

Earth Science Partnership

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Pantteg Landslide, Pantteg

Interpretative Report; Hazard and Risk Assessment

Report Reference: ESP.5859e.09.2930 Volume 2

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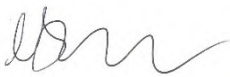
Pantteg Landslide, Pantteg Interpretative Report; Hazard and Risk Assessment

Prepared for:

Neath Port Talbot County Borough Council

The Quays, Baglan Energy Park, Brunel Way, Briton Ferry, SA11 2GG


 Report Reference: **ESP.5859e.09.2930 Volume 2**

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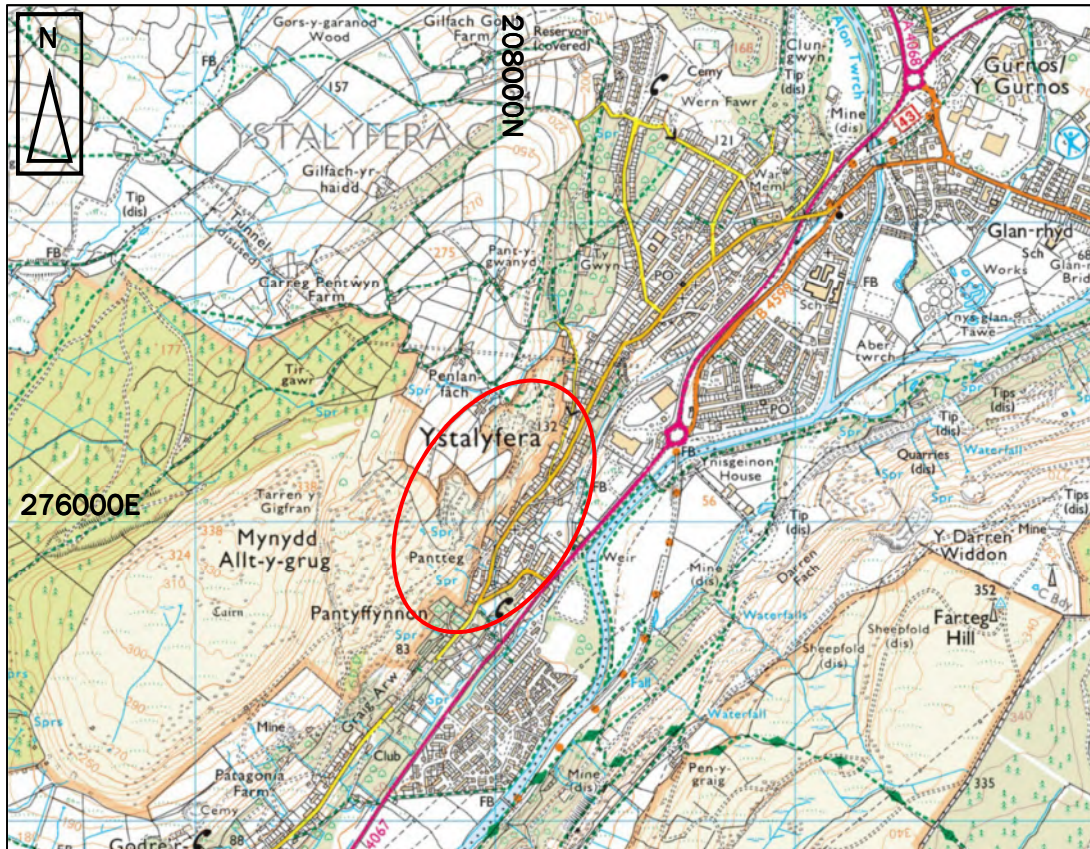
General Notes

1 Introduction and Assessment Approach

1.1 Background

Neath Port Talbot County Borough Council (NPTCBC), hereafter known as the Client, have appointed Earth Science Partnership Ltd (ESP) to assess the hazards and risks associated with the Pantteg Landslide near Ystalyfera in the Lower Swansea Valley. The general site location is shown on Figure 1a below.

Figure 1a: Site Location Plan 1:25,000 (Ordnance Survey License No.: AL100015788).



The ESP focus, on behalf of NPTCBC in 2015 and 2016, was to highlight options for a management approach to the Pantteg landslide, generally focussing towards a minimal cost strategy to discharge NPTCBC's duty of care to the residents of Pantteg. However, duty of care responsibilities were not previously well defined.

There is consensus that it would be uneconomical to stabilise the Pantteg landslide to a suitable degree without excessive cost and other options must be explored in the management of the landslide.

A series of landslides to the rear of Cyfyng Road, Pantteg occurred in early 2017 which re-focussed attention on the area and ESP were then asked to commence investigation works recommended that had been recommended previously (Ref. ESP5859e.2393, July 2016).

Following appeal against NPTCBC Emergency Prohibition Orders served on a number of Cyfyng Road properties, a series of additional exploratory positions and notes were produced by ESP as part of a separate expert commission, representing NPTCBC at the Residential Property Tribunal (Wales) through late 2017 and early 2018. The findings of the tribunal can be found in turn here:

- 84 Cyfyng Road, RPT/0012/10/17: <https://gov.wales/docs/rpt/publications/180524-rpt-decision-84-cyfyng-rd-ystalyfera.pdf>
- 86 Cyfyng Road, RPT/003/04/17: <https://gov.wales/docs/rpt/publications/180524-rpt-decision-86-cyfyng-rd-ystalyfera.pdf>
- 90-92 Cyfyng Road, RPT/003/10/17: <https://gov.wales/docs/rpt/publications/180524-rpt-decision-90-92-cyfyng-rd-ystalyfera.pdf>

In summary, the Residential Property Tribunal accepted the evidence and conclusions that the slopes to the rear of these areas of Cyfyng Road were/are unstable.

1.2 Aims, Objectives and Scope of Works

The aim of this assessment is to develop the understanding of the historical and current Pantteg landslide conditions, hazards and risks, such that options for the future management of the landslide can be considered along with strategies for informing residents of the hazards and risks. ESP have been supported in this work by Steve Parry¹ of Parry Engineering Geological Services Ltd (PEGS), in particular with the assessment of landslide hazard and risk.

Considering the need to review and reclassify the historical hazard and risk assessments/plans for the Pantteg area (e.g. the Cyfyng Road area had not been considered previously), the overall approach to hazard and risk was reviewed. It was decided in conjunction with NPTCBC that the new risk assessment process for the study area should be carried out using the AGS Guidelines for Landslide Susceptibility Hazard and Risk Zoning, 2007. Specifically: The assessment of landslide hazard and risk, Fell et al (2008) reporting on behalf of JTC-1 (Joint Technical Committee on Landslides and Engineered Slopes - IAEG, ISRM ISSMGE collaboration (the international professional geotechnical societies)). JTC-1 is largely based on AGS (2007) with minor modification for international implementation. The Engineering Group of the Geological Society is the UK National Group of the International Association of Engineering Geology (IAEG).

Draft assessments and plans of hazard and risk, based on the AGS Guidelines for Landslide Susceptibility Hazard and Risk Zoning, were presented to NPTCBC and Pantteg residents at public meetings held at Ysgol Gyfun Ystalyfera on the 7th September 2017 and the 29th January 2018. Physical works and monitoring to refine the Ground Model has continued through 2017, 2018 and 2019. At the time of writing, the monitoring work is still ongoing, as at least several years' worth of monitoring would be beneficial to obtain seasonal fluctuations at Pantteg. It is anticipated that the monitoring will continue for the foreseeable future.

To achieve the above, the following objectives were derived:

- 'Data mining' of the NPTCBC archives relating to landslides in the valley;

¹ Co-editor of: Developments in Engineering Geology. Geological Society Special Publication. 2016.
 Author of: Landslide hazard assessments: problems and limitations. Examples from Hong Kong. 2016.
 Chair of the IAEG commission C25 'Use of Engineering Geological Models'.
 Member of the European Federation of Geologists' 'Group of Experts' on Natural Hazards and Engineering Geology.
 Member of the International Association of Geomorphologists' Working Group on Applied Geomorphological Mapping.

- Review of previous reports and information;
- Update the assessment of the current conditions through investigation and instrumentation of key locations across the Pantteg landslide to improve resolution within the Ground Model relating to topography, geology, hydrology and hydrogeology;
- Obtain high resolution topographical data from LiDAR (Light Detection and Ranging) to aid assessment of geomorphological features, drainage channels and future management of these to enhance stability along with the provision of accurate topographical mapping and as a tool to assess zones of ground movement;
- Establish a basis for hazard and risk assessment; and
- Provide assessments and recommendations for next steps.

Additional works (e.g. geophysics) were also implemented as site conditions and assessment requirements emerged. These are detailed in Section 3.

This assessment was awarded on the basis of competitive tender quotations in line with the South West Wales Framework. This assessment and report was undertaken through 2017, 2018 and 2019.

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 across the Pantteg area and to provide suitable detail for a contemporary hazard and risk assessment.

1.3 Report Format

For ease of reference, all factual site investigation information has been combined into a single report volume (Volume 1), which includes all the investigation and monitoring information from various parties to date. Volume 2 represents the interpretation and Volume 3 provides an Executive Summary, as detailed below:

- Pantteg Landslide Assessment, Volume 1 – Factual Ground Investigation Report (Ref. ESP5859e.09.2930 Volume 1). Earth Science Partnership Ltd, October 2018;
- Pantteg Landslide Assessment, Volume 2 – Interpretative Report; Hazard and Risk Assessment (Ref. ESP5859e.09.2930 Volume 2);
- Pantteg Landslide Assessment, Volume 3 – Executive Summary (Ref. ESP5859e.09.2930 Volume 3).

The reports are issued in digital format only.

Information in the above reports is generally not duplicated and the above list is provided as a reference point to obtain further information and background to the site and proposed works. Pertinent information from the above reports is used to develop the Ground Model discussed and presented in Section 4.

1.4 Limitations of Report

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 client may require further advice in this regard.

2 Existing Ground Investigation and Assessment Data

2.1 Introduction

As discussed in Section 1.3, the site has been the subject to numerous desk study assessments, visits and site investigations.

A 'data mining' exercise of Neath Port Talbot County Borough Council archives provided further documents that included information on ground movements in Pantteg, and the wider area. Not all the information viewed is reproduced or listed within this report. The archive did not generally include significant information for the generation of the Ground Model; however, it does include some information to aid the Landslide Inventory, as discussed in Section 5 (for example, it includes general photos, public meeting records where actions to land movements were discussed, meeting notes, newspaper clippings and other reports). This information can be provided upon request.

The exercise was carried out in 2017 and the following provides a chronological summary of the pertinent information obtained.

The hillside of Pantteg has been the subject to previous investigations and assessments, some of which, considered pertinent, are listed below:

1. Geological Report on the Landslide Area on the Southeast Slopes of Graig-Arw, Ystalyfera, Brian Simpson, 14th November 1957.
2. Report on Tip Condition and Adjoining Ground at Allt y Grug, above Pantteg. West Glamorgan County Council, 26th September 1975.
3. Geological report on the landslip areas of Pantyffnnon and Pantteg, near Ystalyfera, South Wales, Institute of Geological Sciences, 10th March 1978.
4. Report on Landslip Investigation, Pantteg. Special Surveys Division, Engineering Geology Unit, Institute of Geological Sciences, 11th July 1978.
5. Godre'r Graig & Pantteg Landslides, Report on Hazard Mapping, report for the Lliw Valley Borough Council by Sir William Halcrow and Partners, July 1987.
6. Pantteg Landslide, Report on Ground Investigation, report for Lliw Valley Borough Council by Sir William Halcrow and Partners, December 1989.
7. Pantteg and Godre'r Graig Landslide Area, Report on Assessment of Landslide Hazard, Neath Port Talbot County Borough Council, February 1998.
8. Pantteg and Godre'r-Graig Landslips Slope Stability Review, Jacobs Engineering UK Limited, December 2013.
9. Price, C. E., 2015. Hydrometric thresholds for use in a landslide warning system at Pantteg in the Afon Tawe catchment, South Wales. MSc thesis, School of Earth and Environmental Sciences, University of Portsmouth.
10. Pantteg Landslip, Data Review and Management Proposals (Ref. ESP5859e.2393). Earth Science Partnership Ltd, July 2016.
11. Pantteg Landslip, Preliminary Factual Ground Investigation Report (Ref. ESP5859e.03.2715). Earth Science Partnership Ltd, March 2017.
12. Pantteg Landslip, Cyfyng Road – Factual Ground Investigation Report (Ref. ESP5859e.04.2923). Earth Science Partnership Ltd, July 2017.
13. Cyfyng Road Landslip, Atkins Technical Note, August 2017.
14. Pen-y-Graig Quarry Inspection Report, The Coal Authority, August 2017.
15. Cyfyng Road Landslip, Quantum Geotechnical. August 2017.

16. 96 Cyfyng Road, Pantteg Landslip, Ground Investigation Report. (Ref. 5859e.07.2937)
Earth Science Partnership, January 2018.
17. Pen-y-Graig Quarry Inspection Report, The Coal Authority, August 2017.
18. 100 and 111 Cyfyng Road, Pantteg, Ground Investigation Report. (Ref. 5859e.08.2943)
Earth Science Partnership Ltd, January 2018.

2.2 Summary and Discussion of Data by Others

Relevant data by others from the above information has been discussed and incorporated in the following sections in general chronological order.

2.2.1 Dillwyn and Jones, Mining Engineers, November 1957

The report provides a discussion on the coal seams in the area and suggests three groups of material present in the area of Pantteg, which were: solid rocks, superficial deposits and quarry and mining spoil.

It is stated that the exposed rock above Pantteg, in the quarries show strong jointing and beds were noted to be from 'several inches to several feet' in thickness. In addition, large rock masses were observed to be involved in the movements, as the dip of rock in the landslide was different to the known dip in the valley.

The site was visited to produce the report and observations showed 'weeping' joints and suggested that water was flowing through the joints. Observations also noted the presence of seepages from rock at coal seams and stated 'there is no doubt that water is deflected out on to the hillslope along these coal seams'.

The report was commissioned following a landslide in October 1957 and the probable cause of this movement is stated as excessive water, effectively increasing pore water pressures and inducing failure.

The report stated that it would be difficult to provide practical remedial works, but did suggest that drainage, notably near coal seams and associated seepages, may provide some betterment but conceded that ongoing maintenance would be required.

The report also provides several drawings, which include cross sections of Pantteg, these are generally not discussed in the text of the report but some pertinent information from these drawings includes:

- The section drawn opposite Pantteg Chapel suggests a coal seam at a level of approximately 400 ft (121.9m OD), our recent understanding indicates that it is not likely to be the Lower Welsh as suggested, as this is at a level of around 80m OD.
- The sections suggest the cause of rock fall from tension cracks in the top area of instability.

2.2.2 Tip Condition Report, West Glamorgan County Council, September 1975

Allt-y-Grug, above Pantteg was viewed as part of a spoil heap and tip inspection by West Glamorgan County Council, dated 26th September 1975. The brief report suggested that the ground and area around the slip area was saturated due to heavy rain. A small stream was noted to be flowing over the back scarp of Pantteg onto the landslide above the former location of Pen-

y-Graig House. The stream was in part collected by a drainage system, but some water was flowing down the slope.

The report recommended to contain this issue of water and direct it to the nearest manhole (drainage), there is no further record if this advice was followed.

2.2.3 Institute of Geological Sciences, March 1978

The Institute of Geological Sciences (now the British Geological Survey) undertook a two-day visual inspection of both landslides known as Godre'r Graig and Pantteg in December 1977 and their subsequent report was issued in March 1978.

The report states that Pantteg is an immediate post glacial landslide and the report discusses the regional geology, stating that the regional dip is around 10° to the south, and that there is a component (apparent) dip of around 3.5° into the valley.

The report indicates that the Pantteg Landslide is separated into two distinct areas. One of the areas lies above the village, on the eastern flank of Mynydd Allt-y-Grug, and the other lies below the main village which it is built upon. Furthermore, the upper area is stated to be separated by a bench, which is reportedly rib like in structure and comprises siltstone. The report states that the slip plane of the upper system merges at the top of the bench, and that the steep slope below the bench is the slip scar of the lower system, that underlies the village.

The presence of a cross level tunnel that leads from levels at the base of Clees Lane, within workings of the Red Vein, to some level in the slope above the Chapel was confirmed. Access into the tunnel was not possible during the walkover due to safety concerns.

The report discusses the contrasting permeabilities of the overlying (mainly) sandstones with underlying argillaceous rocks, notably the coal seams and associated seat earths and that the contrasting permeability will produce spring lines at these junctions.

The report states that the movement of the upper system occur along the same geological seam, or group of seams, being the Lower Pinchin, however instability also occurs above and below it.

The lower slopes of the landslide below the village, are considered to comprise 'Head and weak mainly argillaceous coal measures which descended the slope in immediate post-glacial time in a series of rotational and bedding plane slips and are now generally considered to be 'stable', although they do not define stable in their report.

2.2.4 Institute of Geological Sciences, July 1978

The Institute of Geological Sciences produced a follow up report in July 1978; this outlined a broad investigation scope and provided some potential remedial measures. However, it appears that was no subsequent investigation until the late 1980's, supervised by Halcrow.

2.2.5 Hazard Mapping Report by Sir William Halcrow and Partners, July 1987

Sir William Halcrow and Partners were instructed by Lliw Valley Borough Council (now part of NPTCBC's jurisdiction) to prepare a landslide hazard map of the Godre'r Graig and Pantteg landslide complex, with a description and history of landslide occurrences and the site setting including geology, mining/quarrying and hydrogeology.

2.2.6 Halcrow Investigation, 1989

The earliest intrusive investigation was undertaken by Exploration Associates, on the instructions of Halcrow, on behalf of Lliw Valley Borough Council and comprised ten trial pits and four boreholes, with the installation of piezometers within all the boreholes. Geotechnical testing was carried out on samples of obtained from that investigation.

An overview of the Halcrow ground investigation is presented in Table 1.

Table 1: Summary of Halcrow 1989 Investigation

Exploratory Hole Type	Exploratory Hole ID	Quantity	Maximum Depth (mbgl)
Trial Pits	TP1 – TP10	10	3.5
Boreholes (cable percussion with rotary core follow on)	BH1 – BH4	4	36.5

The investigation point positions are shown on Figure 2a.

2.2.6.1 Ground Conditions

2.2.6.1.1 Landslide Deposits

Soils associated with what Halcrow defined as the upper landslide subsystem were encountered in their trial pits TP1 to TP5 and BH2. The soils in these investigation points typically comprised gravel, cobbles and boulders of angular siltstones and sandstones with a varying degree of a loose silty sand matrix. BH2 showed these soils to extend to a depth of 7.8m.

The trial pits showed this material to have an ‘open structure’ and poor stability was observed in the trial pit sides. Halcrow inferred that these soils were representative of displaced rock, produced from rotational sliding of one or more blocks of the Llynfi Rock, near the horizon of the Lower Pinchin Seam.

Soils in the lower landslide system, as defined by Halcrow, were encountered in their investigation points, BH3, BH4, TP6 and TP10. BH3 indicated the landslide deposits to extend to a depth of 4.45m and comprise sandstone cobbles and boulders with a fine sandstone and siltstone gravel with a loose sand matrix, however, recovery in this material was poor. These soils were interpreted by Halcrow to represent displaced rock.

Below Made Ground (associated with a nearby previous house) at a depth of 1.5m in BH4, a 2.9m thick layer of firm dark brown silty sandy clay with angular gravel and cobbles was encountered, this was underlain by a thin (0.1m thick) layer of gravel whereupon weathered sandstone bedrock was encountered at a depth of 4.5m.

2.2.6.1.2 Bedrock

The boreholes proved a succession of sandstones, siltstones and mudstones of the Middle Coal Measures and the overlying Llynfi Beds of the Upper Coal Measures.

Strong, thinly to medium bedded sandstones form the solid strata visible in the back scarp of the landslide system and contained thin moderately weak to moderately strong, thinly laminated siltstones in the upper part.

The borehole above the landslide area (BH1) showed the Lower Pinchin Seam to comprise three leaves, or seams, the upper seam was 0.2m thick, the middle was 0.4m and the lowest leaf was 0.95m thick.

The Lower Welsh coal seam was encountered approximately 38m lower than the Lower Pinchin Seam. Halcrow's drillholes, BH2 and BH3 showed the strata in-between the two coal seams to comprise moderately strong, laminated arenaceous siltstone. A 10m thick weak to moderately weak mudstone with a thin coal was encountered in its central part and it was postulated that the Upper Cwmgorse Marine Band (UCMB) lies within the weaker mudstone strata, although type fossils were not encountered, and thus the exact location of the UCMB was not confirmed.

The Lower Welsh coal seam was found to be 0.45m thick and was directly underlain by a 2m thick, weak, argillaceous, fissured seatearth.

Within the landslide system, the bedrock was initially found to be highly weathered in BH2, BH3 and BH4. Poor recovery was encountered in these soils and no slip surfaces were identified.

2.2.6.2 Groundwater

No groundwater was encountered within the landslide deposits whilst drilling the boreholes in the upper parts of the landslide, BH2 and BH3. Monitoring of piezometers installed in these boreholes to the base of the landslide materials showed heads of water in the piezometers of between 0.01m and 0.97m.

BH4 was drilled near the 'toe' of the landslide and encountered water at depth of between 3.1m and 4.2m within the landslide deposits before being sealed by casing at a depth of 5.5m. Standpipe piezometers installed within the landslide deposits, which extended to a depth of 10.7m, indicated the lower 9m of landslide deposits in this borehole to be saturated.

Groundwater was encountered in BH3 at a depth of 21.5m within a layer of siltstone, the water rose to a depth of 19.2m after a period of 20 minutes. The borehole log shows this strike was within Siltstones, and the Halcrow text states that it was above the thin coal, above the Lower Welsh coal seam. Monitoring data from a piezometer installed within the siltstone at the strike depth show fluctuations in head to the order of 2.5m, with a maximum head of water of around 4m.

A piezometer installed in the Lower Pinchin Seam in BH1 showed fluctuations of the head of water by up to 4m.

2.2.7 Neath Port Talbot County Borough Council - Landslide Hazard, February 1998

A site assessment was carried out by NPTCBC in April 1997 and the subsequent 1998 report provides a reassessment of hazard and risk to Pantteg and Godre'r Graig, under the same principals as the previous Halcrow assessment.

The reassessment suggested the landslide area is larger than indicated by the 1987 Halcrow report and subsequently altered the hazard zones.

The report concluded with an indication that the landslide area remained active, or potentially active and suggested that further investigation, to the aim of stabilisation would not be possible at an economic level. It suggests that the identification of houses most at risk allows the council to prioritise expenditure accordingly.

2.2.8 Slope Stability Review - Jacobs Engineering UK Limited, December 2013

Jacobs were engaged by NPTCBC in January 2013 following a large landslide event in December 2012 that blocked the road through Pantteg. Jacobs initially assisted in the remediation of the December 2012 movement, but in 2013 they carried out a series of site inspections and produced an updated the Hazard and Risk map for Godre'r Graig and Pantteg Landslides.

Jacobs concluded that ground conditions and instability at the site are complex and operate on a range of scales, and that rates of movement vary across the site and movement can be triggered by a variety of influences, the intensity of which all vary across the site. Their assessment allowed them to populate an amended hazard and risk map and they suggested a comprehensive range of recommendations, which included (but not limited to): future monitoring and inspections in winter months, regular inspections and a monitoring system to allow rates of movement to be measured. Other recommendations included: alter current rock barrier near Pantteg Chapel, clearing of trees, regrade slopes and also consider using the planning system to prevent developments in certain areas of the study area.

2.2.9 Cyfyng Road Landslide – Atkins Technical Note, August 2017

Atkins, instructed by NPTCBC, produced a geotechnical technical note on the landslide to the rear of 86 Cyfyng Road. This included a visual survey of 85, 86, 88 and 90/92 Cyfyng Road by a structural engineer (CB3 Consult) to identify any structural defects and any signs of structural movement caused by the landslide to the rear of the properties.

Atkins conclude the landslide to be associated with Made Ground used to build up the gardens of the property, rather than natural deposits. The landslide has resulted in the potential for further movement of the gardens associated with; over-steepening of the upper part of the slope, resulting in small regressive failures; undermining and loss of support of garden retaining walls; washout, gulying shallow failures due to ongoing discharge from the combined sewer; and washout and gulying due to the bare erodible surface exposed from the original landslide.

Atkins consider these factors contributing to future movement will further expose the foundation on the rear walls and foundations of the properties, and the reaction (and resulting geotechnical hazard designation) of the buildings will depend on whether they are founded on rock or colluvial material, and whether the foundation acts as a retaining structure to uphill material.

Following this Technical Note, 2no. rotary cored boreholes were constructed under ESP's supervision near to 86 Cyfyng Road and at 96 Cyfyng Road, at either end of the terrace of houses in question. These boreholes are detailed in section 2.3.3 and 2.3.6 respectively.

2.2.10 Pen-y-Graig Quarry Inspection Report by The Coal Authority, August 2017

The Coal Authority, by request of Neath Port Talbot County Borough Council, have undertaken an inspection of the Pen-y-Graig Quarry, with the purpose of providing an assessment of the stability and safety issues pertinent to the Quarry. The inspection consisted a walkover survey by representatives of the Coal Authority in August 2017.

The inspection identified the quarry to consist:

- A generally vertical high wall on the northern perimeter, consisting predominantly sandstone with subordinate siltstone;

- Various, generally vegetated spoil mounds in the central and southern portions of the quarry, with some spoil mounds less than 2m from the southern boundary (the backscarp to Pantteg landslide);
- Spoil mounds were noted to comprise generally flat sandstone [gravel, cobbles, blocks] within a fine matrix. The mounds are noted to sit at the maximum angle of repose, and are assumed to have undergone little to no compaction (end tipped);
- There was no evidence of significant slope failures on any of the spoil mounds, with only localised scour and erosion, suggested to probably be due to water erosion; and
- No evidence of standing water or obvious major surface water flow routes with the main quarry floor area, suggesting the quarry spoil is permeable, with any surface water infiltrating rapidly. They go on to suggest that water would likely emerge at the junction of the sandstone and mudstone strata, at the position of the Lower Pinchin coal seam, at the base of the cliff on the eastern boundary.

The Coal Authority report recommended an inspection during winter months, when vegetation conditions should allow inspections of the eastern boundary cliff face, and to assess and seepages and surface water routes which may provide recharge to groundwater.

2.2.11 Pen-y-Graig Quarry Inspection Report by The Coal Authority, January 2018

As discussed in Section 2.2.10, the Coal Authority recommended revisiting the quarry in the winter months and the findings of their second visit, undertaken on 22nd January 2018, as requested by NPTCBC, was reported in January 2018.

The pertinent findings of the inspection report are summarised below, however the report should be read in full for context:

- The inspection was carried out during wet weather and preceding 48hrs had reportedly seen significant rainfall in the area;
- There are no significant drainage features on the site, and despite very heavy rain during the inspection, no areas of standing water were identified;
- Numerous seepages were noted in the high wall face, generally at the interface of sandstone and siltstone units;
- A small shallow circular slip was evident at the south east corner, at the crest of the cliff face. The slip appears to be fresh and is likely to be a consequence of surface water flows emanating from the toe of the adjacent rock top. A minor flow of water from the toe was evident during inspection.
- Where spoil mounds were noted to be unvegetated, the material was noted to be relatively loose;
- There was no evidence of significant slope failures on any of the spoil mounds, with only localised scour and erosion, probably due to surface water erosion;
- Despite the very heavy rainfall in the preceding 48hrs, there was no evidence of standing water or obvious major surface water flow routes within the main quarry floor area;

- A small issue of groundwater was observed emanating at the northern edge of the recently de-vegetated access track, which follows the track and disappears into the ground some 50m to the south;

The Coal Authority report suggests that the consequences of failure have not changed since issue of their previous report, in that:

- Localised spalling and surface erosion of the bare spoil mound sections adjacent the cliff edge may result in small amounts of spoil escaping over the cliff edge during extreme weather events. As described above, there was visual evidence of slumping at the south east corner at the crest of the cliff edge to support this scenario.
- A significant failure of the eastern cliff edge would result in destabilising of the adjacent spoil mounds, leading to collapse and deposition onto the plateau area / bench at the base of the cliff. Based on a visual assessment this scenario is considered to present a low risk under current conditions.
- The quarry location is in close proximity to a recorded landslide. Although there is no obvious visual evidence of active landslide activity affecting the quarry at present, it is recommended that the site should be inspected on an annual basis to monitor conditions and should also be visited following reports of instability in the general area and after periods of intense rainfall.

The Coal Authority recommended a further inspection of the second bench below the cliff face once ongoing vegetation clearance works were complete.

2.3 Summary of ESP Investigation Information

2.3.1 ESP Data Review and Management Proposals, 2015 and 2016

Under an instruction from NPTCBC, Earth Science Partnership undertook a Data Review and Management Proposals assessment which included a review of previous reports and assessments. The work included an updated assessment to describe the condition of the area and a basis for future management of the risks, with recommendations for possible tools and strategies for future management of the landslides was proposed. The report also included provision of a scope for recommended site investigation to further develop a Ground Model for the site.

The key aims of the further work proposed was to help move the assessments from a mainly qualitative approach, to a more robust and defensible, quantitative assessment, some of which have been undertaken and are discussed within this report.

2.3.2 Introduction

The ESP 2016 report included, amongst other items, the scope of works for a ground investigation to provide information for the development of the Ground Model. As discussed in Section 1.2 the aim of the investigation altered to include an updated risk assessment for Pantteg and the scope of works was therefore altered.

Earth Science Partnership have carried out numerous phases of investigation at Pantteg. Some of the phases were planned to provide information on the wider landslide Ground Model, other phases were however in response to ground movements, notably near Cyfyng Road.

2.3.2.1 Intrusive Elements

A preliminary phase of investigation (BH101-BH103) was carried out in December 2016 and the aim of the investigation was to provide a cost-effective way of installing groundwater monitoring standpipes in three areas of Pantteg. The information would provide a snapshot of the ground conditions and allow preliminary groundwater monitoring to take place and if necessary, allow the amendment of the proposed scope of main investigation.

Investigations in response to ground movements in properties to the Cyfyng Road Property Tribunal included borehole references BH200s, BH401 and WS500s. The information obtained from these boreholes has been considered in developing the Ground Model but was primarily used to support the tribunal.

The Ground Model has been populated with historical information and new information from investigation points refs 300s and 600s. The rationale for each borehole and trial pit is discussed in the relevant sections, but is summarised in Tables 2 and 3.

Table 2: Borehole and Installation Details

Ref	Location	Depth (m)	Installation type and depth (m)			Investigation Point Rationale and Comments
			Stand pipe(s)	Vibrating Wire Piezometer(s)	Inclinometer	
BH101	Opposite Chapel	25	8.18 & 17.6	-	-	Borehole drilled via open hole methods to enable a cost-effective way to briefly understand the ground conditions, depth to rock and allow the installation of 19mm nested piezometers. Borehole positioned where no access was needed to be made, near signs of movement and in close proximity to houses and Cyfyng Road. Borehole also targeting Lower Welsh seam.
BH102	Clees Lane	21	5.25 & 18.3	-	-	Borehole drilled via open hole methods to enable a cost-effective way to briefly understand the ground conditions, depth to rock and allow the installation of 19mm nested piezometers. Borehole located in easily accessible area of the lower portion of the landslide and determining if Red Seam present.
BH103	Graig y Merched	25	4.4 & 15.1	-	-	Borehole drilled via open hole methods to enable a cost-effective way to briefly understand the ground conditions, depth to rock and allow the installation of 19mm nested piezometers. Borehole positioned to determine the presence of the Lower Welsh and confirm ground conditions in the northern portion of Pantteg landslide.
BH202 ¹	86 Cyfyng Road	10.1	10 ²	-	-	Borehole drilled in response to local ground movement at a property on Cyfyng road. Borehole confirmed ground conditions in nearest easily accessible area and allowed the installation of groundwater monitoring equipment.
BH301	Quarry	60	-	6, 21, 32	41.5	Borehole drilled to confirm stratigraphy, notably the presence of coals as part of the Lower Pinchin Group, and the Upper Cwmgorse Marine Band. Vibrating wire piezometer installed within the Lower seam of the Lower Pinchin Group to assess groundwater. Inclinometer to assess if large scale rotational failure occurring.
BH302	Graig y Merched	30.2	-	6.5, 10.5, 21.5	-	Borehole located in a relatively easily accessible area and also located where surface movement identified. Borehole to confirm ground conditions, location of Lower Welsh seam and installations were placed to provide information on groundwater within Colluvium and shallow bedrock.
BH303	Graig y Merched	35	-	6	35	Borehole located in a relatively easily accessible area and also located where surface movement identified. Borehole to confirm ground conditions, location of Lower Welsh seam. Vibrating wire piezometer placed within Lower Welsh coal seam and associated seat earth, inclinometer installed to provide information on any ground movement within soils and bedrock.
BH304	Clees Lane	29	-	5, 15	-	Borehole located in the lower system of the landslide and confirm ground conditions. Vibrating wire piezometers were placed within the colluvium and a fractured zone within the bedrock to confirm the groundwater conditions within the lower landslide system. Borehole position easily accessible next to roadway.
BH305	Opposite Chapel	25	-	7, 14	25	Borehole located at the base of the 2013 regraded slope that is showing signs of movement. Borehole position easily accessible. Borehole to confirm ground conditions and allow the installation of two vibrating wire piezometers , one in the Colluvium and one deeper within weathered bedrock. Inclinometer placed to determine if movement in slope visually noted occurring at the base. Borehole may also confirm the location of the Lower Welsh and Lower Cwmgorse Marine Band.
BH306	Church Road	33.8	-	10	30	Borehole located in area of notable surface movement, near a drainage run and in the southern portion of the Pantteg area. Borehole to provide information on ground conditions and allowed the installation of vibrating wire piezometer and inclinometer. Vibrating wire placed within Colluvium and inclinometer placed to determine if ground movements are occurring.
BH401	96 Cyfyng Road	12	-	10	12	Borehole drilled in response to local ground movement at a property on Cyfyng road and to provide information for the residential property tribunal. Borehole confirmed ground conditions at 96 Cyfyng Road and allowed the installation of groundwater and ground movement equipment
WS501	100 Cyfyng Road	2.6	2.5	-	-	A series of window sampler boreholes were drilled in the properties of 100 and 111 Cyfyng road to understand the ground conditions in the rear gardens along Cyfyng Road. The boreholes were drilled to provide information for the residential property tribunal and allow the installation of several 19mm standpipes. Access to these areas was only possible on foot and the scope of the investigation was therefore limited to hand held equipment. This impacted upon the depth achievable by the investigation equipment, however, it was sufficient to obtain the surface ground conditions. In addition to the window sampling, mackintosh probes were carried out adjacent to each window sampler location and the results are provided in our volume 1, factual report.
WS502		2.8	-	-	-	
WS503		2.6	-	-	-	
WS504		2.7	2.5	-	-	
WS505	111 Cyfyng Road	2.6	2.5	-	-	Borehole references WS501 to WS504 were drilled within the rear garden of 100 Cyfyng Road. Borehole references WS505 to WS508 were drilled within the rear gardens of 111 Cyfyng Road.
WS506		2.5	2.5	-	-	
WS507		2.5	-	-	-	
WS508		2.5	2.5	-	-	
BH601	Pen y Graig	51	-	12	17.5	Following the provision of access, and suitable health and safety checks, two boreholes were drilled in the upper landslide system, BH601 and BH602. Borehole BH601 was drilled in the area identified by Halcrow (1989) to have recent or active cracking features. The borehole was drilled to confirm the thickness of any Made Ground, landslide material and try and identify a slip surface. The location of the Upper Cwmgorse Marine band and the Lower Welsh coal seam were also targeted to help confirm the stratigraphy in the area. A vibrating wire piezometer was installed below the anticipated slip surface to allow the monitoring of water pressure within the Landslide Material and Lower Pinchin Group (lower). An Inclinometer was installed through the Made Ground and Landslide material into the bedrock to provide an indication of any movement.
BH602		11.7	11.7	-	-	BH602 was also drilled in the Upper Landslide System and aimed to confirm the depth of any Made Ground, Landslide Material and any slip surface. A 19mm standpipe piezometer was installed with a response zone within the Made Ground, Landslide Material and weathered bedrock to help correlate to the vibrating wire piezometer installed in BH601.

Notes:

1.

BH201 information is omitted from this table as it was re-drilled and information from BH202 more pertinent.

2.

50mm diameter standpipe installed with Herron logger.

Table 3: Trial Pits

BH Name	Depth (m)	Geology	Location	Rational and Comments
TP301	3m	Made Ground and Colluvium	Opposite Chapel, near BH305	Trial Pits located opposite Chapel in area regraded during the 2013 work and former location of houses along Cyfyng Road. Trial pits to confirm the thickness of Made Ground, if any and provide information on Colluvium.
TP302	3.5m	Made Ground and Colluvium	Opposite Chapel, near BH305	
TP303	2.9m	Made Ground	Near top of Clees Lane	To determine local ground conditions in easily accessible location.
TP304	3m	Made Ground	Cawr Pen-y-Graig Quarry	Trial pits positioned in and around the disused Cawr Pen-y-Graig quarry to determine if it had been backfilled and the materials present. TP306 provided information on weathered rock as located in an area unlikely to have been altered by quarry or farming practices.
TP305	2.9m	Made Ground	Cawr Pen-y-Graig Quarry	
TP306	3.2m	Made Ground and weathered rock	Just outside Cawr Pen-y-Graig Quarry	
TP307	3.3m	Made Ground and weathered rock	Cawr Pen-y-Graig Quarry	
TP308	4.9m	Colluvium	Bottom of Clees Lane	Trial pit excavated within anticipated Colluvial lobe of lower Landslide System. The Colluvium comprised a clayey gravel with boulders.
TP601	4.0m	Made Ground – coarse discard colliery spoil and probable rotated/toppled blocks	Pen-y-Graig, near adit	Trial pits all located in Upper Landslide system. Trial pits to confirm shallow ground conditions and assess if a shallow slip surface present and note any groundwater observations. Trial pits TP604 and TP605 excavated near to BH601 and BH602 respectively, to provide greater detail on shallow soils in boreholes.
TP602	2.6m		Pen-y-Graig	
TP603	2.9m		Pen-y-Graig	
TP604	4.25m		Pen-y-Graig area, near BH601	
TP605	4.0m		Pen-y-Graig area, near BH602	
TP606	1.7m		Pen-y-Graig	
TP607	1.5m		Pen-y-Graig	
TP608	2.7m		Pen-y-Graig, near adit	
TP609	2.5m		Pen-y-Graig	
Notes:				
1, Trial Pit located north of 86 Cyfyng road originally proposed omitted due to the presence of services and lack of access.				

2.3.2.2 Non-Intrusive Elements

In addition to the intrusive elements discussed above (trial pits and boreholes) other data gathering was carried out to aid our assessment and these are discussed below.

2.3.2.2.1 Rainfall Data via Rain Gauge

An automatic rain gauge was installed at the site which measures daily rainfall to an accuracy of 0.1mm. The data is presented in our factual report, Volume 1, and is also shown on the groundwater monitoring information for ease of reference.

2.3.2.2.2 River Level Data

Our original scope of works was to collect river data for the Tawe at two nearby locations, and compare this with our rain, groundwater and movement information. As discussed in Section 1.2, the scope of the investigation has changed, and this information was therefore not obtained.

2.3.2.2.3 LiDAR and GPS Survey

As discussed in our factual report, the trial pit and borehole locations were surveyed once completed and the information regarding the positions and levels are provided in Volume 1 of our report.

In addition to this LiDAR surveys were carried out to obtain a topographic survey of Pantteg and the wider area. The LiDAR surveys and their respective comparison are discussed in Section 3.7.

2.3.2.3 Monitoring Regime

Instrumentation (rain gauge, vibrating wire piezometers, water level loggers and inclinometers) have been monitored on a roughly monthly basis since installed.

Throughout the monitoring, some of the installations have recorded gaps in the data and this is thought to be due to several reasons, including tampering/vandalism of the monitoring instrumentation. The monitoring data is included in our first volume of the report and the interpretation of the data is presented where necessary below.

This report includes all monitoring date up to March 2019.

2.3.3 ESP Preliminary Investigation, December 2016

On the instruction of Neath Port Talbot County Borough Council, ESP undertook a preliminary Factual Ground Investigation between December 2016 and March 2017, which comprised three rotary boreholes, installation of nested standpipe piezometers and a period of monitoring.

A summary of the investigation carried out is provided in Table 4.

Table 4: Summary of ESP March 2017 Investigation

Exploratory Hole Type	Exploratory Hole ID	Quantity	Maximum Depth (mbgl)
Boreholes (rotary open hole)	BH101 – BH103	3	25

2.3.3.1 Ground Conditions

Boreholes BH101 was drilled on the northern side of the A469 opposite Pantteg Chapel, which is in the middle to lower portions of the landslide system. BH101 encountered 3.2m of Made Ground comprising clay with boulders over Colluvium that comprised alluvium with gravel to a depth of 4.6m over weathered mudstone with clay to a depth of 9.6m. The driller was unsure if the strata between 4.6m and 9.6m was weathered rock or disturbed material, however, given that the hole was collapsing between these depths, and required casing below 9.6m, it is considered to be disturbed and has therefore been logged as Colluvium.

Alternating layers of siltstone and mudstone were encountered below the colluvium to the maximum depth of the borehole, of 25m.

Borehole BH102 was positioned near in the lower landslide system at the bottom of Clees Lane and below the tarmac surface, colliery spoil was encountered and extended to a depth of 3.2m, whereupon Colluvium was encountered, and extended to a depth of 13.3m. Bedrock of mudstone and sandstone was then encountered and extended to the base of the borehole, at 21m.

Borehole BH103 was positioned on the northern edge of Graig-y-Merched, in the eastern extent of the landslide system. Below a tarmac surface, Made Ground extended to a depth of 0.3m whereupon weathered shale was encountered and extended to a depth of 4.2m. A 0.4m thick layer of coal was then encountered, and extended to a depth of 4.6m. The coal was intact and no sign of workings was observed. This coal seam is anticipated to be the Lower Welsh coal seam. Below the coal, a thin band of mudstone was encountered and extended to a depth of 5.2m, whereupon siltstone was encountered and extended to the base of the borehole, of 25m.

2.3.3.2 Groundwater

The investigation techniques used as part of the investigation did not easily allow the identification of water strikes as a water mist flush or waster flush masks potential inflows. However, suspected water strikes were recorded by the driller and are summarised in Table 5 below:

2.3.3.2.1 Groundwater encountered during Investigation

Table 5: Summary of groundwater ingress in ESP March 2017 investigation

Table 5: Summary of groundwater strikes in 2017 March 2017 investigation		
Hole ID	Stratum of Strike	Groundwater Strike Depth
BH101	Colluvium	Becoming wet at 7.0m
BH102	Colluvium	Becoming wet 5.2m
BH103	No strike identified	
Notes to Table 5:		
1. Details of groundwater strikes shown on exploratory hole records, within Volume 1, the Factual Report. 2. Groundwater monitoring information is presented in Volume 1, the Factual Report.		

2.3.3.2.2 Groundwater Monitoring

The standpipes installed into the three boreholes were subsequently monitored on four occasions as part of the ESP March 2017 investigation. The standpipes in BH101 and BH103 were

monitored shortly after installation whilst the site works were progressing on BH102, all the current groundwater monitoring information is provided in Table 6.

Table 6: Summary of ESP groundwater monitoring data

Borehole and standpipe		Depth to Water (m)					
		Monitoring Date					
		15/12/16	22/12/16	13/1/17	27/1/17	23/2/17	10/9/18
BH101	shallow 8.18m	7.98	8.05	8.03	8.05	8.05	-
Near Chapel	deep 17.6m	15.60	15.50	16.44	17.52	17.51	-
BH102	shallow 5.25m	-	4.00	3.75	3.95	3.52	4.1
Clees Lane	deep 18.3m	-	17.95	17.95	17.96	15.73	Dry
BH103	shallow 4.4m	3.75	3.70	4.13	4.13	4.12	4.1
Graig y Merched	deep 15.1m	12.77	14.92	14.95	15.05	14.96	15.1 (wet at base)
Comments on weather preceding monitoring visit		During site works, generally dry	After rainy period	After rainy period	After and during dry period	Following storm Doris ¹ , rainy period.	Following dry period
Notes: - Storm Doris produced yellow and amber Met Office warnings for wind, snow and rain. Met Office data indicates over 20mm (and up to 25mm) of rain were recorded in Snowdonia, Northumberland and Berwickshire. - Standpipe buried by Gabion Wall Construction.							

2.3.4 ESP Investigation at 86 Cyfyng Road, July 2017

ESP undertook a Ground Investigation between June and July 2017, on the instruction of NPTCBC which comprised the construction of a single dynamic sampled with rotary core follow on borehole with the subsequent installation of a groundwater monitoring standpipe with a data logger.

Poor recovery was encountered whilst drilling this borehole (BH201) in the zone between weathered rock and bedrock. To obtain better recovery, a second borehole, (BH202) was drilled next to the positioned of BH201.

An overview of the ESP July 2017 ground investigation is presented in Table 7, below.

Table 7: Summary of ESP July 2017 Investigation

Exploratory Hole Type	Exploratory Hole ID	Quantity	Maximum Depth (mbgl)
Boreholes (dynamic sampler with rotary core follow on)	BH202 (Replaced BH201)	2	10.10

2.3.4.1 Ground Conditions

The borehole was positioned as close as practically possible to 86 Cyfng Road, within the access granted; the position of the borehole was on the southern side of Cyfng Road, near to 81 Cyfng Road which is in the north-eastern extents of the landslide system.

Below a tarmacadam surface, Made Ground associated with suspected backfilled basements was encountered and extended to a depth of 3.9m. The underlying weathered bedrock initially comprised firm to stiff brown gravelly slightly sandy slightly silty clay and graded into a dark grey clayey slightly sandy gravel. Rock head was encountered at a depth of 6.5m and typically comprised strong light grey coarse grained sandstone to the full depth of the borehole, of 10.10m.

2.3.4.2 Groundwater

Groundwater was not encountered during drilling, however, the use of a water flush to assist the drilling process may have masked inflows.

