. *Disadvantages:* • Some residual risk (probably low or very low) will remain. • General betterment objective depends on conditions being as good or better than assumed to date. • Access to tip would need to be improved. • Earthworks required - excavation operations will need to be very carefully controlled and implemented to avoid health and safety risks. Temporary work designs required, some risk whilst works carried out. • Cost to install drainage/materials. • Ongoing maintenance, visits and responsibility. • Ground Model not completely known for groundwater recharge and dewatering options not easily designed at this stage. Investigation prudent during initial stages of earthworks. • Several types of dewatering may be needed (borehole pumping, surface water drainage, directional drilling). • Monitoring would be needed after drainage works are complete to ensure of its effectiveness and this cannot be guaranteed at this stage. • Monitoring may show ongoing risk if dewatering not effective or if slope becomes actively unstable. • School will have to have an evacuation procedure if warning shown instability.	Effectiveness	1	2
		Durability	0	
		Practicability	0	
		Sustainability	1	
		Cost	0	
	Comments: • Further investigation may show confidence in material parameters, which will effectively increase the stability or decrease the risk, however, it may show more variability which may increase risk. • Betterment objectives to be defined and agreed; this may be considered to be less extensive than the drainage solution/strategy outlined in Table 12.			

Notes to Table 13

* The suggested score, and thus the total score is based upon our opinions and should be reviewed, amended as necessary based upon knowledge held by Neath Port Talbot County Borough Council as required.

1, Reprofiling on its own is not considered to be a plausible mitigation measure and is not discussed separately.

7.4.2 Summary

There are a number of advantages and disadvantages for the range of remedial approached. However, using the semi quantitative assessment set out in Tables 12 and 13, the options that score the highest are:

- Close the school, 1 point;
- Combined approach (Table 13), 2 points; it is possible the risk could be considered 'very low' with this strategy, provided the tip is not actively unstable (see definition in Section 6.7).

The assessment showed that removing the tip to landfill or some combination of hard engineered structure(s) are unlikely to be favourable.

It would be prudent for Neath Port Talbot County Borough Council to review and agree, or adjust, the above suggested scores as necessary given their knowledge about the possible costs, acceptable social impacts and practical implications of the remedial options outlined. Consideration of the remaining design life of the school may impact the scores chosen for each option.

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