A groundwater monitoring standpipe was installed with a response zone between 1.0m and 10.10m. A Heron dipperLog Nano Water Level Logger was installed at the base of the standpipe and has shown groundwater at levels of between 102.6m OD and 103.15m OD.

2.3.5 Light Detection and Ranging (LiDAR) Surveys

An initial LiDAR survey of the Pantteg and Godre'r-Graig Landslides was undertaken over two days, on the 17th August 2017 and 4th October 2017. A repeat survey of the whole area was undertaken on the 9th April 2018. A comparison of the two LiDAR surveys has been undertaken in the form of an Isopachyte Map.

A LiDAR survey was the chosen method of surveying for the following reasons:

- Cost-effective and relatively rapid compared to more traditional methods of topographic surveying for such a large study area;
- Surveys are easily repeatable, and can be compared to one another;
- Large areas of Pantteg are inaccessible by foot due to dense vegetation and very steep, dangerous slopes. Remote surveying negates these Health and Safety concerns.

The digital information is available upon request and the results of the LiDAR data is discussed further in Section 3.7.

2.3.6 ESP Investigation, July to December 2017

An intrusive investigation was undertaken by ESP between July and December 2017, on the instructions of NPTCBC and comprised eight trial pits and six boreholes, with the installation of a variety of vibrating wire piezometers and inclinometers within the boreholes. Geotechnical testing

was carried out on samples of obtained. Monitoring of vibrating wire piezometers and inclinometers is ongoing and data held to date is presented in Volume 1 of our report, and the results are discussed in Section 3.3.

Table 8: Summary of ESP Investigation (July to December 2017)

Exploratory Hole Type	Exploratory Hole ID	Quantity	Maximum Depth (mbgl)
Trial Pits	TP301 – TP308	8	4.90
Boreholes (dynamic sampler/cable percussion with rotary core follow on)	BH301 – BH306	6	60

The positions of the above trial pits and boreholes are shown on Figure 2a, 2b and 2c.

2.3.6.1 Ground Conditions

2.3.6.1.1 Made Ground

Trial pits in the quarry (BH301, TP304-TP307) showed the Made Ground to comprise either loose to medium dense very clayey gravel of angular siltstone and sandstone with variety of man-made fragments including metal sheeting, metal wire, whole rubber tyres, glass plastic and bricks or a loose to medium dense sandy gravelly cobbles of tabular siltstone and sandstone which extended to the maximum depth of the trial pits, of 4.2m.

At the lower end of Clees Lane, (BH304 and TP308): Made Ground was encountered to a maximum depth of 2.8m as either; a loose dark grey slightly clayey sandy gravel of angular fine to coarse tabular mudstone, with fine angular coal; or as a gravelly very sandy clay with occasional pieces of blue subrounded coarse gravel with a strong smell of Hydrogen Sulphide.

Made Ground encountered in BH305, BH306, TP301, TP302 extended to a maximum depth of 3.8m in BH306, with a covering of between 0.3m and 2.5m over the landslip area. This unit is recovered as a brown gravelly clay, with occasional bricks, ceramic fragments and slag.

Demolition Backfill (Made Ground): encountered in the location of TP301 and TP303, as a medium dense to dense sandy gravelly cobbles and boulders of subangular to angular sandstone with rare brick fragments.

2.3.6.1.2 Colluvium

Encountered in BH302, BH304, BH305, BH306 and TP301, TP302 and TP308 to a maximum depth of 20.5m (BH306) as a gravelly clay or clayey gravel with cobbles and boulders. Gravel, cobbles and boulders are angular to subrounded mudstone, siltstone and sandstone. Boulders are up to 1.2m by 1.5m.

Field SPT N-values within the gravelly clays varied between 12 and in excess of 50 where cobbles and boulders were present, with most results greater than 45.

2.3.6.1.3 South Wales Upper Coal Measures Bedrock

Encountered in BH301 to a depth of 50.5m.

The weathered soils of this strata generally comprised firm to stiff orange-brown slightly sandy slightly gravelly clay and coarsened between 1.3m-3.0m. Grade C weathered bedrock was

encountered in TP306, TP307 and BH301 to a maximum depth of 5.2m as a weak to medium strong coarse-grained sandstone or siltstone.

Three coal seams have been identified as part of the Upper Coal Measures, the details of which are shown below;

- Unnamed coal seam between 6.6-7.0m, with an associated very organic mudstone seatearth to 7.7m. Coal seam is fresh with slightly stepped 70° joints.
- Lower Pinchin Group – Upper Seam: encountered between 22.0m-22.2m in BH301 with an associated very organic mudstone seatearth to 23.0m. Coal seam is partially weathered and has been recovered as a slightly clayey gravel. This coal seam notably occurs below a 0.1m thick conglomerate bed at 21.6m.
- Lower Pinchin Group - Lower Seams: encountered between 31.2m and 33.85m depth in BH301, recovered as three separate coal seams with coal partings of sandy siltstone with a very high fossilised plant debris content. The coal recovered is fresh with smooth, slightly striated, 45° joints.

This Upper Coal Measures varies between mudstone, siltstone and sandstone. A summary of the different lithologies encountered is shown below:

- Moderately strong to strong fresh sandy siltstone, locally with thinly bedded to thinly laminated sandstone;
- Weak black fissile mudstone;
- Strong grey fresh sandstone, locally with thickly to thinly bedded sandy siltstone and siltstone;
- Very thin to thin beds of strong dark grey and grey siltstone conglomerate with a sandstone matrix. Clasts are rounded fine to coarse gravel sized, with slight iron oxide staining around the perimeter of the clasts.

The boundary of the Upper and Middle Coal Measures is defined by the Upper Cwmgorse Marine Band (Archer, 1968), which has been identified at a depth of 48.0m to 50.5m in BH301 as a weak fissile mudstone with occasional nodules of pyrite.

2.3.6.1.4 South Wales Middle Coal Measures Bedrock

Encountered to the base of BH301 to BH306.

The weathered expression of the Middle Coal Measures has been encountered widely across site in BH301, BH303, BH304 and BH305, with thickness of between 0.55m and 5.5mm beneath the Made Ground or Colluvium. The weathered rock encountered is between Grade E to Grade B, with unweathered (Grade A) material recovered below. The Grade E weathered rock has been encountered as a grey mottled brown and orange gravelly silty sandy clay, with gravel of subangular siltstone and mudstone.

Two coal seams have been identified in the Middle Coal Measures strata, which are detailed below –

- Unnamed thin coal seam between 56.25m-56.35m in BH301
- Lower Welsh Coal Seam encountered in BH305 and BH303 between 11.0m-11.25m and 4.5m-4.7m respectively, with associated mudstone/siltstone seatearths containing a very high content of plant debris. This has been recovered as a clayey gravel in BH303 and as a fine to coarse gravel in BH305. A probable seatearth has been identified immediately below the colluvium in BH302, and is likely to be associated with the Lower Welsh coal seam.

The Lower Cwmgorse Marine Band has been identified in BH303 and BH302 at thickness of 3.0m and 1.15m respectively as a dark grey/black partially weathered fissile mudstone with amorphous pyrite nodules.

The Middle Coal Measures Formation encountered at the site is predominantly encountered as a moderately strong to strong sandy siltstone, with horizons of fossilised plant debris, varying between a low to high content. Locally this unit is thinly bedded to thinly laminated with siltstone, sandstone, The Middle Coal Measures is also locally expressed as the following lithologies;

- Weak dark grey fissile mudstone; and
- Strong to very strong medium to coarse-grained sandstone, occurring locally with thin to thick laminae of sandy siltstone, siltstone and minor thin coal laminae.

Surface iron oxide weathering is present consistently on the faces of fractures present throughout the stratigraphy encountered.

4no. Uniaxial Compressive Strength (UCS) tests indicate the rock has a maximum strength of between 31.6 and 145MPa. 12no. Point Load Tests indicate a point load index of between 0.12 and 5.26MPa.

2.3.6.2 Hydrogeology

2.3.6.2.1 Groundwater Bodies

The investigation techniques utilised do not easily allow identification of water strikes as a water mist flush or water flush masks potential inflows. Suspected water strikes were recorded by the driller and are summarised in Table 9.

Table 9: Summary of Groundwater Ingress in the Investigation

Hole ID	Stratum	Comment on groundwater encountered
TP301	Colluvium	Slow inflow at 3.0m.
TP302	Colluvium	Seepage at 2.3m
TP308	Colluvium	Seepage at 4.0m.
BH301	Upper Coal Measures (Siltstone)	Seepage at 25.0m
BH305	Colluvium	Becoming wet at 3.0m to the base of the Colluvium
BH306	Made Ground	Moderate seepage at 2.0m, wet below throughout weathered bedrock.
BH306	Middle Coal Measures (Siltstone)	Slow seepage at 22.0m.
BH306	Middle Coal Measures (Siltstone)	Slow seepage at 29.5m.

Further information on the groundwater, and the change in groundwater over time is illustrated in the Vibrating Wire Piezometer results presented in Volume 1 of our report.

2.3.6.3 Instrumentation

2.3.6.3.1 Vibrating Wire Piezometers

9no. Vibrating Wire Piezometers have been installed in the boreholes. The detail of the installations are shown in Table 10:

Table 10: Summary of Vibrating Wire Piezometer installations.

Borehole ID	Depth (m)	Response zone stratum	Rationale
BH301	6	Thin Coal	Assess the range of groundwater levels in the thin coal and overlying quarry spoil.
	21	Thin Coal	Assess the range in groundwater level in the thin coal.
	32	Lower Pinchin Coal Seam	Assess the range in groundwater level from the Lower Pinchin Coal Seam.
BH302	6.5	Colluvium	Assess the range of groundwater in the colluvium
	10.5	Middle Coal Measures	Assess the range of groundwater in the bedrock
	21.5	Bedrock	
BH303	6	Lower Welsh Coal Seam/Seat earth	Assess the range in groundwater levels in the Lower Welsh Coal Seam.
BH304	5	Colluvium	Assess the range of groundwater level in Colluvium.
	15	Weathered fracture zone	Assess the range of groundwater levels in a pronounced weathered fracture zone.
BH305	7	Colluvium	Assess the range of groundwater level in Colluvium.
	14	Weathered fracture zone	Assess the range of groundwater levels in weathered fracture zone.
BH306	10	Colluvium	Assess the change in groundwater level in the colluvium/weathered bedrock.
Notes on Table 10: 1. Details of each monitoring well are presented on the individual borehole, within Volume 1 of the Report.			

2.3.6.3.2 Inclinerometers

6no. inclinometers have been installed to a maximum depth of 42.0m using 70mm inclinometer casing. A summary of the installs is shown in Table 11.

Table 11: Summary of Inclinerometer installations

Borehole ID	Depth (m)	Summary of Response Zone
BH301	41.5	Quarry spoil to 4.2m, over bedrock of Upper and Middle Coal Measures. Coal and associated seatearths identified between 6.6m-7.7m, 22m-23m, 31.2m-33.9m (Lower Pinchin) and 56.25m-56.35m.
BH303	35	Glacial Diamicton to 2.6m over Middle Coal Measures bedrock. Lower Welsh Coal seam and associated seatearth at 4.5m-5.7m. Lower Cwmgorse Marine Band at 24.5m-25.6m.
BH305	25	Colluvium to 11m over Middle Coal Measures bedrock. Lower Welsh coal seam and associated seatearth between 11m-12m.
BH306	30	Made Ground to 3.8m over weathered bedrock to 20.5m. Siltstone of the Middle Coal Measures to the base at 33.8m.
Notes on Table 11: 1. Details of each inclinometer and the ground conditions are presented on the individual borehole logs – within Volume 1 of our Report.		

The inclinometer casing has been monitored using a digital biaxial inclinometer system, with the results of each monitoring visit to date presented in Volume 1 of our Report.

2.3.6.4 Rain Gauge

An Adcon Rain Gauge has been set up in the graveyard of Pantteg Chapel to record the time and level of rainfall, to an accuracy of 0.1mm. This has been set up following World Meteorological Organisation (WMO) guidelines outlined in by WMO, 2014 (Chapter 6 – Measurement of Precipitation). The rain data is presented in Volume 1 of this report.

2.3.7 ESP Investigation at 96 Cyfyng Road, November 2017

ESP undertook a Ground Investigation between October and November 2017, on the instruction of Neath Port Talbot County Borough Council which comprised the construction of a single dynamic sampled with rotary core follow on borehole with the subsequent installation of a vibrating wire piezometer and inclinometer.

An overview of the ESP 96 Cyfyng Road, November 2017 ground investigation is presented in Table 12.

Table 12: Summary of ESP, 96 Cyfyng Road, November 2017 Investigation

Exploratory Hole Type	Exploratory Hole ID	Quantity	Maximum Depth (mbgl)
Borehole (dynamic sampler with rotary core follow on)	BH401	1	12

2.3.7.1 Ground Conditions

The borehole was positioned on the southern side of Cyfyng Road, within the boundary of No 96 Cyfyng Road, and the findings are summarised below.

Made Ground comprising either, sandy gravel and cobbles of sandstone and some coal, brown mottled orange gravelly clay, with gravel of fine to coarse mudstone, siltstone and coal, or grey silty sandy gravelly clay with wood and possible slag fragments and extended to a depth of 2.4m.

A SPT N-value of 0 was measured in the Made Ground at a depth of 1.2m. The seating blows of this test were 2 and 1, and it is likely that the Made Ground at this depth is very soft, rather than a void being present, which may be indicated by a SPT-N of zero.

Weathered bedrock soils initially comprised firm brown, orange and grey gravelly sandy clay, with a gravel of fine to coarse, angular, tabular siltstone. Less weathered material then comprised very dense occasionally clayey, sandy gravel of fine to coarse angular siltstone or mudstone and Grade B weathered rock comprised very weak to weak black partially weathered mudstone with orange discoloration on fracture surfaces. Unweathered bedrock was encountered at a depth of 9.45m as a moderately strong to strong dark grey sandy siltstone, with a high content of fossilised plant material.

2.3.7.2 Hydrogeology

The groundwater conditions encountered during the investigation are summarised in Table 13 below:

Table 13: Summary of groundwater encountered during the investigation.

Hole ID	Stratum	Comment on groundwater encountered
BH401	Made Ground	Slow inflow at 4.2m.
BH401	Middle Coal Measures	Water strike at 11m ¹ , rising to 9.7m after around 40 minutes.
Notes: 1. Strike tentatively identified by driller – inflow potentially masked due to water flush drilling method.		

2.3.7.3 Instrumentation

2.3.7.3.1 Vibrating Wire Piezometer

A single Vibrating Wire Piezometer was installed in the borehole BH401 and the summary of the installation is presented in Table 14 below:

Table 14: Summary of Vibrating Wire Piezometer installations.

Borehole ID	Depth (m)	Response zone stratum	Rationale
BH401	10	Colluvium/Weathered bedrock	Assess the change in groundwater level in the colluvium/weathered bedrock.
Notes on Table 14: 1 Details of the monitoring well is presented in the borehole record within Volume 1 of the Report.			

The data collected to date from the data loggers is shown in a series of graphs within Volume 1 of our Report.

2.3.7.3.2 Inclinator

A single inclinometer was installed to a depth of 12.0m using 70mm easy-connect inclinometer casing and details are provided below in Table 15.

Table 15: Summary of Inclinator installations

Borehole ID	Depth (m)	Summary of Response Zone
BH401	12	Made Ground to 4.0m and weathered bedrock (soils) to 9m whereupon weathered bedrock encountered and extended to a depth of 12m.
Notes on Table 15: 1 Details of the inclinometer and the ground conditions are presented in the individual borehole logs within Volume 1 of our Report.		

The inclinometer casing has been monitored using a digital biaxial inclinometer system, with the results of each monitoring visit to date presented in Volume 1 of the Report.

2.3.8 ESP Investigation, 100 and 111 Cyfyng Road, December 2017

ESP undertook a Ground Investigation in November 2017, on the instruction of Neath Port Talbot County Borough Council which comprised the drilling of a series of windowless sampler boreholes and mackintosh probing and subsequent installation of groundwater monitoring standpipes in a selection of the boreholes.

An overview of the ESP 100 and 111 Cyfyng Road, November 2017 ground investigation is presented in Table 16.

Table 16: Summary of ESP, 100/111 Cyfyng Road, November 2017 Investigation

Exploratory Hole Type	Exploratory Hole ID	Quantity	Maximum Depth (mbgl)
Boreholes (hand held window sampler)	WS501 to WS508	8	2.8

2.3.8.1 Ground Conditions

The boreholes were positioned on the eastern side of Cyfyng Road, within the rear, steeply sloping gardens of 100 and 111 Cyfyng Road.

2.3.8.1.1 Made Ground

Encountered in all window sample boreholes from ground level to a maximum depth of 1.9m as either; very loose black slightly clayey gravel with occasional rootlets and wood fragments, gravel is fine to coarse angular mudstone; loose brown very clayey gravelly sand with rootlets and possible orange slag fragments, gravel is angular fine to coarse sandy siltstone and coal; soft orange mottled black gravelly sandy clay with occasional brick and wood fragments, gravel is fine to coarse angular sandy siltstone and coal.

2.3.8.1.2 Colluvium

Encountered below the Made Ground in WS502 to WS506 to a maximum depth of 2.60m as a soft orange mottled grey and black very gravelly to gravelly clay. The gravel is fine to coarse subangular sandy siltstone and siltstone.

2.3.8.1.3 Weathered South Wales Middle Coal Measures Formation Bedrock

Encountered to the base of all boreholes, except WS505, as a loose to medium dense clayey sandy gravel of angular fine to coarse siltstone.

2.3.8.2 Hydrogeology

Groundwater was not encountered during construction of the boreholes.

Details of the single groundwater monitoring visit is presented in Table 17 below.

Table 17: Groundwater Monitoring Results

Date		WS501	WS504	WS505	WS506	WS508
7 th December 2017	Depth of water (m)	Dry	Dry	1.86	Dry	Dry
	Base of standpipe	2.5	2.5	2.5	2.5	2.5

2.3.9 Geophysical Survey of the Pen-y-Graig Area, June 2018

A geophysical survey was undertaken by TerraDat, instructed by Earth Science Partnership on behalf of NPTCBC, across the Pen-y-Graig area. This included 2no. 142m lines extending parallel to the break in slope, with resistivity tomography (ERT), seismic refraction and Multichannel Analysis of Surface Waves (MASW) to give an indication of the ground conditions. The survey lines were positioned in areas where trial pits and boreholes were proposed as part of further investigation. This allowed the geophysics information to be correlated to the findings of the investigation and the resulting report is presented in Volume 1.

A discussion of the results and how they correlate to the borehole drilled in the area is present as Section 3.8.

2.3.10 ESP Investigation of the Pen-y-Graig Area, June to September 2018

ESP undertook a Ground Investigation between June and September 2018, on the instruction of Neath Port Talbot County Borough Council which comprised the drilling of 2no. dynamic sampling with rotary follow-on boreholes and 9no. trial pits. An overview of the ESP Pen-y-Graig ground investigation is presented in Table 18.

Table 18: Summary of ESP Pen-y-Graig Investigation

Exploratory Hole Type	Exploratory Hole ID	Quantity	Maximum Depth (mbgl)
Trial Pitting	TP601 to TP609	9	4.25
Boreholes (dynamic sampling with rotary core follow on)	BH601 and BH602	2	51

2.3.10.1 Ground Conditions

The boreholes have been positioned to investigate an area of the landslide which has been identified by Halcrow (1989) as an 'area of distress', showing recent and continued signs of movement. The position of the investigation points is shown on Figure 2.

2.3.10.1.1 Made Ground (Colliery Spoil – Coarse Discard)

Made Ground has been interpreted to be present across the Pen-y-Graig Area, to a maximum depth of around 6.9m in BH602.

This consists:

- Dominantly brown mottled black clayey silty slightly sandy tabular subangular sandstone gravel, with pockets of coal ash.
- Locally occurring as a brown mottled black gravelly to very gravelly sandy clay, with gravel of tabular sandstone and siltstone and some fine angular coal.

Boulders are encountered across the Pen-y-Graig area both at surface level and within the Made Ground Colliery Spoil. They occur with highly variable size, from less than 1m and to in excess of 4m wide (see TP604).

The shallow soils are locally very coal rich, notably in the area of TP607 and TP601. This occurs as a black and brown slightly clayey slightly sandy gravel with cobbles and boulders. Gravel cobbles and boulders are highly variable but include highly to slightly weathered sandstone, siltstone and mudstone with fine to coarse coal gravel. Laboratory testing indicates this coal rich material to be up to 34.6% organic content.

2.3.10.1.2 Probable Landslide Material/Colluvium

Landslide Material is interpreted to be present beneath the Made Ground across the Pen-y-Graig area in BH601 and BH602 at depths of 3.5 and 6.8m respectively.

As with the previously described Made Ground in the Pen-y-Graig area, boulders occur throughout within the landslide materials, and are interpreted as either toppled blocks from the above Llynfi Sandstone cliffs, or as rotated blocks. A boulder of at least 2.6m diameter has been encountered in BH601, as a strong grey coarse grained sandstone, with a bedding dip of 45°.

There is also evidence of sag ponds forming in crevasses between the boulders, as shown by an organic rich clay identified at the base of TP604 along side a boulder.

The base of the Probable Landslide Material is defined in both boreholes by a potential slip zone immediately above the Lower Pinchin Group (Lower seam) as between 5-17cm. This occurs in BH601 as an extremely weak, sheared mudstone, over clayey silt with quartz and pyrite nodules,

over weathered mudstone and the Lower Pinchin. This is represented in BH602 as a soft dark grey clayey silt below layers of orange brown gravelly clay and coal gravel.

2.3.10.1.3 South Wales Upper Coal Measures Formation Bedrock

Encountered to a depth of 25.4m in BH601.

The lower leaf of the Lower Pinchin Coal Seam is encountered immediately below the identified landslide materials in both BH601 and BH602 with a thickness of 0.35-0.40m. There is a seatearth associated with the coal, encountered as a dark grey sandy siltstone with a very high content of fossilised plant debris.

The upper coal measures in the area are predominantly encountered as a medium strong dark grey sandy siltstone with thinly laminated to thinly bedded sandstone and mudstone. A mudstone layer occurs between 17.5-18.5m.

The Upper Cwmgorse Marine Band (UCGMB) represents the base of the Upper Coal Measures is encountered at a depth of 25m, as a black mudstone with pyrite nodules, with a thickness of between 0.4m.

2.3.10.1.4 South Wales Middle Coal Measures Formation Bedrock

The south wales middle coal measures are encountered from 25.4m to the base of BH601.

The middle coal measures in BH601 are encountered as either:

- Moderately strong grey to dark grey thinly laminated to thinly bedded sandy siltstone or siltstone with laminae and thin beds of sandstone and mudstone and a varying content of plant debris;
- Strong light grey fine to medium-grained sandstone;
- Weak black thinly laminated to thinly bedded mudstone with a low content of fossilised plant debris.

The Lower Welsh Coal Seam has been identified at a depth of 49.4m, with a thickness of 0.2m and a 0.9m thick associated seatearth. A further unnamed thin coal seam is encountered at a depth of 32.15m.

2.3.10.2 Hydrogeology

Groundwater was not encountered during construction of the boreholes, although it should be noted a water or water with polymer additive was used as the flushing medium for the boreholes, which can mask any water strikes. It should also be noted that past 12m in BH601, the flush did not return and was presumably lost within highly fractured portions of the bedrock.

Return monitoring visits indicate the main groundwater body to be within the Middle Coal Measures bedrock, around 2m below the Lower Pinchin Coal seam in each monitoring position. Continuous monitoring indicates a change in head of around 0.5m in BH601.

2.3.10.3 Instrumentation

2.3.10.3.1 Vibrating Wire Piezometer

A single vibrating wire piezometer was installed in borehole BH601. Details of the installation is shown in Table 19 below:

Table 19: Summary of Vibrating Wire Piezometer Installations.

Borehole ID	Depth (m)	Response zone stratum	Rationale
BH601	12	Probable landslide material and weathered bedrock	Determine the change in groundwater level in the landslide material and underlying coal seam, and weathered bedrock.
Notes on Table 19: 1. Details of each monitoring well are presented on the individual borehole records within Volume 1 of the Report.			

The data collected to date from the data loggers is shown in a series of graphs within Volume 1 of our Report.

2.3.10.3.2 Inclinator

A single inclinometer was installed to a depth of 12.0m using 70mm easy-connect inclinometer casing and details are provided below in Table 20.

Table 20: Summary of Inclinator Installations

Borehole ID	Depth (m)	Summary of Response Zone
BH601	17.5	Landslide material to 8.7m and base of inclinometer within unweathered bedrock, comprising sandstone and siltstone.
Notes on Table 20: 1. Details of each inclinometer and the ground conditions are presented on the individual borehole logs within Volume 1 of our Report.		

The inclinometer casing has been monitored using a digital biaxial inclinometer system, with the results of each monitoring visit to date presented in Volume 1 of our Report.

2.4 Other Work at Pantteg

2.4.1 Vegetation Management

2.4.1.1 Tree Surveys and Management

NPTCBC instructed Arboricultural Technician Services (ArbTS) to undertake a tree condition assessment across the Pantteg landslide area. This work was completed by a professional member of the arboricultural association and the findings were presented in two reports:

- Tree Condition Survey and Management Work Recommendations, 15th November 2017. Ref. ArbTS_385.2_Pantteg; and
- Tree Condition Survey and Management Work Recommendations, 9th May 2018. Ref. ArbTS_385.4_Pantteg.

Both reports are included in Appendix A and provide a tree condition assessment of the respected areas studied that are a potential risk to person or property.

The main scope of the tree inspections were to identify hazardous trees in a poor physiological or structural condition and provide work management recommendations to reduce the risk of these hazardous trees to an acceptable level as detailed by the Health and Safety Executive in Management of the risk from falling trees or branches.

Recommendations for tree management across the Pantteg area included, reinspection, pollarding, felling and coppicing. All recommendations within the reports were followed and work was carried out by a specialist contractor throughout 2017 and 2018.

2.4.1.2 Other Vegetation Clearance

Removal of vegetation from a landslide can have both positive and negative impacts on stability.

Neath Port Talbot County Borough Council have only removed vegetation in order to provide access for the site investigation works carried out in 2018 which was necessary for Health and Safety reasons. No other vegetation clearance (except for trees as discussed in Section 2.4.1.1 above) has been carried out.

2.4.2 Work undertaken by NPTCBC

One part of NPTCBCs work at Pantteg, has been upgrading/rebuilding retaining walls and the construction of a gabion basket wall, in several specific areas of the village. The drawing presented in Appendix B shows the relative locations of the retaining walls at Pantteg, Figure 3 shows the location of the gabion basket. The walls are referenced as follows:

- Retaining Wall 1 – Located along western side of Graig road, from junction of Graig road, Church road and Cyfyng road, towards Owens Lane;
- Retaining Wall 2 – Located on the western side of Cyfyng Road, in the south of Pantteg;
- Retaining Wall 3 – also known as wall no 11-146 is located on Cyfyng road, inbetween Cyfyng road and Graig y Merched;
- Retaining Wall 4 – is located on the eastern side of Graig Road and Church Road; and
- New gabion wall – is located along the western side of Cyfyng road, typically in front of the 2013 remediated area.

ESP understand that no works have been undertaken on retaining wall 4, however, works to other walls are detailed in the following sections.

2.4.2.1 Retaining Wall 1

NPTCBC have recently reconstructing retaining wall 1 as it was showing signs of distress, no details of the wall are known at this stage.

2.4.2.2 Retaining Wall 2 - Cyfyng Road

A retaining wall was constructed by Neath Port Talbot County Borough Council on the western side of Cyfyng Road. The location of the retaining wall is shown on the drawing in Appendix B.

The wall construction comprises concrete with a brick front that measures some 39m in length, and between 1.3m to 2.5m in height. A drawing of the wall provided by NPTCBC can be seen in Appendix C.

2.4.2.3 Retaining Wall 3 - Cyfyng Road

A retaining wall was constructed by Neath Port Talbot County Borough Council on Cyfyng Road near where Graig-y-Merched joins from the west. The location of the retaining wall is shown on Figure 3 and in the drawing in Appendix B.

The wall was constructed adjacent to an old garden wall that was retaining some higher ground to the west that had fallen into disrepair and was noted to be leaning outward, details of retaining wall provided in Appendix C.

2.4.2.4 Gabion Basket Wall

A gabion basket wall was constructed on the instruction of Neath Port Talbot County Borough Council along the western edge of the Cyfyng Road, broadly opposite the Chapel, in front of the 2013 remediated area.

The position of the gabion basket wall is shown on Figure 3. The as built drawing for the gabion wall (Appendix C) shows it to be two meters in height and approximately 177m in length.

The primary reasoning behind the construction of the gabion basket was to provide some protection from small rock falls onto the road.

3 Data Contributing to the Ground Model

3.1 Site Observations

3.1.1 Drainage

As discussed in our previous Report (ESP 2016), there are two drainage systems in place above the village of Pantteg (a third is located further south of the Pantteg) that transport water from mine adits, spring water and surface water runoff into water courses within the village, that eventually flow in to the River Tawe.

The position of the current drainage, the Church Road System and Pen-y-Graig-Arw systems are shown on Figure 3. Since 2017 NPTCBC have been regularly checking the condition of the drainage network and undertaking repairs when necessary.

As shown in Figure 3, there are two main drains extending towards the south-east in the south-western portion of the site.

Surface water was present seeping through the retaining wall (Retaining Wall 1) on the western side of Graig Road (Insert 1) in April 2018. This has been observed constantly during the site works, only not present following a dry period in the peak of summer. Works were implemented by NPTCBC in 2018 to address/divert this flow of water.



Insert 1 Photograph showing area of excess surface water on the northern retaining wall of Graig Road. Colluvium present on top of the retaining wall. Photograph taken looking south-west on 9th April 2018.

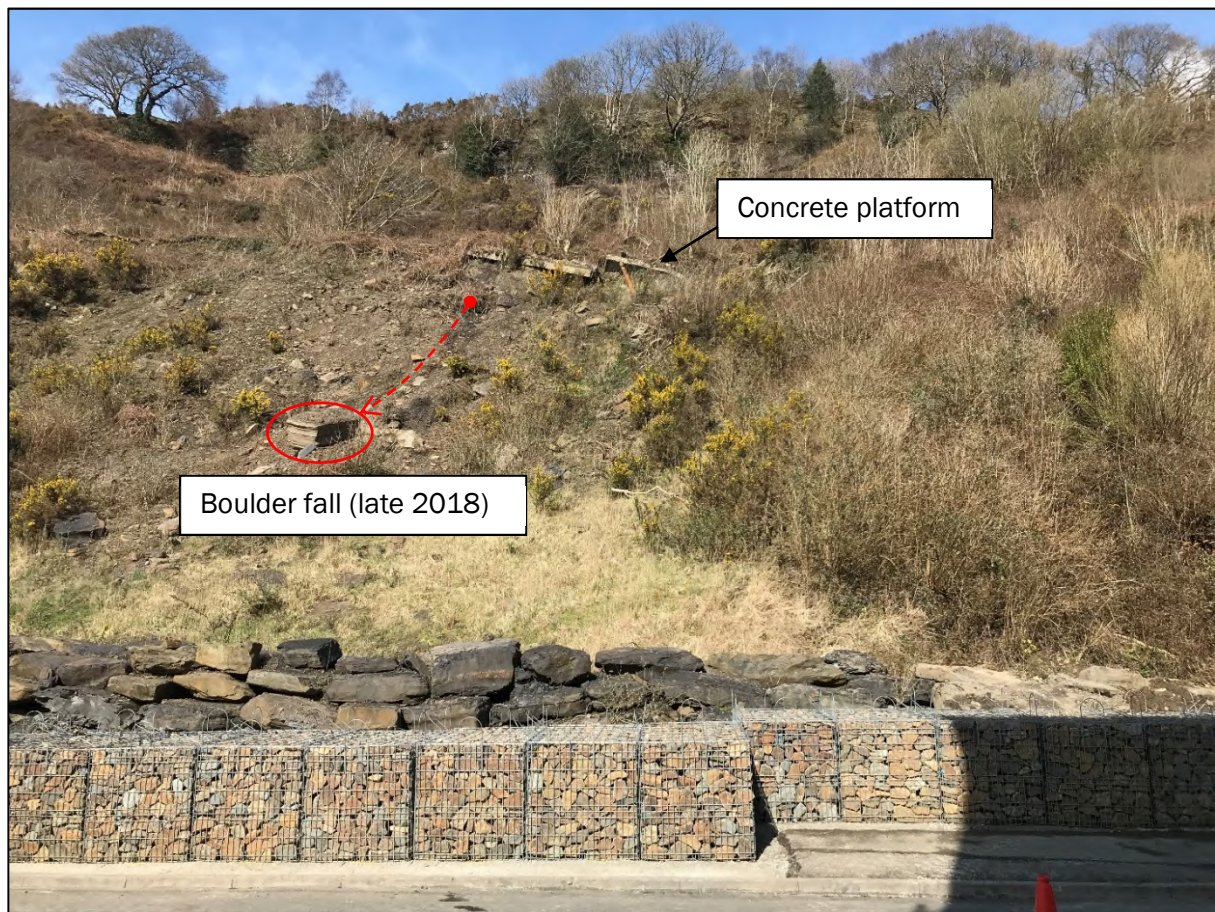
A similar spring line is observed during heavy rainfall from the retaining wall opposite 96 Cyfyng Road and this feeds in to the highway drainage system.

Landslides occurred in the rear gardens of the 86 to 96 Cyfyng Road terrace in 2017; a break in the sewer behind the properties was reported and/or became apparent during the time of the landslide and may have contributed to further instability through 2017.

3.1.2 Regraded Slope

Following the instability of the slope across the road from Pantteg Chapel, Jacobs undertook remediation works involving removing the landslide material and regrading the slope to expose bedrock. The slope is reported (Jacobs, 2013), as unstable and shown to be regressing upslope.

This instability continues to the present day, with evidence of regression of the back of slope to the north-west, undermining of a concrete platform (presumably associated with the tunnel in the area) and boulders falling downslope (Hazard type 5). Passive protection measures, in the form of a boulder barrier and gabion baskets, have been constructed by NPTCBC. The current state of the regraded slope is shown in Insert 2.



Insert 2 - Photograph of slope regraded by Jacobs 2013 taken on 9th April 2018 looking north-east.

On-site observations, API and monitoring of installations (BH305) indicate the land to the south of Cyfyng Road (between Graig Road and Clees Lane) to be generally stable. This area is underlain by Colluvium presumed to be from the initial post-glacial failure of the slope (Figure 4).



Insert 3 - Photograph of tension cracking on the break of slope above Pantteg Chapel exposing boulders of Llynfi Sandstone. Aerial photographic interpretation has identified several landslides to occur along this break in slope. Hazard Type 2 and 6. Photograph taken 28th October 2015 looking south-west



Insert 4 - Potential rock fall block along cliff-line

3.1.3 Halcrow 'Zone of Distress'

Halcrow (1987/1989) identified a zone of distress on the plateau opposite the Chapel. This is evident currently from a number of tension cracks along, and immediately below the break of slope below the Pen-y-Graig area (see). This area correlates with a line of historical landslide events identified in the aerial photographic interpretation (API).

Monitoring of the inclinometer in BH601 installed within the Pen-y-Graig Area has shown a cumulative displacement of 21mm downslope. The movement is associated with the identified slip zone, just above the lower leaf of the Lower Pinchin Group.

The cliff line at the northern edge of the 'Zone of Distress' or Pen-y-Graig area shows signs of recent rockfall from the cliff, with numerous boulders present at the surface and encountered throughout trial pits excavated in the area. Insert 4 shows a large block of Llynfi Sandstone which could potentially topple.



Insert 5 - Ad-hoc earthworks west of Graig-y-Merched.

3.1.4 Land at No.6 Graig-y-Merched

Around October 2018 ad-hoc earthworks to create a path have been undertaken up the side of the mountain (see Insert 5) in the area of the backscar of the 1986 landslide which impacted a number of properties along Graig-y-Merched. Initial observations indicate the cuttings to be within colluvium/landslide materials and includes over steepening and some loading of the downslope side of the path. The work being undertaken appears to have been done without formal engineering design or regard for slope stability and safety.

3.1.5 Graig-y-Merched

Possible signs of movement are evident along Graig-y-Merched, and within the slope that is designated a cut slope hazard west of Cyfyng Road. Signs of movement including an inclined telephone mast (insert 6), cracks within the road parallel to the break in slope and inclined concrete and metal barriers between the road and the slope (insert 7).



Insert 7 - Inclined barrier east of Graig-y-Merched opposite No. 12 and 13 Graig-y-Merched. Photograph taken 28th October 2015 looking north.



Insert 6 - Inclined telephone mast adjacent to BH302 shown in the left of the image. Photograph taken 28th October 2015 looking north.

3.2 Stratigraphy

This section provides detail of the stratigraphy encountered across the Pantteg Landslide, as identified in all phases of investigation, including those of Halcrow in 1989.

3.2.1 Made Ground

3.2.1.1 General

Made Ground is encountered in all investigation points across Pantteg village, ranging from 0.3m to more significant thicknesses of up-to 3.8m.

Notable occurrences of Made Ground include:

- BH306 constructed near the Graig Road/Church Road junction showed around 3.8m of Made Ground consisting either a brown clayey gravel or gravelly clay including slag, coal, brick and ceramic fragments. This is likely associated with bringing the level of the natural ground up for construction of the road. As described in Section 3.4.5, subsequent monitoring of the inclinometer installed in BH306 has showed a cumulative displacement of up to 5mm downslope in the Made Ground over a year.
- TP302 excavated at the top of Clees Lane showed up-to 3m of Made Ground consisting sandstone cobbles and boulders. This trial has been excavated in the footprint of a former building, with the ground encountered in the pit representing backfill of building stones. The depth of the basement could not be determined due to extremely unstable sides, but it is more than 2.9m. Similar ground conditions are encountered in the area of BH202 adjacent to 96 Cyfyng Road, where the basement was 4.1m thick. Although in this locality, recovery was poor due to nature of the material and the drilling technique utilised. Similar ground conditions are anticipated in the footprint of demolished properties with basements. It should be noted, BH202 found the basement to be immediately underlain by completely weathered Coal Measures Bedrock.

3.2.1.2 Colliery Spoil – Coarse Discard

The majority of the material recovered from the surface to a depth of up to 6.8m (BH602) across the Pen-y-Graig Area has been interpreted as the Coarse Discard from nearby mine adits and quarries.

This material is very loose, and constant spalling of the sides of Trial Pits excavated in the Pen-y-Graig area prevented excavating the pits to the maximum reach of the excavator. There is also evidence of downslope movement in this unit, with a series of ~1m deep tension cracks immediately above the break in slope above the Chapel.

There is a distinction between the definition of the material which makes up the near surface soil within the Pen-y-Graig area. Halcrow (1989) have classified it as a colluvium, whereas ESP (2018) interpret the shallow soils to be the accumulation of discarded material from the nearby coal mine adits and quarries.

3.2.1.3 Colliery Spoil

Pockets of coal and mudstone rich colliery spoil are encountered across the Pen-y-Graig area. TP301 and TP309 are excavated adjacent to a former mine adit and there are pockets of colliery spoil of around 1m in diameter, and contain up to 34.6% organic matter, and will be associated with the numerous adits present along the foot of the cliff line.

There is also some colliery spoil encountered beneath Clees Lane which is likely to be associated with the nearby adit/shaft.

3.2.1.4 Quarry Spoil

Quarry Spoil is encountered north-west of the Pen-y-Graig cliff-line, in Cwar Pen-y-Graig in BH301 and TP304-307 to a maximum depth of 4.2m, with a significant thickness present in the ~7-8m tall spoil mounds. The bulk of the quarry spoil material in the current floor level and spoil mounds, is composed of predominantly of sandy tabular sandstone gravel, cobbles and some boulders. The material is likely to be free draining, with little to no standing water observed during the site works.

It is evident the quarry has been used to for fly-tipping/land-fill at some point in the past, with metal sheeting, metal wire, whole rubber tyres, glass plastic and bricks encountered in the area of TP304.

3.2.2 Superficial Deposits

3.2.2.1 Colluvium

Colluvium is encountered widely across the Pantteg Village area, with around 10m present across most of the area, but up to 20m as encountered in BH306 on Graig Road. This material is a product of the initial ancient post-glacial landslide (described as Hazard Type 1 in Section 5).

The south-eastern boundary of the landslide is poorly defined by previous studies and the geological map. Colluvium has been encountered as far downslope as TP308, situated just above the base of the slope, and is recovered as a clayey sandy gravel with cobble and boulders (a boulder is also observed at the surface directly adjacent to the trial pit). Boreholes constructed at bottom of Clees Lane show there to be around 13m of colluvium, again consisting of clayey gravel with likely boulders and cobbles. This indicates Clees Lane to be within the boundary of the ancient landslide, with the landslide extending further towards the floor of the valley.

3.2.2.2 Toppled Blocks

As described in Section 5, one the Hazard types identified at the site is Rock Fall (Hazard type 6).

Throughout the investigation points in the Pen-y-Graig area (BH601 and TP600s of ESP 2018, and BH2 of Halcrow 1989) large boulders have been present to a depth of at least 6.3m. The maximum size of the boulders present is not known, but is likely to be more than 5m wide in diameter.

These occur as sandstone and siltstone, with a highly variable irregular dip angle and direction. The degree of weathering is also highly variable, and ranges from largely unweathered strong sandstone blocks (with the exception of partial surface staining) to laminated siltstone blocks which can easily be peeled apart by hand.

3.2.2.3 Landslide Materials

Landslide materials are present beneath the Made Ground encountered across the Pen-y-Graig area. These have been encountered as clayey sandy gravel, with horizons of gravelly clay and, and include the above described toppled blocks. Given the depth these have been encountered across the Pen-y-Graig area, they have only been described from borehole samples, and are therefore limited.

These have been defined to represents currently actively moving natural soils (colluvium) and weathered rock.

3.2.2.4 Landslide Slip Zone

In the Pen-y-Graig area, a possible slip zone has been identified in BH601 and BH602 (ESP, 2018) immediately above the rockhead and the Lower Pinchin. This is more well defined in BH602 than BH601, but both show a similar sequence of disturbed material over a very soft/loose laminated weathered rock with a soft ~10-12mm thick clayey silt layer followed by more competent weathered rock.

It is likely that this zone represents the original ancient post-glacial slip surface, and is the base of landslide material/colluvium.

Spot monitoring of the inclinometer in BH601 through this slip zone has showed around 21mm overall displacement downslope over a six month period.

3.2.3 Bedrock: South Wales Upper Coal Measures

3.2.3.1 Llynfi Sandstone

The Llynfi Sandstone, of the Upper Coal Measures, occurs within Cwar Pen-y-Graig and composes the prominent north-east - south-west trending cliff line immediately south of the quarry. The generalised stratigraphic section on the geological map for the area (SN7ONE) shows the lowest leaf of the Lower Pinchin Coal Seam to be the base of the Llynfi Sandstone.

This has been identified during the current phase of investigation in BH301 (in Cwar Pen-y-Graig) as a light grey strong thinly to moderately bedded sandstone with moderately strong grey thickly laminated to thinly bedded siltstone. Both BH301 (ESP, 2017) and BH1 (Halcrow, 1989) show thin beds of siltstone conglomerate with a sandstone matrix to occur above the Lower Pinchin, with a thin bed immediately above the upper leaf of the Lower Pinchin Seam.

3.2.3.2 Lower Pinchin Group

The Lower Pinchin Group (formerly known just as the Pinchin) in the area is described by Strahan and Cantrill (1907) and noted to crop out along the foot of the cliff line south of Cwar Pen-y-Graig. The generalised geological section on the geological map (SN7ONE) shows the Lower Pinchin Group to consist of at least three seams, with thicknesses of between 1.5 ft and 2ft, and around 12m between the upper and lowest seams.

The Lower Pinchin Group has been identified in BH301 (ESP, 2017) and BH1 (Halcrow, 1989), with a slight variation in its occurrence between the two boreholes. Both show the upper leaf to be around 0.15m – 0.20m thick, with a siltstone conglomerate immediately above the seam. BH301 (ESP, 2017) shows the lower leaf to comprise 3no. very thinly to thinly bedded anthracite coal seams, with partings of sandy siltstone with a high content of fossilised plant debris at an elevation of between 165mOD and 162mOD. BH1 (Halcrow, 1989) differs in that two seams are present below the upper leaf, at elevations of around 157.8m and 154.2m respectively.

A coal seam has also been intercepted at rockhead across the Pen-y-Graig area in BH601 and BH602 (ESP, 2018) and in BH2 (Halcrow, 1989), and is likely representative of the base of lower leaf of the Lower Pinchin Group.

3.2.3.3 Upper Cwmgorse Marine Band

The Upper Cwmgorse Marine Band (UCMB) is shown on the geological map for the area, and described in the literature (Woodland and Evans, 1964), to separate the Upper and Middle Coal Measures. The generalised geological section presented on the geological map for the area (SN70NE) shows the UCMB to be around 18m below the lower leaf of the Lower Pinchin Coal Seam.

The UCMB is described in Woodland and Evans (1964) as a micaceous mudstone with pyritic concretions. Although the referenced memoir is for a different part of the coal field, the occurrence of the Marine Band will be similar across the coal field. The memoir for the area (Strahan and Cantrill, 1907) It is also described as containing type fossils, no fossils have been identified in the investigation to date.

The UCMB has been identified in BH301 as a 2.3m thick black fissile mudstone with pyrite nodules, and BH601 as a 0.4m thick black mudstone with pyrite nodules, both occurring around 17m below the base of the Lower Pinchin Seam. In both occurrences of the UCMB, there is a 0.05m to 0.1m thick coal seam, with an associated seatearth.

Observed depths in BH301 (ESP, 2017) and BH601 (ESP, 2018) shows around 15m and 17m separating the Lower Pinchin and Upper Cwmgorse Marine Band.

3.2.3.4 General Lithology

Between the coal seam and marine band, the South Wales Upper Coal Measures varies between mudstone, siltstone and sandstone. A summary of the different lithologies encountered is shown below:

- Moderately strong to strong fresh sandy siltstone, locally with thinly bedded to thinly laminated sandstone;
- Weak black fissile mudstone; and
- Strong grey fresh sandstone, locally with thickly to thinly bedded sandy siltstone and siltstone.

3.2.4 Bedrock: South Wales Middle Coal Measures

3.2.4.1 Lower Welsh Coal Seam

The geological map for the area (SN70NE) infers the crop of the Lower Welsh Coal Seam to extend roughly parallel to Graig-y-Merched where the outcrop is not shown to extend beneath the 'Mass Movement' deposits. It is assumed the inferred outcrop would follow parallel to the Lower Pinchin and UCMB, which would have the Lower Welsh seam extending parallel to Cyfyng Road, and south of the Graig Road-Church Road junction. The generalised geological section presented on the geological map for the area (SN70NE) shows the Lower Welsh to be around 20m above the Lower Cwmgorse Marine Band.

The Lower Welsh Coal Seam has been identified in BH303, BH305 (both ESP, 2017), BH601 (ESP, 2018) and BH3 (Halcrow, 1989). There is some discrepancy in the position of the Lower Welsh between these boreholes, as shown by Figure 7. This is possibly caused by the Lower Welsh occurring as a series of large lenses of coal at a similar stratigraphic level, rather than a continuous bed of coal across the whole of the site. It has been identified around 21m above the LCMB in BH303, and inferred to be between 10m and 15m elsewhere at the site (see Figure 7).

3.2.4.2 Lower Cwmgorse Marine Band

The Lower Cwmgorse Marine Band (LCGMB) is inferred on the geological map to crop out below the Lower Welsh and is roughly parallel in outcrop.

The LCGMB has been identified in BH302 and BH303 as a black fissile mudstone with pyrite nodules, the same as the UCGMB. This is stratigraphically below the Lower Welsh seam, as described in Section 3.2.4.1.

3.2.4.3 General Lithology

Between the coal seams and marine band, the South Wales Middle Coal Measures at the site is predominantly encountered as a moderately strong to strong sandy siltstone, with horizons of fossilised plant debris, varying between a low to high content. It is also locally expressed as the following lithologies;

- Weak dark grey fissile mudstone;
- Strong to very strong medium to coarse-grained sandstone, occurring locally with thin to thick laminae of sandy siltstone, siltstone and minor thin coal laminae.

3.2.5 Structure

The geological map for the area suggests the bedding in the area to dip at around 10° to the south. However, identification of coal seams and marine bands in multiple boreholes suggests a dip of closer to 5° (assuming a dip direction towards the south), as shown by Figure 7. This means there is a slightly lower apparent dip than previously described (Halcrow, 1989) at around 3.5° towards the valley floor.

This is also lower than the dip observed at outcrop scale, of between 9° and 12° in the cliffs of Cwar Pen-y-Graig, and the cliff line extending north-east – south-west. This is likely to be caused by the undulating nature of the bedding, distorting to dip on the small/outcrop scale.

3.3 Hydrogeology and Groundwater Monitoring

Given the relatively discrete points of investigation across the Pantteg Landslide area undertaken, the below section is split up into areas where investigation points are relatively close together and provide an indication on the groundwater conditions.

3.3.1 86 to 96 Cyfyng Road (BH202 and BH401)

Intrusive investigations and monitoring has been undertaken at either end of the 86-96 Cyfyng Road Terrace, Borehole refs. BH202 and BH401 respectively and shown on Figure 2c. A Heron groundwater data logger was installed at the base of a 50mm standpipe in BH202 (on 28 September 2017) and a Vibrating Wire Piezometer (VWP) was installed at 10m in BH401 on (13 November 2017).

There are periods of time through the monitoring where the logger box in BH401 has not recorded. Investigation into the possible causes of this led to the outcome of probable vandalism/tampering of the logger box. The loss of information coincides with the loss of information from another position (BH302), as discussed below. Gaps in the data from BH202 were due to software failures at the time of monitoring. Action to address functionality will be required for ongoing data collection.

Groundwater monitoring data generally shows a good correlation across both installations, although the range in head is greater in BH202. The maximum and minimum levels in BH202 are 105.9mOD and 102.6mOD and in BH401 the range is between 100mOD and 98.4mOD.

The monitoring has shown that in the winter of 2017 to 2018, the piezometer in BH202, little change in head was observed, some 0.3m. However, for the winter of 2018/2019, a range in head of 3.6m has been recorded. It is not known why the change in groundwater has been greater over this recent winter.

Adopting a very broad generalisation, the apparent difference in head between summer and winter in BH401 it is around 1m, with groundwater higher in the winter in both instances.

The monitoring data from BH202 generally shows groundwater at or around the base of the interface with weathered bedrock and intact rock, i.e. on top of the rock head profile. However, the monitoring over the 2018 and 2019 winter shows groundwater to rise significant and a head of water is measured which correlates to the base of the Made Ground. The monitoring data from the vibrating wire piezometer in BH401, suggested a groundwater body above rock head.

When comparing the higher groundwater peaks with the measured rainfall, there is an apparently lag of around 3 days, although this does vary.

3.3.2 Cwar Pen-y-Graig (Quarry) - BH301 and Halcrow BH1 and TP07, TP08, TP304-307

Three vibrating wire piezometers were installed at depths of 6m (190.15mOD in Weathered Bedrock), 21m (175.15mOD in Coal Measures Bedrock) and 32m (164.15mOD in the Lower Pinchin Coal Group).

The vibrating wire piezometers at 6m and 21m indicate no head of water, this is due to the probability that they are above the groundwater table. However, they do indicate slight increases in pressure in response to rainfall and it is anticipated this possibly represents the piezometers measuring slight increases of porewater pressure as water percolated downward.

The vibrating wire piezometer at 32m is placed in the middle of the Lower Pinchin Coal seam and shows a head of water between 168.15mOD and 166.15mOD. This places water in the siltstone at depths of 27.95m and 30m, suggesting there is a groundwater body associated with the Lower Pinchin Coal Group. The 32m deep vibrating wire piezometer appears to show a correlation with a rise in groundwater following heavy rainfall, with around a 1 to 2 day lag. Additionally, there appears to be two peaks after a rainfall event, this may suggest that there are two different permeabilities for the flow of groundwater in the lower Pinchin, such as a quicker fracture flow and a slower intergranular flow.

Although drilled some distance from BH301, Halcrow (1989) encountered groundwater at a depth of around 35m in BH1, the water had an overnight depth of 34.75m (154.52mOD). A piezometer installed at a depth of 35.95 (153.32mOD) measured a head of water between 4m and 3.1m (ignoring a suspected anomalous result identified by Halcrow). This suggests that there is a groundwater body within the Lower Pinchin coal seam, or the top of the groundwater table is at, or near the elevation of the Lower Pinchin.

No groundwater was encountered in trial pits excavated by Halcrow and ESP in the quarry area, or above the suspected backscarp.

3.3.3 Graig-y-Merched (Lower) - BH302

Three vibrating wire piezometers were installed at depths of 6.5m (117.4mOD in Colluvium), 10.5m (113.4mOD in Coal Measures Bedrock) and 21.5m (102.4mOD in Coal Measure Bedrock).

There are two periods of time where data was not recorded by the logger box, between 8/1/2018 to 8/2/2018 and 12/2/2018 and 9/4/2018 due to vandalism.

The installations within the bedrock have shown a similar trend, in that they are generally unresponsive to rainfall. They do however show a general rise in groundwater pressure, but given that this is not responding to rainfall as other installations, this it unlikely to be monitoring the groundwater horizon.

The installation at 6.5m, within the probable Colluvium, initially shows a negative pressure until the monitoring in April 2018 indicate a positive head of water, which also appears to respond to rainfall. The monitoring suggests a head of water at the base of the Colluvium, with a maximum head of water to a level of 119.5mOD. A groundwater strike was encountered at a similar level whilst drilling, 116.80mOD, thus suggesting a body of water just above the rock head.

3.3.4 Graig-y-Merched (Upper) – BH103, BH303

Two 19mm standpipes were installed in a rotary open-holed borehole in December 2016 and had response zones of between 4.2m – 4.6m and 13.5 – 15m respectively. Monitoring visits have showed water at levels of around 4.15m and 15m (wet at base) respectively.

A single vibrating wire piezometer was placed at a depth of 5m in BH303, in the suspected weathered expression of the Lower Welsh, at a depth of 6m, or level of 127.5mOD. There are periods of time through the monitoring where the logger box in BH303 has not recorded due to vandalism. The loss of information coincides with the loss of information from BH401, which is located relatively near to BH401.

The monitoring initially showed a sharp, smooth decrease and increase in groundwater pressure, which has been interpreted as the piezometer tip initially 'drying out' as the grout set. Then stabilising as the piezometer tip re-hydrated to surrounding ground conditions in. The smooth nature of the curve suggests the piezometer was not malfunctioning, as a more erratic records would be expected.

During this phase of stabilisation, there was no apparent correlation to rainfall, however, since March 2018, the monitoring information does show a somewhat muted response to rainfall and groundwater is indicated to be at a level of 131.3mOD, which suggests a head of water up to approximately 3.9m.

It is probably that the piezometer is measuring a perched groundwater table within the Lower Welsh.

3.3.5 Clees Lane Area - BH102, BH304, TP303 and TP308

In December 2016, BH102 was drilled at the bottom of Clees Lane and two 19mm standpipes were installed with response zones within the Colluvium and South Wales Middle Coal Measures bedrock at depth of between 4.0m – 5.5m and 16 – 18m respectively. Monitoring of these standpipes showed a marked rise in the water level shortly after Storm Doris (February 2017), which increased the groundwater level in the standpipes by approximately 0.5m in the Colluvium

and 2m in the bedrock. Monitoring since has shown the deeper standpipe to be dry, and water is near the base of the shallower standpipe. A monitoring results after Storm Callum, October 2010 did not show an increase in groundwater, however, no investigation to the rainwater data has been made for this comparison.

Within BH304, which was drilled near BH102, two vibrating wire piezometers were installed at depths of 5m (66.85mOD within Colluvium) and 15m (56.85mOD within bedrock). Both piezometers were placed below the groundwater depths identified from the BH102 monitoring and the deeper piezometer was placed in a fractured zone of rock that showed signs of weathering and was thought could be a conduit for secondary permeability.

The interpretation of the vibrating wire piezometer results show the piezometers to be measuring two different bodies of water, one within the Colluvium, and another with the bedrock. The shallower piezometer within the Colluvium show a body of water between levels of 68.78mOD and 67.54mOD which is within the Colluvium. The monitoring information suggests a good response to rainfall; the typical change in head due to rainfall is around 0.5m and the 2018 heat wave period in June, July and August is apparent, with a steady decline in groundwater pressure.

The deeper piezometer indicated a head of water at a level of 62.71mOD and 60.06mOD which is likely to be representative of a body of water up slope within the bedrock. Again, the piezometer appears to show a good correlate to rainfall, and the typical change in head is greater than the shallower piezometer, with ranges in the region of 1m generally, however, it has a much larger range of 2m on occasion, i.e. more pronounced, lower troughs and higher peaks on the graph. The 2018 heat wave is again apparent in this piezometer with a more noticeable decline in groundwater pressure between June, July and August of that year.

In addition to the boreholes at the bottom of Clees Lane, a trial pit was excavated at the top of Clees Lane and one near the bottom. No groundwater was encountered in the trial pit at the top of Clees Lane, and a slow seepage was encountered in TP308 within the colluvium near the bottom of Clees Lane.

3.3.6 Cyfyng Road (Chapel Area) - BH4, BH101 and BH305 and TP301, TP302 and TP06

Halcrow's 1989 report states that water was encountered during drilling of BH4, and 'stood' at depths of between 3.1m and 4.1m, no record of groundwater strikes are shown on the borehole log. Two standpipes piezometers were installed in the suspected landslide deposits, or suspected Colluvium at depths of 4.32m (96.38m OD) and 10.25m (90.45m OD). They measures water with maximum levels of 99.05m OD and 98.45m OD and minimum levels of 97.22m OD and 96.47m OD respectively, and it is therefore likely that they were measuring the same body of water.

A trial pit Halcrow excavated in this area did not encountered groundwater to a depth of 2.5m, although they noted damp soils below 0.5m.

In December 2016, BH101 was drilled and two 19mm standpipes were installed with response zones within the Colluvium and South Wales Middle Coal Measures bedrock at depth of between 6m – 8m and 16 – 18m respectively. Monitoring of these standpipes has shown water generally near the base of the standpipe, however, monitoring on the 21st November 2018 and 12th February 2019 showed water at a depth of about 2m, which is a marked rise of around 6m from the other monitoring points in the standpipe. Similarly, monitoring of the deeper standpipe has

shown water to be near the base of the standpipe, however, on occasion it has been about 2m above the base, at a level of around 85mOD.

BH305 was drilled opposite the chapel in Pantteg and close to BH101 and upon completion two vibrating wire piezometers were installed at depths of 7m (93.1mOD within Colluvium) and 17m (83.1mOD within mudstone bedrock below Lower Welsh).

It is considered likely that the two piezometers are measuring two different groundwater bodies. The shallow piezometer has indicated a water levels between 104.57mOD, which is approximately 4.5m above ground level, and 98.2mOD. The borehole was constructed immediately adjacent to the main slope of Pantteg and it is considered that the piezometer is measuring water pressure within the slope at a higher level, but within the Colluvium. A groundwater strike noticed whilst drilling, at 3.0m, is within the levels that the piezometer is measuring water. In addition, the two ESP trial pits near to BH305 also showed a water body at depth of 2.3m and 3m, with seepages noted in the trial pit. The monitoring typically shows a good response to rainfall and groundwater level typically rises approximately 1m in response to rainfall, however, over the winter of 2018 to 2019, much larger responses have been measured, in the region of 5m. This information broadly correlates to the information obtained by Halcrow's BH4 standpipe piezometers.

The piezometer at 17m indicates a larger head of water which has been measured to levels of between 93.4mOD and 88.3mOD, which is again likely to represent a groundwater body further up slope within the bedrock, possibly associated with the Lower Welsh coal seam, although this is not conclusive. The response to rainfall is similar to that of the shallow piezometer, which to some extent is expected, however, it may also indicate that the groundwater bodies are hydraulically connected, or possibly the same water body.

The data from both vibrating wire piezometers suggest an approximate lag of 1 to 2 days.

3.3.7 Graig Road/Cyfyng Road Intersection - BH306

Difficulties retrieving data from the data logger has reduced the amount of monitoring available for this installation and work is proposed to alter the installation to continue monitoring. It should also be noted that a drainage pipe from the above quarries discharge to a stream at this point and it is not known if there are any leaks, issues, from the steam or pipework into the surrounding ground.

During drilling, groundwater was encountered at a shallowest depth of 2m and overnight resting levels were noted around a depth of 4m. A single vibrating wire piezometer was installed within BH306 at a depth of 10m which is at a level of 72.2m OD, which is within Colluvium. The monitoring data suggests a maximum head of water of 78.88m OD and minimum of 78.29m OD which suggests a body of water within the Colluvium, and the top of which is near the junction of the Made Ground and Colluvium.

The graph shows a good response to rainfall and head changes are typically in the order of 0.2m, and an approximate lag time to rain fall is around 2 days.

3.3.8 Pen-y-Graig Area (BH601, BH602, Halcrow BH2 and BH3 and trial pits)

Halcrow drilled two boreholes within the 'landslide area', BH2 (at an elevation of 155.2m OD) and BH3 (130.54m OD). Groundwater was not encountered during drilling of BH2, however, water was struck in BH3 at depth of 21.5m (109.04m OD), within bedrock, which rose to a depth of

19.2m (111.34m OD) after a 20 minute rest period. Two subsequent overnight measurements showed water at depths of 20.5m (110.04m OD) and 21m (109.54m OD), following casing the borehole to 26m.

In brief, Halcrow installed two piezometers in both BH2 and BH3. In both boreholes, a shallower piezometer was installed at the base of their identified landslide deposits and a deeper piezometer was installed within rock below.

The shallow piezometer in BH2 showed a small amount of water, with a range in head above the piezometer of 0.01m and 0.15m, suggesting an intermittent head of water in this location. The shallow piezometer in BH3 showed a greater head of water, with a maximum head of water measures as, 0.97m. However, a minimum head of water of 0.01m was noted in this standpipe piezometer, again suggesting an intermittent body of water.

As discussed above, no groundwater was encountered in BH2, and the deeper piezometer was installed at the base of the borehole, at a depth of approximately 20m (110.54m OD) and did not measure any significant amount of water. The deeper standpipe in BH3 was placed 6.5m (124.58m OD) above what they identified as the Lower Welsh coal seam; this standpipe showed a head of water between 1.5m (108.99m OD) and 4m (111.49m OD).

A vibrating wire piezometer has been installed in BH601 at a depth of 12m, or at a level of 132.77m OD, within South Wales Upper Coal Measures. Monitoring over a six month period has shown a maximum head of water of around 1m (133.74m OD), but on occasion, no head of water has been measured, possibly suggesting that it is not within a water body. However, pressure variations indicate that water is present as a result to rainfall.

In order to allow spot checks of the vibrating wire piezometer, and to provide general groundwater information elsewhere on Pen-y-Graig, a 19mm diameter standpipe was installed within BH602, which has a response zone between 2.7m (143.8m OD) and 11.7m (134.8m OD).

Six monitoring visits have been carried out to date, the first two visits showed water at a depth of about 9m, within bedrock, which correlates with the vibrating wire piezometer in BH601. The last four visits have all shown water at a depth of about 2.8m, or at a level of 143.78m OD. This information suggests that water is present within Coarse Discard above the suspected base of the landslide.

Trial pits excavated by Halcrow in 1989 generally showed damp soils below a depth of around 0.5m, only a single seepage was encountered in one of the ten trial pits excavated in the area. Trial pits excavated by ESP did not encounter any groundwater.

3.3.9 Summary of Groundwater Conditions

A review of the groundwater conditions encountered and measured across the several phases of investigation has generally confirmed the following:

- There appears to be a groundwater body within the Colluvium, noted in several trial pits and boreholes (TP301, TP302, BH4, BH302, BH304, BH305 and BH306). The recent vibrating wire piezometer monitoring shows this water body is responsive to rainfall;
- A groundwater body was intercepted in BH1 (Halcrow) and BH301 (ESP) near the Lower Pinchin coal seam and monitoring by Halcrow and ESP has indicated either a perched groundwater body within the Lower Pinchin coal seam or it is possibly the top of the main groundwater table. Recent monitoring information from the vibrating wire piezometers

suggests that it is responsive to rainfall and the water measured by the piezometer within the Lower Pinchin has a 'double peak' after a rain fall event, possibly suggesting two rates of permeability;

- Deeper groundwater monitoring points in BH304 and BH305 show a groundwater table within the South Wales Middle Coal Measures bedrock, that was similarly responsive to rain;
- A possibly separate, groundwater body was noted within the Lower Welsh coal seam in BH303, however, this piezometer could be measuring water in the overlying weathered soils above bedrock, as this was noted in the northern area of Pantteg, along Cyfyng road. The information from BH202 and BH401 suggests that there is a groundwater horizon at the base of the weathered soils and the underlying bedrock which is responsive to rain, on occasion this head of water is high and correlates to the base of the Made Ground;
- Water struck during drilling, and measured in the standpipe piezometer in BH3 indicates the presence of a water body above the Lower Welsh and there may therefore be a continuous water body near the Lower Welsh stratigraphically; and
- Trial pits, boreholes and monitoring within the main landslide material suggest an inconsistent water body within the 'landslide materials', as water has been measured within piezometers but not at a consistent level, indeed, water appeared to be absent on occasion, with only 0.01m of water within Halcrow's standpipe piezometers. The monitoring we have to date from BH601 generally supports this view, however, recent spot monitoring of the standpipe in BH602 has shown water within the Made Ground above the suspected base of the Landslide.

3.4 Ground Monitoring Movements

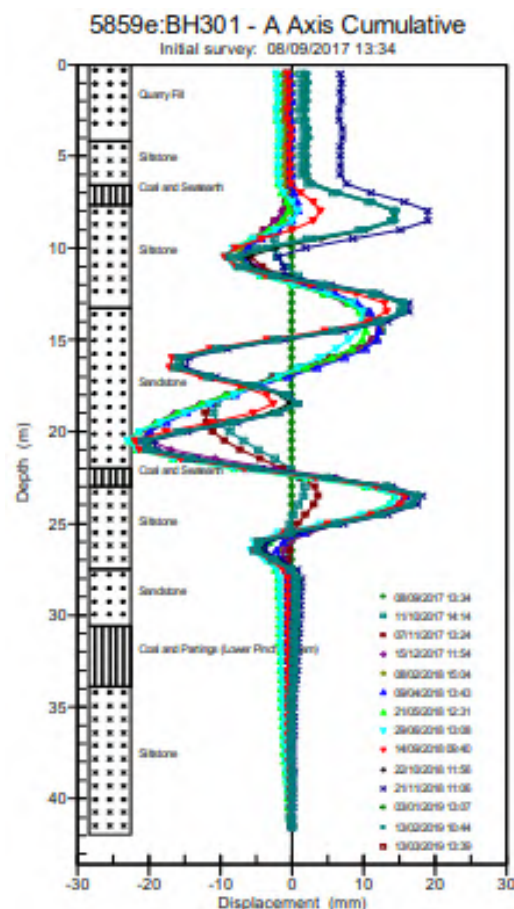
3.4.1 Introduction

Inclinometers were installed in a number of boreholes across Pantteg in the various phases of investigation. Due to the staged nature of the works, some monitoring points have only been monitored seven times, whilst earlier inclinometers have been monitored on 15 occasions. The results are presented in Volume 1 of this report.

Given their relatively large spatial spread, each inclinometer is discussed individually in turn.

3.4.2 BH301 – Quarry

The inclinometer in BH301 was installed to a depth of 42m and the results have shown the inclinometer to have a suspected 'spiral' shape, which to date has shown movements of around 30mm in all directions. The results show the top



Insert 8 – BH301 Inclinometer (Cumulative)

and bottom of the inclinometer casing to have not moved and the suspected spiralling occurs between depths of around 7m to 28m.

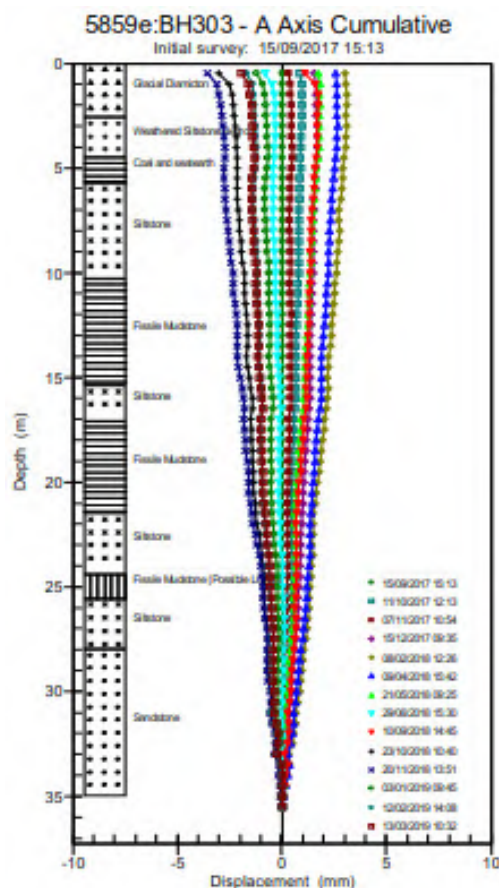
The cause of the movement is not known, however, given that the inclinometer is showing relatively no movement in the top 5m to 10m there is not considered to be a wide scale sign of movement. A likely cause of the movement is collapse of roof rock above the worked Lower Pinchin seam causing the inclinometer to move or twist.

3.4.3 BH303 – Graig-y-Merched

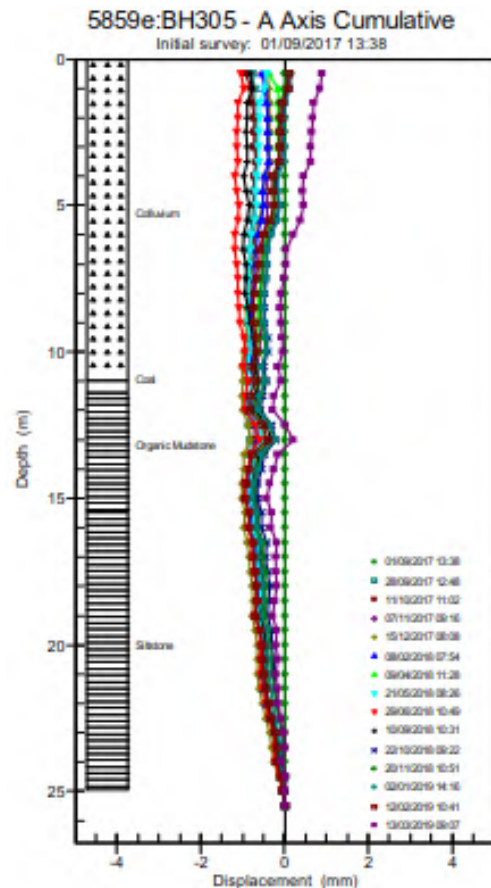
Although the monitoring information of the inclinometer in BH303 have shown displacement of up to 4mm downslope; the movement is within the realms of the sensitivity of the instrumentation and software and the reading may be a result to a bias shift error.

3.4.4 BH305 – Opposite Pantteg Chapel

The inclinometer was installed to a depth of 25m and although some movement, in the region of 3mm has been recorded, it is not considered to be representative of any downslope, or significant movement occurring.



Insert 9 – BH303 Inclinometer (Cumulative)



Insert 10 – BH305 Inclinometer (Cumulative)

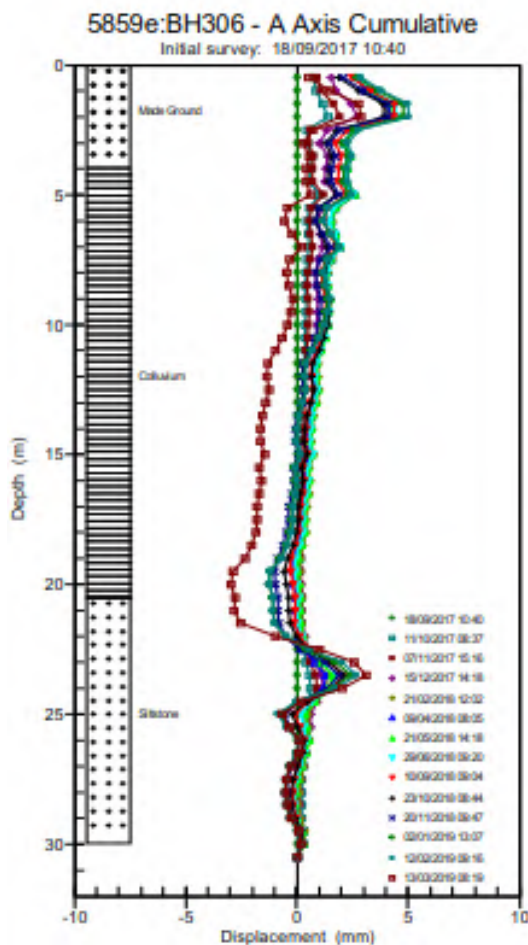
3.4.5 BH306 – Graig Road

An inclinometer was installed in BH306 to a depth of 30m. Monitoring has shown some small amounts of movement (3mm cumulative) at a depth of around 23m to 25m within the bedrock.

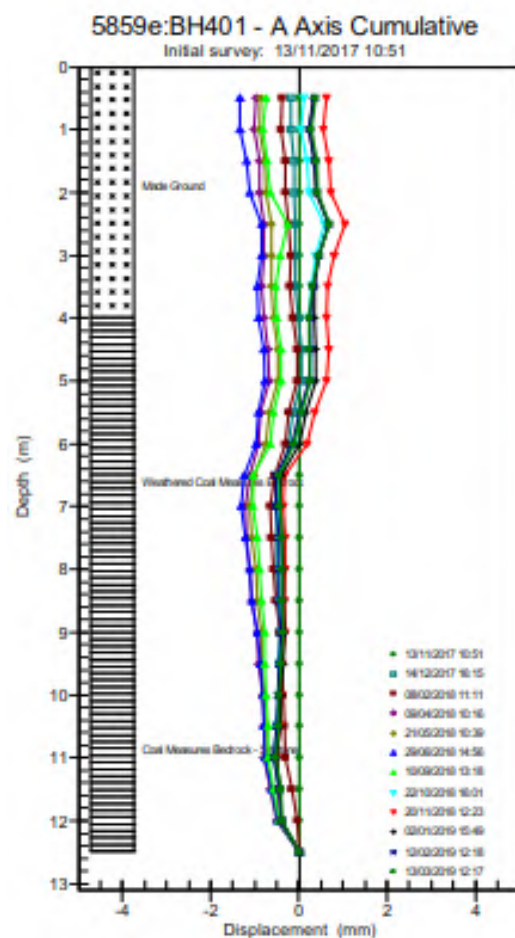
Further suspected movement is occurring within the Colluvium and more so with the shallow Made Ground, with downhill movements in the region of 5mm (cumulative) being measured.

3.4.6 BH401 – 96 Cyfng Road

The results from the inclinometer at BH401 show no significant signs of movement with displacements recorded generally less than 2mm, which is within the realms of the accuracy of the inclinometer.



Insert 11 – BH306 Inclinometer (Cumulative)

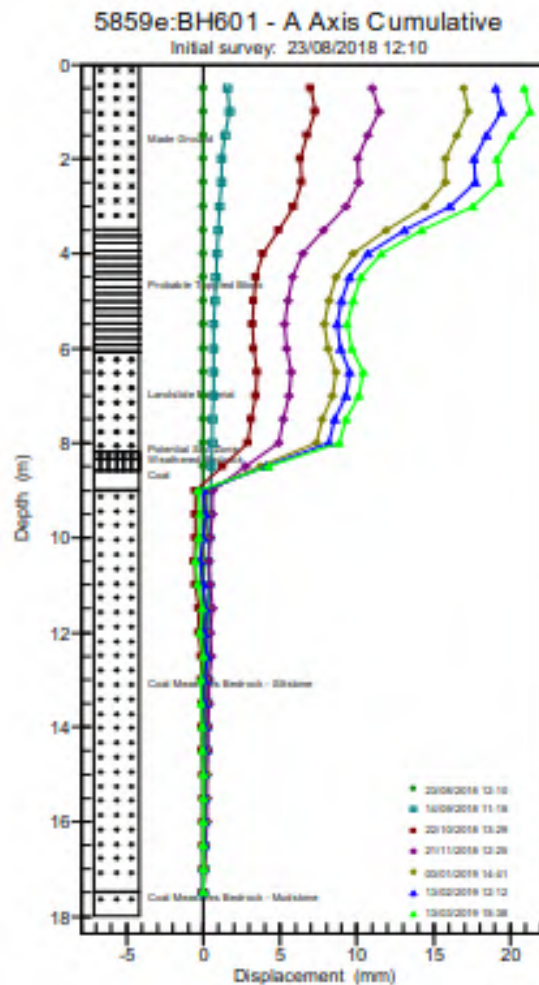


Insert 12 – BH401 Inclinometer (Cumulative)

3.4.7 BH601 – Pen-y-Graig

At the time of writing, seven monitoring visits have been carried out and further monitoring is recommended.

The inclinometer shows movement from above a depth of 8.5m to 9m and approximately 21mm of cumulative downslope movement has occurred. The movement appears to be greater in the top 4m, which is noted to be Made Ground, less movement is noted below this depth, which is within a suspected rotated block.



Insert 13 – BH601 Inclinometer (Cumulative)

3.5 Hydrology, Drainage and Rainfall

3.5.1 Hydrology

Our previous report discussed the location of streams, springs in the Pantteg area and the locations of known springs are shown on Figure 3.

The mapping typically shows streams in the southwestern portion of the Pantteg Landslide area, all of which flow toward the southeast, downhill.

As discussed by Halcrow, groundwater emerged in the backscarp of the 1986 landslide above Graig y Merched. Recent mapping has however not identified this feature.

3.5.2 Drainage Systems

As discussed in our previous Report (ESP 2016), there are two drainage systems in place above the village of Pantteg (a third is located further south of the Pantteg) that transport water from mine adits, spring water and surface water runoff into water courses within the village, that eventually flow in to the River Tawe.

The position of the current drainage, the Church Road System and Pen-y-Graig-Arw systems are shown on Figure 3.

Since 2017 NPTCBC have been regularly checking the condition of the drainage network and undertaking repairs when necessary.

3.5.3 Rainfall

Rainfall data has been collected with a monitoring station placed near Pantteg Chapel. The data collected has been processed and shown on the groundwater monitoring results to provide a visual indication of periods of rainfall in relation to groundwater response. The data is presented in Volume 1 of our report.

3.6 Mining

No further assessment of the mining situation has been carried out since our 2016 report and pertinent information from that previous assessment on the mining setting is presented below, along with information our recent boreholes have provided.

As discussed in our previous report (ESP, 2016), coal was extracted in the hills surrounding Pantteg, Ystalyfera and beyond, both on a large, hundreds of men colliery scale, and, also probably on a small scale, with a few men working a single adit.

The Lower Pinchin Seam, Lower Welsh Seam and Red Vein are present beneath the hillslope at Pantteg and have been worked, there is also evidence of thin coals between these seams stratigraphically, but it is not known if they were worked extensively.

3.6.1 The Lower Pinchin Seam

The Lower Pinchin Seam has been worked from numerous small levels on the outcrop of the seam along the uphill margin of the Pantteg landslide. Vine Colliery worked the seam more extensively between 1952 and 1960 from two levels and two associated airways. It is noted that these workings extended south west immediately and encroached into the area immediately uphill of Graig-y-Merched, immediately uphill of the 1986 landslide.

No evidence of workings within the Lower Pinchin Coal seam were encountered in BH301, however, it must be stressed that the borehole location was positioned for stratigraphical and practical reasons, rather than to locate workings.

3.6.2 The Lower Welsh Seam

It was not clear previously if the Lower Welsh Seam has been mined beneath the site, but has been mined off site. From the abandonment plans obtained in 2016 (SW431), extensive workings, mouths of levels and airways are shown to the west of Graig y Merched. The workings

are annotated with elevations ranging from 513ft to 551ft AOD (156m to 168m) and the seam thickness is noted to be up to 4ft (1.2m).

The Lower Welsh was intercepted in BH601, BH305 and BH303 and no workings were identified in any of these positions, however, as above, these boreholes were located in accessible areas and were not placed to identify works.

3.6.3 The Red Vein

The Lower Cyfyng Level for the Red Vein was probably active from the 1830's onwards, during which time the north and central areas of the wider landslide and the southern part of the Pantteg landslide were undermined.

The seam was also worked from Crimea Pit beneath the extreme southern corner of the wider landslide in the 1850's. The workings would have been executed by the pillar and stall type. The earliest workings were free-draining towards the mouth of the Lower Cyfyng Level but later workings extended below this elevation and would have required pumping.

The northern part of the Pantteg landslide was undermined in the seam from Ystalyfera Colliery in two periods of working (circa 1909 and 1927), by longwall mining.

From the abandonment plans obtained in 2016 (9737 & SWR1539), extensive workings, mouths of levels and a pit are shown to the east and west of Cyfyng Road. The workings are annotated with elevations ranging from 192ft OD to 306ft OD (58m OD to 93m OD) and the seam thickness is noted to be up to 2ft 8in (0.85m).

A Mine Tunnel is shown, indicated to be a cross measure drift extending from 425ft OD (129m OD) to 232ft OD (70m OD). These elevations match the ground levels of a mine entry opposite the chapel and a mine entry identified off Clees Lane.

Both BH102 and BH304 were drilled at the base of Clees Lane and did not encounter a coal seam, suggesting that the subcrop of the coal seam is further to the west of these positions.

3.6.4 Mine Entries and Infrastructure

A series of adits are shown on Figure 3 which have been collated from the geological sheet and historical mapping. The adits are linked to the out crop of the Lower Pinchin Seam in the upper portion of the landslide system and mine entries in the east, or lower part of the valley are associated with the Red Vein.

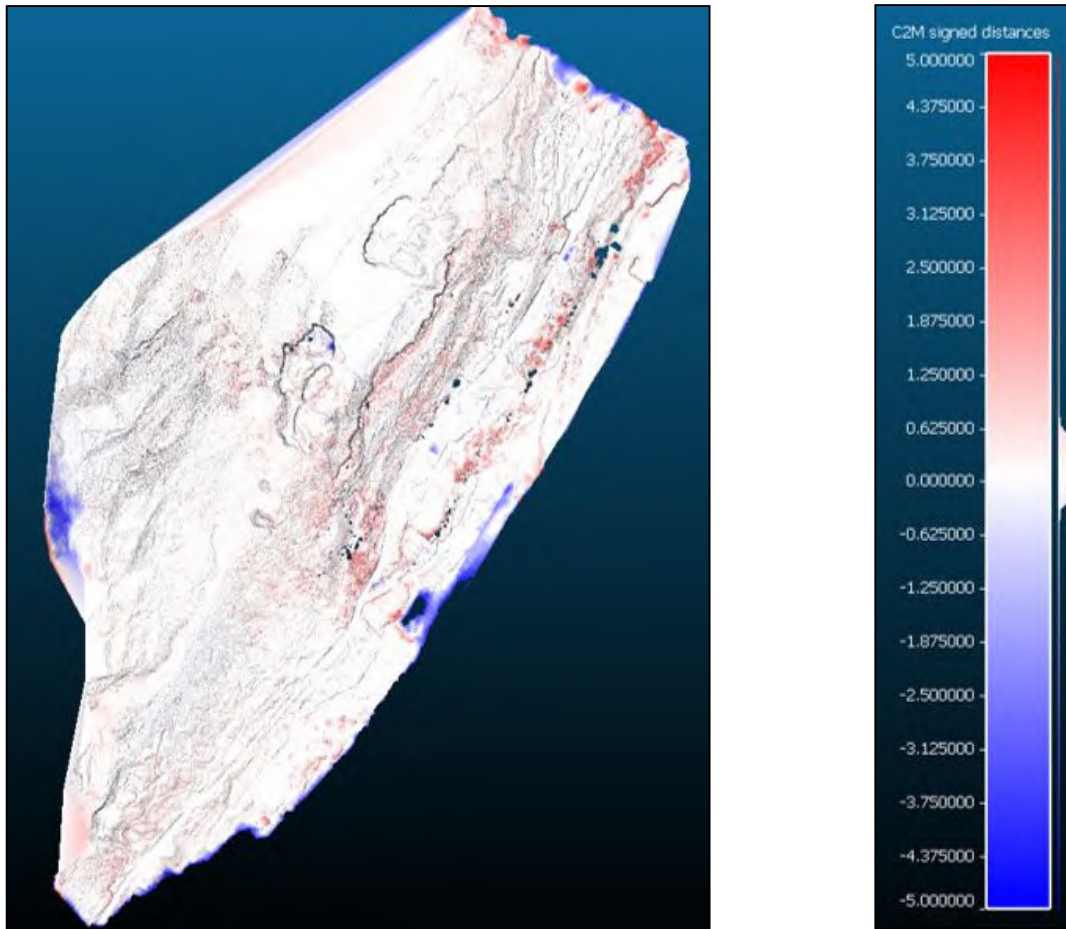
A plan provided by NPTCBC entitled Landslide and Godre'r Graig and Pantteg – Information and Record of Incidents Since 1955 (Ref: Drg No. M2) shows the approximate line of a tunnel. The eastern portal of which correlates with the mine entries indicated at this location (near Clees Lane). From the plan, the western portal of this tunnel is indicated at Mount Hill, to the north of the now demolished Penygraig House.

The site walkover in 2016 identified the eastern most portal of this tunnel near to Clees Lane.

3.7 LiDAR and InSAR Data

3.7.1 Zones of Potential Movement

The isopachytes from the LiDAR data has been generated using Cloud Compare (<https://www.danielgm.net/cc/>) to show displacements of $\pm 50\text{cm}$, with $+50\text{cm}$ shown by the red, -50cm shown by the blue and negligible/no displacement uncoloured. We consider that the tree felling work, along with variations in vegetation coverage has had an impact on the LiDAR surveys carried out. Insert 14 provides a graphical representation of the three-dimensional model.



Insert 14 – Extract of LiDAR Isopachyte information. Not to scale.

The isopachyte has highlighted the following areas of interest:

- Positive displacement along and below the break in slope immediately north-west of Cyfyng road, between the Chapel and Clees Lane and is in the order of 15cm to 25cm. The slope is heavily vegetated with scrub and trees, indicating the displacement could be due to a difference in vegetation between seasons, although the downslope movement of soil can not be discounted;
- Positive displacement along the foot of the cliff-line/backscarp in the Pen-y-Graig area. This is in the order of 15-25cm and could simply be due to the difference in vegetation height, or from downslope movement of rockfall material from the above cliffs;

- Localised positive displacement on the slope immediately south-east Graig-y-Merched. In the order of 20-30cm, and away from areas of tree felling, this is possibly due to the downslope displacement of shallow soil;
- Positive displacement on the slope immediately west of Cyfyng Road (north of the junction with Graig Road/Church Road) in the order of 30cm. Again, no trees have been felled in this area, but there is some scrub vegetation which could have caused the observed displacement; and
- There are areas of notable shading on the boundaries of the survey which have been interpreted as errors.

These findings are preliminary, and further repeat surveys, preferably undertaken during winter, would be required to confirm these trends.

Interferometric Synthetic-Aperture Radar (InSAR) data has been acquired for the area and is presented as Appendix F and is discussed further in Section 5.7.

3.7.2 Limitations of Survey

The LiDAR surveys have produced a Digital Terrain Model (DTM) of the area, which is a model of the ground surface with all surface objects (vegetation, buildings cars etc) stripped out during processing of the raw data. Given the first survey was undertaken in August (i.e. the peak of vegetation growth), the data will have been thinned out to give to remove the dense vegetation, resulting in a relatively low-density point cloud. Due to commitments made by NPTCBC during public meetings, the repeat survey was undertaken in April when the vegetation would have been less dense and resulted in a higher density point cloud. This difference could have negatively impacted the isopachyte comparison of the surveys.

The resulting isopachyte comparison of the two surveys is likely to be limited in its use due to the timing of the initial survey being undertaken in August, the height of vegetation growth. This caused a lower density of points in the survey, with A significant number of trees have been felled in the time between the surveys, although this appears to have little to no effect on the Isopachyte.

The individual LiDAR surveys have an accuracy of $\pm 20\text{mm}$, meaning the resulting isopachyte comparison of the two surveys will have an accuracy of around $\pm 40\text{mm}$, indicating the observed movements between them are more than the margin of error in the model.

3.8 Geophysics Data

As discussed previously, geophysical survey of the Pen-y-Graig area consisting 2no. resistivity and seismic refraction profiles has been undertaken. The geophysical report is presented as an appendix within Volume 1 of our report.

The resistivity survey has showed there to be a near-surface highly resistive dry granular superficial/backfill layer, which extends to 10m depth in places. There is also an area in the centre of the survey lines with a relatively low resistivity, indicating a zone of increased moisture or clay content. Excavation of trail pit and boreholes in the area of the survey has the Made Ground soils to granular in nature, with no significant water bodies present. Instrumentation in BH601 and BH602 has showed the groundwater to be present just below the rockhead. This

indicates the relatively low resistivity layer to be due to an increased clay content in the soil, with BH602 confirming this with clay rich layers identified between 2m and 5m depths.

BH601 has been constructed ~5m to the north-west of Profile 2 and BH602 ~5m north-west of Profile 1. Comparison of the boreholes and the seismic refraction and shows a good correlation between the depth to rockhead and the P-wave boundary of layer 3.

The seismic survey shows the bedrock to be roughly subparallel to the ground surface, with rockhead at around 8.5 to 11m below the surface. This survey also indicates that the rockhead dips the south by around 14°, and up to 27° in places. This roughly ties in with the dip of the bedrock in the area between ~8° to 12° to the south.

The angles presented for the slope of the rockhead have been interpolated from the two line of seismic refraction data, similar surveys perpendicular to the cliff line and break in slope would be required to confirm and refine the rockhead profile. Significant vegetation clearance and slope access are likely required to carry out these surveys.

3.9 Landslide Morphology and Aerial Photographic Information

3.9.1 Introduction

The Tawe Valley was over steepened during the last glaciation (Devensian), and at the end of this periglacial period, some 10,000 years ago, it is likely that high groundwater pressures were present and triggered instability at Pantteg, and within the wider valley. M. D. Wright and Siddle (2000) suggests the majority of superficial deposits on the valley slopes of South Wales have been disturbed by the effects of deglaciation and periglacial weathering.

The valley of Pantteg has steep sided slopes of up to around 40° and a vertical back scarp cliffs. For ease of reference, the landslide has been separated into an Upper and Lower Landslide System, which are different to those previously reported by Halcrow (1989). The new Upper and Lower Landslide Systems are shown on Figures 5 and 6 and discussed separately below.

For ease of reference, the junction between the upper and lower landslide system is broadly Cyfyng road.

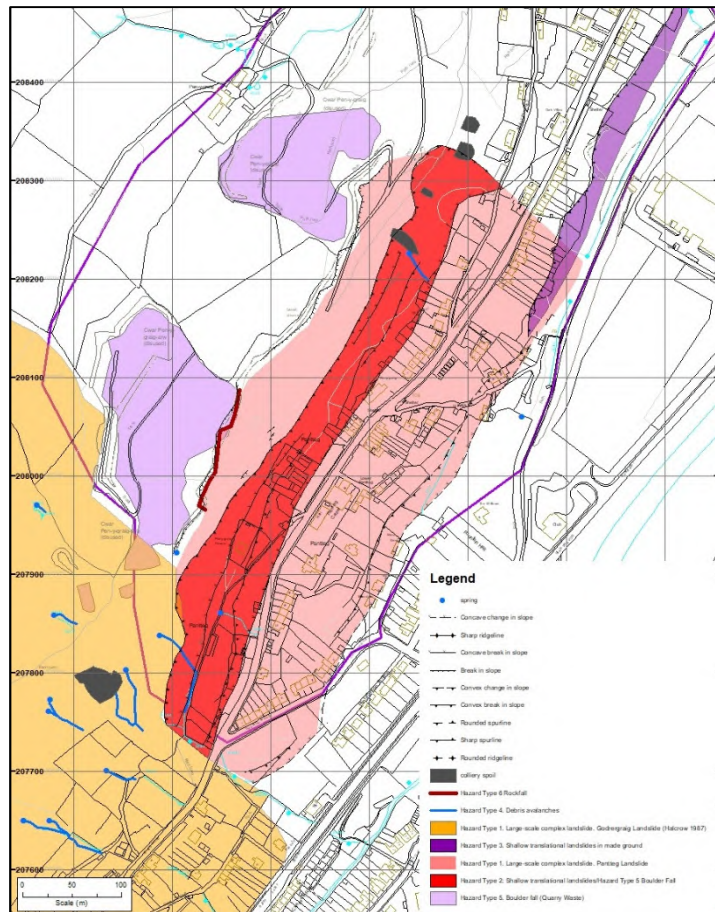
3.9.2 LiDAR data and Aerial Photographic Interpretation

3.9.2.1 Upper Landslide System

The 1m contours generated from the LiDAR surveys have been reviewed in conjunction with the aerial photographs and they show the backscarp of Pantteg landslide to be relatively 'rough' in plan view. This may be due to anthropogenic reasons, i.e. quarrying for coal or sandstone, or it

could be due to preferential weathering of the joints in the sandstone providing this irregular outcrop. Based upon our current understanding, it may be likely that both of these reasons contributed to the backscarp appearance.

As you traverse the slope from the backscarp, toward the south east or the River Tawe, the slope gently dips downward toward the southeast until it reaches a notable convex break in slope, as identified on Insert 15, which shows the main morphological breaks in slope across Pantteg. To the west of the break in slope, there are numerous tension cracks and the ground is hummocky/distressed in nature, although this is covered by thick vegetation for the majority. This break in slope, is where the aerial photographic interpretation has shown the majority of the historical landslide to originate from. A bench is located lower down the slope and forms an approximate lower boundary to the instability; however, some do go over this bench further downhill to Cyfyng Road.



Insert 15 – Map showing major breaks of slope – see Figure 11 for full scaled drawing.

There are notable differences of this generalisation along the slope, however the bench discussed above appears to be persistent along the majority of the slope.

In the north of Pantteg, the LiDAR contours suggest the presence of tracks with a series of hairpin bend which was most likely to be related to the former Vine Colliery; numerous adits can be interpreted within the contours, and their position correlate to the location of the Lower Pinchin Group (Lower) outcrop.

The conceptual Ground Models presented as Figures 5, 5A, 6 and 6B show that either a mudstone or Upper Cwmgorse Marine Band subcrop at the same location as the bench, and it is likely that the bench is as a result from differential weathering of the more friable mudstone, to the siltstone.

The upper Landslide System continues to show signs that it is an active landslide, within three notable areas. Tension cracks are noted above the break in slope, suggesting ongoing movement in this area. The aerial photographic information also suggests translational movement to the east of the convex break in slope, and signs of slow movement is occurring at the crest of the area remediated in 2013.

3.9.2.2 Lower Landslide System

For our assessment, Cyfyng road has been judged to be the highest boundary of the Lower Landslide system. The lowest point of Pantteg Landslide is also the lowest point of the Lower Landslide System, and this has been assumed to be the concave break in slope that is roughly located half way between Cyfyng road and the A4067 (on a section line through Pantteg Chapel).

With the exception to the 2017 landslides behind Cyfyng road in the north of the Pantteg, the aerial photographic interpretation has shown no landslides originating in the lower landslide system. Thus, the lower Landslide System, i.e. to the east of Cyfyng Road, excluding the steep slopes in the northern portion of the landslide area where the residential tribunal reviewed, are considered to be 'stable'.

The land Cyfyng road lies upon is generally level in the central portion of Pantteg, the ground rises upward in the north and a convex break of slope is present on the eastern boundary of the Pantteg Chapel land which generally trends north and south. This convex break in slope does alter due to previous landslide lobes that have flowed to the lower part of the Landslide System, such as seen on Clees Lane. It has also been altered by made for the purposes of mining and to form development platforms.

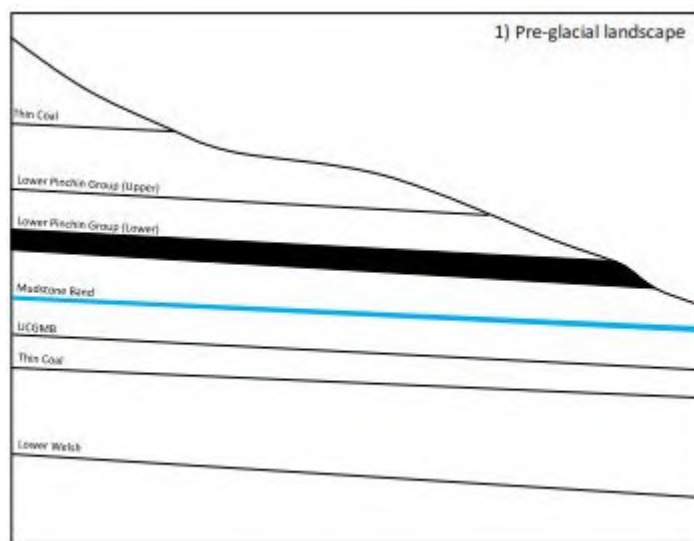
4 Ground Model

4.1 Conceptual Ground Model Timeline

The instability at Pantteg and the wider landslide system is considered to have three main components. Two of these components are within the Upper Landslide System and are considered to be 'active'; the third is within the Lower Landslide system and is considered to be inactive and ancient.

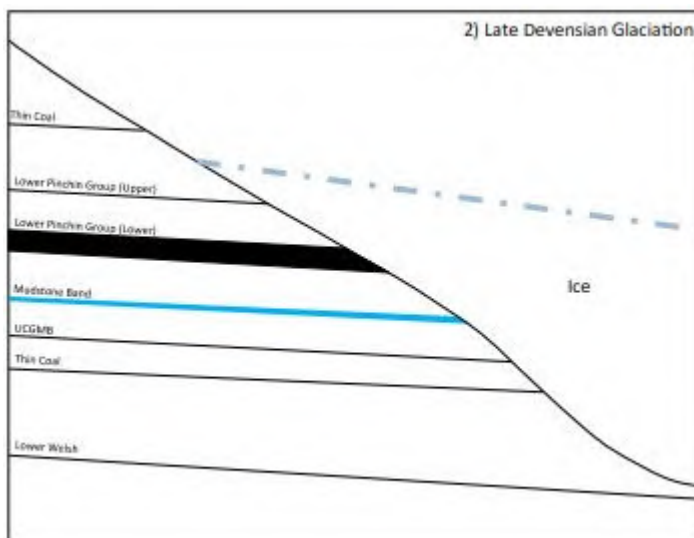
Figure 5 and Figure 6 show the current Ground Models for the site. However, to explain the Ground Model, it is necessary to consider the valleys formation in recent geological time (i.e. post glaciation):

Stage 1: Unglaciaded Tawe Valley, possibly with a 'V' shaped valley.



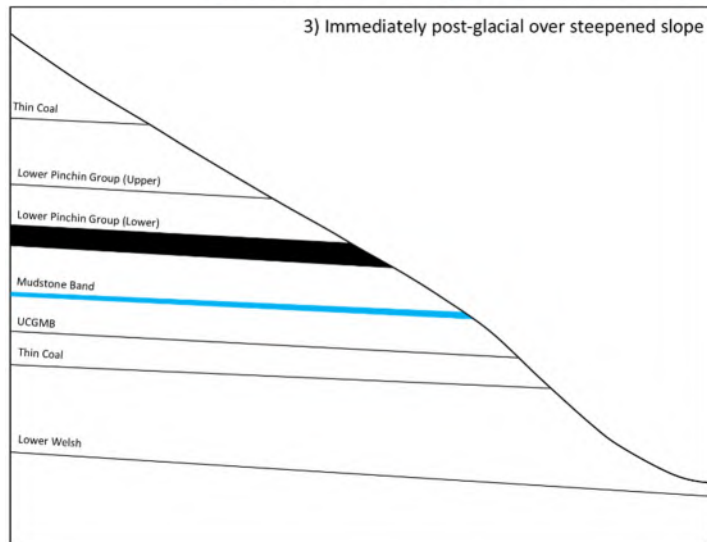
Insert 16 – Stage 1

Stage 2: Glaciated Valley, eroding valley sides, depositing Till and other glacial deposits in the valley floor.



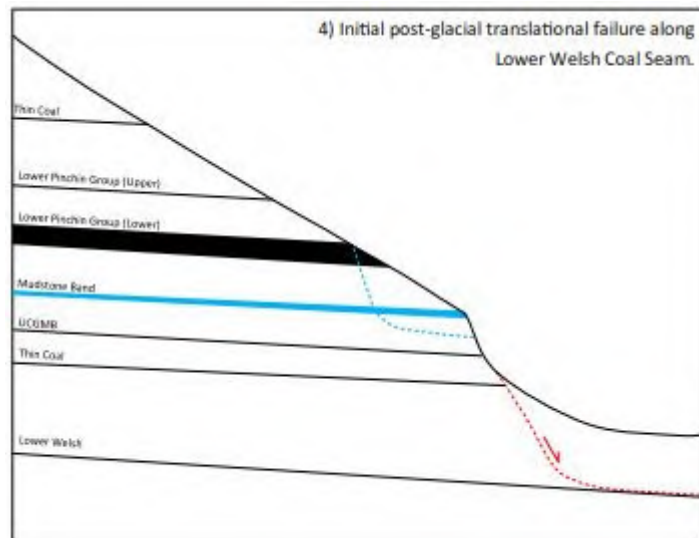
Insert 17 – Stage 2

Stage 3: Immediately after glacial retreated, valley in periglacial environment. Valley sides over steepened and mudstone, coal seams and marine bands (organic rich mudstones) suffer from periglacial weathering (compared to siltstones and sandstones).



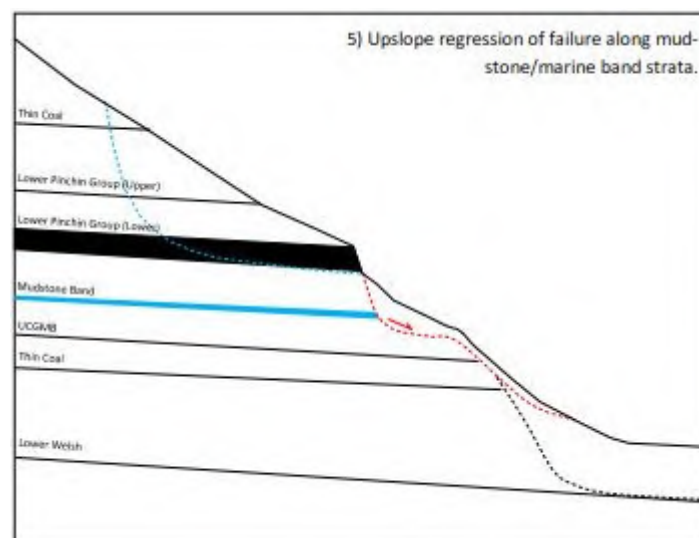
Insert 18 – Stage 3

Stage 4: Initial failure along Lower Welsh coal seam, depositing the Colluvium currently in the Lower Landslide System on to the valley floor.



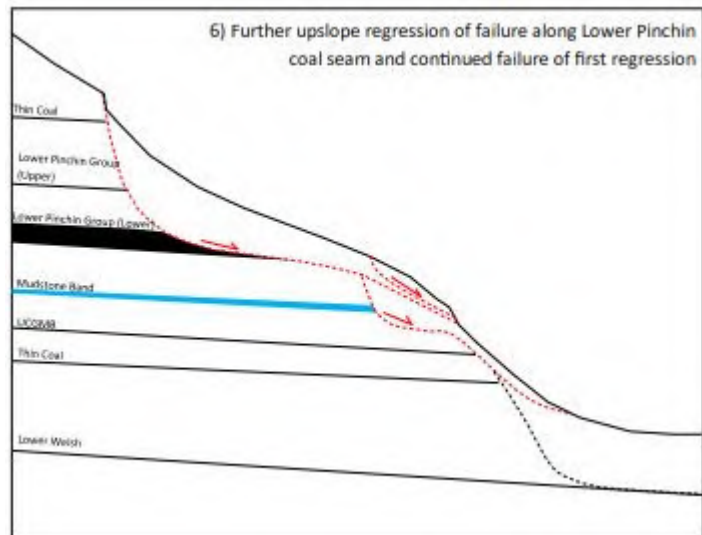
Insert 19 – Stage 4

Stage 5: Previous instability over steepens the valley side above a mudstone, or Upper Cwmgorse Marine Band. The landslide regresses and instability occurs with the base near the Mudstone or Upper Cwmgorse Marine Band with colluvium flowing onto the valley floor.



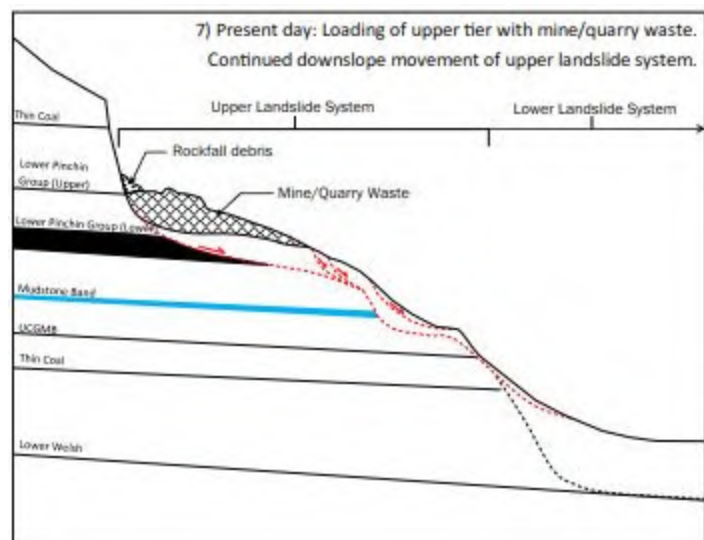
Insert 20 – Stage 5

Stage 6: The previous failure along the mudstone/Upper Cwmgorse Marine Band has again over steepened the valley side and the landslide regresses again, the failure plane is the Lower Pinchin Group (lower) outcrop.



Insert 21 – Stage 6

Stage 7: Represents the present-day situation. The landslide has not regressed as the back scarp is within the Llynfi Rock (sandstone). The top of the landslide system has been loaded with mine waste and downward movement is occurring along the top two failure planes - The Lower Pinchin Group (lower) outcrop and the mudstone/Upper Cwmgorse Marine band.



Insert 22 – Stage 7

The above model suggests that Pantteg Landslide initially comprised a failure associated with the Lower Welsh coal seam, which has been found to subcrop out beneath Graig-y-Merched and Cyfyng Road. This occurs roughly at the base of the Colluvium in the lower parts of the valley, and potentially forms the original slip surface. The landslide has regressed twice to form the current day landslide system, which comprises an active upper, and inactive lower system. There are considered to be two active landslides in the upper system and a single inactive landslide in the lower system.

4.2 The Lower Landslide System

The Lower system generally represents the first failure to occur at Pantteg and evidence of this is the thick 10-20m of Colluvium in the valley base. Inclinometers and other evidence generally demonstrate little or no movement in this material and confirms the view that this is generally

inactive. Exceptions are where steep slopes are made by locals and destabilise material that has historically failed.

4.3 The Upper Landslide System

The borehole information at Pantteg suggest that the large-scale dip of the stratigraphy is around 5° to the south, based on the position of distinguishable beds across three boreholes (see Figure 7). This produces a slightly lower apparent dip of between 3-4° towards the valley floor.

The benches noted on the slopes (Figure 5 and 6) are likely to be somewhat controlled by the geology of the hillside, the conceptual cross sections shows the bench in the middle of the upper landslide system to be at or near the subcrop of a mudstone band in Section A-A' and the Upper Cwmgorse Marine Band in Section B-B', which is some 6.5m vertically apart.

It is considered likely that there are two areas of instability in the Upper Landslide System, the furthest uphill is below the Pen-y-Graig Plateau, the second is down slope, between a convex break in slope and a bench associated with a mudstone bed or the Upper Cwmgorse Marine Band.

Investigation has shown the instability in the Pen-y-Graig area can be attributed to a slip surface that is thought to be the lowest expression of the Lower Pinchin Coal Group. The slip surface comprised extremely weak weathered rock and a thin clayey silt layer, which is interpreted as being the base of the landslide materials. Inclinator monitoring shows the material above the Lower Pinchin slip surface to be moving down slope. Groundwater monitoring suggests an inconsistent body of water present within the material above the suspected slip surface.

Blocks have fallen from the cliff, forming the toppled blocks and there is also likely to be some rotated blocks of sandstone, siltstone within the landslide materials as they detach(ed) from the back scarp. In addition, numerous adits are present along the foot of the cliff in this area, presumably working the Lower Pinchin, or possibly extracting building stone from the cliff, and deposited Made Ground upon the hillside. The material would have likely been 'end tipped' and will be unstable beyond its natural angle of repose. Tension cracks in this material suggest downward movement and instability and where the slope becomes steeper, instability via translational land sliding occurs, see below.

The aerial photographic interpretation has shown a second area of instability which is broadly delineated by a convex break in slope in the west and a lower bench in the east. Numerous translational landslides have occurred along this bench and it is likely to receive material slowly moving from the plateau area, and periodically over steepening the second area until failure reduce the slope angle.

In addition to the above, rock fall is occurring due to block release in tension cracks and blocks will also be falling from the sandstone back scarp.

In addition to the main setting for the instability discussed above, other factors that will also contribute to the destabilisation of the upper system include:

- Continual block fall from the back scarp;
- Naturally over-steepened slopes;
- Low strength weathered rock and man made materials;

- Collapse of old mine workings, notably the cross drift tunnel opposite the Chapel;
- Probably preferential mine water drainage through Lower Pinchin Group feeding into the landslide material;
- Workings in seams further up slope, Upper Pinchin and Upper Welsh may also provide a preferential drainage path for water to feed into Pantteg Landslide;
- The Llynfi sandstone is jointed and will provide a preferential flow into the landslide system;
- Periods of heavy rainfall, which may be effected over time through climate change (surface water runoff and recharging groundwater);
- Blockages from roof collapse and sedimentation in the tunnel may enhance instability through the retardation of water flows;
- Anthropogenic activities on, above and below the slope (e.g. the construction of houses);
- Alternating competent and incompetent strata;
- The presence of loose/soft material from previous landslides; and
- Trees in areas of instability may enhance movement and present a risk in themselves.

It is also worth noting the points below:

- Instability has been noted at the locations of springs. The 1986 landslide (debris avalanche) originated near a spring and although aerial photographic interpretation indicates colliery spoil was placed over the spring, it is considered likely that the failure was within the natural soils and the presence of the colliery spoil decreased instability, i.e. increased porewater pressures;
- The possibility of a deeper seated failure, i.e. regression of the main back scarp are considered unlikely. The borehole stratigraphy correlates which suggests no movement within bedrock, the inclinometer movement in BH301 is not considered to represent this type of movement; and
- The stability in the Godre'r Graig area has not been assessed further since our 2016 report.

4.4 Interaction with adjacent landslides and ground

The boundary between the two landslide areas (Pantteg and Godre'r Graig) is taken to be at the junction of Graig Road, Pantteg and Church Road, extending southeast (downslope) along the line of the stream, and northwest (upslope) to the entrance to the sandstone quarry above the location of the former Penygrraig House. No detailed assessment of the interactions at this location has been carried out to date given the policy of abandonment of the settlement of Pantyfynnon by the predecessors of NPTCBC.

4.5 Potential Links to Rainfall and River Flow

Previous investigation and assessment in the 1980's, 1990's and most recently in 2013 has considered the likely link between high rainfall and slope instability. Based on the geology, hydrology and hydrogeology we concur with this assessment.

As discussed in Section 1.2, the focus of the assessment was modified following issue of our 2016 report and the potential links between rainfall, river flow and possible instability was not included as part of the updated brief. There is considerable variation in the available data at present and formal statistical analysis is required to provide confidence in the link between rainfall, river flow and periods of instability/events. A long time-series of data is required to enable this.

However, recent monitoring (start of 2018/2019 winter) has shown movement to occur in the upper landslide system (BH601) following a period in which Storm Callum occurred over the British Isles.

Further regular monitoring is planned for this area.

4.6 Preliminary Slope Stability Assessment

The Lower Landslide area was modelled in 1989 and we previously carried out model reviews as part of our 2015/2016 assessment. Rockhead and sub-soil boundaries were determined by interpolation of borehole and trial pit data. The water table was based on the maximum water levels recorded in the piezometers over the period of the investigation/monitoring, although as discussed, this may not be fully representative.

NPTCBC instructed ESP to consider the stability of the following slopes which are all located in the northern portion of the landslide area:

- The slope above Graig y Merched;
- Land between Graig y Merched and Cyfyng road; and
- The slope to the east of Cyfyng road.

For the purposes of the assessment, a single, line of section has been considered which transects these areas and has been positioned where we have information to populate the Ground Model. It should be noted, that, due to limited access and lack of investigation data, the Ground Model presented is based upon many assumptions, and conservative judgement has been used where necessary to populate the Ground Model shown.

This element of work should be used as a guide to the sensitivity of the slopes to instability and not used as engineering guidance in the current form.

4.6.1 Existing Slope and Comments on General Stability

4.6.1.1 Above Graig y Merched

No access has been possible to this area for a visual inspection, however, historical maps, aerial photos and other information suggest that this area has been significantly altered by man due to

mining activities. With the creation of spoil mounds and access tracks evident. It is not known if the current slope is moving, but it is set within the Pantteg landslide area and signs of slow movement are occurring along Graig y Merched.

It is not known if any movement is occurring at present, or recently in this area. However, there have been no large scale movements reported to the council from residents and on this basis, it is reasonable to assume that the factor of safety is likely to be greater than unity (1).

4.6.1.2 Between Graig y Merched and Cyfyng Road

Visual observations from Graig y Merched and Graig road show a relatively steep bank with an angle of around 40 - 60 degrees, this is predominantly the area identified as a cut slope hazard. Jacobs (2013) indicated that the retaining wall adjacent to Cyfyng Road showed no signs of distress but did indicate signs of distress along Graig y Merched, noting telegraph poles that had moved. Recent observations showed parts of the retaining wall to be leaning outward suggesting some movement occurring. Cracking of the road up Graig-y-Merched is also evident.

The design of the retaining wall is not known and although it shows no sign of significant distress, we have assumed a conservative design in our Ground Model.

A borehole has been drilled on Graig y Merched (BH302) and indicated Colluvium to extend to a depth of 7.2m where upon bedrock of the South Wales Middle Coal Measures formation was encountered. Monitoring instrumentation has indicated groundwater to be present with the Colluvium at an approximate depth of 5m to 6m.

Given that there are some signs of movement, it is reasonable to assume that the factor of safety is likely at or around unity (1).

4.6.1.3 Below Cyfyng Road

Instability in the slopes below Cyfyng road have occurred recently and was be translational in nature with material comprising Made Ground and the underlying weathered rock. Backscarps of these landslides encroached the rear elevations of properties along Cyfyng Road.

Window sampling borehole excavated in the rear gardens and other anecdotal information from residents and local members of the public have been used to inform the Ground Model in this location.

Given that movement has recently occurred, it is reasonable to assume that the factor of safety is likely to be at or very near unity (1).

4.6.2 Assessment Methodology

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

For the purposes of this assessment, the likely worst case slope profile has been adopted, 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, BH302, BH401 and WS501 to WS508.

The line of Section is shown on Figure 2.

4.6.3 Local Ground Model

The slope profile has been generated using the 2017 LiDAR survey information and is based upon 1m contours of that data.

In the assessment the Ground Model has broadly been determined from the findings of the exploratory holes completed. With the exception to the monitoring information we have at several discrete points in the slope, visual observations on site and anecdotal information provided by residents, 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 draw the groundwater profile on the Ground Model.

Given the general lack of information to accurately represent the ground conditions, the soil parameters used in the model have been adopted from a combination of in-situ testing and laboratory testing across the wider Pantteg area, or established correlations from other soil characteristics. We consider that this has provided a realistic indication of the soil and water conditions at the site. Table 21 below, identifies the parameters used in the analysis for the individual layers.

We have assumed that no additional load will be added to any of the slopes; for the roads, we have used a variable load of 10kN/m² to model loads from potential traffic.

4.6.4 Assumptions

As discussed above, the Ground Model, parameters and groundwater conditions are generally assumed to populate the slope profile, which is the main assumption for this model, however, there are some other assumption, as listed below:

- Lateral extent of Made Ground, up and downslope slope assumed;
- Ignoring global stability issues of the wider Pantteg landslide;
- Made Ground associated with drainage known to cross rear gardens of Cyfyng Road ignored;
- Weathering profile generally based upon information from BH401 at 96 Cyfyng Road;
- No loadings from Houses used in preliminary models;
- Assume no leaking drains/sewers/services in slope; and
- Assuming a constant groundwater level – as shown.

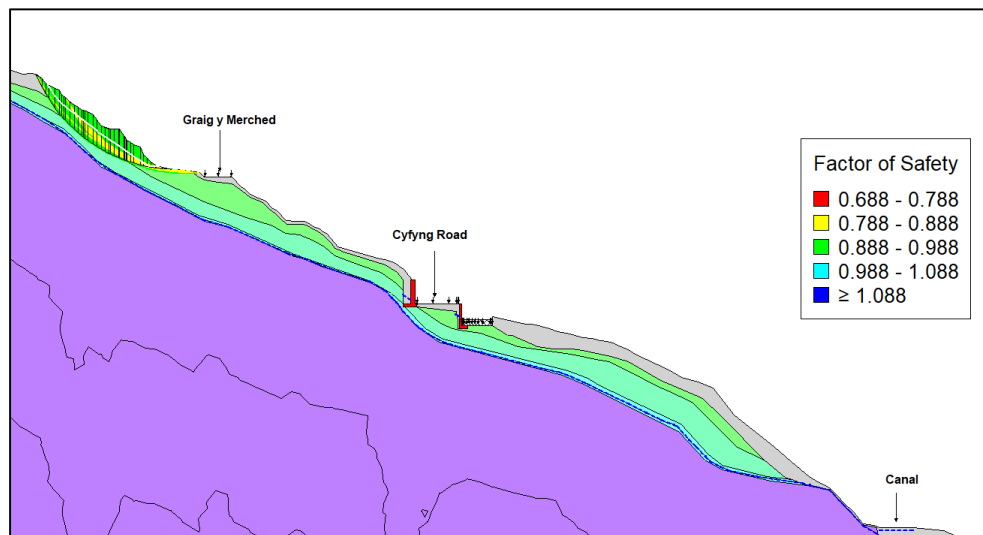
Table 21: Parameters Assumed for Slope Stability Assessment

Strata Unit	Soil Type	Bulk Density	Effective Cohesion (c')	Angle of Friction (ϕ')
Made Ground (In parts of sections, may actually be Colluvium)	Variable	1.8 Mg/m ³	0kPa	26° ⁴
Weathered Rock Grade E	mainly clay	1.8 Mg/m ³	0kPa	28°
Weathered Rock Grade D	Clayey coarse-grained soils	1.9 Mg/m ³	3kPa	30°
Weathered Rock Grade C	Coarse-grained soils	2.0 Mg/m ³	3kPa	36°
Rock	Siltstone, Mudstone, Sandstone ^{3, 5}	-	-	-
Notes: 1. For full details of strata see Volume 1, ESP Factual Report. 2. Derivation of soil parameters discussed above. 3. Assume impermeable and hard boundary for assessment. 4. Angle reduced to allow for variability in Made Ground. 5. Possible impact of coal seam/seal earth providing possible weak horizon ignored.				

4.6.5 Results of the Preliminary Assessment

4.6.5.1 Above Graig y Merched

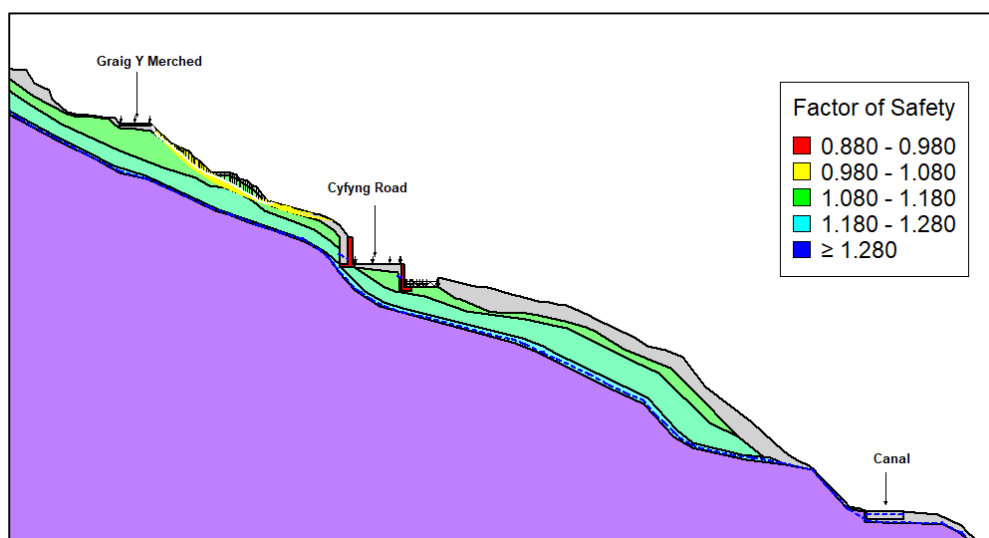
Analyses of the section has shown that for the strength parameters outlined in Table 21 and on the assumed piezometric surfaces shown, a minimum factor of safety of around 0.7 can be assumed when considering the current slope geometries. This assessment assumes a relatively large slip surface to be created and failure to occur with suspected Made Ground upslope of the site. It should be noted that further assessment shows smaller failures within the steeper section of suspected Made Ground up slope, however, as there is no evidence of these currently occurring, this is likely to be due to the simplifications and relatively conservative parameters adopted.



Insert 23 – above Graig y Merched

4.6.5.2 Between Graig y Merched and Cyfyng road

Analyses of the section has shown that for the strength parameters outlined in Table 21 and on the assumed piezometric surfaces shown, a minimum factor of safety of around 0.9 can be assumed when considering the current slope geometries. This assessment assumes a slip surface to occur from near the Graig y Merched road and near the top of the retaining wall to Cyfyng road.

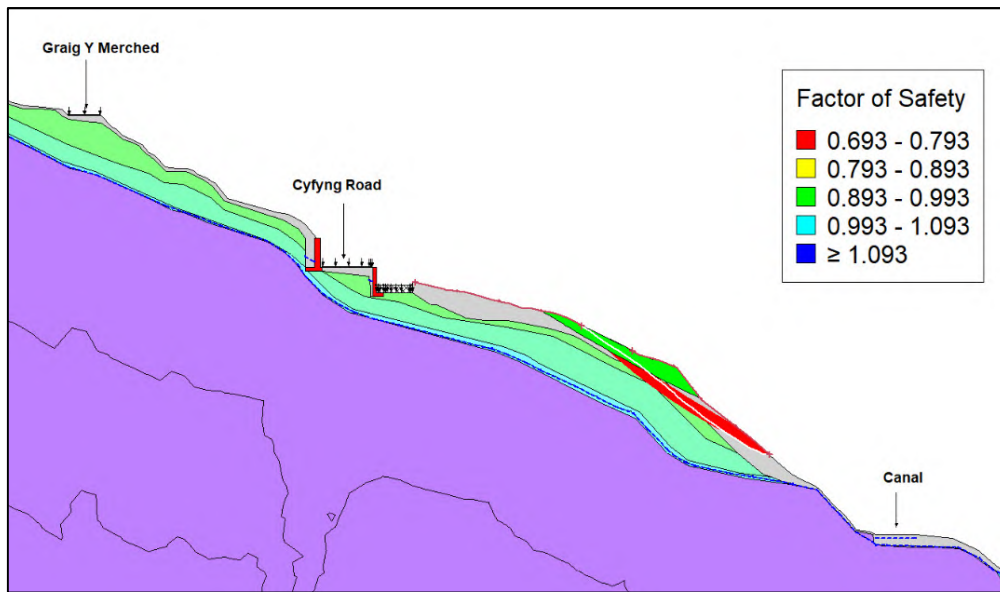


Insert 24 – Between Cyfyng Road and Graig y Merched

4.6.5.3 Below Cyfyng Road

Analyses of the section has shown that for the strength parameters outlined in Table 21 and the assuming piezometric surface shown, a minimum factor of safety of around 0.7 can be assumed when considering the current slope geometries. This assessment assumed a slip surface to

occur within the rear garden area of houses along Cyfyng Road, and forming a similar slip surface to those previously noted in the area.



Insert 25 – Below Cyfyng Road

4.6.6 Summary

On all three slopes considered, the stability sensitivity analysis has shown potentially unstable conditions to be present (e.g. below a Factor of Safety of 1.4). This is likely to be due to the assumed conservative parameters being adopted in the assessment, however, the geometries of the slopes suggest that favourable parameters would be needed to provide a satisfactory factor of safety; and without further investigation, inspection and assessment, this cannot be applied without justification.

Given the above, it would be beneficial to undertake further work to understand the ground conditions such that less conservative material parameters could be adopted and a more robust slope assessment could be carried out (See Section 6).

4.7 Ground Model Summary

The instability at Pantteg and the wider landslide system is considered to have three main interrelated landslides. Two of these landslides are within the Upper Landslide System and are considered to be 'active'; the third landslide is within the Lower Landslide system and is considered to be inactive and ancient.

Figure 5 and Figure 6 show the current conceptual Ground Models for the site. However, to explain the Ground Model, it is necessary to consider the valleys formation in recent geological time and the time line proposed in Section 4.1 should be viewed.

The initial movement probably occurred associated with the end of the last glaciation, some 10,000 to 12,000 years ago and was probably a relatively deep-seated failure located below the present day Cyfyng Road. The back scarp of this landslide was probably located near the current location of Cyfyng Road and this unloading appears to have resulted in regression movement upslope of the backscarp in the form of translational landslides associated with basal shear surfaces developing along two, relatively weak, geological horizons namely the Lower Pinchin and either the Upper Cwmgorse Marine Band or an unnamed mudstone band above it.

In order to show the current Ground Model, 2no. (3no. including a Strike Section) conceptual Ground Models have been produced and are presented as Figure 5 to 7, the line of section for each conceptual Ground Model is presented on Figure 2.

The topography presented on the sections has been taken from LiDAR data acquired from the last survey of the site.

Key points identified during investigation to date, which have fed into the production of the conceptual Ground Models, are outlined below:

1. Our boreholes suggest that the large scale dip of the stratigraphy is around 5° to the south, based on the position of distinguishable beds across three boreholes (see Figure 7). This is lower than the previously assumed dip of around 10°, and produces a slightly lower apparent dip of between 3-4° towards the valley floor.
2. Pantteg landslide is considered to have originally comprised a single landslide with a failure horizon around the Lower Welsh coal seam, which has been found to subcrop out beneath Graig-y-Merched and Cyfyng Road. This occurs roughly at the base of the Colluvium in the lower parts of the valley, and potentially forms the original slip surface.
3. The landslide has regressed twice to form the current day landslide system, which comprises an active upper, and inactive lower system.
4. The benches noted on the slopes are likely to be somewhat controlled by the geology of the hillside, the conceptual cross sections show the bench in the middle of the upper landslide system to be at or near the subcrop of a mudstone band in Section A-A' and the Upper Cwmgorse Marine Band in Section B-B'.
5. Investigation has indicated the presence of a slip surface in the upper landslide system beneath the Pen-y-Graig plateau that is thought to be the lowest expression of the Lower Pinchin Coal Group. The slip surface comprised extremely weak weathered rock and a thin clayey silt layer, which is interpreted as being the base of the landslide materials.

6. Inclinator monitoring shows the material above the Lower Pinchin slip surface to be moving down slope.
7. Numerous adits are present along the foot of the cliff in this area, presumably working the Lower Pinchin, or possibly extracting building stone from the cliff, and deposited Made Ground upon the hillside.
8. Blocks have fallen from the cliff, forming the toppled blocks and there is also likely to be some rotated blocks of sandstone, siltstone within the landslide materials and they detach(ed) from the back scarp.
9. Man has also altered the landform in certain areas of the slope, heavily in some areas, i.e. near the former Vine Colliery or behind the houses along Cyfyng Road in the northern portion.
10. Aerial photographic interpretation shows that instability is occurring at a break in slope that is likely to be associated with the second historic failure at Pantteg, with the slip surface being within/near the mudstone in Section A-A' or the Upper Cwmgorse Marine Band in section B-B'. It is considered that groundwater cannot pass downward through the mudstone or marine band and issues from the slope, providing pore water pressures and instability for the failure.
11. Colluvium is encountered widely around Pantteg Village, usually to a depth of 10m, with up-to 20m depth occurring locally. Colluvium is encountered downslope as far as Clees Lane.
12. Groundwater is encountered above the Lower Pinchin, with possibly a separate groundwater body present above the Lower Welsh seam. The shallow soil encountered in Cwar Pen-y-Graig and across the Pen-y-Graig area are largely free of any major groundwater bodies, as they are relatively coarse grained and anticipated to be free draining. However, a constant groundwater body has been recorded within the colluvium area of Pantteg Chapel. Monitoring of a standpipe within the Landslide material has indicated the presence of a groundwater body above the anticipated slip surface, although it appears to be inconsistent along the whole area of Pantteg.
13. Coal mines are anticipated in the Lower Pinchin seam, which will act as a preferential pathway for water to flow. With a slight apparent dip towards the valley floor, the mines are likely to channel water towards Pantteg Village.
14. Workings in seams further up slope, Upper Pinchin and Upper Welsh may also provide a preferential drainage path for water. Jointing in the Llynfi sandstone will provide a preferential flow and possible evidence of this can be seen in the monitoring equipment in BH301, twin peaks of groundwater pressure.
15. Non-intrusive geophysics survey, parallel to the break in slope across the Pen-y-Graig area shows the depth to bedrock across the area to roughly mimic the topography. Rockhead is interpreted to dip to the south at around 14°, but steeper in places and reaches 27°.
16. Monitoring of inclinometers installed across Pantteg Village, including Cwar Pen-y-Graig have shown little to no movement. Movement which has been recorded is unlikely to be caused by ground movement and more likely due to installation error, or collapse of mine working/heavily fractured rock around the installation. The inclinometer in BH601 (Pen-y-Graig Area) requires further monitoring before conclusions can be made, however initial monitoring suggests movement downhill.

17. Repeat LiDAR surveys have been undertaken, with a comparison in the form of an isopachyte map and has shown movement in the area in the order of up to 50cm. Due to the timing and accuracy of the technology, further surveys would be required to determine if these areas are true of actual movement, or a product of changing vegetation.
18. The link between movement, groundwater and river level has yet to be fully investigated. Recent monitoring suggests movement in the region of 6mm downslope of the Pen-y-Graig inclinometer during the period storm Callum occurred.

4.7.1 Limitations/Uncertainties of Conceptual Ground Model

Given the density of points compared to the area of the site, there are still a number of uncertainties in the Ground Model, with interpolation between the investigation points. The main areas of uncertainty (in terms of intrusive site investigation) are listed below:

1. No extensive investigation has been undertaken of the slope between the Pantteg Chapel and plateau beneath the cliff line due to the steepness of the slope. Thus, the presence of the second failure plane is conceptual; however, it is based upon considerable secondary information from the aerial photographic interpretation and surveys.
2. Limited investigation of the ground above Graig-y-Merched, and below Cwar Pen-y-Graig primarily due to the slope being very steep and stepped. Vegetation in this area is also well established.
3. No investigation of the slope above the road between the Chapel and Graig Road due to steep and potentially unstable topography..

Further, and targeted investigation will be of value for refinement of the Conceptual Ground Model. The investigation will increase the data resolution and result in an increased understanding. However, such investigations should consider the requirement for working in a safe environment and some of the limitations discussed above will still hinder, or prohibit investigations, such as the steep and stepped topography.

5 Hazard Identification and Risk Assessment

5.1 Introduction

As discussed in Section 1.2, the Hazard Identification and Risk Assessment has been done in collaboration with Steve Parry of Parry Engineering Geological Services Ltd (PEGS) with the objective of undertaking landslide hazard and risk assessment for Pantteg, South Wales (Figure 1b).

In accordance with good practice, an independent peer review of the hazard identification and risk assessment was undertaken by Dr Mark Lee² of Ebor Geoscience. This report takes into account the recommendations of that peer review.

5.2 Landslide Hazard and Risk

There are no British Standards or Eurocodes for the assessment of landslide hazard and risk. However, Fell et al (2008) reporting on behalf of JTC-1 (Joint Technical Committee on Landslides and Engineered Slopes, an International Association of Engineering Geology and the Environment (IAEG), International Society for Rock Mechanics and Rock Engineering (ISRM) and International Society for Soil Mechanics & Geotechnical Engineering (ISSMGE) collaboration exercise, i.e. all relevant international professional geotechnical societies) provide guidelines for landslide hazard and risk assessments. JTC-1 is largely based on AGS (2007) with minor modification for international implementation. The Engineering Group of the Geological Society is the UK National Group of the International Association of Engineering Geology (IAEG).

The guidelines provide:

- Definitions and terminology for use internationally;
- Description of the types and levels of landslide zoning;
- Guidance on where landslide zoning and land use planning are necessary to account for landslides;
- Definitions of levels of zoning and suggested scales for zoning maps taking into account the needs and objectives of land use planners and regulators and the purpose of the zoning;
- Guidance on the information required for different levels of zoning taking account the various types of landslides;
- Guidance on the reliability, validity and limitations of the methods; and
- Advice on the required qualifications of the persons carrying out landslide zoning and advice on the preparation of a brief for consultants to conduct landslide zoning for land use planning.

² Author of:
Landslide Risk Assessment. 2nd Edition. Thomas Telford. 2013.
Engineering Geomorphology: Theory and Practice. 2007.
Evaluating risk in a rural environment; a case study. 2006 (IAEG2006 Paper number 535).
Geomorphology for Engineers. 2005.
Landsliding in Great Britain. 1994.
Quarterly Journal of Engineering Geology and Hydrogeology Editorial Board Member.

The guidelines also provide the following definitions:

Hazard: A condition with the potential for causing an undesirable consequence. The description of landslide hazard should include the location, volume (or area), classification and velocity of the potential landslides and any resultant detached material, and the probability of their occurrence within a given period of time.

Elements at risk: The population, buildings and engineering works, economic activities, public services utilities, other infrastructures and environmental values in the area potentially affected by the landslide hazard.

Vulnerability: The degree of loss to a given element or set of elements within the area affected by the landslide. It is expressed on a scale of 0 (no loss) to 1 (total loss). For property, the loss will be the value of the damage relative to the value of the property; for persons, it will be the probability that a particular life (the element at risk) will be lost, given the person(s) is (are) affected by the landslide.

Risk: A measure of the probability and severity of an adverse effect to health, property or the environment. Risk is often estimated by the product of probability of a phenomenon of a given magnitude times the consequences. However, a more general interpretation of risk involves a comparison of the probability and consequences in a non-product form. For these guidelines risk is further defined as: (a) For life loss, the annual probability that the persons at risk will lose their life taking into account of the landslide hazard, and the temporal-spatial probability and vulnerability of the person (b) For property loss, the annual probability of a given level of loss or the annualised loss taking into account the elements at risk, their temporal-spatial probability and vulnerability.

Zoning: The division of land into homogeneous areas or domains and their ranking according to degrees of actual or potential landslide susceptibility, hazard or risk or applicability of certain hazard-related regulations.

The guidelines note that 'Qualitative methods are often used for susceptibility zoning, and sometimes for hazard zoning. When feasible it is better to use quantitative methods for both susceptibility and hazard zoning. Risk zoning should be quantified. More effort is required to quantify the hazard and risk but there is not necessarily a great increase in cost compared to qualitative zoning'.

Lee and Jones (2014) note that there are three broad types of risk estimation:

- Qualitative risk estimations are 'those where both likelihood and adverse consequences are expressed in qualitative terms. They are therefore highly subjective estimations';
- Semi-quantitative risk estimations which are 'combinations of qualitative and quantitative measurements of likelihood and consequence'; and
- Qualitative risk estimations (or quantitative risk assessments, QRA) which 'combine values of detriment with probabilities of occurrence. It must be noted that such an approach frequently does not produce a single answer'.

Whilst the AGS/JTC-1 guidelines were developed for hazard and risk zoning, i.e. assessing landslide hazard and risk for new developments, they are equally applicable for evaluating landslide hazard and risk to existing developments. Where appropriate, the AGS guidelines were used as the basis of this assessment.

5.3 Landslide Classification

Landslides are typically classified in terms of material type (rock, debris, earth) and movement type (fall, topple, slide, flow) following the definitions of Cruden & Varnes (1996). However, landslides can be complex processes. For example, a landslide may initiate as a slide, disaggregate and become a debris avalanche, enter a drainage line and become a debris flow, enter a flatter area, deposit the coarse material but continue downstream as a debris flood. Hungr et al., 2001 noted problems with the use of the flow terminology as proposed by Cruden & Varnes (1996) and proposed amended terminology (Table 22).

Table 22: Classification of Landslide Types (after Hungr, et al., 2001).

Movement Type	Rock	Debris	Earth
Fall	1. Rock fall	2. Debris fall	3. Earth fall
Topple	4. Rock topple	5. Debris topple	6. Earth topple
Rotational sliding	7. Rock slump	8. Debris slump	9. Earth slump
Translational sliding	10. Block slide	11. Debris slide	12. Earth slide
Lateral spreading	13. Rock spread	-	14. Earth Spread
Flow	15. Rock creep	16. Talus flow	21. Dry sand flow
	-	17. Debris flow	22. Wet sand flow
	-	18. Debris avalanche	23. Quick clay flow
	-	19. Solifluction	24. Earth flow
	-	20. Soil creep	25. Rapid earth flow
Complex	-	-	26. Loess flow
	27. Rock slide-debris avalanche	28. Cambering, valley bulging	29. Earth slump-earth flow

Consequently, where a landslide is interpreted as involving ‘a rapid to extremely rapid flow of saturated non-plastic debris in a steep channel’ (Hungr et al., 2001), it is classified as a debris flow, where it is interpreted as involving ‘very rapid to extremely rapid shallow flow of partially or fully saturated debris on a steep slope without confinement in a channel.’ (Hungr et al., 2001), it is classified as a debris avalanche.

As noted by Hungr et al., 2014 ‘the practical consequences of the distinction between debris flow and debris avalanches are obvious. A debris flow hazard study begins with the definition of the path and at least the lateral limits of the deposition area (fan). The path and the debris fan can be expected to contain evidence of past occurrences which can be used to derive information on magnitude and frequency. Debris avalanche studies, on the other hand, must examine tracts of steep slopes, many segments of which may not have experienced debris avalanches during the observable past’.

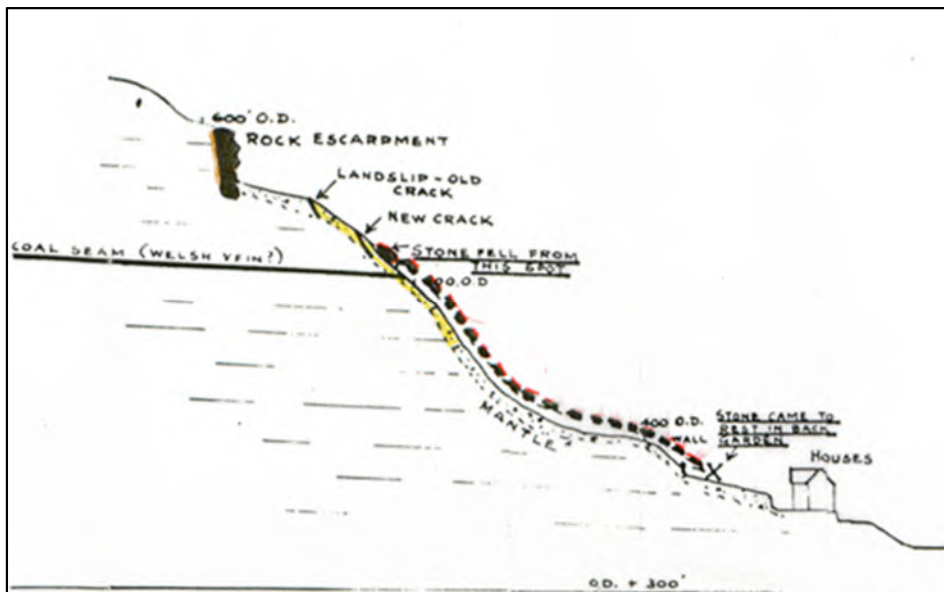
5.4 Review of Previous Landslide Assessments at Pantteg

Assessments of landslides at Pantteg have been undertaken on an ad-hoc basis since the late 1950s. The earliest known assessment was by Dillwyn and Jones (Glamorgan County Council) (1957/8), followed by the Institute of Geological Sciences (IGS, forerunner of the present day British Geological Survey) (1978), Halcrow (1987 & 1989), Neath and Port Talbot County Borough Council (1998) and Jacobs (2013). Some of these reports also evaluated the Godre'r Graig landslide to the south west of Pantteg. However, the geological setting of the Godre'r Graig landslide (a large deep seated landslide complex with rotational and translational components, refer to Section 6.5.1) is considered to be considerably different to the Pantteg landslide.

Further review of previous data is discussed in earlier sections of this report.

5.4.1 Dillwyn and Jones, Mining Engineers, November 1957

A rock fall occurred at the rear of No. 3 Graig y Merched Road in August 1957. The landowner subsequently commissioned a mining report from Dillwyn and Jones, Mining Engineers (Dillwyn & Jones, 1957). Dillwyn and Jones commissioned a geological report from a Brian Simpson of Swansea (Dillwyn and Jones, 1957). The mining report includes a location plan (Appendix D) and cross sections showing the locations of three areas of distress, one of which was related to the rock fall. The Mining report notes that the three areas of distress are located immediately above the outcrop of a coal vein (Welsh Vein?). The cross section from the area of rock fall is reproduced below. It is noted that the rock fall occurred from within a landslide rather than from the rock face.



Insert 26. Brian Simpson/Dillwyn and Jones/Glamorgan Council Cross Section

A meeting was held by Glamorgan County Council on 16 June 1958 to discuss the rock fall and above referenced reports. The meeting concluded that short term drainage improvement should be undertaken but that long term *'the dangers inherent in the slip proneness of the hillside were continuing and long term were incurable by any known and practicable means. All that could be recommended, therefore was that the situation should be kept under careful and continuous observation so that boulders could be dealt with and broken up as and when they appeared. Moreover, no further building development should take place in the affected areas and as and when opportunity offered, the existing buildings should be abandoned or cleared to ground level'*.

5.4.2 Institute of Geological Sciences, March and July 1978

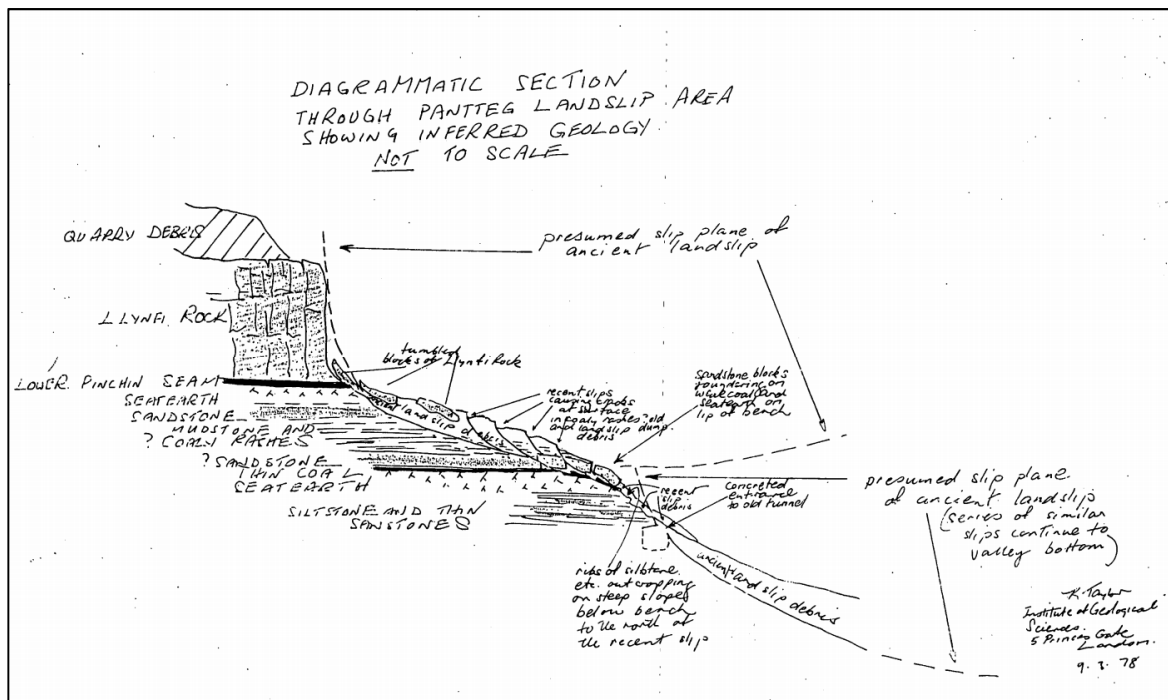
The Institute of Geological Sciences (now the British Geological Survey, BGS) produced two reports, the first the findings of a site inspection (IGS 1978a) and the second making recommendation for additional work (1978b). The additional work was apparently not undertaken. An extract of the IGS map is contained in Appendix D.

The IGS 1978b concluded that:

'The landslips above the village may be divided into an upper and lower area, separated by a considerable thickness of intact Llynfi sandstone. The upper landslips appear to be inactive, while the lower area is currently unstable' and 'the lower landslips have been reactivated, are essentially shallow and are shearing within either 'Head' (solifluction material) or weathered argillaceous Coal Measures. It is probable that water from the overlying Llynfi sandstone is maintaining a high-water table within the slips resulting in a seasonal movement'.

The '*upper landside*' referred to in the IGS Report is part of the Godre'r Graig landslide.

IGS 1978a contained a cross section through the upper part of the Pantteg landslide which is reproduced below (Insert 27). The geological setting is similar to that reported by Dillwyn & Jones (1957) except two coal seams are shown, the upper being referred to as the Lower Pinchin and the lower coal seam being unnamed.



Insert 27. IGS Conceptual Cross Section

The IGS (1978a) report and the above sketch interprets the Pantteg Landslide itself as comprising two components; an upper and a lower part, with recent movement occurring in the upper part controlled by a thin coal or seat earth as well as failure of the Llynfi Rock along the lower Pinchin Seam. The failure of the Llynfi rock is stated as being the reason for *'the fall of rocks onto the houses on the north side of the road'* (this contradicts the observations of Dillwyn & Jones, 1957). The *'remainder of the lower landslip area which includes most of south of the road and north of the church seems to be unaffected by these recent movements and is presently stable'*. The report notes that *'the dip of the strata is about 10° south with a component of 3.5° south east into the valley'*

The 1978a report also contains a map showing areas of 'recent cracks' one of which is located above Pantteg Chapel.

5.4.3 Hazard Mapping Report by Sir William Halcrow and Partners, July 1987

The Pantteg landslide (together with Godre'r Graig) was evaluated using relatively small-scale geomorphological mapping. The report states that classifications of '*hazard*' and '*risk*' were produced and these were combined with the geomorphological map to generate qualitative maps of '*hazard*' and '*risk*'.

However, there are a number of limitations with the approach adopted. These include:

- Definitions are not provided for many of terms the adopted, e.g. active processes, abnormally large rainfall, recent activity, low probability, etc. The lack of definitions makes any subsequent repetition of the assessment problematic;
- The report discusses different hazard types present at the site e.g. rotational slumps, boulder falls, debris flows. Each of these identified processes will have a different magnitude and frequency relationship. However, the individual hazard types are not considered separately for the purpose of the assessment;
- A landslide inventory is provided but there is limited information on landslide type, magnitude and run out. The report notes an apparent relationship between landslide frequency and anthropogenic influence i.e., the closure of a quarry in 1940. However, this has not been specifically taken into account in the assessment;
- Hazard is directly linked to landslide activity. Such an approach may be suitable where a pre-existing, large-scale landslide undergoes sporadic reactivation, but would not apply to first time, rapid failures which the inventory includes;
- The report states '*hazard*' is assessed but this is actually susceptibility using the definitions of AGS/JTC-1;
- The report attempts to include an evaluation of runout within risk estimation e.g. '*within likely trajectory of the landslide*'. This makes the application of hazard problematic. For example, properties within the landslide complex and properties outside the complex have been given the same risk category;
- Consequence is not separately defined, but is subsumed within risk;
- Different consequences are evaluated within the same methodology i.e. structural damage and risk to life.

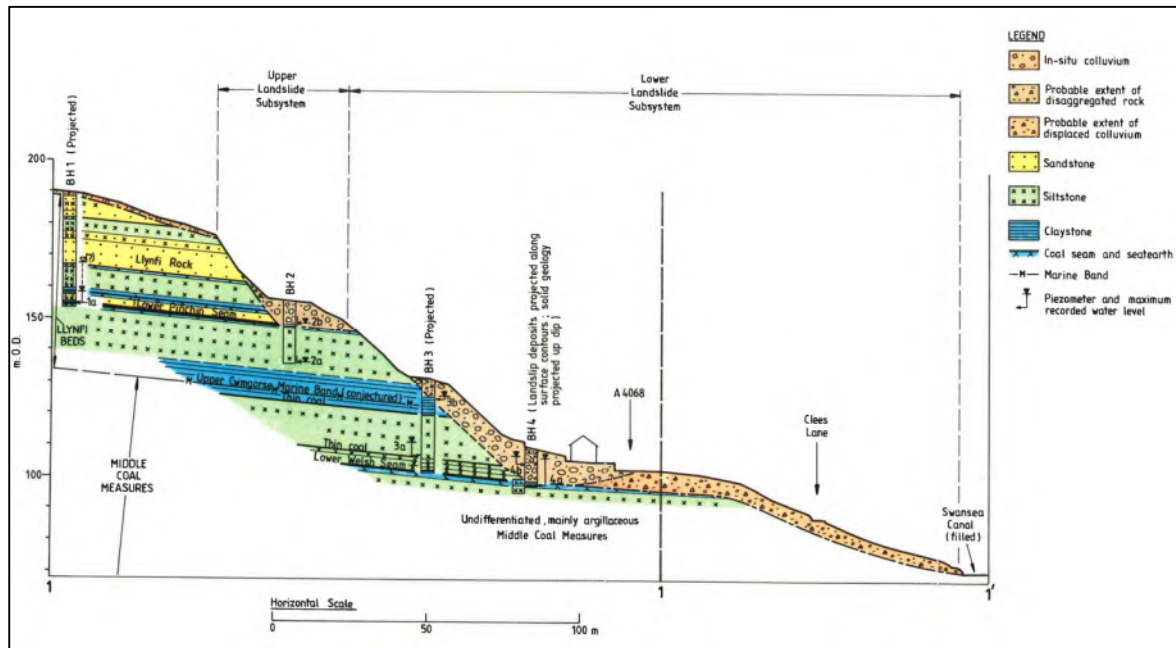
5.4.4 Halcrow Investigation, 1989

A morphological map was produced, albeit of limited extent. The copy of the report provided does not contain the morphological map, but a copy is included in the Jacobs (2013) report, a copy of which is available online. The map shows areas of '*fissured ground*' above Pantteg Chapel (their Figure 3) which broadly corresponds to the area of '*recent cracks*' delineated by the IGS (1978a).

A hazard map was not produced, instead '*risk categories*' are shown on the morphological map based on the approach contained in Halcrow's 1987 report.

The report appears to be the result of the landslide adjacent to No. 29 in 1987. This area was classified as '*Low Hazard*' in the 1987 report. A ground investigation was also undertaken.

A Ground Model was developed which considered the landslide to have two components; an upper and a lower sub-system. A cross section from the report is reproduced below:



Insert 28 - Halcrow Cross Section. 1989

The cross section varies from the IGS interpretation in that it is the Lower Pinchin and associated seat earth is considered to control the basal shear surface of the upper component of the landslide and the Lower Welsh seam possibly forming the basal shear surface of the 'lower sub-system'.

Based on the mapping and the ground investigation, a number of houses were recategorised with respect to risk.

5.4.4.1 Observations on the Halcrow 1989 Report:

The same approach to hazard and risk were adopted as in 1987, together with the same limitations. The adoption of activity to represent hazard is particularly problematic given the 1987 landslide apparently showing no activity prior to failure. No hazard map was provided.

Two boreholes were undertaken (BH1 and BH2) but they provide no vertical overlap so it is unclear if there is any deeper-seated movement. The Ground Model contains a number of anomalies:

- Section 1.03 states 'a rotational failure in the upper part of the slope has displaced rock down the slope where it has failed again'. However, Section 4.33 states the upper 'terrace' 'is interpreted as the surface of one or more blocks of rock which have been rotationally displaced from the rear scarp along a failure surface within or beneath the Lower Pinchin Seam' whilst 4.34 states the lower system is a 'second rotational slide' with a rear scarp in rock outcrop.

The boreholes had poor recovery in landslide debris and potential slip surface locations.

Section 4.38 discusses the 1986 landslide at Graig y Merched and refers to this as a first-time failure. However, the Halcrow 1987 Report notes that distress had been evident since 1972 and failure occurred due to colliery spoil being placed over a spring.

The morphological map shows the landslide as a continuum from the top to the base of the valley, whilst the cross section implies the lower lobate features, comprising colluvium, are older and have been overlain by the upper, more recent, landslides.

The cross section makes no reference to the working of the Red Vein but notes that these are (Section 4.53) '*considered unlikely to have a significant influence on the landslide.*'

The morphological mapping shows extensive fissured ground to the south west of the 1987 failure (upslope of the 2013 failure). However, this is not described in detail.

The 1986 and 1987 landslides scarps are both above the mapped outcrop of the Cwmgorse Marine Band which is not discussed in the report. The re-categorisation of Dan yr graig and 1-11 Twyneglur to only a '*Category 3 risk*' conflicts with the locations of the 1986 and 1987 landslides.

5.4.5 Neath Port Talbot County Borough Council – Landslide Hazard February 1998

The review resulted in revision of the risk categories of several properties. However, the report has a number of limitations, namely:

- Hazard and risk maps are not provided and no critical review of previous data or Ground Model was undertaken.
- The boundary of the landslide was modified but this does not correspond to Halcrow's original geomorphological mapping and the reasons for this are not provided.
- The same approach to 'hazard' and 'risk' as used by Halcrow were adopted resulting in the same limitations.

5.4.6 Slope Stability Review – Jacobs Engineering UK Limited, December 2013

This review was undertaken following a landslide in December 2012. The report notes that there was evidence of movement two years prior to 2012 failure, but no details are provided.

The report notes the apparent correlation with 1986, 1987 and 2013 landslides with Cwmgorse Marine Band. An area of '*extensional cracking*' was recorded, broadly corresponding to that observed by IGS (1978a) and Halcrow (1989).

The report has a number of limitations, namely:

- The same approach to 'hazard' and 'risk' as used by Halcrow were adopted resulting in the same limitations;
- No critical review of previous data or Ground Model was undertaken;
- The Neath and Port Talbot modified boundary of Godre'r Graig Landslide was adopted which does not correspond to Halcrow's original geomorphological mapping; and
- No geomorphological map was produced.

5.5 ESP Ground Investigation, 2018

Based on the desk study and initial landslide hazard mapping, a supplementary ground investigation strategy was developed, primarily focused on evaluating the geological controls on the debris slides. This comprised two boreholes (one with an inclinometer), three trial pits and a series of vegetation clearances to enable access and visual assessment.

This was subsequently modified to include geophysics, additional trial pits and boreholes. In addition, piezometers and inclinometers have been installed in selected locations. The key observations from the ground investigation, with respect to the landslides are:

- The trial pits indicate that the Made Ground, likely to comprise colliery water from working the Lower Pinchin via adits as well as quarry waste from the working the Llynfi Sandstone, is commonly in excess of 4m;
- Within the Made Ground large blocks of sandstone are present which have been rotated, suggesting they may have been associated with landslide processes;
- In TP604, the downslope side of a possible rotated sandstone block is infilled with soft grey, with orange surface oxidation, gravelly slightly sandy silty CLAY (Insert 29) with high organic content and partially decomposed roots, possibly a sag pond deposit;
- BH601 and BH602 recovered disturbed material to depths of 8.7m and 6.4m respectively. It seems likely that the lower portion of this material is landslide debris;
- In BH601 a sheared mudstone was recovered from 8.43m to 8.45m (Insert 30);
- In BH602 an 18mm thick layer of clayey silt with no apparent structure was recovered above a thin coal seam (Insert 31). This was overlain by soft orange brown silty clay. The clayey silt has been interpreted as being a shear surface; and
- The inclinometer installed in BH601 shows movement commencing at between 8.5m and 9.0m in BH601.



Insert 29 - Possible sag pond deposits



Insert 30 - Sheared mudstone in BH601.



Insert 31 - Silty clay infill in BH602. Interpreted as a shear surface.

5.6 Landslide Hazard and Risk Assessment Methodology

JTC-1/AGS (2007) suggest the following stages for a landslide hazard and risk assessment:

- Hazard identification which comprises classification of landslides, extent of landslides (area and volume), travel distance of landslides and rates of movement;
- Frequency analysis comprising estimation of frequency, historic performance, relate to initiating events;
- Consequence analysis comprising elements at risk, temporal probability and vulnerability, and;
- Risk calculation.

Once these steps have been undertaken an evaluation of risk can be undertaken and risk mitigation options assessed.

5.7 Hazard Identification

5.7.1 Landslide Inventory

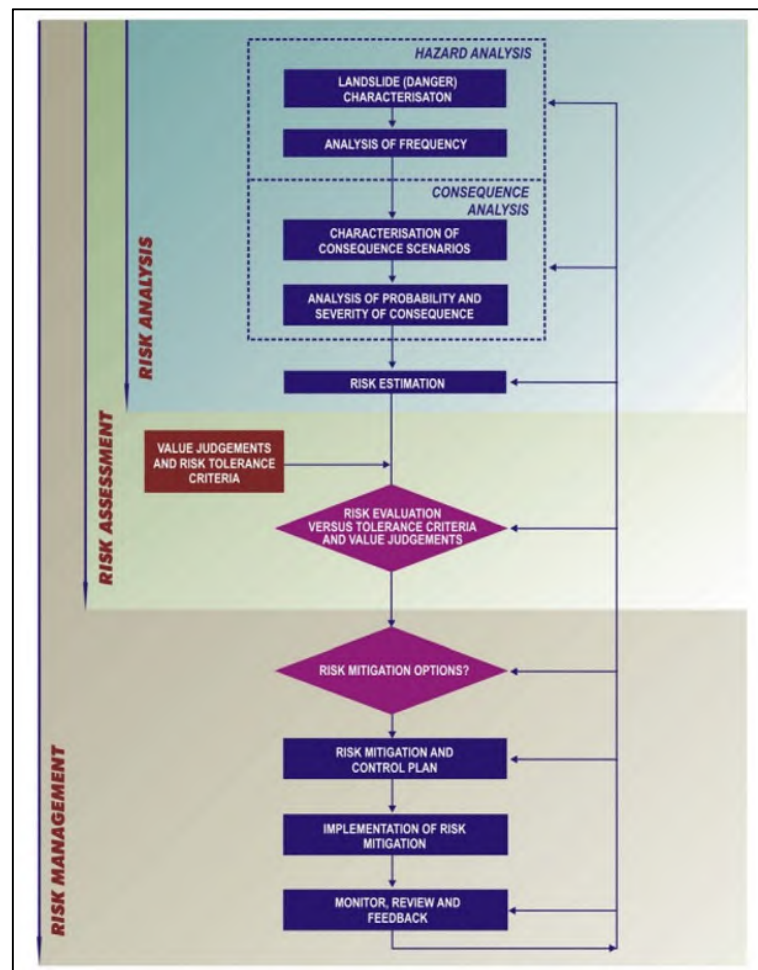
A landslide inventory has been generated using the previous reports and aerial photograph interpretation (API). With respect to the existing data, the majority is from the Halcrow 1989 report. Additional data was provided by ESP, extracted from the mining report by Dillwyn and Jones (1957) and IGS (1972) (Appendix D).

Of the 15 landslides within the Halcrow 1987 inventory, eight are related to the Godre'r Graig landslide (Halcrow landslides D, F, G, J, M, N, O and P) and therefore have been excluded from the Pantteg assessment. A

further incident (A) is considered to be related flooding and has not been considered further. With respect to the remaining landslides in the Halcrow inventory, limited information is provided for each event (probably because limited information was available). Consequently, the landslide type, areal extent, volume and run out is not known for this data. The Halcrow 1989 report shows the mapped extent of two landslides occurring in 1986 and 1987, with the 1986 landslide comprising two events a debris slide and a debris flow.

In addition to the published data, an Aerial Photograph Interpretation (API) has been undertaken and the photographs evaluated are documented in Appendix E. Some photographs are single images, whilst others are stereo pairs. The most useful photographs are those stereo pairs taken at a relatively low level (<8000'). These provide a relatively complete inventory from 1969 to 1993. The interpreted landslides relate to the 1969, 1982 and 1993 images (Appendix E).

The API was carried out using a Sokkisha stereoscope with x3 binocular attachments. The API was made on a basis of shape, pattern, size, tone/colour and texture together with morphographical position.



Insert 32 - Framework for landslide risk management
(Fell et al, 2008)

The interpretation has two key aims:

- to generate engineering geological and engineering geomorphological maps of the study area, and
- to enable a site-specific landslide inventory to be developed.

The engineering geological and engineering geomorphological mapping was undertaken predominantly using the 1969 aerial photographs given their high quality. However, all the aerial photographs were reviewed to develop a landslide inventory.

The aerial photographs were imported into a Geographical Information System (GIS) using the software ArcGIS and the images orthorectified to assist with the locations of features observed in the API.

Three further landslides have occurred in 2012, 2017 and 2018 as reported by the Neath and Port Talbot Council (ESP, pers com). However, these were not mapped and, with the exception of the 2012 landslide, their precise location is unknown.

The Landslide Inventory is contained in Appendix F. The updated inventory contains 40 incidents which have been classified as landslide related. Of these, 25 landslides have data on length and width and a depth of failure has been estimated. Based on this an estimate of the landslide volume has been made using the equation:

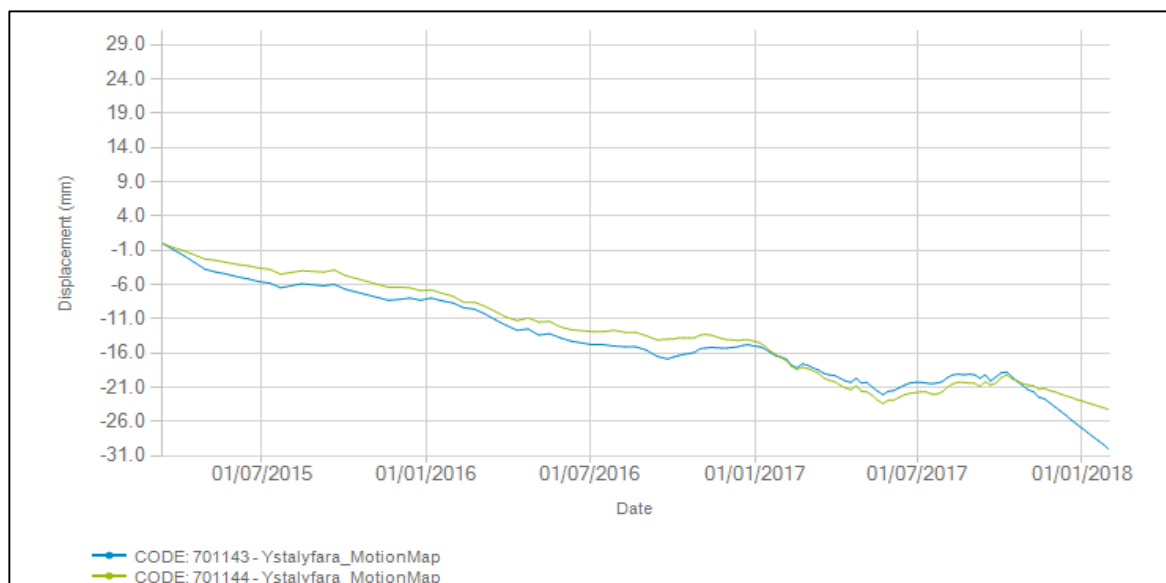
- $Vol = 1/6\pi \times Dr \times Lr \times Wr$ (IAEG, 1990)

Where Dr maximum depth, Wr maximum width and Lr maximum length, assuming the landslide is ellipsoid in shape. The landslide inventory is shown in Figure 8.

In addition to the above, an evaluation of available InSAR data has been undertaken.

Interferometric synthetic aperture radar (InSAR) is a radar technique used in remote sensing. It uses two or more synthetic aperture radar (SAR) images to generate data on surface deformation, using differences in the phase of the waves returning to the satellite.

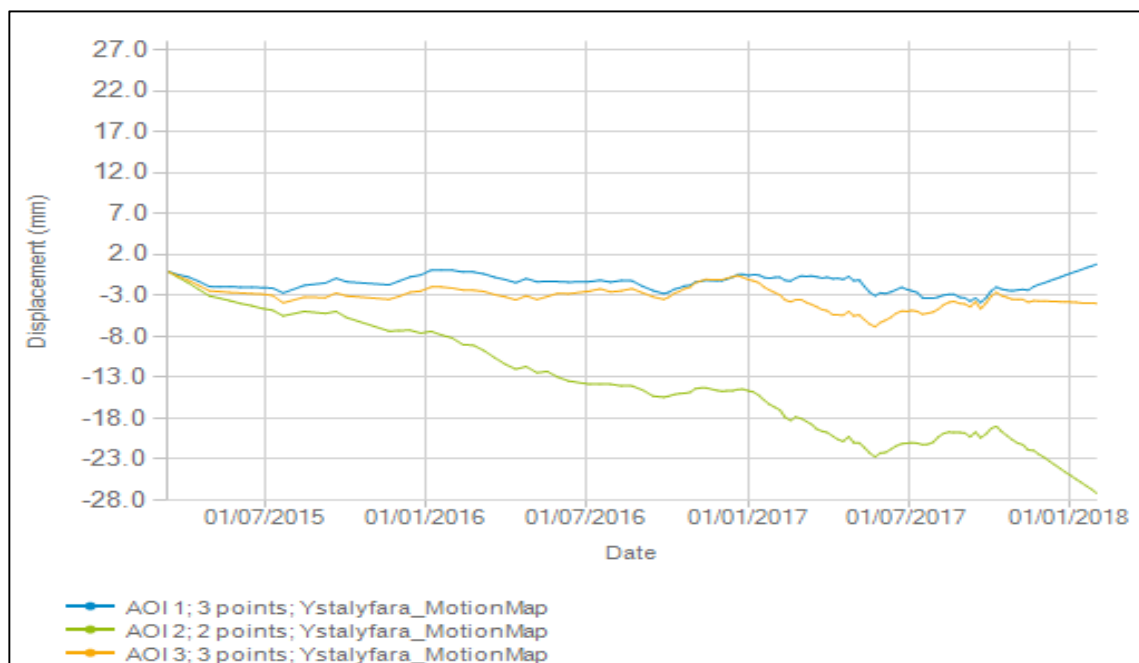
Appendix G contains a plot of the InSAR data for Pantteg and the surrounding area. Within this, several higher velocity points are evident within the Pantteg Landslide. The second image in Appendix G is a close up within the Pantteg landslide and there are two locations, close to a marked break in slope that appear to be showing 'real' deformations (marked as area A0I2). Plotting the data from these locations against time shows a consistent downward movement of >20mm over 3 years.



Insert 33 - InSar data against time

Given the consistent movement with time it seems likely this is the result of on-going, localised, erosion.

A comparison between an average of the movements in AOI2 compared with the average movements in the two areas upslope (AOI1 and AOI3) shows that the fluctuations upslope are in the order of 4-5mm which is about the precision of the time-series measurements so they are probably related to 'noise' within the data set itself.



Insert 34 - InSar data comparison.

Below Cyfyng Road there is no data suggesting consistent movement. This suggests there is no evidence of ongoing deep-seated movement of the Pantteg Landslide within the time frame of the data set i.e. March 2015 to January 2018 but that localised surface erosion is occurring.

5.7.2 Site Inspections

In addition to the API a number of site visits were undertaken. The key purpose of which was to undertake engineering geomorphological mapping and, in particular, evaluate features interpreted from API to be landslides.

A site visit was undertaken on 15 August 2017. However due to the density of the vegetation, access was largely restricted to roads and footpaths. A further site visit was undertaken on 19 December 2017 following vegetation clearance. This allowed access from Pen-y-Graig farm, to the north of the site, into the 'upper landslide'. However, the full vegetation clearance had not been undertaken and consequently only a partial inspection could be undertaken. The inspection confirmed the area of distress noted in the IGS (1978a) Halcrow (1989) and Jacobs report (2013) and allowed the current extent of this to be broadly delineated. In addition, what appear to be the rear scarp of a debris slide possibly associated with regression of the 2015 landslide. This had a depth of 1m.

A further site visit was made on 9 May 2018 during the excavation of trial pits.

5.7.3 Conceptual Ground Model Summary

The conceptual model of the site is a landslide complex comprising a number of interrelated landslides. The initial movement probably occurred associated with the end of the last glaciation, 12,000BP and was probably a relatively deep-seated failure located below the present day Cyfyng Road. The back scarp of this landslide was probably located near the current location of Cyfyng Road and this unloading appears to have resulted in regression movement upslope of the backscarp in the form of translational landslides associated with basal shear surfaces developing along two, relatively weak, geological horizons namely the Lower Pinchin and either the Upper Cwmgorse Marine Band or an unnamed mudstone band above it.

The lower part of the complex below Cyfyng Road appears to be Inactive (*'a landslide or site of instability that is stable under prevailing conditions'*) and Ancient (*'an inactive landslide developed under climatic, environmental or geomorphological conditions different from those prevailing at present'*) (Jones and Lee, 1994). Above Cyfyng Road a discrete area is Active (*'currently moving or currently unstable site such as an eroding sea cliff or a site that displays a cyclical pattern of movement with a periodicity of up to 5 years'*) (Jones and Lee, 1994). The movement comprises a series of debris slides which comprise the main hazard at the site.

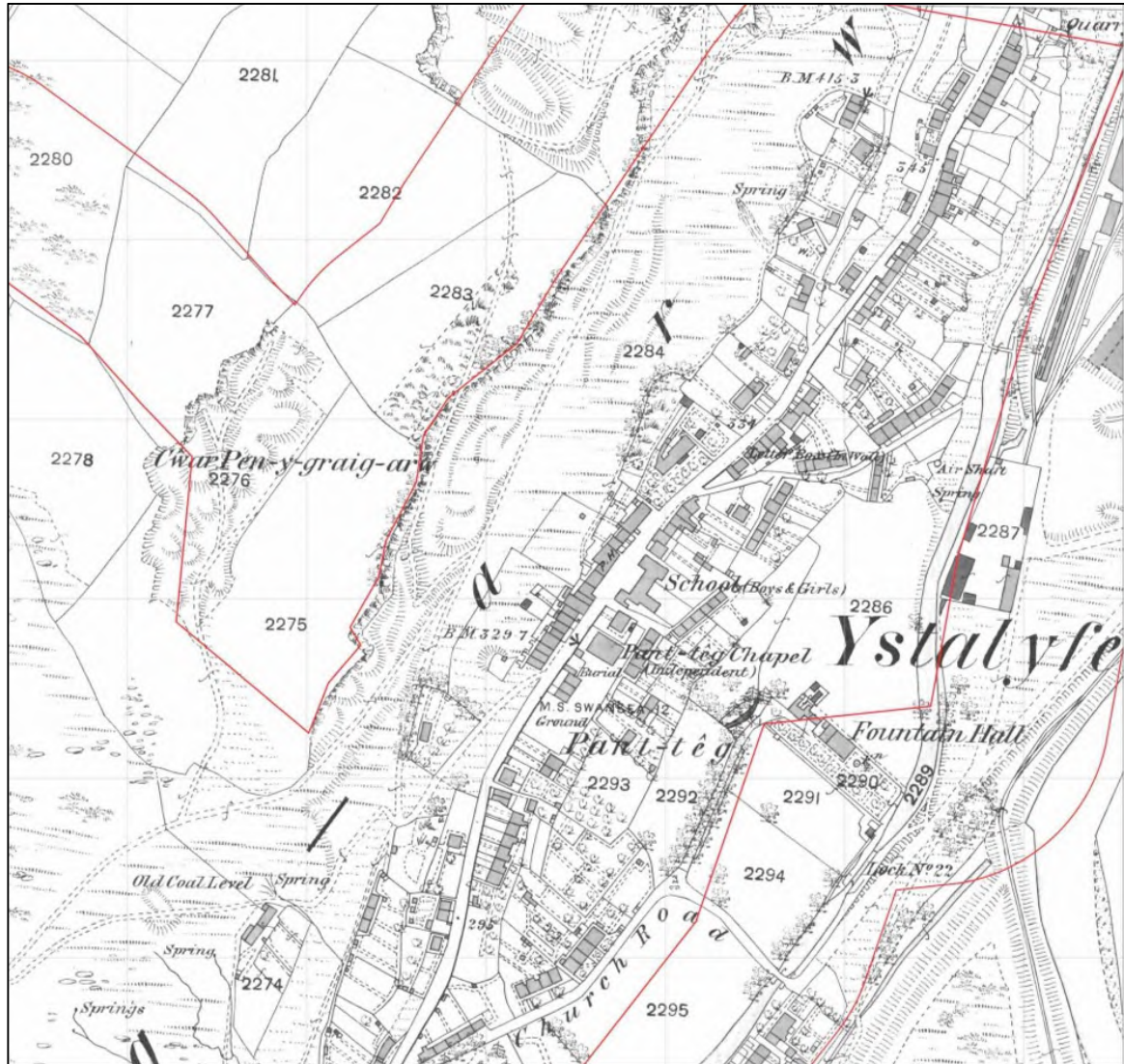
Based on the landslide inventory and the ground investigation data, the majority of the recent landslides are associated either the Upper Cwmgorse Marine Band or an unnamed mudstone band which outcrop at approximately 120-130mOD.

It is considered likely that these failures unload the toe of the translational landslide associated with the Lower Pinchin and trigger movement upslope and the development of the tension cracks observed in this area.

The upper boundary of Pantteg Landslide complex is interpreted as being the base of the rock cliff, formed by the outcrop of the Lynfi Rock, approximately 115m to the north west and upslope of Cyfyng Road.

The presence of a bench below the cliff, suggests that the rock cliff may represent the working of the Lynfi Rock as building stone, together with the extraction of any underlying coal. The cliff and apparent mine/quarry waste is evident on the earliest located map dated 1877.

It is likely that the workings exploited a pre-existing topographical feature (probably a landslide back scarp).



Insert 35 - 1877 Map showing the rock cliff and irregular topography commonly associated with quarry/mine waste.

5.7.4 Hazard Types

Based on the landslide inventory the following hazard types are present:

Hazard Type 1: Slow ground displacement leading to vertical or lateral displacement or undermining of structures and infrastructure related to large-scale complex landslide.

Hazard Type 2: Debris impacts from shallow translational landslides – impact loading on structures, impact/burial of people, impact on vehicles, burial of people inside buildings (ground floor) if of sufficient volume.

Hazard Type 3: Regressing shallow translational landslides in Made Ground resulting in structural damage and potentially building collapse.

Hazard Type 4: More mobile debris avalanches impact loading on structures, impact/burial of people, impact on vehicles, burial of people inside buildings (ground floor) if of sufficient volume.

Hazard Type 5: Boulder Fall , possible structural damage, impact on people/vehicles.

Hazard Type 6: Rock Fall, possible structural damage, impact on people/vehicles.

5.7.4.1 Hazard Type 1. Large-scale complex landslides

Two separate landslide complexes are present, the Godre'r Graig Landslide and the Pantteg Landslide.

Godre'r Graig Landslide

The Godre'r Graig Landslide is a large-scale landslide, involving both rotational and translational movement. Based on the API and site inspection, the right flank of this landslide is located close to the junction of Church Road and Graig Road, i.e. at the location mapped by Halcrow. The distress evident in the road at this location corresponds with the termination of a NE-SW trending convex break in slope which corresponds to the backscarp of the 'lower-subsystem' identified in Halcrow's 1989 report. There is considerable distress evident in the road to the south west of this point (Inserts 36 and 37) which is interpreted as being the result of intermittent ongoing movement of the Godre'r Graig Landslide.

Pantteg Landslide

The upper boundary of the Pantteg Landslide is associated with the base of the rock cliff where rotated rock blocks were encountered in the trial pits (Section 5.5). This break in slope diminishes to the north



Insert 36 - 20mm tensional opening in retaining wall with distress continuing across Graig Road (15/8/17)



Insert 37 - Left stepping en-echelon distress in Graig Road crossing recent repairs (15/8/17)

east beyond the rock cliff and the left flank of the Pantteg Landslide Complex has been interpreted as the boundary of a large arcuate depression.

The lower boundary of the Pantteg Landslide has been interpreted as a concave break in slope on the valley floor. This interpretation is broadly in line with the interpretation of Halcrow (1987).

Both these large-scale landslide complexes are likely to have been triggered at the end of the last glaciation, associated with glacial unloading of the valley sides and periglacial activities, i.e. approximant 12,000BP.

These types of landslides are typically marginally stable, with relatively small slow displacements occurring associated with significant rainstorm events. Associated movement velocities are likely to be very slow (5×10^{-5} mm/s to 5×10^{-7} mm/s, i.e. 1.6m/yr to 13m/month)). These movement rates are considered to pose a low risk to life due to their slow rate but could result in significant structural damage over time to properties within the landslide.

The Godre'r Graig landslide has a history of on-going movement resulting in the abandonment of Godre'r Graig village and the realignment of the road in the 1970s and there is clear evidence of recent movement of the Godre'r Graig Landslide to the south west of junction of Church Road and Graig Road.

However, within the interpreted Pantteg Landslide, whilst many properties have been demolished, there is no definitive evidence to suggest this was related to landslide damage from deeper seated movement and there is no conclusive evidence of any large scale, recent movement.

An evaluation of InSAR satellite data (Section 5.7.1) has been undertaken which suggests no recent movement below Cyfyng Road.

5.7.4.2 Hazard Type 2. Shallow, translational landslides



Insert 38 - 2012 Landslide (<http://www.bbc.co.uk/news/uk-wales-south-west-wales-21409439>)

These form the majority of the landslides within the inventory and are associated with the break in slope which corresponds to the outcrop of the Upper Cwmgorse Marine Band or an unnamed mudstone band above it. The largest recent event is that in 2012 (Insert 38). These landslides are relatively rapid and can comprise relatively large volumes (up to 1700m³) with the debris run out potentially impacting on buildings and infrastructure. Associated movement velocities are likely to be rapid (5×10^1 mm/s to 5×10^{-1} mm/s i.e., 1.8m/hr to 3m/min). As such they pose a relatively high risk to life and risk of significant structural damage. The failure of this material is postulated as resulting in small scale translational sliding up slope associated with the Lower Pinchin. This is evident in the formation of tension cracks rather than the large-scale detachment of material.

5.7.4.3 Hazard Type 3: Shallow translational landslides in Made Ground.

These are located in the terrain below Cyfyng Road and are associated with Made Ground placed above the crest of oversteep, former river slopes. This hazard type is represented in the landslide inventory by the 2017 landslide (Insert 39) with headward progression potentially undermining buildings and infrastructure. There is limited information with respect to the type and depth of foundations for the houses, the thickness and extent of the Made Ground, the subsurface geology and the hydrogeological conditions in this area. The largest extent upslope, from the over steep terrain that bounds the lower part of this Made Ground, that a landslide has extended is approximately 40m. A 40m buffer has therefore been tentatively adopted upslope of the break in slope forming the over steep terrain to indicate the possible extent of this hazard. Associated movement velocities are likely to be rapid (5×10^1 mm/s to 5×10^{-1} mm/s i.e., 1.8m/hr to 3m/min). However, given their location, these are likely to have a relatively moderate risk to life but could result in structural damage if they regress upslope and undermine building foundations.



Insert 39 - 2017 landslide at rear of No. 86 Cyfyng Road
<http://www.walesonline.co.uk/news/wales-news/homes-evacuated-after-swanssea-valley-12680597>

5.7.4.4 Hazard type 4. Debris avalanches.

The 1986 landslide was associated with a debris avalanche. Based on an evaluation of the historical maps it appears that colliery spoil was placed over a pre-existing spring. However, the landslide scar is considerably larger than the area of spoil recorded on the historical map,

suggesting that the landslide may have been due to the failure of the in-situ ground rather than the spoil alone. This location is also associated with the outcrop of Upper Cwmgorse Marine Band or an unnamed mudstone band above it. However, the spring probably added additional water to the landslide debris, resulting in part of the failure comprising a debris avalanche. Debris landslides are relatively rapid and could result in a risk to life where individuals are outside. Where individuals are within buildings, and based on the relatively low volume associated with the 1986 landslide, it is considered this hazard presents a relatively low risk to life and limited structural damage.

Associated movement velocities are likely to be rapid to very rapid (5×10^1 mm/s to 5×10^3 mm/s i.e., 3m/min to 5m/sec). The boundary between rapid and very rapid is approximately the average human running speed.

Based on the review of the historical maps there are only two springs with associated drainage lines within the study area. One is that associated with the 1986 landslide and the second occurs outside the boundary of the Pantteg Landslide but flows through its south west corner. As such it is considered that the hazard from debris avalanches is restricted to the location of the 1986 landslide.

5.7.4.5 Hazard Type 5 Boulder Fall

Boulder falls are present in the landslide inventory. Possible origins of these blocks are:

1. Small unrecorded landslides resulting in boulders being ejected from landslide debris and traveling further down slope;
2. Rock blocks being eroded by surface water, particularly in the areas of distress (Insert 40) or
3. Associated with quarry spoil. The quarry spoil appears to be predominantly angular rock blocks (Insert 41) and as such the spoil heaps are likely to be relatively free draining and have a high angle of friction. In addition, the quarry spoil is located a significant distance from the elements at risk and are separated a relatively flat bench at the base of the Llyfin Beds.



Insert 40 - Tension crack behind block exposed block of sandstone in are modified following the 2012 landslide (15/8/17)



Insert 41 - Spoil heaps associated with quarrying (19/2/17)

Boulder falls could be relatively rapid (5×10^1 mm/s to 5×10^{-1} mm/s i.e., 1.8m/hr to 3m/min).

Boulder falls could result in a risk to life where individuals are outside. Buildings will offer significant protection and any structural damage is likely to be limited. Excluding the quarry spoil it has been assumed that this hazard is limited to the same area as the Type 2 Hazard i.e. shallow, but relatively large areal extent, translational landslides.

5.7.4.6 Hazard Type 6. Rock fall

This is associated with outcrop of the Llynfi Beds (Insert 42) and could result in a risk to life where individuals are outside, although buildings will offer significant protection and any structural damage is likely to be limited. Movement velocities are likely to be rapid (5×10^1 mm/s to 5×10^{-1} mm/s i.e., 1.8m/hr to 3m/min).

However, to impact on elements at risk a significant run out is required, and a large number of blocks have previously come to rest on the bench below the Llynfi Beds (Insert 43).



Insert 42 - Dilated rock blocks within the Llynfi Beds (19/2/17)



Insert 43 - Rock fall from the former quarry face/back scar

The locations of the source of each hazard type are shown on Figure 5.

5.8 Frequency Analysis

5.8.1 Landslide Frequency

The area in which the majority of the landslides (Hazard type 2) occur is bound by distinctive breaks in slope (Section 5.7) associated with Upper Cwmgorse Marine Band or an unnamed mudstone band above it. and comprises approximately 37,000m².

Based on the available landslide inventory an evaluation of magnitude, frequency and run out has been undertaken. An estimate of landslide source volumes was made assuming a 'bowl' shaped failure ($1/6\pi D \times L \times W$, IAEG, 1990). The width and length were estimated from API and are considered reasonably accurate within the limitations of orthorectifying the aerial photographs. Depth has a higher degree of uncertainty as it is based on an estimated depth based on expert judgement.

Evaluating the landslide frequency for the complete inventory gives 40 landslides between 1951 and 2018 or approximately one landslide every two years (0.59 LS/yr). Based on an area of 37,000m² this indicates a landslide frequency of approximately 16 LS/km²/yr which, based on small landslide on a natural slope, classifies as a very high hazard (AGS, 2007).

Evaluating the landslide frequency based only on landslides occurring within the timescale of the aerial photograph images suggests 21 landslides occurred between 1969 and 1993, i.e. almost one landslide per year (0.95 LS/yr). Based on an area of 37,000m² this indicates a landslide frequency of approximately 27 LS/km²/yr which, based on small landslide on a natural slope, classifies as a very high hazard (AGS, 2007).

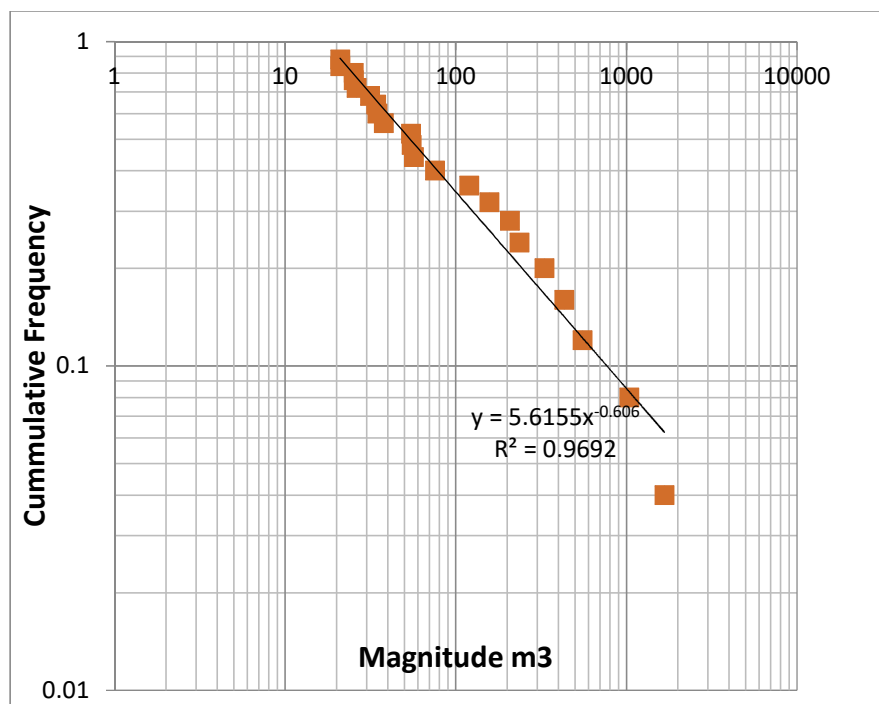
The lower frequency for the entire inventory is likely to be due to the fact that only landslides which impacted on properties are likely to be reported.

To place this into context, Gibson et al., (2013), note that between 2006-2010 the maximum number of landslides reported by the media for the entire of the UK was 38 per year.

The above only considers the probability of a landslide of any volume size occurring. It has been widely reported that landslide magnitude-frequency distributions can be described by an inverse power-law equation (Guthrie and Evans, 2004). As the event magnitude increases, so the frequency of occurrence decreases i.e. there should be far fewer of the largest events than the smaller ones. Taking the API derived landslide dataset and assuming these records cover a 24-year period the cumulative annual probability of an event of a particular magnitude (M) being equalled or exceeded is calculated as: $P(\geq M) = m/(n+1)$, where n is the number of years in the time series (assumed to be 24 years) and m is the rank order of the event magnitude.

There is a clear power law relationship between cumulative frequency and magnitude (the R² value is 0.9692). This can be interpreted to indicate that there are not many 'missing' events within the data set.

Based on the magnitude-frequency plot, the 1987 landslide (source volume 1000m³) has an indicated return period of 1:24-years (i.e. there is a 4% probability of a landslide of that volume occurring in one year). In comparison, the 1986 landslide (source volume 550m³) has an indicated return period of 1:8-years or a 12% probability of occurring in one year.



Insert 44 – Cumulative Frequency against Magnitude

Based on the above relationship, the annual probability of three ranges of landslide magnitudes have been estimated.

Table 23: Annual Probability

Landslide Volume Range	Adopted Volume	Annual Probability
0-100m ³	50m ³	0.524
100-500m ³	300m ³	0.177
>500m ³	750m ³	0.102

Based on an interrogation of the landslide inventory each landslide volume range has been assigned an assumed landslide width.

Table 24: Assumed Width

Landslide Volume Range	Assumed Width (m)
0-100m ³	10m
100-500m ³	25m
>500m ³	100m

5.8.2 Runout Evaluation

Landslide runouts are typically evaluated in terms of the landslide debris travel angle i.e. the slope of a line joining the furthest extent of the landslide debris to the crest of the main scarp. Travel angles of landslides at the site were evaluated primarily from the aerial photographs and are likely to be minimum values, as the landslide debris appears to rapidly revegetate, whereas the source areas remain evident in the aerial photographs for a number of years.

In addition to the API, an estimation of runout is available for the 1986 and 1987 landslides which were mapped by Halcrow (1987).

The 1986 landslide has an estimated volume of 550m³, a horizontal run out of 37m and a travel angle of 33°. The 1987 landslide had two components; a translational landslide with an estimated volume of 1000m³, a horizontal run out of 60m and travel angle of 30° and; a debris avalanche with an estimated volume of 300m³, a horizontal run out of 100m and a travel angle of 26°.

Given the limited site-specific data, as well as limited data on the runout of similar landslides in the UK, the travel angles for the landslides have been included in a published dataset in Hong Kong (Parry, 2015). The Hong Kong data is for open hillslope landslides, i.e. landslides that do not involve additional surface water. The Hong Kong data together with the site-specific data is shown on Figure 6 with the site-specific data typically sitting in the mid-range of the Hong Kong data, with the exception of the 1987 debris avalanche, i.e. the only landslide involving surface water mixing with the landslide debris. The maximum travel angle recorded is 20°.

As shown in Figure 12, the larger the landslides the lower the travel angle i.e. the further debris travels.

Table 25: Landslide Volume and Maximum Travel Angle

Landslide Volume (m ³)
<100m ³ Max travel angle 25°
100m ³ -500m ³ Max travel angle 22°
>500m ³ Max travel angle 20°

Of the thirty-eight landslides within the landslide inventory 21 were identified by API and 17 from historical records.

None of the 21 API landslides (with a maximum estimated vol <300m³) reach the houses on the north side of Cyfyng Road (the nearest elements at risk).

Of the 17 recorded landslides, eight impacted on the nearest elements at risk (i.e. those North of Cyfyng Road). Unfortunately, it is only possible to estimate the volume of four of these landslides. One is in the range 100-500m³ and three are >500m³.

This indicates a probability of impact of 0.2 (8 in 38) for the total dataset increasing to 1.0 (3 in 3) for landslides >500m³.

It has been assumed for the north side of Cyfyng Road that landslides <500m³ have a 0.2 probability of impacting the elements at risk and landslides >500m³ have a 1.0 probability of impacting the elements at risk.

Only a single landslide (>500m³) is recoded as reaching the south side of Cyfyng Road (1 in 38) (but not impacting on buildings), suggesting a probability of impact of <0.02 for the entire dataset and <0.3 (1 in 3) for landslides >500m³.

It has been assumed for the south side of Cyfyng Road that landslides <100m³ have a 0.002 probability of impacting the elements at risk, 100-500m³ a 0.02 probability and >500m³ a 0.1 probability of impacting the elements at risk.

5.9 Hazard Map

The length of the lower scarp (the hazard zone) associated with land sliding is 630m.

Data on magnitude frequency and runout is only available for Hazard Type 2 (shallow, translational landslides). Consequently, a quantitative hazard and risk assessment has only been undertaken for this hazard type

For each landslide of a specified magnitude (L), the probability of that event occurring is estimated for a specified time frame [P(L)]. However, the landslide must impact of the elements at risk i.e. the probability the landslide will impact on elements at risk [P(T)]. Hence the probability of the hazard [P(H)] from a landslide of a specific magnitude within a specific time frame impacting on elements at risk is [P(L)] x [P(T)]. The adopted values are shown below.

Table 26: Probability of Hazard

Landslide volume (m ³)	North of Cyfyng Road		South of Cyfyng Road	
	P(L)	P(T)	P(L)	P(T)
<100	0.524	0.2	0.524	0.002
100-500	0.172	0.2	0.172	0.02
>500	0.102	1.0	0.102	0.1

The maximum runout has been assumed to be represented by the 20° travel angle.

The resulting hazard maps for each landslide volume range are shown in Figure 13 to Figure 15.

5.10 Risk Estimations

The specific risk from a hazard (R_s) varies depending on what is exposed to the hazard i.e. the elements at risk (E), how vulnerable the elements at risk are to that specified hazard (V) and how much time the element at risk spends within the zone of hazard (exposure time Ex).

Elements at risk (E) have been assumed to be people within buildings, people within vehicles and pedestrians.

Vulnerability (V) of elements at risk to the hazard also varies, for example people within a building will be offered some protection which will vary depending on the landslide magnitude and type. Vulnerability varies from 0 (no protection) to 1 (full protection). There is presently no single methodology for defining the vulnerability of elements at risk to different types or intensities of landslides and as a result the vulnerability values adopted in virtually all consequence assessments are generally subjective being based on expert judgment (Lee and Jones, 2014).

Exposure time (Ex) will vary depending on whether the elements are mobile or not. For fixed elements, e.g. buildings with a person permanently present, the exposure time will be 1, For mobile elements, e.g. pedestrians, the time they are in the hazard zone needs to be assessed.

The specific risk (R_s) for a hazard of a specified magnitude is defined by:

- $R_s = P(H) \times \Sigma(E \times V \times Ex)$ (Lee and Jones, 2014)

Total Risk (R) is the sum of specific risks for the full range of potential magnitudes of landslides

Lee and Jones (2014) note that risk assessments are estimates and increased precision should be tempered by pragmatism. Furthermore, they consider that the quality of a landslide QRA is related to the extent to which hazards are recognised, understood and explained, not necessarily related to the extent that they are quantified.

5.10.1 People within Buildings

Vulnerability of People within Buildings

There are two different types of scenario for people:

- people caught up in the debris that enters the building (direct impact); and
- people in buildings that are hit by debris and then suffer some form of structural failure, leading to impact of the collapsing structure on people (indirect impact).

For $<100\text{m}^3$ landslide volume it has been assumed that only superficial structural damage only occurs at the rear of the building. The relatively slow-moving debris will be $< 1\text{m}$ thick and unlikely to come in through the windows.

A vulnerability of 0.001 for persons within the property for direct impact has been assumed and a vulnerability of zero for indirect impact.

For a $100\text{--}500\text{m}^3$ landslide volume impacting the rear of a building, the relatively slow-moving debris will be around 1-2m thick and some might enter through the windows. It is unlikely that a sound building would collapse, although some structural damage would probably occur but limited to the rear of the property.

A vulnerability of 0.01 for persons within the property for direct has been assumed and a vulnerability of 0.001 for indirect impact.

For a $>500\text{m}^3$ landslide volume impacting the rear of a building, the relatively slow-moving debris will be $>2\text{m}$ thick and debris enter through the windows. People will have some forewarning about the debris coming in through the windows from the noise and should be able to get out of that room. The impact will cause structural damage structural damage which may over a few hours lead to partial collapse of the rear of the building.

A vulnerability of 0.1 for persons within the property for direct has been assumed, and a vulnerability of 0.01 for indirect impact.

Exposure time

Currently there is no data on occupancy. It has been assumed that the house is occupied between 8pm and 8am and for 50% of the time between 8am and 8pm, i.e. a total of 16 hours or 0.67.

Risk to Life

The calculation of INDIVIDUAL Risk is contained in Appendix I and is summarised below

Table 27: Direct Impact

Landslide Volume	North of Cyfyng Road	South of Cyfyng Road
$<100\text{m}^3$	2×10^{-6}	2×10^{-8}
$100-500\text{m}^3$	1.1×10^{-5}	1.29×10^{-6}
$>500\text{m}^3$	1.3×10^{-3}	1.3×10^{-4}

Table 28: Indirect Impact

Landslide Volume	North of Cyfyng Road	South of Cyfyng Road
$<100\text{m}^3$	0	0
$100-500\text{m}^3$	1.3×10^{-6}	1.2×10^{-7}
$>500\text{m}^3$	1.4×10^{-4}	1.36×10^{-5}

The highest risk is related to landslides $>500\text{m}^3$. Although larger landslides are less frequent, this is off set by the fact that they are considerably wider and therefore the probability of a landsliding hitting a property increases.

Table 29: Total Impact (sum of direct and indirect impact)

Landslide Volume	North of Cyfyng Road	South of Cyfyng Road
$<100\text{m}^3$	2×10^{-6}	2×10^{-8}
$100-500\text{m}^3$	1.23×10^{-5}	1.41×10^{-6}
$>500\text{m}^3$	1.44×10^{-3}	1.44×10^{-4}
Total	1.45×10^{-3}	1.45×10^{-4}

The Risk to Life for people within buildings is shown in Figure 16.

5.10.2 People in Gardens

There is a good correlation between rainfall events and landslides, so exposure will be low but conversely their vulnerability would be high.

Vulnerability of People in Gardens

For <100m³ landslide volume it has been assumed that the relatively slow-moving debris will be < 1m thick and people will have some forewarning about the landslide coming from the noise. A vulnerability of 0.1 for persons has been assumed.

For 100m³-500m³ landslide volume it has been assumed that the relatively slow-moving debris will be < 2m thick. and people will have some forewarning about the landslide coming from the noise. A vulnerability of 0.5 for persons has been assumed.

For 100m³-500m³ landslide volume it has been assumed that the relatively slow-moving debris will be > 2m thick. A vulnerability of 1.0 for persons has been assumed.

Exposure time

It has been assumed that garden usage is primarily restricted to summer months, during daylight and at weekends. This gives a potential exposure time of 12 hours x 8 days x four months i.e. approximately 384 hours. Assuming the garden is actually occupied for 25% of this time, reduces this to 96 hours i.e. an exposure time of 96 hours or 0.01.

Risk to Life

The calculation of **INDIVIDUAL** Risk is contained in Appendix I and is summarised below

Table 30: Individual Risk to people in Gardens

Landslide Volume	North of Cyfyng Road	South of Cyfyng Road
<100m³	3x10 ⁻⁶	3x10 ⁻⁸
100-500m³	8.8x10 ⁻⁶	8.8x10 ⁻⁶
>500m³	2.1x10 ⁻⁴	2x10 ⁻⁵
TOTAL	2.2x10⁻⁴	2.9x10⁻⁵

5.10.3 Pedestrians

It has been assumed that where buildings are present upslope of the footpath these will mitigate the landslide hazard:

- On the northern side of Cyfyng Road the footpath is of limited extent and there are only two locations where upslope buildings are absent, with a total length of 35m of exposed footpath.
- On the south side of Cyfyng Road the footpath is present over the entire length of the road with a length of 350m where there are no upslope buildings present.

Vulnerability of People on Footpaths

For <100m³ landslide volume it has been assumed that the relatively slow-moving debris will be < 1m thick and people will have some forewarning about the landslide coming from the noise. A vulnerability of 0.1 for persons has been assumed.

For 100m³-500m³ landslide volume it has been assumed that the relatively slow-moving debris will be < 2m thick. and people will have some forewarning about the landslide coming from the noise. A vulnerability of 0.5 for persons has been assumed.

For 100m³-500m³ landslide volume it has been assumed that the relatively slow-moving debris will be > 2m thick. A vulnerability of 1.0 for persons has been assumed.

Exposure time

It has been assumed that 2 people per hour use the footpaths on each side of the road for 12 hours a day which equates to 48 people/day

Walking speed has been assumed to be 2.5km/hr (2500m/hr).

Risk to Life

The calculation of **INDIVIDUAL** Risk is contained in Appendix J and is summarised below

Table 31: Individual Risk to pedestrians

Landslide Volume	North of Cyfyng Road	South of Cyfyng Road
<100m ³	5.6x10 ⁻⁸	4.7x10 ⁻⁸
100-500m ³	1.3x10 ⁻⁷	8.5x10 ⁻⁷
>500m ³	3.9x10 ⁻⁷	6.7x10 ⁻⁶
TOTAL	5.5x10⁻⁷	7.6x10⁻⁶

5.10.4 People in Vehicles

Based on a traffic census undertaken by Neath and Port Talbot between 28 March 2018 and 6 April 2018 there were on average 110 cars/day in each direction or one car every 13 minutes:

- It has been assumed that each car has a single occupant and travels at 30mph (48km/h) with a stopping distance of 23m.
- It has been assumed that each car is 5m in length.
- It has been assumed that existing buildings will mitigate the landslide hazard and the length of the road exposed to landslide hazard is 380m.

Vulnerability of People in Vehicles

If a car hits a landslide the vulnerability has been assumed to be 0.03 (AGS 2007 p112).

For <100m³ landslide volume it has been assumed that the relatively slow-moving debris will be < 1m thick. A vulnerability of 0.05 for persons has been assumed.

For 100m³-500m³ landslide volume it has been assumed that the relatively slow-moving debris will be < 2m thick. A vulnerability of 0.5 for persons has been assumed.

For 100m³-500m³ landslide volume it has been assumed that the relatively slow-moving debris will be > 2m thick. A vulnerability of 1.0 for persons has been assumed.

There is the probability the landslide hits a car and the probability the car hits the landslide debris.

The risk calculations are contained in Appendix K.

Table 32: Landslide hits car

Landslide Volume	North	South
<100m ³	2.4x10 ⁻⁸	2.6x10 ⁻¹⁰
100-500m ³	1.6x10 ⁻⁷	1.5x10 ⁻⁸
>500m ³	2.9x10 ⁻⁶	2.8x10 ⁻⁷

Table 33: Car hits landslide

Landslide Volume	North	South
<100m ³	3.4x10 ⁻⁸	3.2x10 ⁻¹⁰
100-500m ³	1.1x10 ⁻⁸	1.1x10 ⁻⁹
>500m ³	3.3x10 ⁻⁸	3.3x10 ⁻⁹

5.10.5 Risk Acceptance

In the UK there are no legally defined values for acceptable risk. AGS suggest that 10^{-4} is tolerable for existing developments and advise against new development where risk $> 10^{-5}$ (AGS 2007 p42).

5.11 Qualitative Risk Assessment for Remaining Hazard Types

AGS (2007) note that when considering the risk to property it may be useful to use qualitative terms, particularly where there is insufficient data and Appendix C of AGS (2007) provides a methodology for this approach. This has been adopted at Pantteg for the identified Hazards. The approach is based on a qualitative assessment of likelihood and qualitative measures of consequences to the property. The risk levels are summarised in Table 34.

5.11.1 Hazard Type 1 Large-scale complex landslide, Godre'r Graig

The portion of the Godre'r Graig landslide which falls into the assessment area has been subdivided into an upper and lower component.

The upper component comprises an area of known distress which previously contained a significant number of properties have been demolished. As discussed in 7.5.1 there is evidence of recent movement and an approximate annual probability of movement of 10^{-1} has been adopted, i.e. movement is considered to be 'almost certain'. The consequences of any movement is considered to result in an approximate cost of damage of 10% of the property value, i.e. minor consequences. This suggests a high level of risk to property.

The lower component, although within the boundary of the previous mapped extent of the Godre'r Graig Landslide shows no current evidence of distress and includes occupied properties. There is no evidence of recent or relict movement and an annual probability of movement of 10^{-5} , has been adopted, i.e. movement is considered to be 'rare'. The consequences of any movement is considered to result in an approximate cost of damage of 20% of the property value, i.e. medium consequences. This suggests a low level of risk to property.

5.11.2 Hazard Type 1 Large-scale complex landslide, Pantteg

The upper component of the Pantteg Landslide comprises Hazard Type 2. The Lower part comprises the previous mapped extent of the Pantteg Landslide. There is no evidence of recent or relict movement and an annual probability of movement of 10^{-5} , has been adopted, i.e. movement is considered to be 'rare'. The consequences of any movement is considered to result in an approximate cost of damage of 20% of the property value, i.e. medium consequences. This suggests a low level of risk to property.

5.11.2.1 Hazard Type 2 Shallow, translational landslides

This area has been assessed quantitatively but is included in this section for completeness. There is evidence of recent and on-going distress and an approximate annual probability of movement of 10^{-1} has been adopted, i.e. movement is considered to be 'almost certain'. Based on >500m³ landslide, the consequences of any movement is considered to result in an approximate cost of damage of 40% of the property value, i.e. medium consequences. This suggests a very high level of risk to property.

5.11.3 Hazard Type 3 Shallow translational landslides in Made Ground

There is limited information with respect to the thickness and extent of the Made Ground, the subsurface geology and the hydrogeological conditions in this area. The largest extent upslope, from the over steep terrain that bounds the lower part of this Made Ground, that a landslide has extended is approximately 40m. A 40m buffer has therefore been tentatively been adopted upslope of the break in slope forming the over steep terrain to indicate the possible extent of this hazard. Two landslides have been recorded in recent years and an annual probability of movement of 10^{-2} , has been adopted, i.e. movement is considered to be 'likely'. The consequences of any movement is considered to result in an approximate cost of damage of 20% of the property value, i.e. medium consequences. This suggests a high level of risk to property.

Table 34: Summary of Qualitative Assessment – Risk to Property

Hazard Type	Likelihood Designation	Consequence Descriptor	Risk
Hazard Type 1 Large-scale complex landslide Godre'r Graig- Upper	Almost certain	Minor	High
Hazard Type 1 Large-scale complex landslide Godre'r Graig- Lower	Rare	Medium	Low
Hazard Type 1 Large-scale complex landslide Pantteg- Lower	Rare	Medium	Low
Hazard Type 2 Shallow, translational landslides	Almost certain	Medium	Very High
Hazard Type 3 Shallow translational landslides in Made Ground	Likely	Medium	High
Hazard Type 4. Debris avalanches	N/A	-	-
Hazard Type 5. Boulder Fall.	Subsumed in Hazard Type 2	-	-
Hazard Type 6. Rock fall	Likely	Minor	Moderate
Remaining area	Barely credible	Minor	Very Low

5.12 Uncertainties

There are a number of uncertainties associated with this assessment. These are related to the identification of past landslides, the depth of the landslide that has occurred and their run out distance. Additional uncertainties are associated with the exposure time of people to the various hazards identified and their vulnerability to them. However, this assessment has been undertaken in accordance with best international practice by an experienced practitioner and subject to peer review. As such it is considered that the values calculated are likely to be accurate to within one order of magnitude.

5.13 Hazard and Risk Conclusions

Although there are uncertainties involved in the quantitative risk assessment the results indicate that the main risk to life is to people in buildings (and gardens).

Whilst there is a risk to life to both pedestrians and people in vehicles, this is three to four orders of magnitude lower.

The combined hazard and risk plans are presented as Figures 17 and 18.

6 Conclusions and Recommendations

The instability at Pantteg is attributed to several interlinked factors. These factors exist across numerous similar landslides across South Wales within similar geological settings, often associated with the Llynfi Beds and specific strata within the sequence.

The ground conditions and instability are complex and operate on a range of scales. Causational factors include:

- Naturally over-steep slopes;
- Lithological controls on stability;
- Low strength superficial materials;
- Geological controls on stability;
- Human influences such as quarrying, coal mining and development;
- Extended periods of heavy rainfall creating excess pore water pressures in soil and rock strata, which may become more pronounced as a result of climate change; and
- Inputs and outputs from the mine drainage system and preferential groundwater flows from the coal seams.

6.1 Hazard and Risk

The aim of the recent work has been to update the historical Hazard and Risk Map based on current engineering geological practice, to develop an understanding of where instability is likely to occur in the future and give us a better understanding of likely impact on roads, land and properties in the area.

The Hazard and Risk map has been reviewed and updated and is presented as Figure 17. This contemporary assessment has significantly progressed understanding of the geomorphology and landslide processes at Pantteg and now provides a basis for communicating hazards and risks to various stakeholders, including the community, statutory service providers and NPTCBC.

A number of different hazard³ types are present at Pantteg and these have been amalgamated onto one plan to communicate the risk⁴:

- Hazard Type 1: Large-scale complex landslide Godre'r Graig – Upper;
- Hazard Type 1: Large-scale complex landslide Godre'r Graig – Lower;

³ Hazard: a condition with the potential for causing an undesirable consequence (e.g. location, volume/area, velocity of the potential landslides and any resultant detached material) and the probability of occurrence within a given period of time.

⁴ Risk: a measure of the probability and severity of an adverse effect to health, property or the environment (risk = probability of a given magnitude x consequences). This can be quantitative or qualitative, depending on the availability of data. A series of risk assessments have been carried out for the study area using the AGS Guidelines for Landslide Susceptibility Hazard and Risk Zoning, 2007.

- Hazard Type 1: Large-scale complex landslide Pantteg – Lower;
- Hazard Type 2: Shallow geologically controlled translational landslides;
- Hazard Type 3: Shallow translational landslides in Made Ground;
- Hazard Type 4: Debris avalanches;
- Hazard Type 5: Boulder Fall;
- Hazard Type 6: Rock fall.

Although there are uncertainties involved in quantitative risk assessment, the results indicate that the main risk to life is to people in buildings and gardens.

The three houses and garages south of the Graig-y-Merched junction are linked to the very high-risk area are in the very high-risk polygon; the properties are denoted as ‘very high risk’ to explain the risk to the residential properties. Mitigation from upslope properties plays a role here; a conservative adopted position has been for landslides >500m³ volume that may engulf the upslope properties and continue downslope.

The high risk zone below Cyfyng Road encompasses the whole terrace. The interconnectivity of the structures is an important factor here.

6.1.1 Quantitative Risk Assessment: Central Village

A Quantitative Risk Assessment has been undertaken for the central Pantteg area for risk to life. This is considered to be the zone with the highest hazard associated with Hazard Type 2 for which there is sufficient data to allow a quantitative assessment. Risk is reported using annual probability of loss of life. Risk to pedestrians, people in vehicles and residents were all evaluated and reflect the annual individual risk for the persons most at risk.

The following risk zonings are being utilised (from Table 6 in the AGS Guidelines for Landslide Susceptibility Hazard and Risk (Section 7.2.4):

Table 35: Annual Probability Classifications

Very High Risk	Annual probability of >1 in 1,000 ($>10^{-3}$ /annum) that the persons at risk will lose their life.
High Risk	Annual probability of 1 in 10,000 to 1 in 1,000 (10^{-4} to 10^{-3} /annum) that the persons at risk will lose their life.
Moderate Risk	Annual probability of 1 in 100,000 to 1 in 10,000 (10^{-5} to 10^{-4} /annum) that the persons at risk will lose their life.
Low Risk	Annual probability of 1 in 1,000,000 to 1 in 100,000 (10^{-6} to 10^{-5} /annum) that the persons at risk will lose their life.
Very Low Risk	Annual probability of <1 in 1,000,000 ($<10^{-6}$ /annum) that the persons at risk will lose their life.

With respect to UK individual risk to life, AGS 2007 quotes UK HSE (2001) which notes that 10^{-6} /annum is broadly acceptable, and 10^{-4} /annum is tolerable (very low to moderate risk).

6.1.2 Qualitative Risk Assessment: Remainder of Village

The approach to the remainder of the village is qualitative using estimates of likelihood and consequences (AGS, 2007) and is based on risk to property rather than risk to life. The terminology is qualitative i.e. it uses words. This is the best approach because 'where the possibility of obtaining numerical data is limited such that a [numerical] quantitative analysis is unlikely to be meaningful or may be misleading' (AGS, Guidelines for Landslide Risk Management 2007, Section 7.2).

Example Risk Level Implications (taken from AGS Practice Note Guidelines for Landslide Risk Management, Appendix C, 2007):

Table 36: Risk Level Implications

Very High Risk	Unacceptable without treatment. Extensive detailed investigation and research, planning and implementation of treatment options essential to reduce risk to Low; may be too expensive and not practical. Work likely to cost more than value of the property.
High Risk	Unacceptable without treatment. Detailed investigation, planning and implementation of treatment options required to reduce risk to Low. Work would cost a substantial sum in relation to the value of the property.
Moderate Risk	May be tolerated in certain circumstances (subject to regulator's approval) but requires investigation, planning and implementation of treatment options to reduce the risk to Low. Treatment options to reduce to Low risk should be implemented as soon as practicable.
Low Risk	Usually acceptable to regulators. Where treatment has been required to reduce the risk to this level, ongoing maintenance is required.
Very Low Risk	Acceptable. Manage by normal slope maintenance procedures.

Table 7 of the AGS guide (2007), should also be referred to when interpreting this information. The implications for a particular situation are to be determined by all parties to the risk assessment and may depend on the nature of the property at risk; the above is a general guide.

6.1.3 Examples of Good and Bad Hillside Practices

Below are examples of good and bad hillside practice (after AGS, 2007). These should form part of planning policy and communication strategies with residents for Pantteg into the future.

Table 37: Examples of Good Hillside Practice (after AGS, 2007)

Good Advice		
Geotechnical assessment	Obtain advice from a qualified, experienced geotechnical consultant at an early stage of planning and before site works.	
Good Planning		
Site Planning	Having obtained geotechnical advice, plan the development with the risk arising from the identified hazard and consequences in mind.	
Good Design and Construction		
House Design	Use flexible structures which incorporate properly designed brickwork, timber or steel frames, timber or panel cladding. Consider use of split levels. Use decks for recreational areas where appropriate.	
Site clearing	Retain natural vegetation wherever practicable	
Access and driveways	Satisfy requirements below for cut, fills retaining walls and drainage. Driveways and parking areas may need to be fully supported on piers.	
Earthworks	Cuts	Retain natural contours wherever possible. Minimise depth. Support with engineered retaining walls or batter to appropriate slope. Provide drainage measures and control.
	Fills	Minimise height. Strip vegetation and topsoil and key into natural slopes prior to filling. Use clean fill materials and compact to engineering standards. Batter to appropriate slope or support with engineered retaining wall. Provide surface drainage and appropriate subsurface drainage.
	Rock Outcrops/Boulders	Remove or stabilise boulders which may have unacceptable risk. Support rock faces where necessary.
Retaining walls	Engineer design to resist applied soil and water forces. Found on rock where practicable. Provide subsurface drainage within wall backfill and surface drainage on slope above. Construct wall as soon as possible after cut/fill operation.	
Footings	Found within rock where practicable. Use rows of piers or strip footings oriented up and down slope. Design for lateral creep pressures if necessary. Backfill footing excavations to exclude ingress of surface water.	
Drainage	Surface	Provide at tops of cut and fill slopes. Discharge to street drainage or natural water courses. Provide general falls to prevent blockage by siltation and incorporate silt traps. Line to minimise infiltration and make flexible where possible. Special structures to dissipate energy at changes of slope and/or direction.
	Subsurface	Provide filter around subsurface drain. Provide drain behind retaining walls. Use flexible pipelines with access for maintenance. Prevent inflow of surface water.
	Septic and Sullage	Usually requires pump-out or mains sewer systems; absorption trenches may be possible in some areas if risk is acceptable. Storage tanks should be water-tight and adequately founded.
Erosion control and landscaping	Control erosion as this may lead to instability. Revegetate cleared area.	
Good Drawings and Site Visits During Construction		
Drawings	Building Application drawings should be viewed by geotechnical consultant	
Site visits	Site Visits by consultant may be appropriate during construction	
Good Inspection and maintenance by owner		
Owners responsibility	Clean drainage systems; repair broken joints in drains and leaks in supply pipes. Where structural distress is evident see advice. If seepage observed, determine causes or seek advice on consequences.	

EXAMPLES OF GOOD HILLSIDE CONSTRUCTION PRACTICE

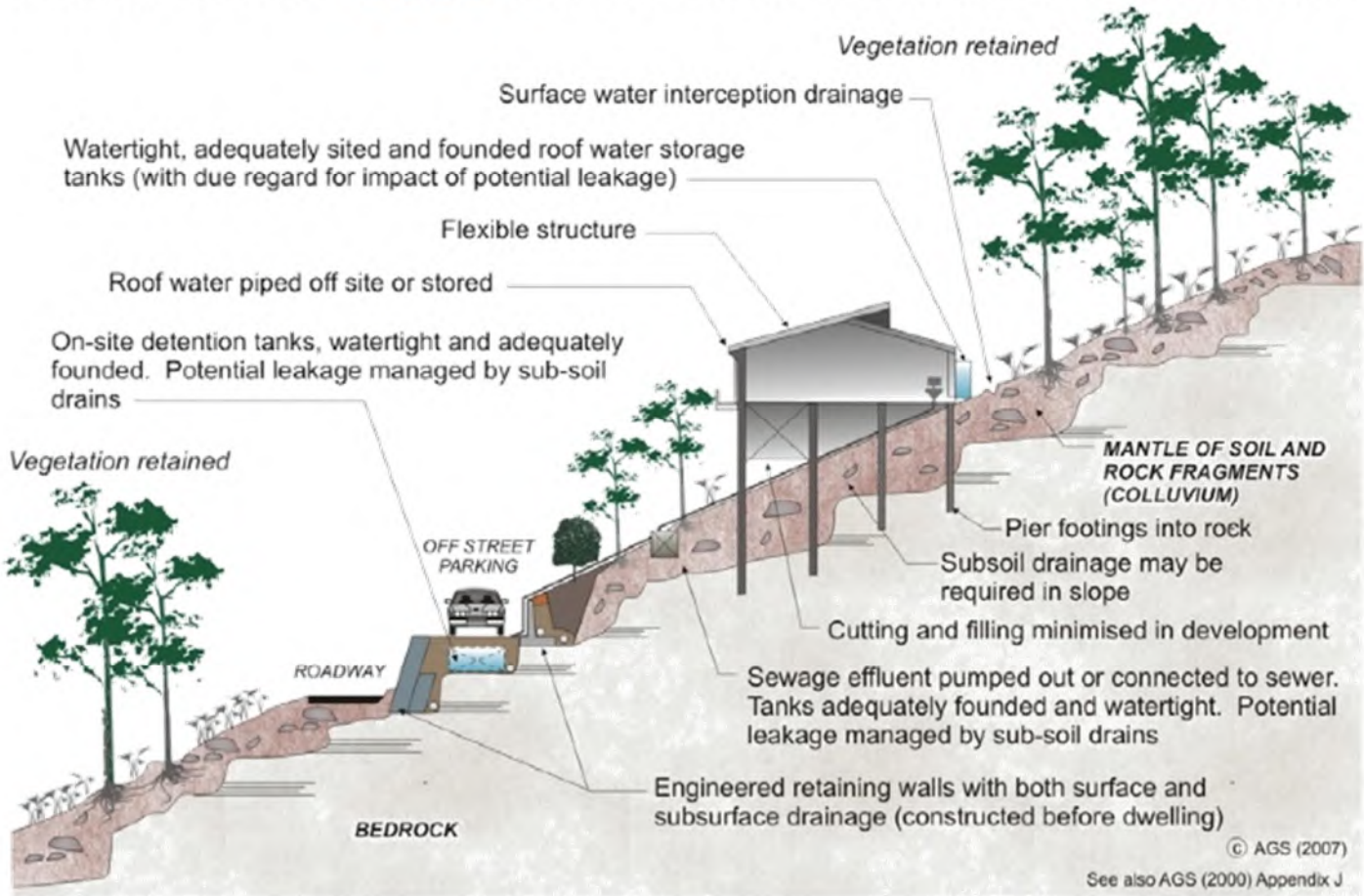
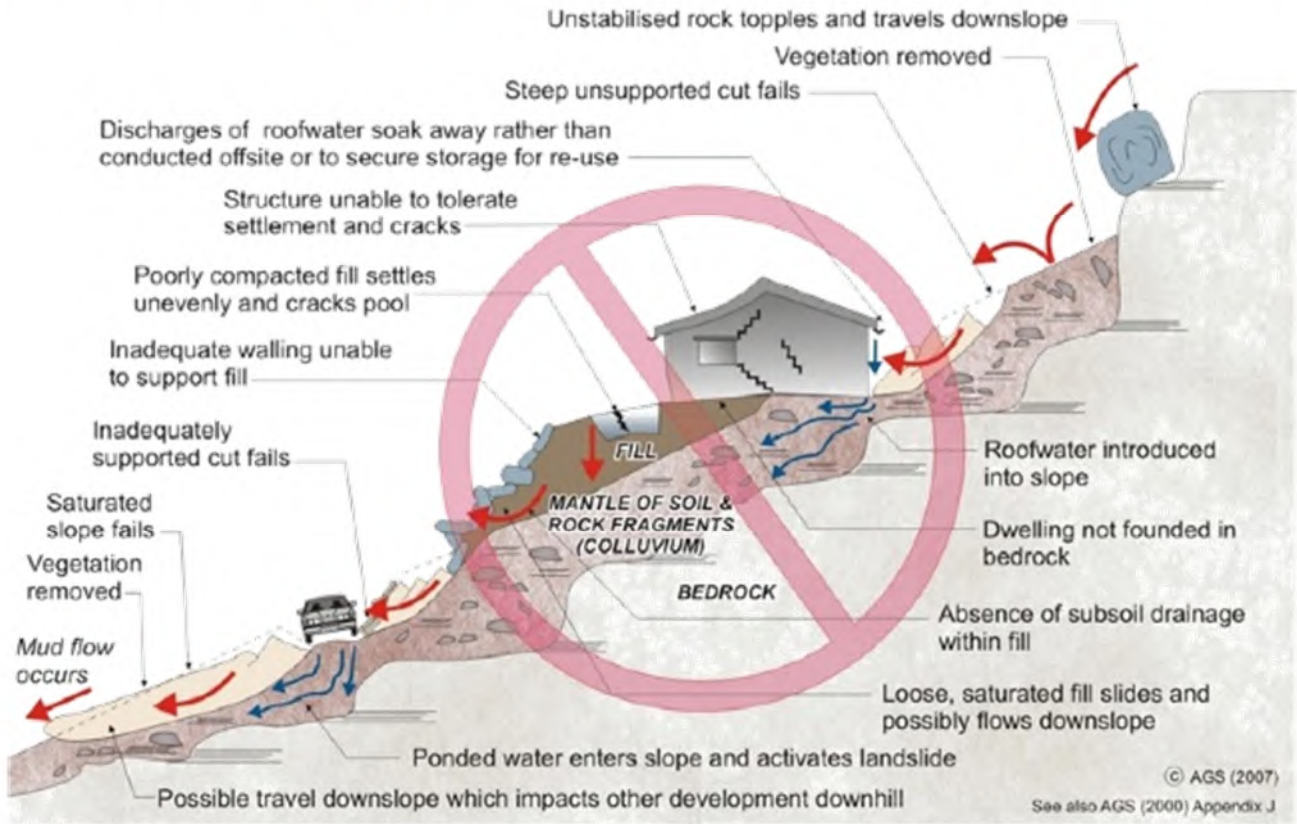


Table 38: Examples of Poor Hillside Management (after AGS, 2007)

Poor Advice		
Geotechnical assessment	Prepare detailed plan and start site works before geotechnical advice.	
Poor Planning		
Site Planning	Plan development without regard for the Risk.	
Poor Design and Construction		
House Design	Floor plans which require extensive cutting and filling. Movement of intolerant structures.	
Site clearing	Indiscriminately clear the site.	
Access and driveways	Excavate and fill for site access before geotechnical advice.	
Earthworks	Cuts	Indiscriminant bulk earthworks. Large scale cuts and benching. Unsupported cuts. Ignore drainage requirements.
	Fills	Loose or poorly compacted fill, which if it fails, may flow a considerable distance including onto property below. Block natural drainage lines. Fill over existing vegetation and topsoil. Include stumps, trees, vegetation, topsoil, boulders, building rubble etc in fill.
	Rock Outcrops and Boulders	Disturb or undercut detached blocks or boulders.
Retaining walls	Construct a structurally inadequate wall such as sandstone flagging, brick or unreinforced blockwork. Lack of subsurface drains and weepholes.	
Footings	Found on topsoil, loose fill, detached boulders or undercut cliffs.	
Drainage	Surface	Discharge at top of fills and cuts. Allow water to pond on bench areas.
	Subsurface	Discharge roof runoff into absorption trenches.
	Septic and Sullage	Discharge sullage directly onto and into slopes. Use absorption trenches without consideration of landslide risk.
Erosion control and landscaping	Failure to observe earthworks and drainage. recommendations when landscaping.	

EXAMPLES OF **POOR** HILLSIDE CONSTRUCTION PRACTICE



6.2 Landslide Management

A Residential Property Tribunal which occurred during 2017 and 2018 (in parallel to this hazard and risk assessment) concluded that a series of slopes below the northern end of Cyfyng Road demonstrate instability and the potential for further harmful conditions (Hazard Type 3). A series of notices served by NPTCBC were upheld by the Residential Property Tribunal in 2018.

The area defined on the hazard and risk map as 'cut slope hazard' has been reviewed using contemporary slope stability modelling methods, however a number of parameters for this area have been assumed based on the limited specific information, general Ground Model proved and experience.

The assessment has found no evidence of a large scale, deeper seated, movement (Hazard Type 1). Although movement in the inclinometer in BH301 is occurring, it is considered to be as a result of coal mine instability; the consistent stratigraphy identified by boreholes across large areas would not be anticipated if a deeper-seated movement was occurring. LiDAR and InSAR data collected do not show any movement of this kind and an updated Ground Model now explains and provides evidence for the movement noted at the site.

Previous reports concluded that the overall landslide system could not be economically stabilised, and we concur with this opinion. We understand that wholesale abandonment of the private residences and infrastructure in Pantteg is not feasible due to various factors including ground movement in other areas, compensation costs and other socio-economic impacts, however this should be reviewed.

It is noted that the solution at Pantyfynnon was to abandon the village (although different landslide processes are active there). We draw attention to some of the very earliest conclusions for Pantteg:

'no further building development should take place in the affected areas and as and when opportunity offered, the existing buildings should be abandoned or cleared to ground level' (Ref: Dillwyn and Jones, Mining Engineers, November 1957).

Hazard Awareness Notices have been issued by NPTCBC to residents within the 'very high risk' and 'high risk' areas as defined on the Residential Property Risk plan presented as Figure 17.

The concepts of '*managed retreat*' or '*gradual vacation*' should be reviewed and explored further to be incorporated into specific planning policy by NPTCBC for the Pantteg area. Mechanisms for capturing individual properties that have become unoccupied or reoccupied need to be considered and formalised.

Occupation of houses within the highest risk zones is not preferable due to the unacceptable risks presented. Residents should consider moving themselves out, or be encouraged to move out of the very high and high risk zones at the earliest point (despite that they are privately owned for the majority of cases). This approach is in addition to 'warning and informing' in terms of a 'Hierarchy of Controls' approach (e.g. Management of Health and Safety at Work Regulations, 1999). NPTCBC have been actively communicating information on the hazards and risk, for example via public meetings, online news updates and direct communication.

A drainage and vegetation management strategy should be developed and agreed for the landslide area to consider individual land owner and key stakeholder responsibilities, e.g. NPTCBCs and private landowners roles in managing the highway infrastructure.

We recommend that monitoring of borehole and other instrumentation continues for the foreseeable future at monthly intervals until a point in time that enough information is available to finalise the Ground Model assumptions made as part of this assessment (e.g. movement along a slip surface in BH601). This work should be carried out in conjunction with routine inspections of the landslide condition and morphology until a management strategy and approach can be agreed. An accurate method of recording and communicating landslide activity/events at various scales should be implemented as this information is critical to review and possible future update of the hazard and risk assessment.

Material has continued to fall from the slopes above the chapel since 2015. Recently, it has become obvious that a resident has been modifying the landform above Graig-y-Merched on an ad-hoc basis and this should be prevented immediately.

Continued downslope movement of material is likely during the next wet periods. This may comprise tens of tonnes, or more, of material. The rock berm constructed at the toe of the slope (opposite Pantteg Chapel) has been designed and constructed by NPTCBC to arrest landslide material and maintain the function of the road carriageway during/after the frequent and smaller landslide types. The primary reasoning behind the construction of the gabion basket was to provide some protection from small rock falls onto the road.

There is a potential that provided the links between rainfall, river flow and instability can be investigated and monitored through time, a trigger or threshold could be developed for the landslide using a suite of information. This will likely be high intensity ground monitoring data to begin until relevant triggers have been established. Once confidence is gained, a simple and reliable Trigger-Action-Response Plan could be established to inform Pantteg residents about the risk of landslide activity. It is clear that most of the landslide events occur during late autumn and winter months and development of baseline conditions within the landslide and relationship with rainfall will be critical to informing and developing a management approach.

The boundary between the two landslide areas (Pantteg and Godre'r Graig) is taken to be at the junction of Graig Road, Pantteg and Church Road, extending southeast (downslope) along the line of the stream, and northwest (upslope) to the entrance to the sandstone quarry above the location of the former Penygrraig House. No detailed assessment of the interactions at this location has been carried out and this could be considered further.

Further targeted ground investigation and monitoring should be carried out to provide further confidence in the Conceptual Ground Model, especially in areas where active movement is occurring and there are critical strata sequences. This will be subject to review of the contents and findings of this assessment and also considering legal advice and NPTCBC planning policy.

We recommend that a formal Management Strategy be developed for the Pantteg landslip to enable decisions on actions to protect human life and property to be taken with an underlying set of triggers, actions and responses. This should be an integral part of NPTCBC planning and policy decisions for Pantteg. In addition:

- Relatively simple physical improvements to, and maintenance of existing drainage should be continued as early as possible for optimum effectiveness of subsequent actions;

- Repair of vandalised logger boxes is being carried out;
- Ongoing assessment of the condition and effectiveness of drains, conduits, gullies and streams should be carried out on land NPTCBC are responsible for and on private land. This includes the possible link between the Mount Hill and the lower landslide area (Lower Pantteg) via the possible mine tunnel. Definition of responsibilities of each party/stakeholder should be confirmed (e.g. The Coal Authority, NPTCBC, Dwr Cymru Welsh Water, private landowners etc.);
- Discussions should be held with the Coal Authority to confirm their responsibilities in relation to maintaining drainage pathways through mine workings, including consideration to the mine tunnel;
- Review the benefits of investigation and instrumentation of key locations across the Pantteg landslide. Agreement on the resolution within the Ground Model and slope stability models, relating to topography, geology, hydrology and hydrogeology should be confirmed. Access, health and safety and cost will need to be considered as part of this review;
- Review the topographical information from LiDAR data in relation to modified technical aims and objectives for Pantteg. The requirement for repeat LiDAR surveys should be reviewed periodically considering changes to the slope system or findings of future investigation and assessment;
- Create a risk register based on emerging conditions and findings. The Risk Register for the site should be updated regularly based on emerging conditions and new information. A Trigger Action Response Plan (TARP) should be formulated to confirm responsibilities and actions to be taken when certain criteria or conditions are met;
- Use the various elements to integrate into a formal Management Plan to enable reliable protection of human life, property and infrastructure (where possible). This will become more accurate, reliable and useful over time.

The planning regime should be utilised as a method of controlling new development, or changes to existing development that could have an adverse effect on the stability of the slope. This would include areas to the east and west of the main road.

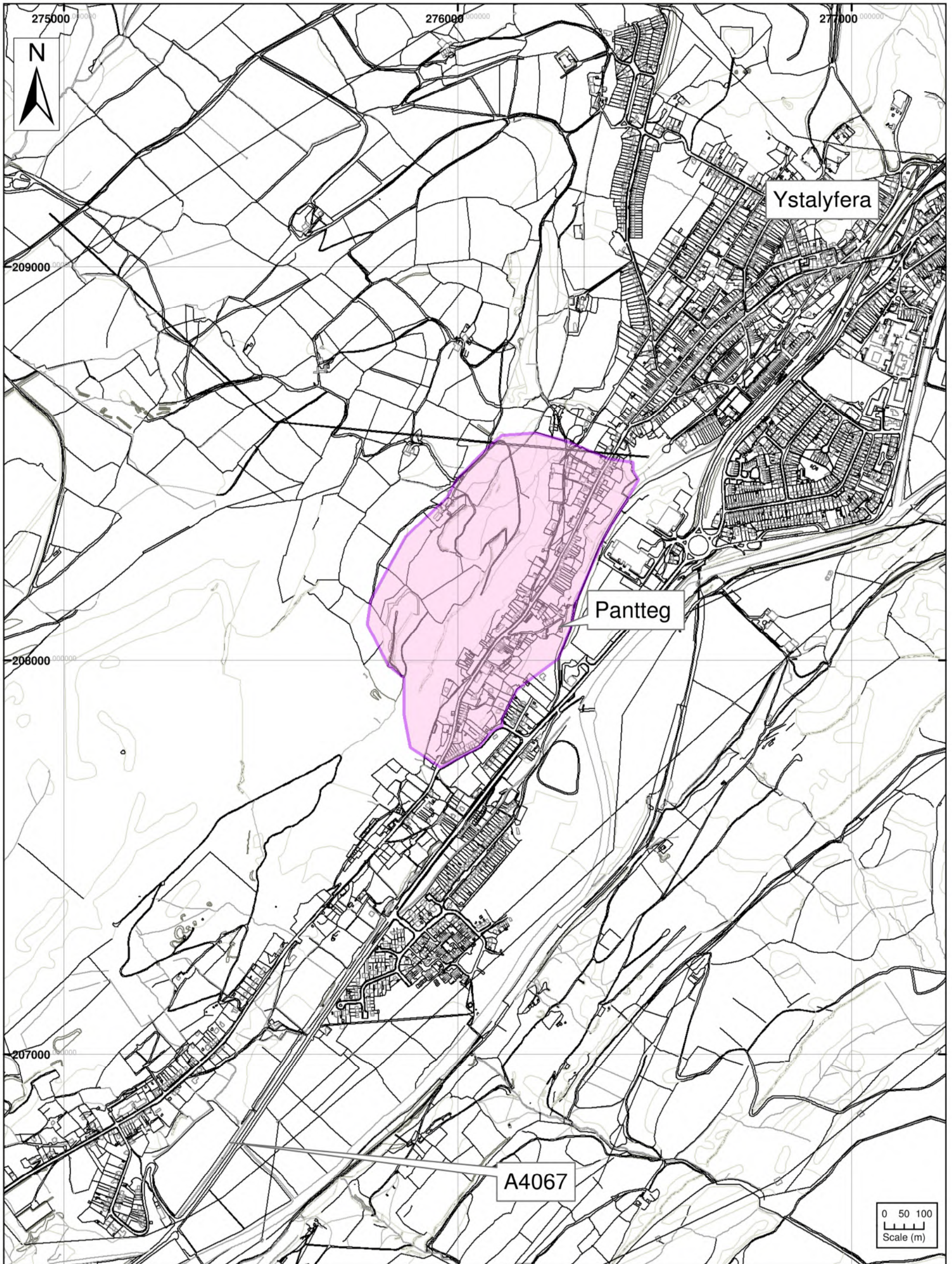
We also recommend a specific policy be developed for Pantteg village; this should include guidance on what actions are possible/appropriate when individual properties become vacant/abandoned.

In addition, confirmation of how the above information links into the multi-agency response plan for Pantteg should be obtained.

7 References

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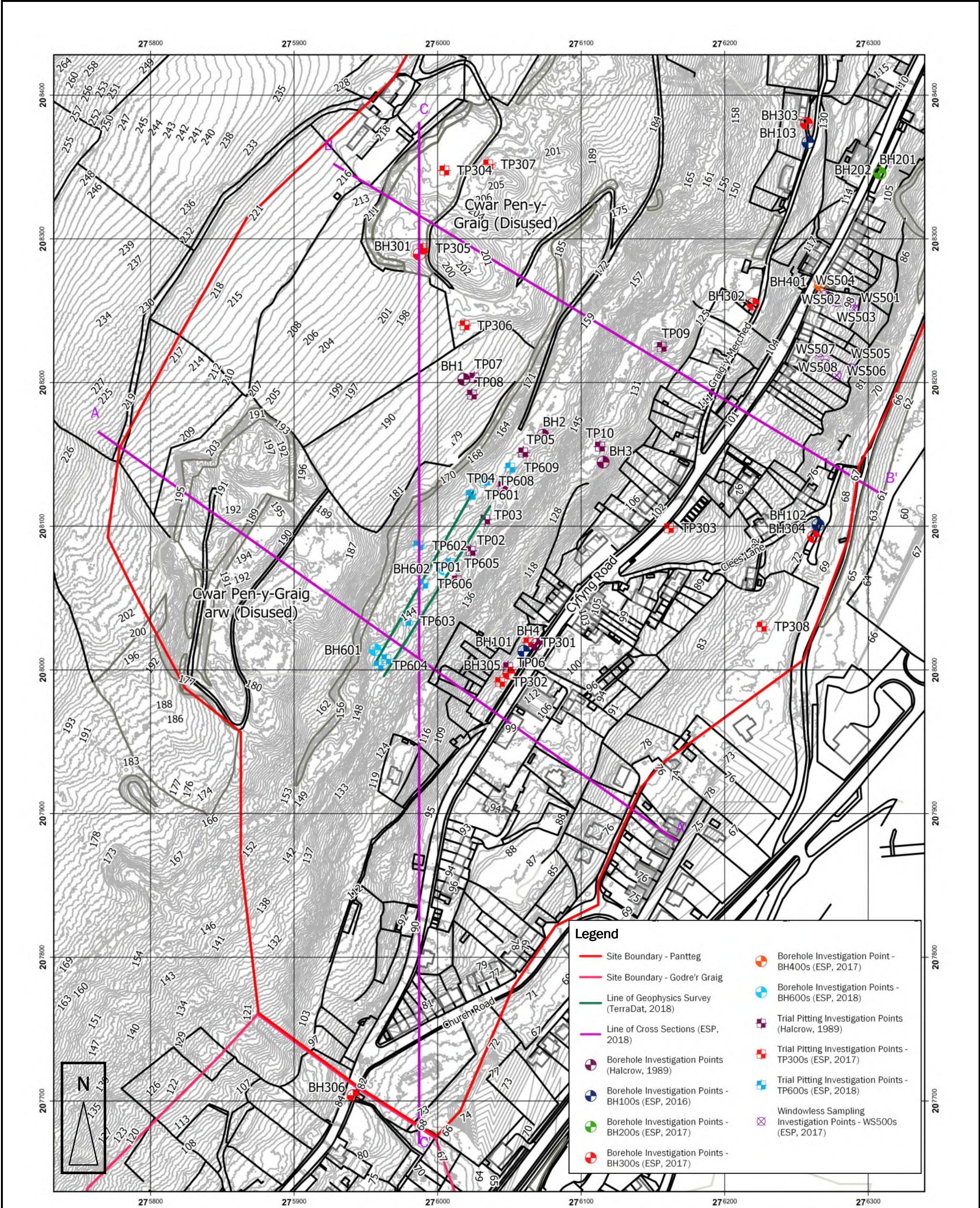
PROJECT: PANTTEG LANDSLIDE

Scale: 1:10,000 (at A3)

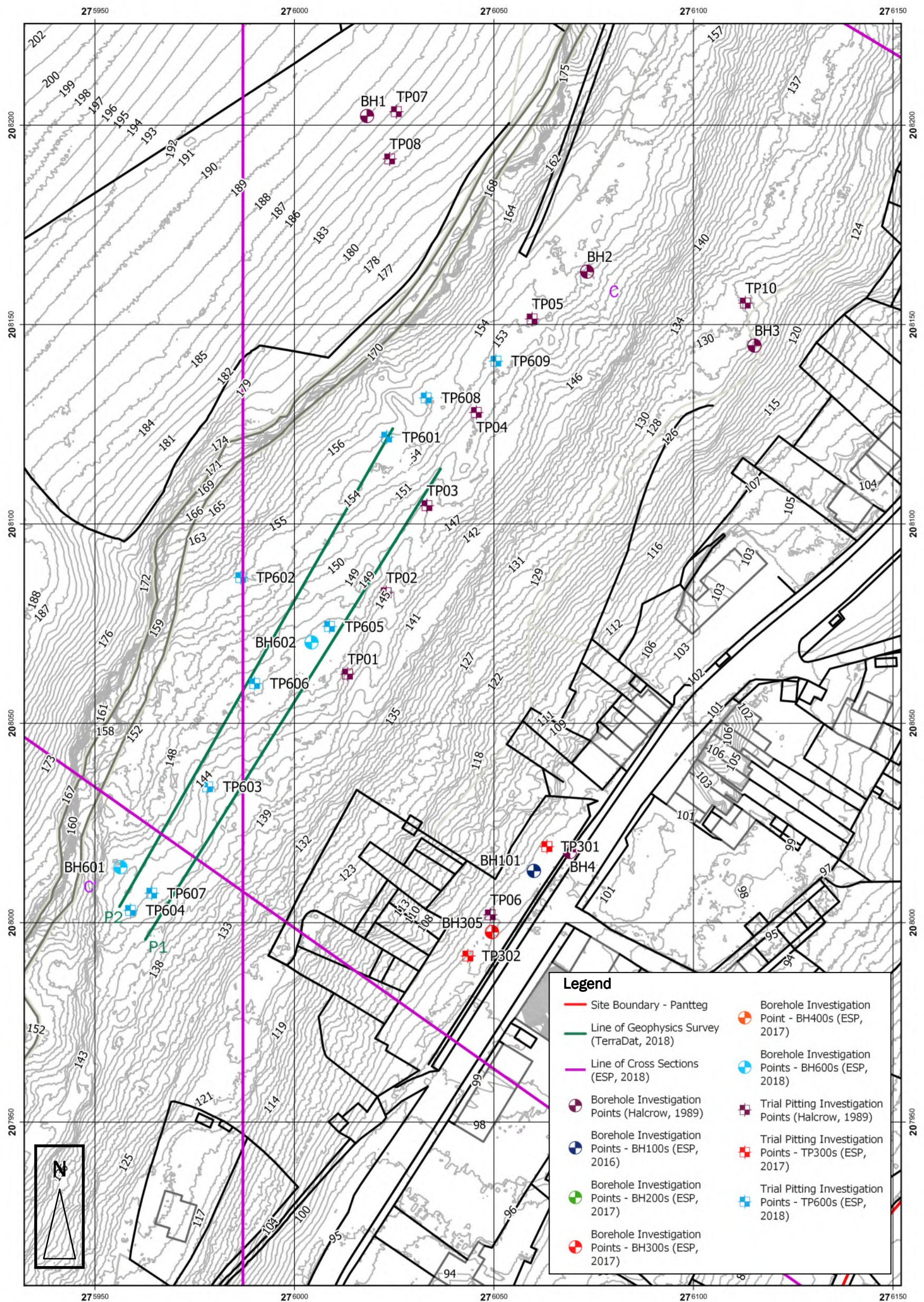
FIGURE 1B - SITE LOCATION PLAN

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Notes 1. Conceptual ground models for each line of section are presented as Figures 5, 6, 7 and 8. 2. Contours presented are from LiDAR data for the site.	PROJECT: PANTTEG LANDSLIDE	
	SCALE: 1:2500 (at A3)	
	FIGURE 2a: INVESTIGATION POINT PLAN – WHOLE AREA	
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PROJECT: PANTTEG LANDSLIDE

SCALE: 1:1000 (at A3)

FIGURE 2b: INVESTIGATION POINT PLAN - PEN-Y-GRAIG AND CHAPEL AREAS



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Legend

- Windowless Sampling Investigation Points - WS500s (ESP, 2017)
- Borehole Investigation Points - BH100s (ESP, 2016)
- Borehole Investigation Points - BH300s (ESP, 2017)
- Borehole Investigation Point - BH400s (ESP, 2017)

PROJECT: PANTTEG LANDSLIDE

SCALE: 1:500 (at A3)

FIGURE 2c: INVESTIGATION POINT PLAN – 100&111 CYFYNG ROAD

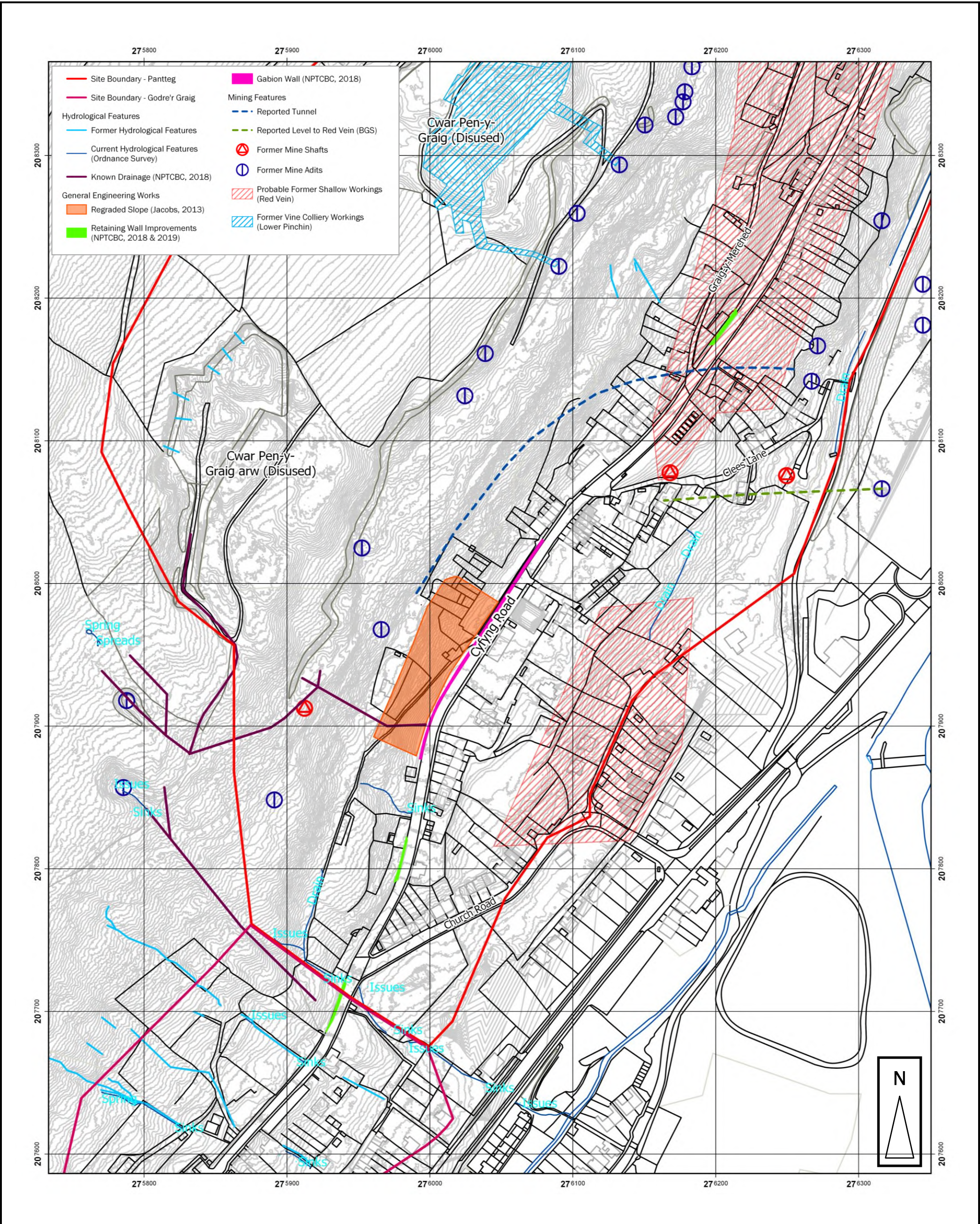
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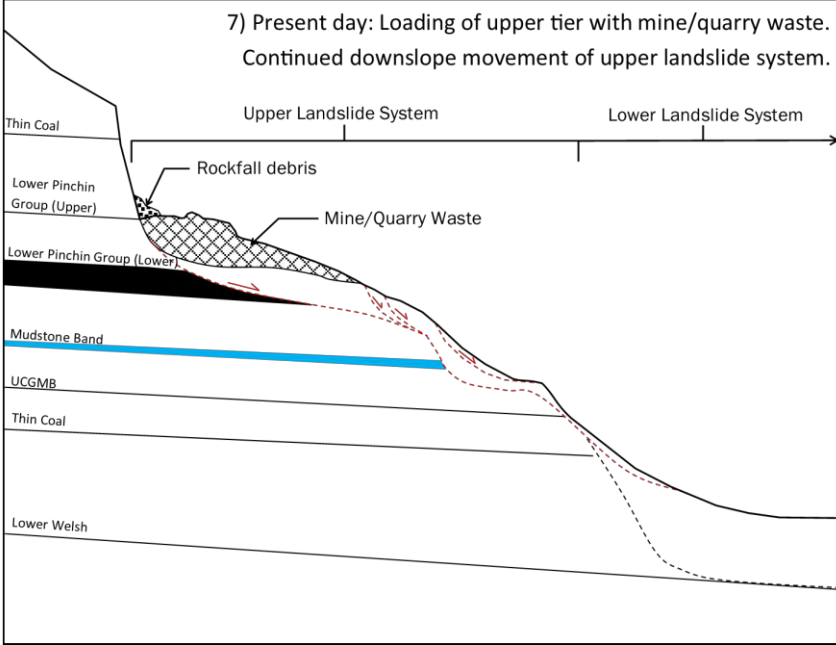
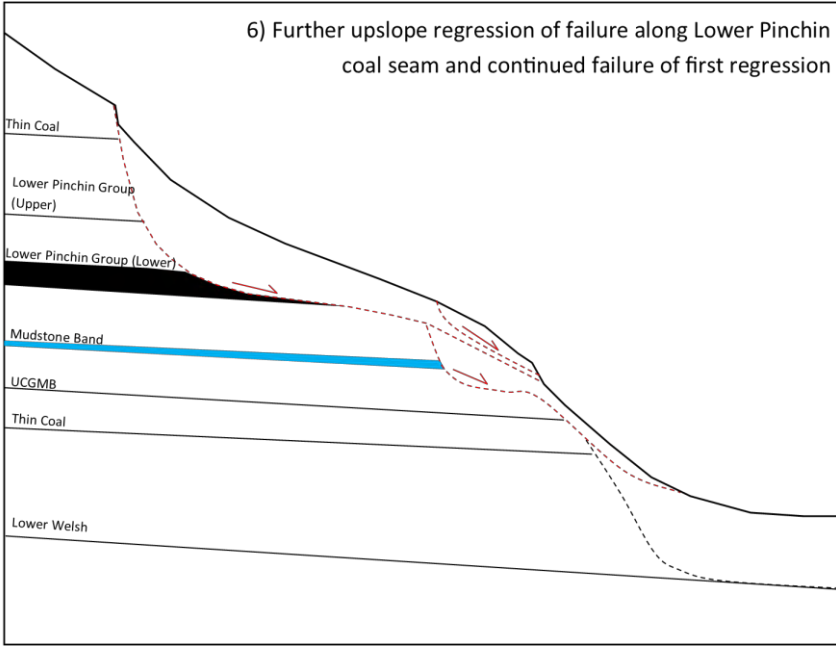
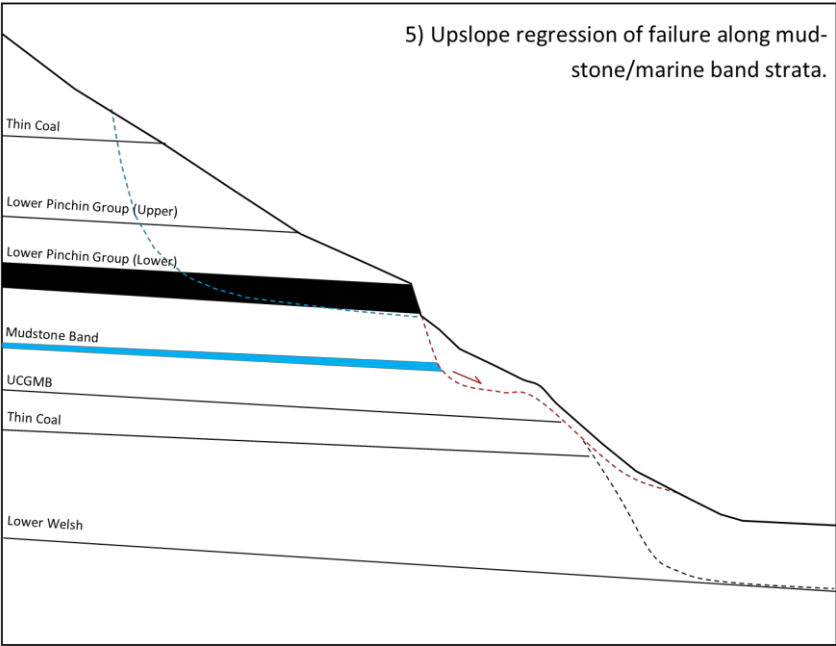
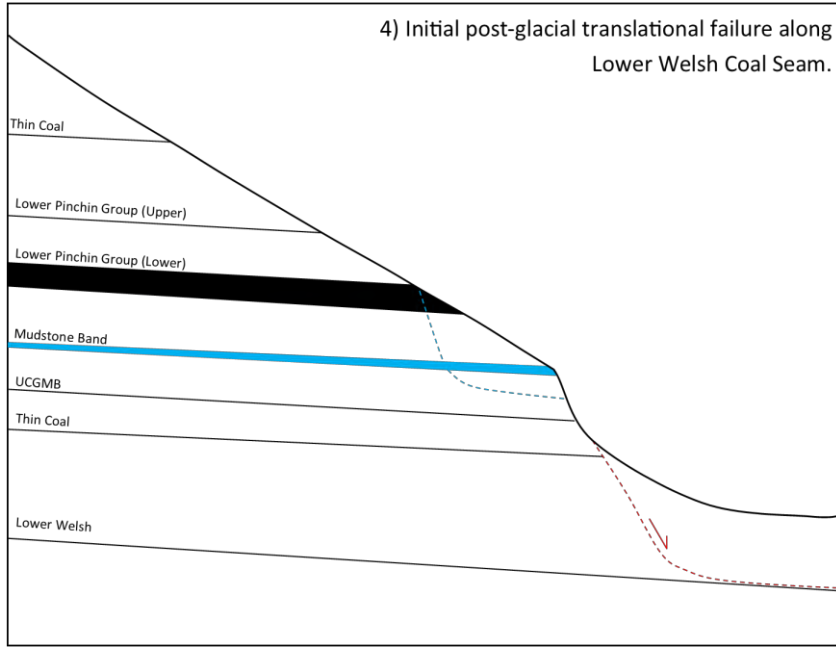
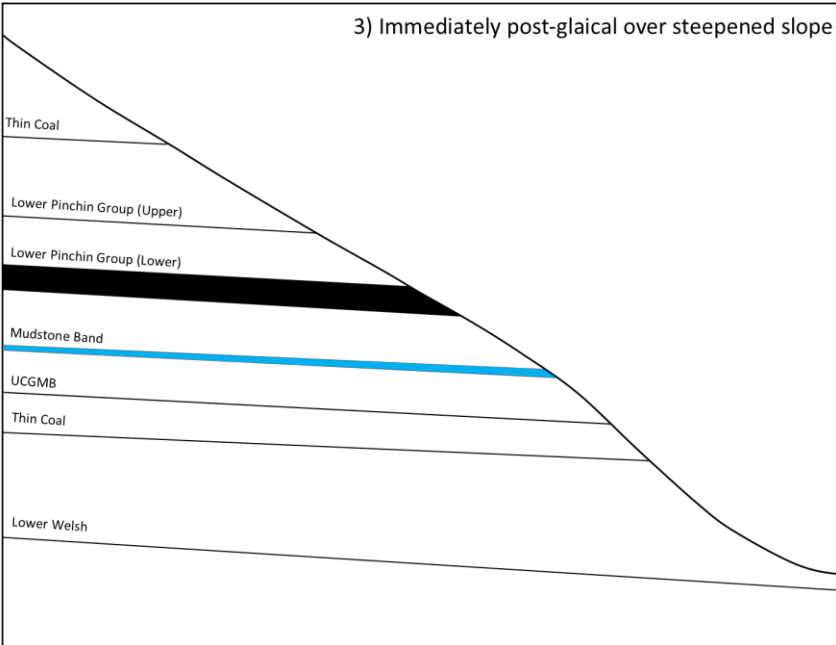
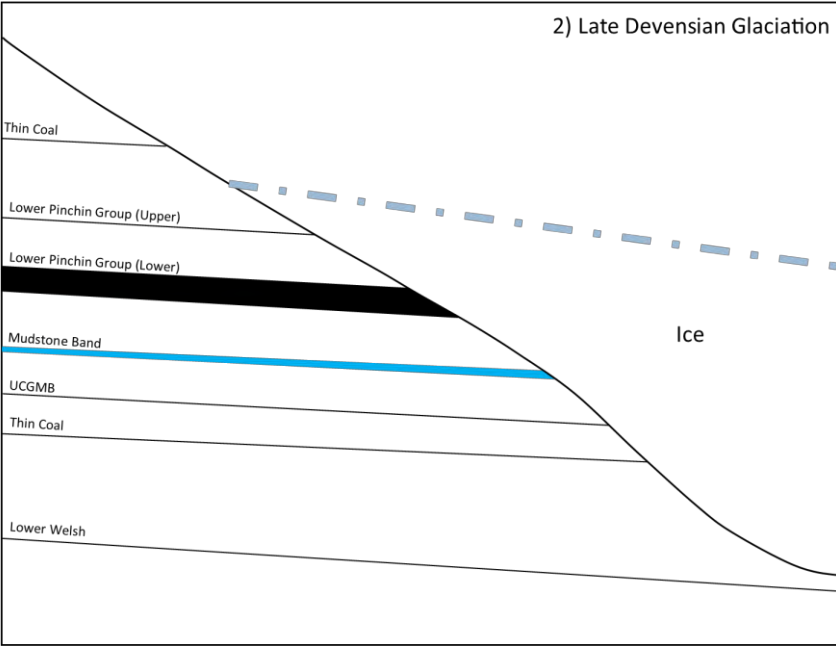
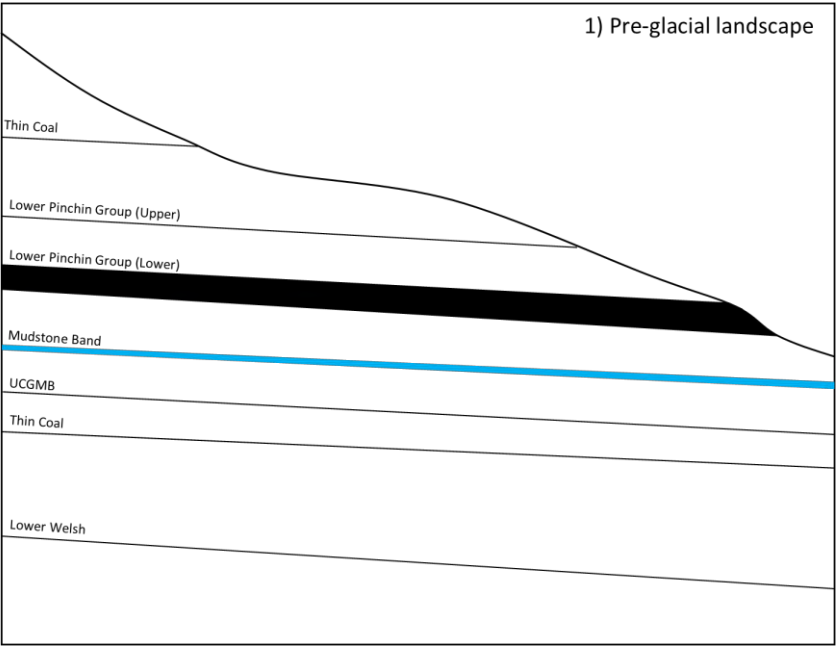
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Notes: 1. Mine adit and shafts positions delineated from historical maps, geological maps and from the coal authority. 2. Contours presented are from LiDAR data (ESP, 2017) 3. Shallow workings defined by the Coal Authority as workings within 30m of the ground surface. 4. Former hydrological features presented are from historical maps and former geomorphological mapping (Halcrow, 1987)	PROJECT: PANTTEG LANDSLIDE	
	SCALE: 1:2500 (at A3)	
	FIGURE 3: GROUND MODEL PLAN	
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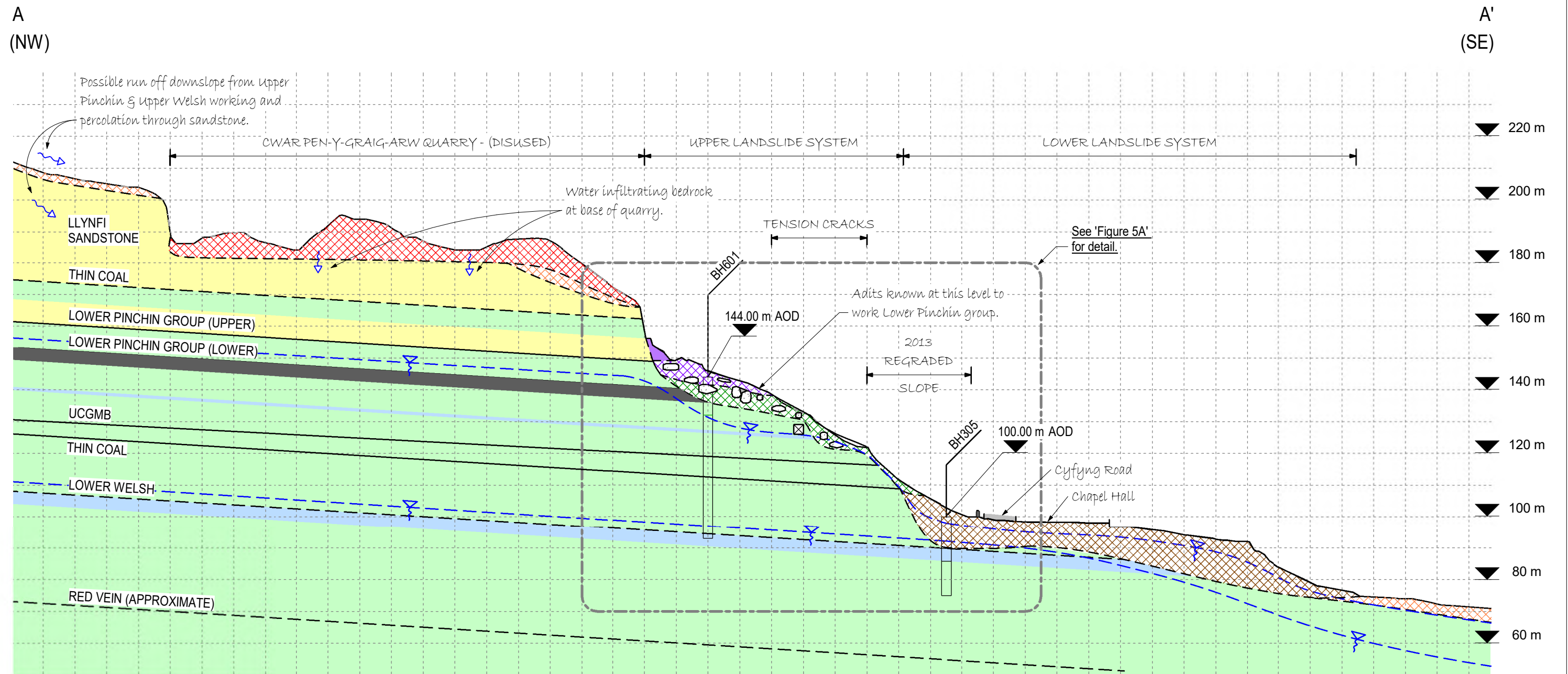


PROJECT: PANTTEG LANDSLIDE

FIGURE 4: CONCEPTUAL LANDSLIDE DEVELOPMENT



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KEY

	MUDSTONE		PROBABLE LANDSLIDE MATERIAL
	SILTSTONE		WEATHERED ROCK (SOIL)
	SANDSTONE		QUARRY SPOIL
	ROCK FALL DEBRIS		COLLUVIUM
	GROUND WATER		COLLIERY SPOIL - PREDOMINANTLY COARSE DISCARD
	INFERRED COAL		POSSIBLE FORMER SAG POND
	COAL		

NOTES

- DASHED LINES DENOTE UNCERTAINTY.
- BOREHOLES MOVED ALONG STRIKE OR DOWN/UP DIP TO HELP POPULATE GROUND MODEL.
- GROUND WATER MONITORING ONGOING.
- ROCK HEAD PROFILE INFORMED BY INVESTIGATION WHERE POSSIBLE. ASSUMED IN OTHER AREAS.
- LOWER PINCHIN GROUP DETAILS FROM BH301, BH1 USED IN SECTION. NOTE SEAT EARTHS GROUPED WITH COAL IN LOWER PORTION.
- RED VEIN POSITION BASED UPON GEOLOGICAL MAP AND VERTICAL SECTION.
- POSITION AND SIZE OF BOULDERS DIAGRAMMATICALLY SKETCHED ONLY.
- GROUND LEVEL BASED UPON LIDAR SURVEY.

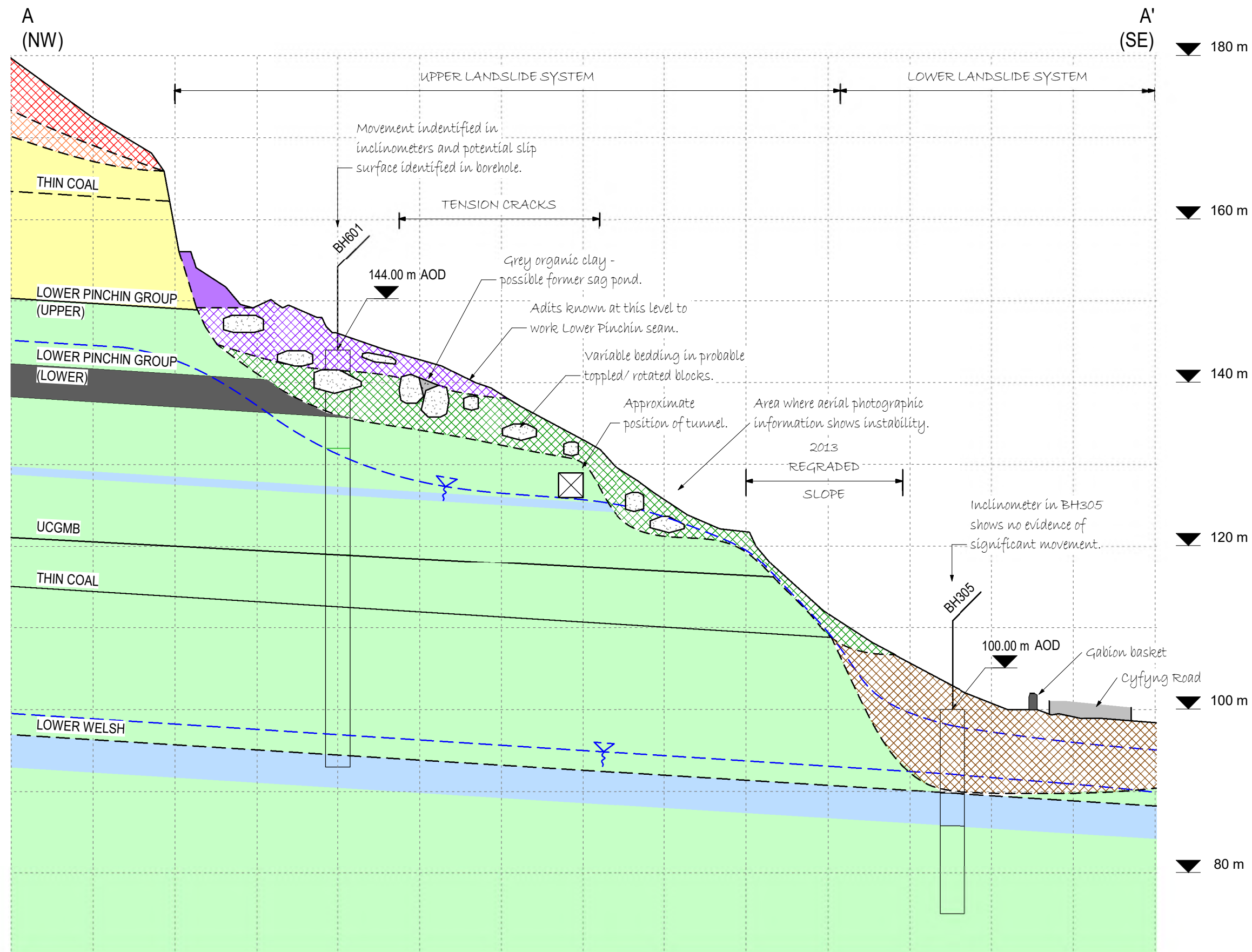
PROJECT: PANTTEG LANDSLIDE

SCALE: 1:1250

FIGURE 05: CONCEPTUAL GROUND MODEL - SECTION A-A

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KEY

- MUDSTONE
- SILTSTONE
- SANDSTONE
- ROCK FALL DEBRIS
- GROUND WATER
- INFERRED COAL
- COAL
- PROBABLE LANDSLIDE MATERIAL
- WEATHERED ROCK (SOIL)
- QUARRY SPOIL
- COLLUVIUM
- COLLIERY SPOIL - PREDOMINANTLY COARSE DISCARD
- POSSIBLE FORMER SAG POND

NOTES

1. DASHED LINES DENOTE UNCERTAINTY.
2. BOREHOLES MOVED ALONG STRIKE OR DOWN/UP DIP TO HELP POPULATE GROUND MODEL.
3. GROUND WATER MONITORING ONGOING.
4. ROCK HEAD PROFILE INFORMED BY INVESTIGATION WHERE POSSIBLE. ASSUMED IN OTHER AREAS.
5. LOWER PINCHIN GROUP DETAILS FROM BH301, BH1 USED IN SECTION. NOTE SEAT EARTHS GROUPED WITH COAL IN LOWER PORTION.
6. POSITION AND SIZE OF BOULDERS DIAGRAMMATICALLY SKETCHED ONLY.
7. GROUND LEVEL BASED UPON LIDAR SURVEY.

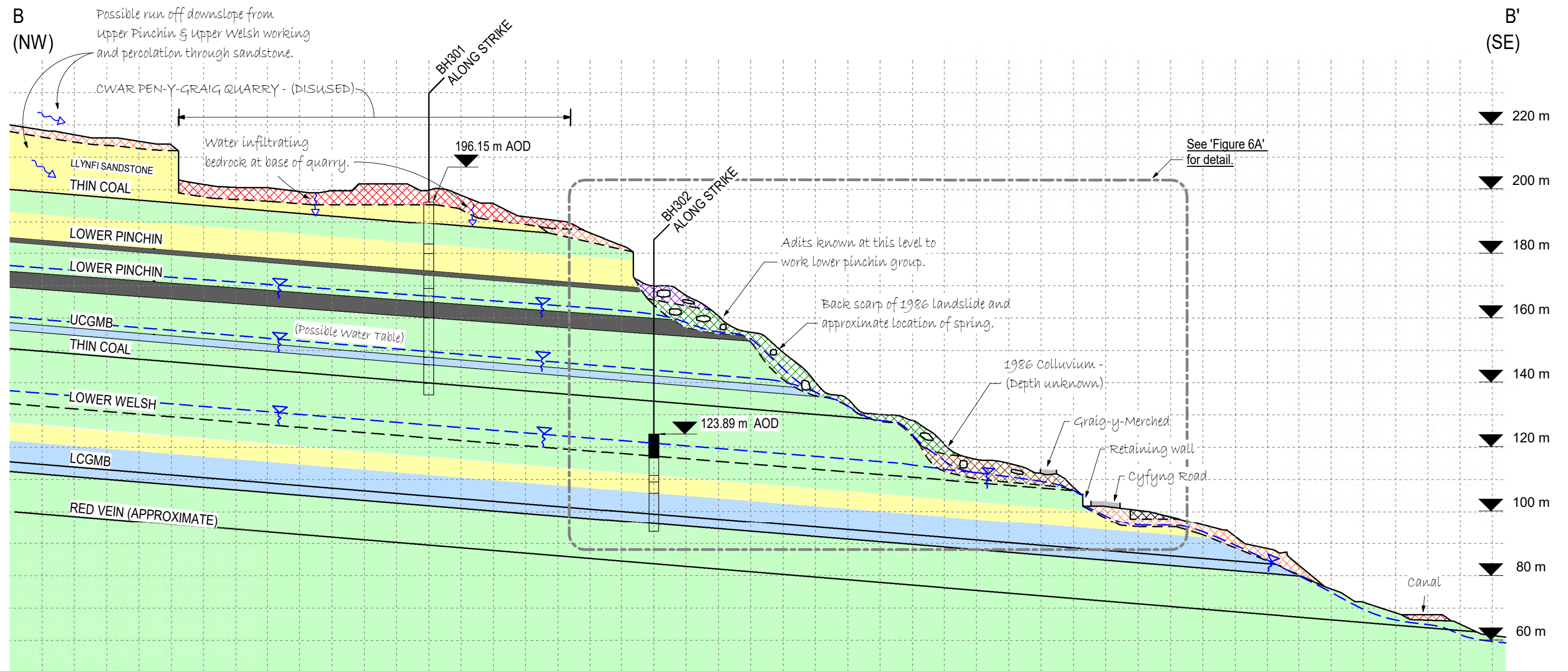
PROJECT: PANTTEG LANDSLIDE

SCALE: 1:500

FIGURE 5A: CONCEPTUAL GROUND MODEL - INSERT FROM SECTION A-A

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KEY

	MUDSTONE		MADE GROUND
	SILTSTONE		PROBABLE LANDSLIDE MATERIAL
	SANDSTONE		WEATHERED ROCK (SOIL)
	GROUND WATER		QUARRY SPOIL
	INFERRED COAL		COLLUVIUM
	COAL		COLLIERY SPOIL - PREDOMINANTLY COARSE DISCARD

NOTES

- DASHED LINES DENOTE UNCERTAINTY.
- BOREHOLES MOVED ALONG STRIKE OR DOWN/UP DIP TO HELP POPULATE GROUND MODEL.
- GROUND WATER MONITORING ONGOING.
- ROCK HEAD PROFILE INFORMED BY INVESTIGATION WHERE POSSIBLE. ASSUMED IN OTHER AREAS.
- LOWER PINCHIN GROUP DETAILS FROM BH301, BH1 USED IN SECTION. NOTE SEAT EARTHS GROUPED WITH COAL IN LOWER PORTION.
- RED VEIN POSITION BASED UPON GEOLOGICAL MAP AND VERTICAL SECTION.
- POSITION AND SIZE OF BOULDERS DIAGRAMMATICALLY SKETCHED ONLY.
- GROUND LEVEL BASED UPON LIDAR SURVEY.

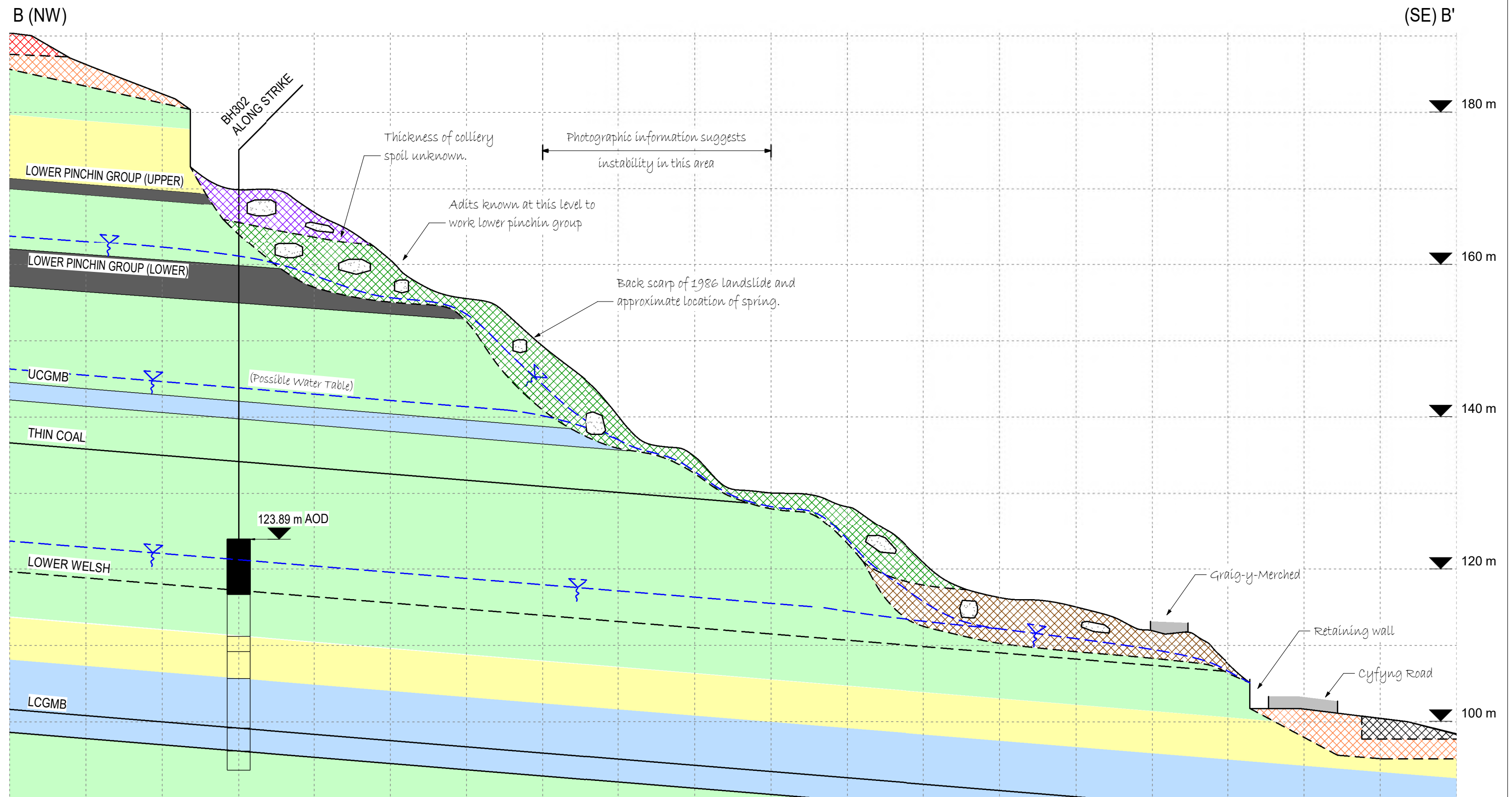
PROJECT: PANTTEG LANDSLIDE

SCALE: 1:1250

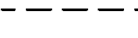
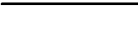
FIGURE 06: CONCEPTUAL GROUND MODEL - SECTION B-B

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KEY

	MUDSTONE		MADE GROUND
	SILTSTONE		PROBABLE LANDSLIDE MATERIAL
	SANDSTONE		WEATHERED ROCK (SOIL)
	GROUND WATER		QUARRY SPOIL
	INFERRED COAL		COLLUVIUM
	COAL		COLLIERY SPOIL - PREDOMINANTLY COARSE DISCARD

NOTES

1. DASHED LINES DENOTE UNCERTAINTY.
2. BOREHOLES MOVED ALONG STRIKE OR DOWN/UP DIP TO HELP POPULATE GROUND MODEL.
3. GROUND WATER MONITORING ONGOING.
4. NO INVESTIGATION UNDERTAKEN BETWEEN GRAIG-Y-MERCHED AND CWAR PEN-Y-GRAIG DUE TO ACCESS RESTRICTIONS. SUPERFICIAL DEPOSITS AND MADE GROUND INFERRED.
5. ROCK HEAD PROFILE INFORMED BY INVESTIGATION WHERE POSSIBLE. ASSUMED IN OTHER AREAS.

6. LOWER PINCHIN GROUP DETAILS FROM BH301, BH1 USED IN SECTION. NOTE SEAT EARTHS GROUPED WITH COAL IN LOWER PORTION.
7. GROUND LEVEL BASED UPON LIDAR SURVEY.

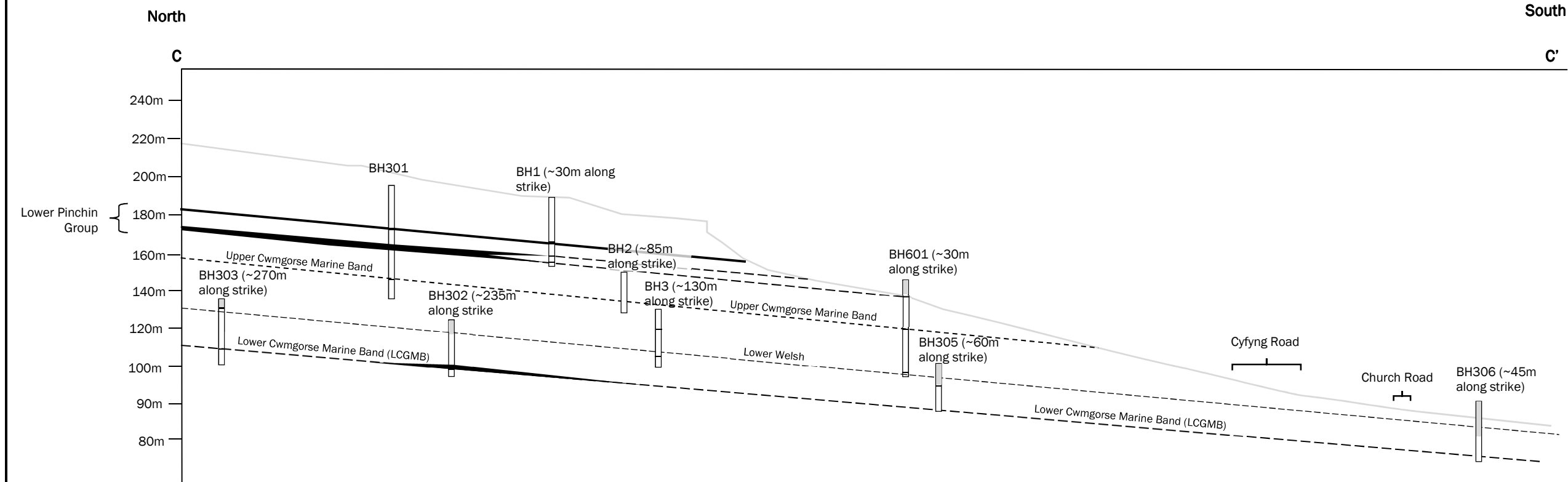
PROJECT: PANTTEG LANDSLIDE

SCALE: 1:500

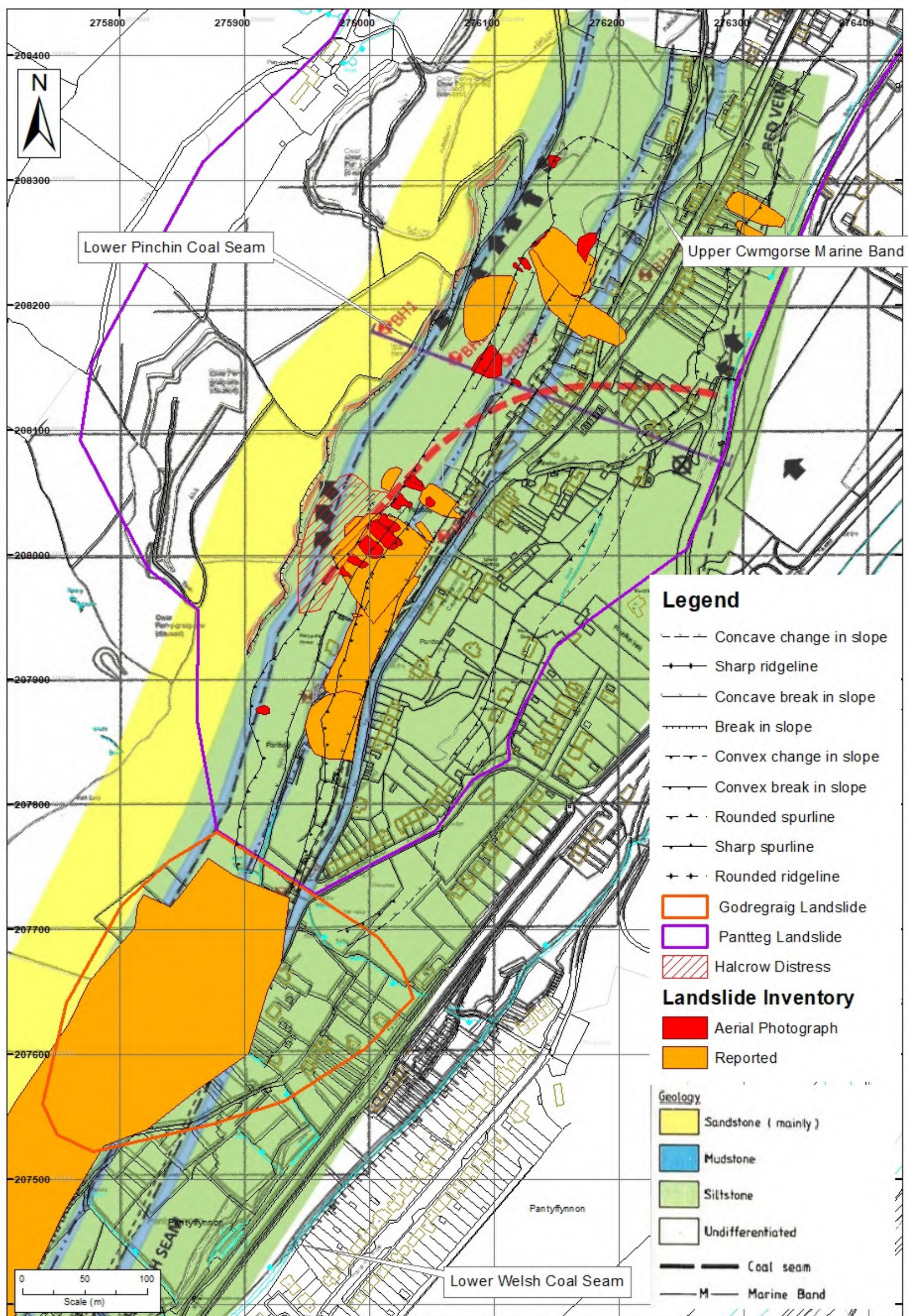
FIGURE 6A: CONCEPTUAL GROUND MODEL - INSERT FROM SECTION B-B

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Legend Superficial Deposits or Made Ground	Notes: 1. Cross Section drawn north to south, and assumes a dip direction towards due south. Boreholes presented are interpolated east-west along strike of the bedding planes. 2. Full detail of the ground conditions encountered are presented in the ESP5859e.09.2930 Vol 1 3. Topography presented is indicative only. 4. Upper Cwmgorse Marine Band is the boundary between the Upper and Middle Coal Measure units.	PROJECT: PANTTEG LANDSLIDE	
		SCALE: 1:2500 (approx. at A3)	
		FIGURE 7: STRATIGRAPHIC CROSS SECTION LINE C-C'	
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PROJECT: PANTTEG LANDSLIDE

Scale: 1:3,000 (at A3)

FIGURE 9 - SITE GEOLOGY (AFTER HALCROW, 1989)

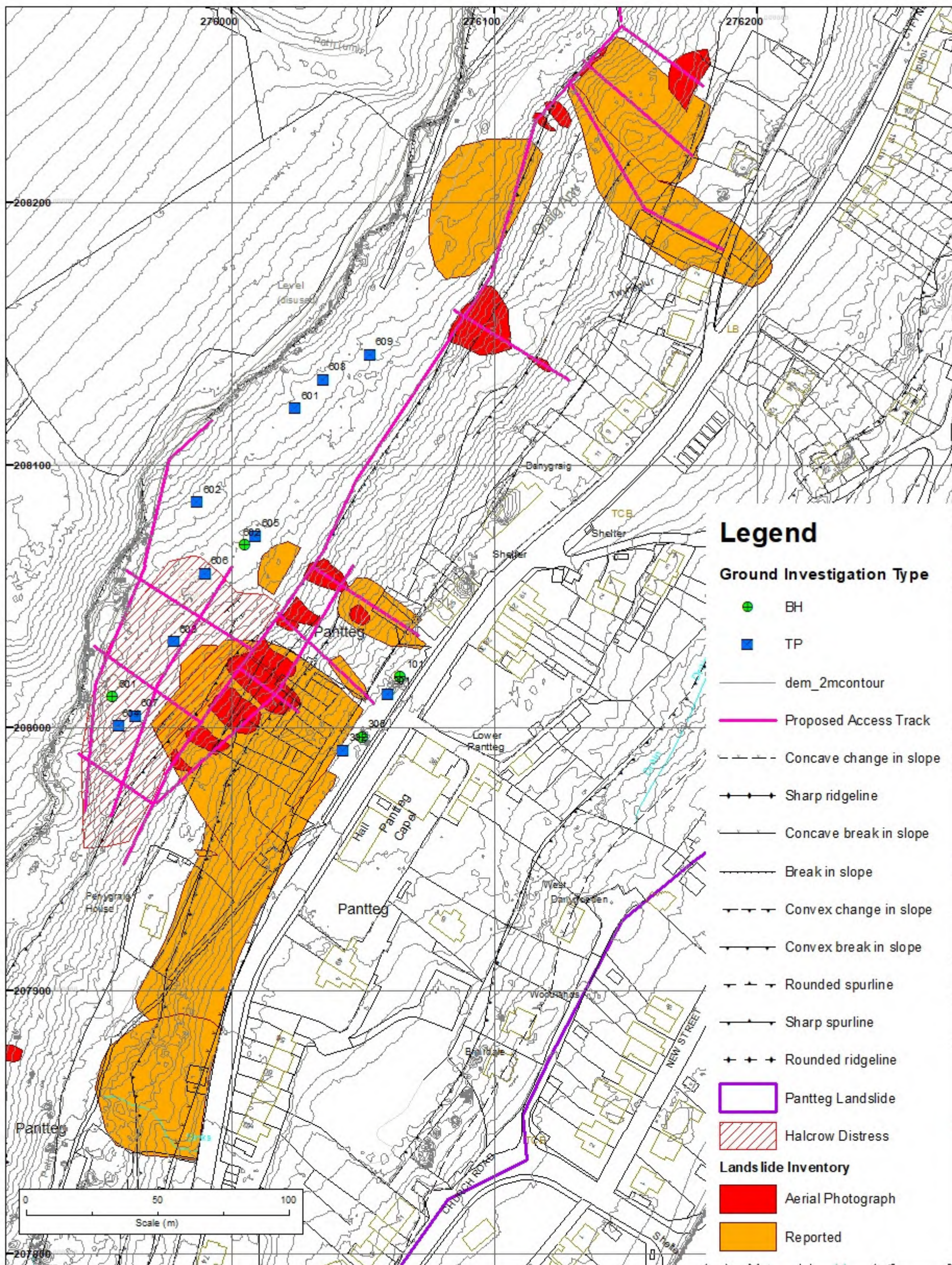
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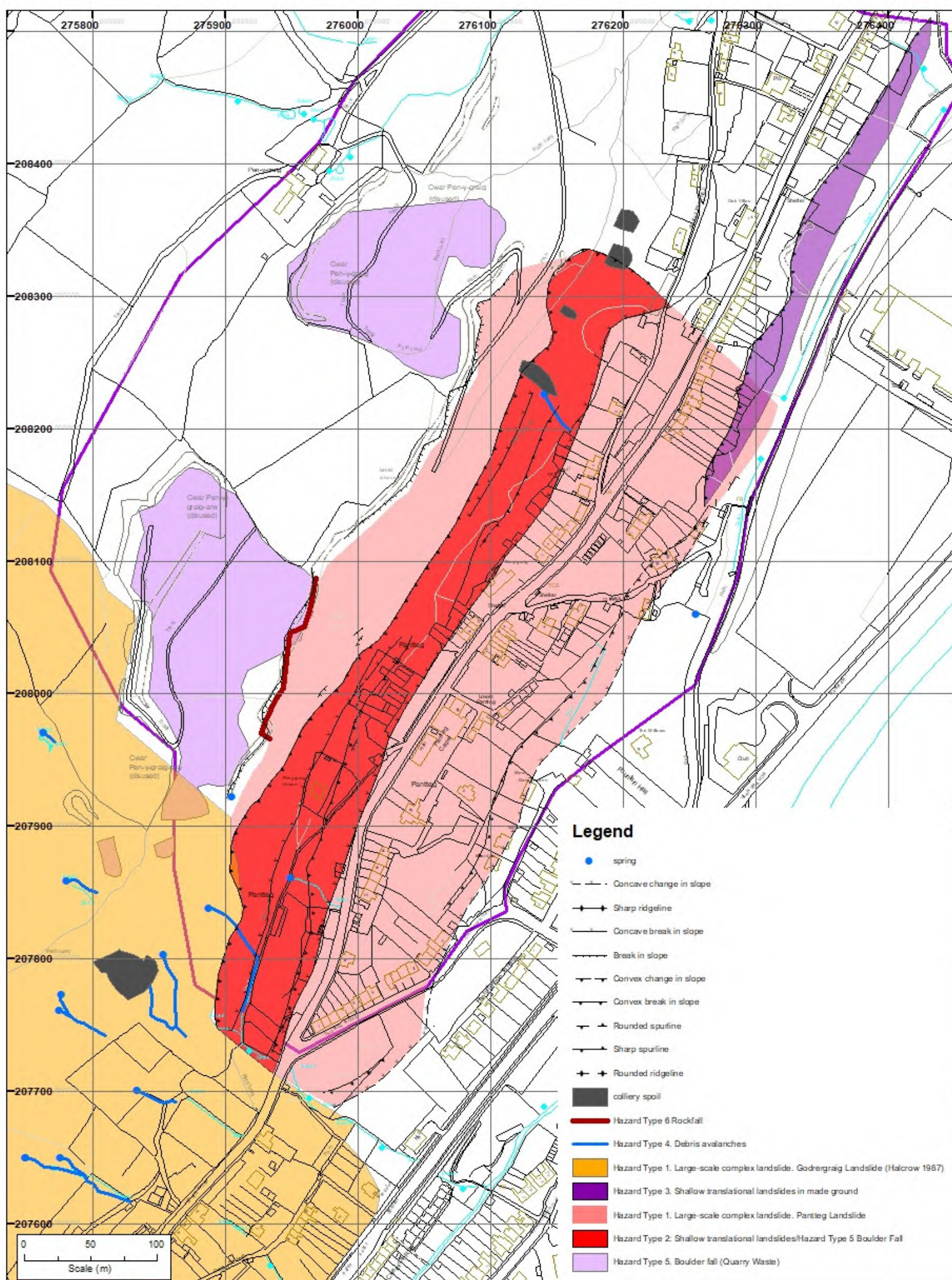
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Scale: 1:1,150 (at A3)

FIGURE 10 - GROUND INVESTIGATION

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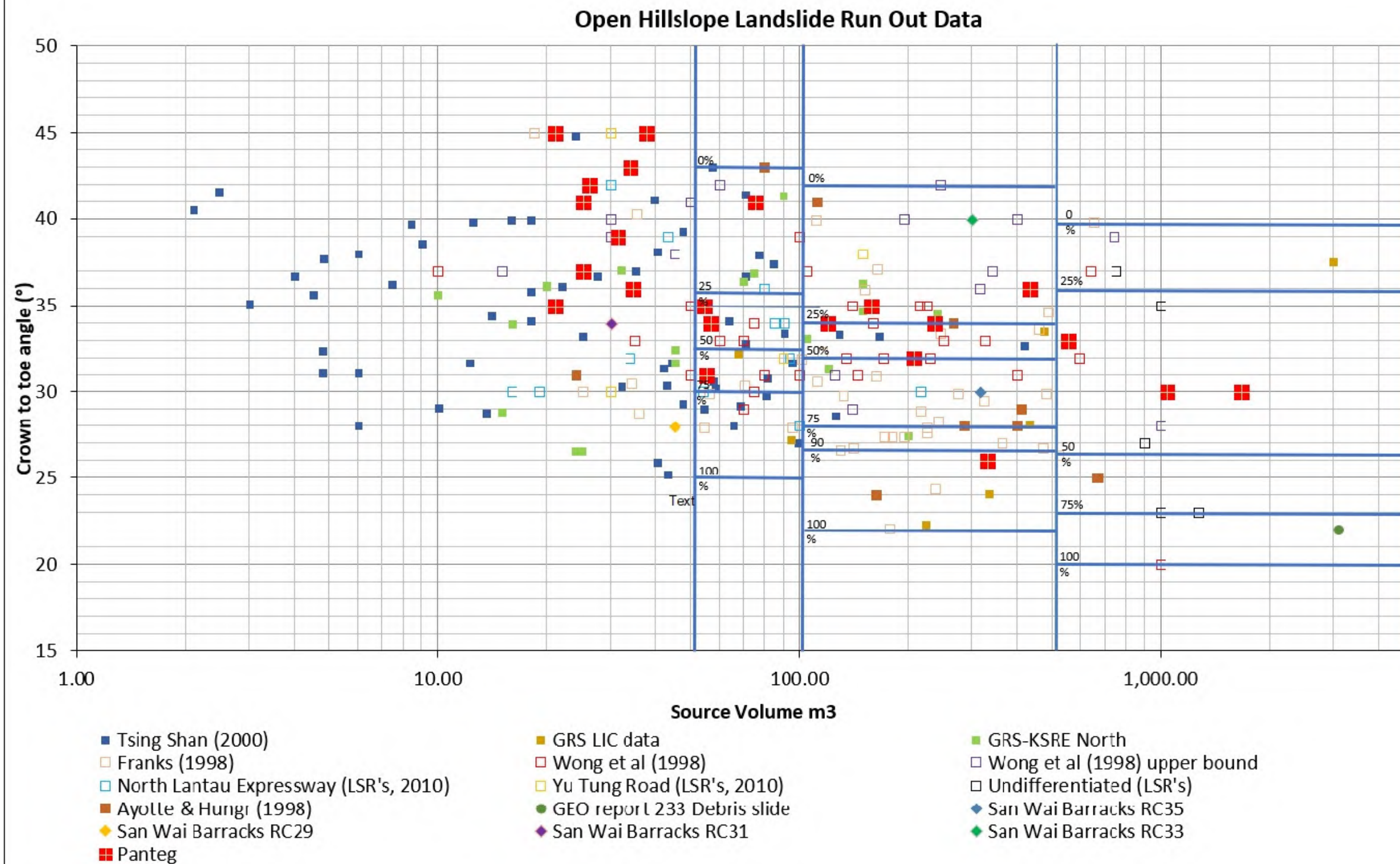
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Scale: 1:3,000 (at A3)

FIGURE 11 - HAZARD TYPES

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PROJECT: PANTTEG LANDSLIDE

FIGURE 12: LANDSLIDE RUNOUT DATA

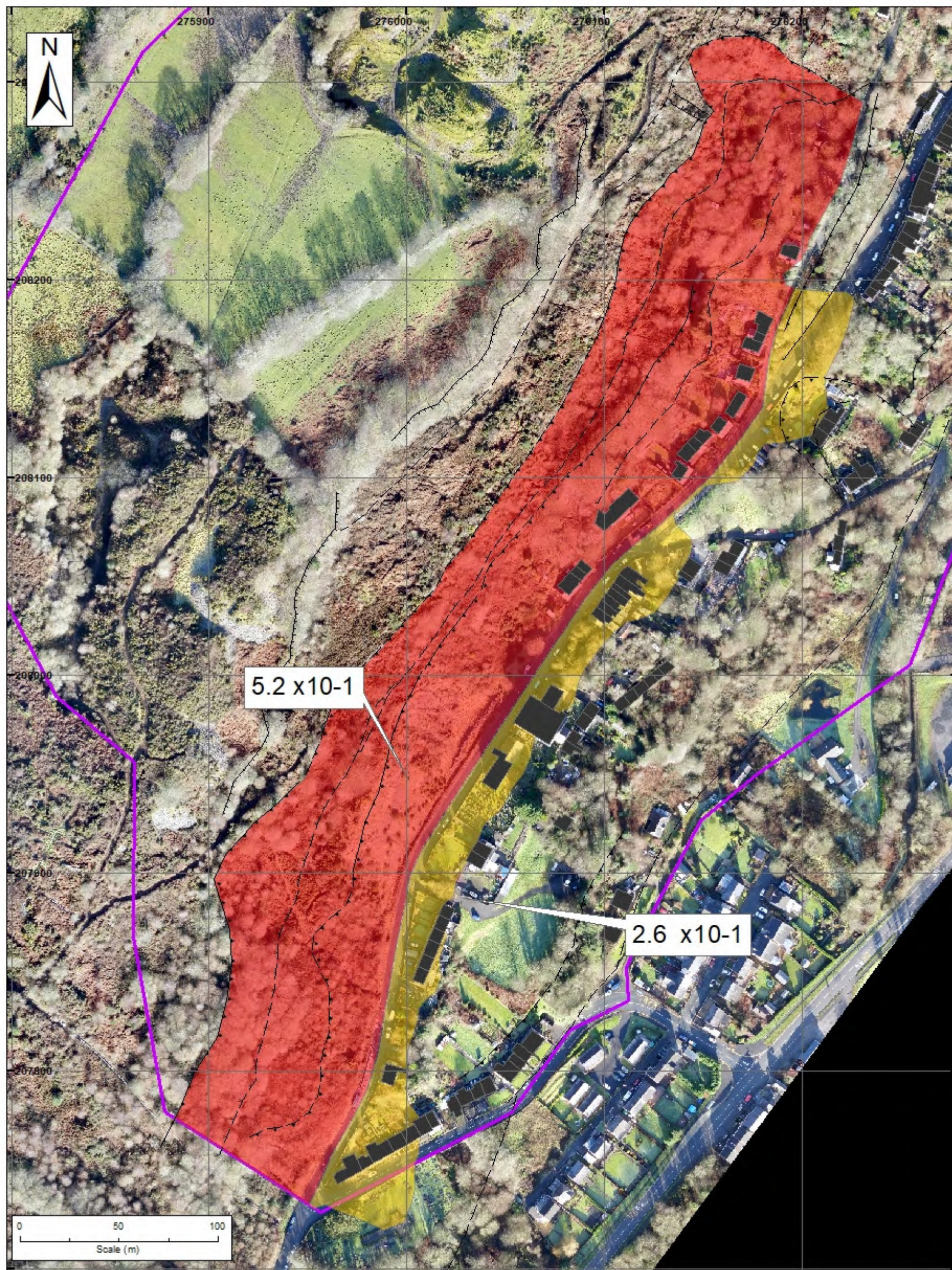


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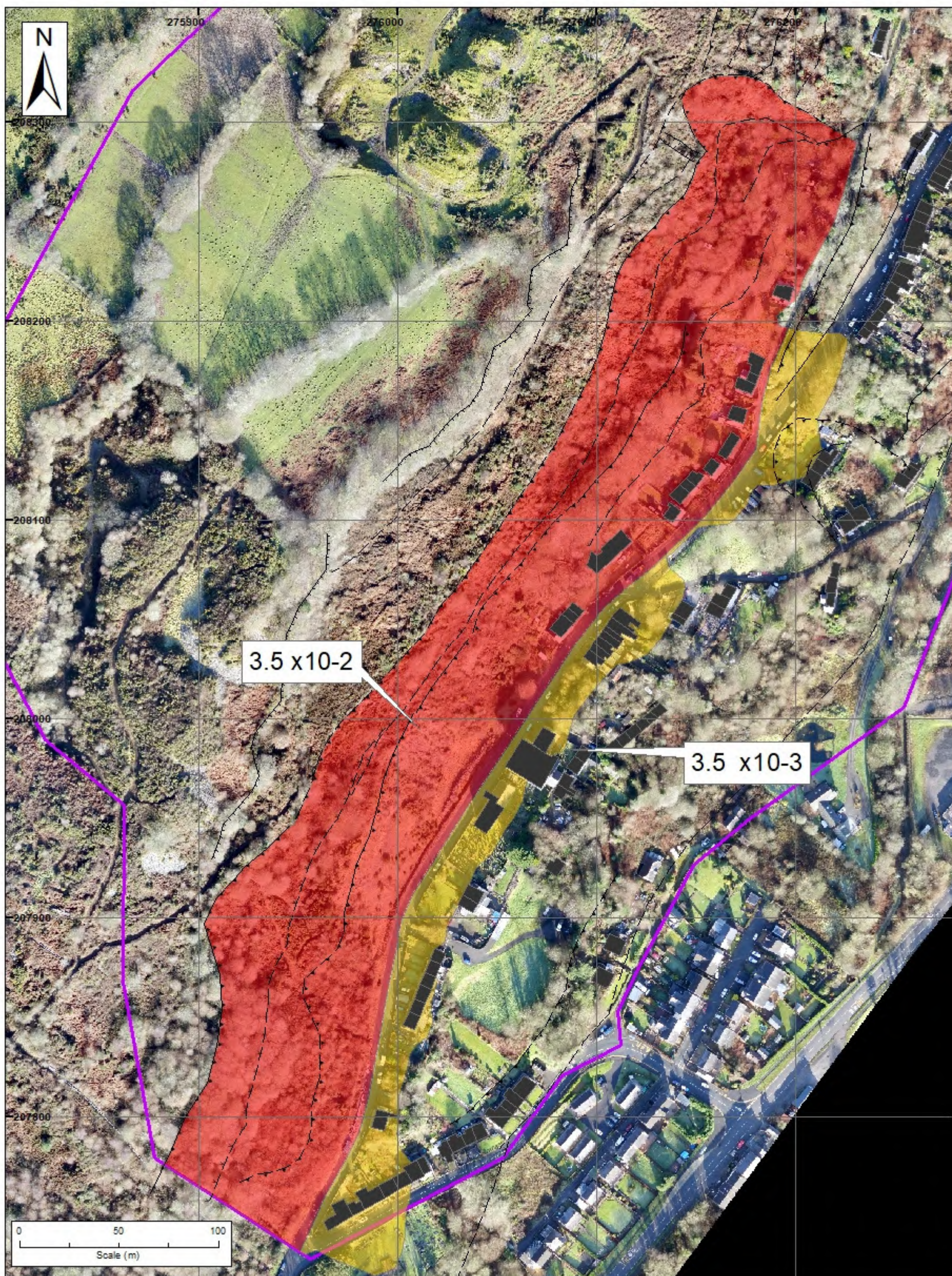
PROJECT: PANTTEG LANDSLIDE

Scale: 1:2,000 (at A3)

FIGURE 13 - HAZARD PLAN <100m³ VOLUME

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PROJECT: PANTTEG LANDSLIDE

Scale: 1:2,000 (at A3)

FIGURE 14 - HAZARD PLAN 100 - 500m³ VOLUME

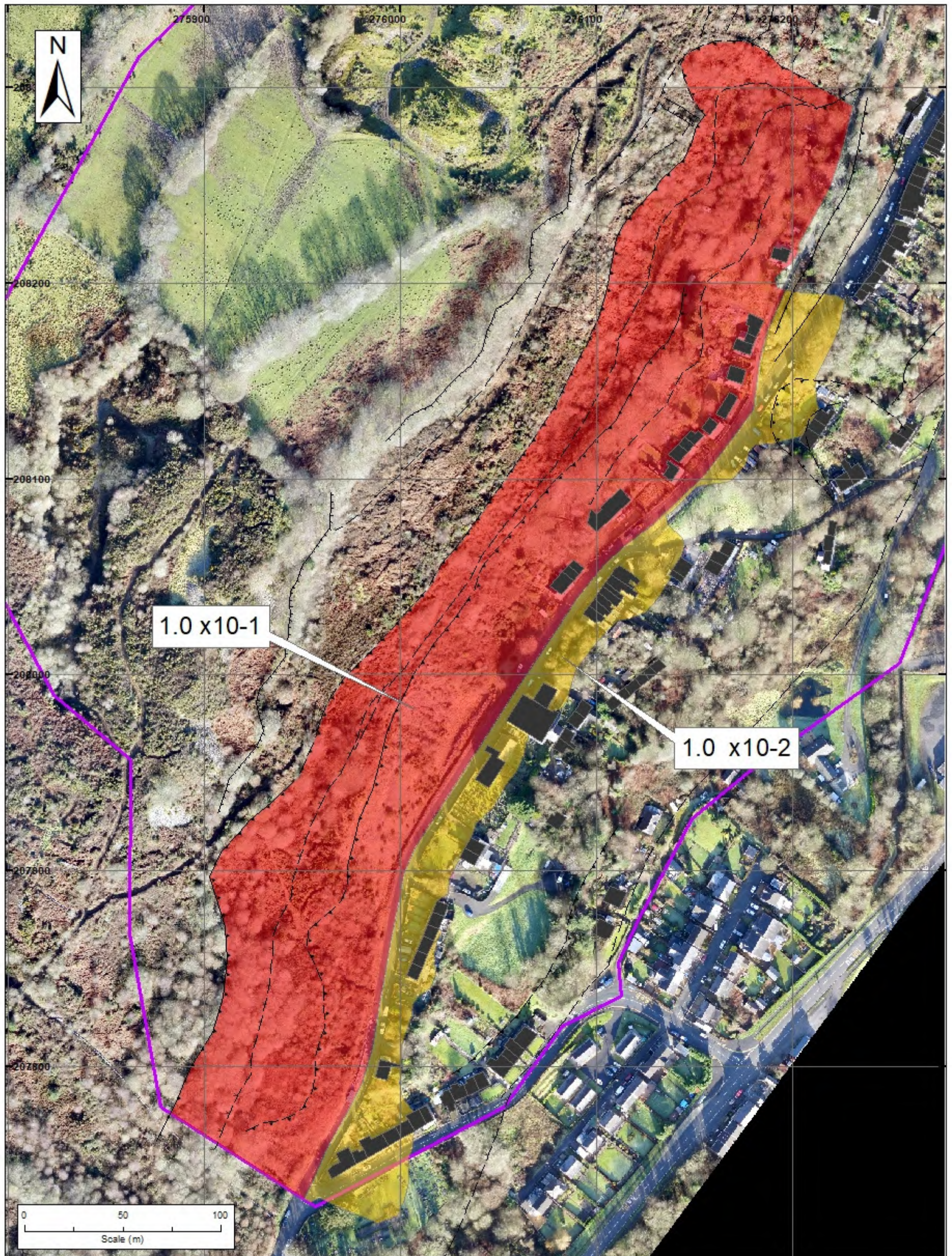
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PROJECT: PANTTEG LANDSLIDE

Scale: 1:2,000 (at A3)

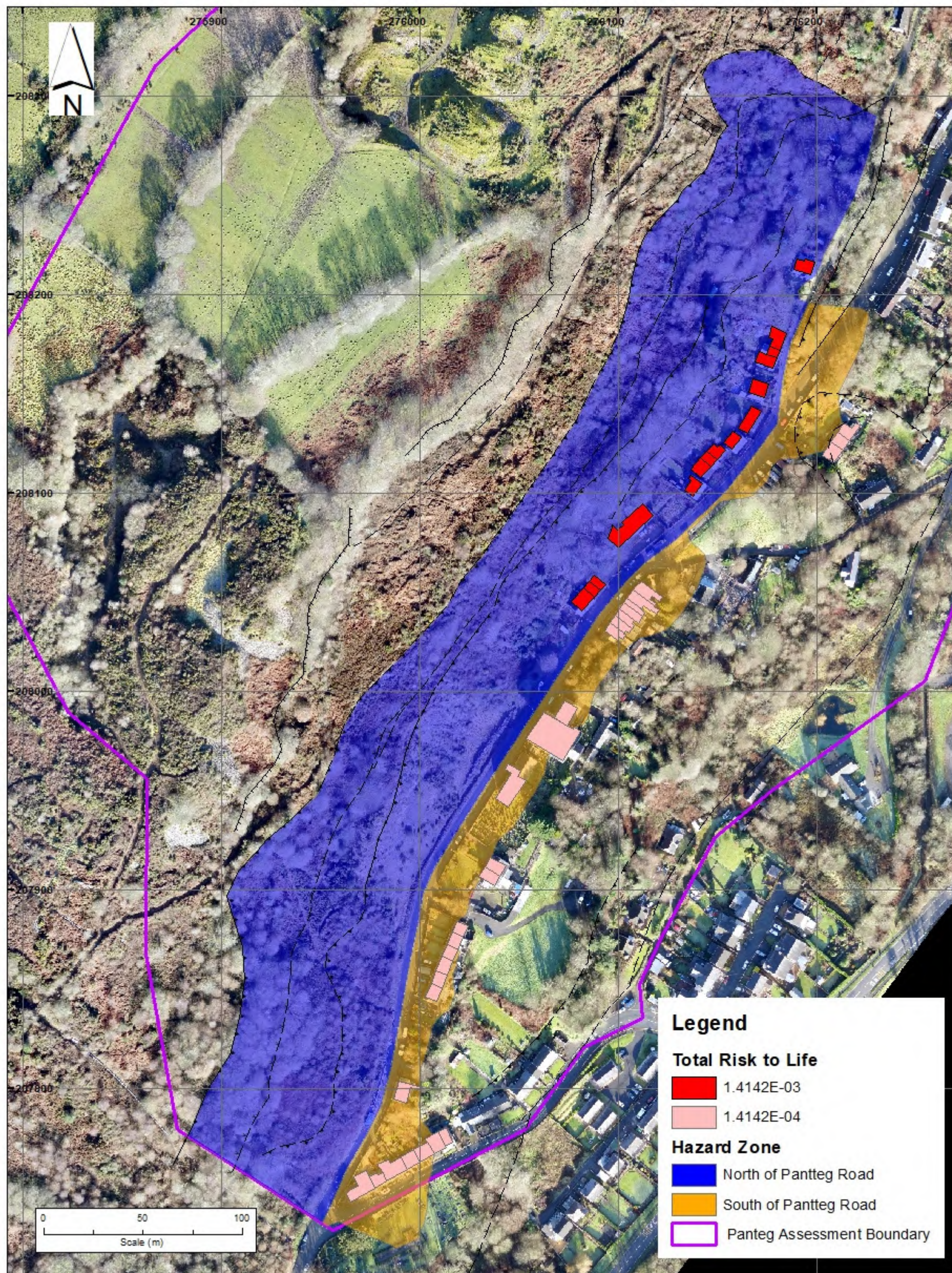
FIGURE 15 - HAZARD PLAN $>500\text{m}^3$ VOLUME

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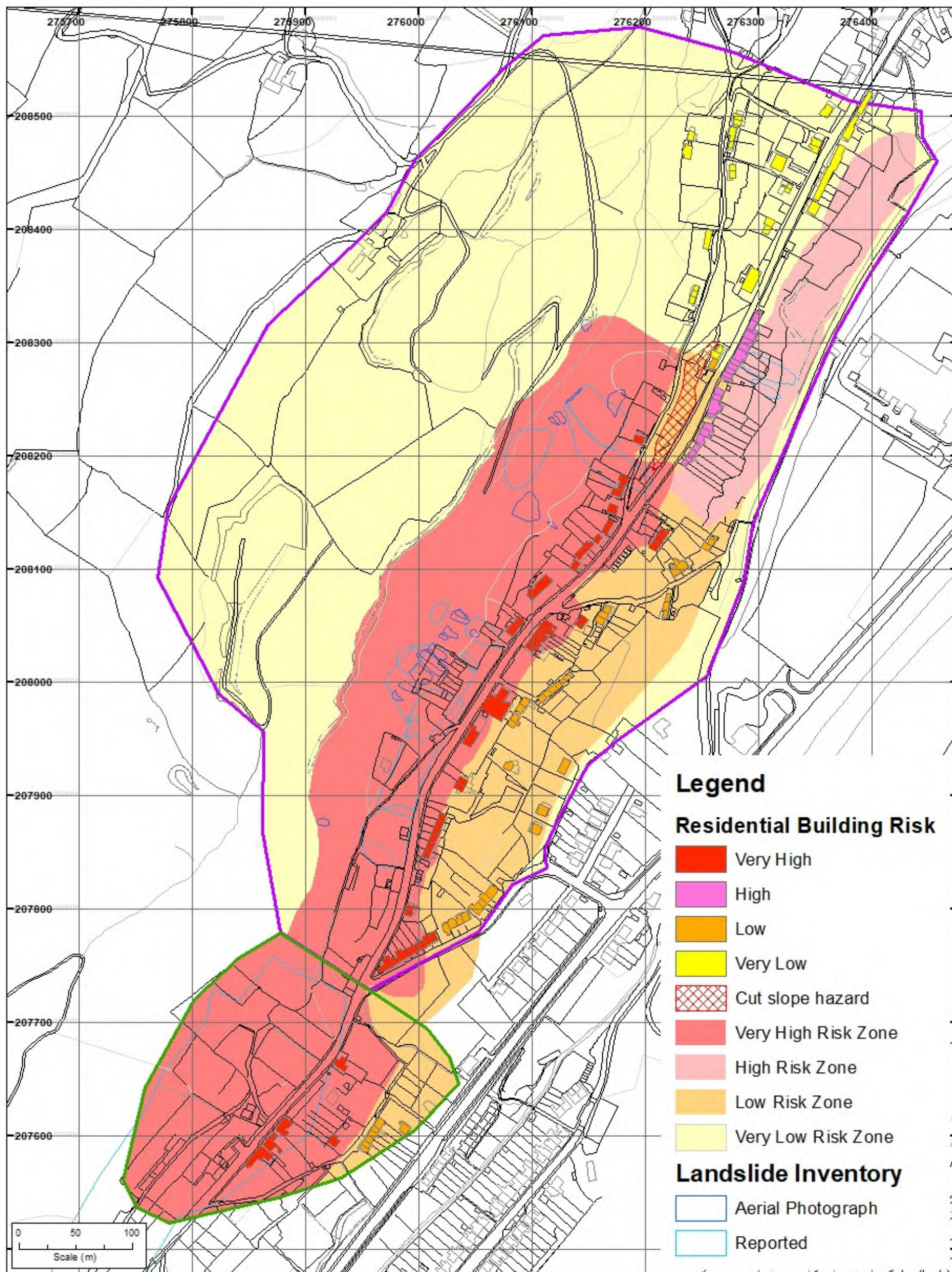
PROJECT: PANTTEG LANDSLIDE

Scale: 1:2,000 (at A3)

FIGURE 16 - TOTAL RISK (PEOPLE IN BUILDINGS)

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PROJECT: PANTTEG LANDSLIDE

Scale: 1:3,000 (at A3)

FIGURE 17 - RESIDENTIAL PROPERTY RISK

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Appendix A
Tree Condition Surveys (ArbTS)



Tree Condition Survey and Report carried out by:

ArbTS - Arboricultural Technician Services

(Tree Consultancy Services)

Stephen Lucocq *BSc (Hons), Tech Cert (Arbor.A), M.Arbor.A*

Professional Member of the Arboricultural Association

Web site: www.ArbTS.co.uk

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Tree Condition Survey and Management Work Recommendations

Date – 15th November 2017

Site – Panteg, Ystalyfera (Full Report)

Project Reference – ArbTS_385.2_Pantteg

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1.0	Introduction
2.0	The Tree Condition Survey
3.0	Tree Inspection Scope
4.0	The Trees
	4.1 Tree Data
	4.2 Tree Management Work Recommendations
	4.3 Tree Location Plan
	4.4 Legal Constraints
5.0	Recommendations
6.0	Qualifications and Further Information
7.0	Bibliography & Web Information
8.0	Appendices
	Appendix 1 Tree Survey Key
	Appendix 2 Tree Data
	Appendix 3 Tree Location Plan
	Appendix 4 Tree Photographs

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1.0 Introduction

- 1.1 The purpose of this report is to give a tree condition assessment within a study area at Panteg, Ystalyfera that are a potential risk to person or property.
- 1.2 The findings of this report provide management work recommendations with the order of work priority given to primarily address any hazardous trees.
- 1.3 The following management work recommendations have been identified as found in Appendix 2 Tree Data. Urgent & Urgent to High work priority are colour coded in red (suggested to be carried out as soon as practicable i.e. 7 days to 1 month) and High & High to Medium work priority are colour coded in yellow (suggested to be carried out within 3 to 6 months).
- 1.4 All tree work should be carried out in accordance with the *British Standard BS3998: 2010 Tree Work – Recommendations*.

2.0 The Tree Condition Survey

- 2.1 The tree condition survey was conducted by Stephen Lucocq BSc (Hons), Tech Cert (Arbor.A), M.Arbor.A. on 4th, 7th, 12th, 14th, 18th September, 3rd, 28th October and 13th November 2017.
- 2.2 All tree inspections were conducted from ground level with the use of an acoustic sounding hammer and probe. No invasive decay detective instruments were used.
- 2.3 All tree inspections were carried out in accordance with current best practise (Visual Tree Assessment) to give a systematic, consistent and transparent evaluation method to tree inspecting.
- 2.4 **Limitations of the Tree Condition Survey/Scope of works:** *Whilst every effort is made to ensure an accurate assessment of the trees condition is made during survey no responsibility can be taken for resultant damage or injury occurred by a failing tree. The survey only gives a snap shot of what is visible, not obscured or accessible on the day of survey. Please note that the findings of this report are only valid for 12 months from the date of the tree inspection. This report does not constitute to a full tree safety policy for the study area nor does it take into account any underground geological activity that may affected the structural condition of the trees.*

3.0 Tree Inspection Scope

- 3.1 The main scope of this tree inspection is to identify hazardous trees in a poor physiological or structural condition and the required work management recommendations to reduce the risk of these hazardous trees to an acceptable level as detailed by the Health and Safety Executive in Management of the risk from falling trees or branches - http://www.hse.gov.uk/foi/internalops/sims/ag_food/010705.htm.
- 3.2 The areas around main roads, occupied houses, well used formal foot paths, public used features, car parks etc. were identified as a priority areas for the tree survey.
- 3.3 Where required trees may be grouped as a whole and tree works recommended for that group.
- 3.4 The level of detail of the tree inspection may vary depending on the target occupation and the size of the tree or tree groups. For example large trees in high target occupation areas may be inspected in much greater detail than small trees in low target occupation areas.
- 3.5 Areas identified to be surveyed in the study area (yellow line) are shown on the Tree Location Plan as found in Appendix 3.

4.0 The Trees

4.1 **Tree Data** - All data regarding the trees inspected for this report can be found in Appendix 2 Tree Data.

4.2 **Tree Management Work Recommendations**

Within Appendix 2 the Tree Management Work Recommendations are colour coded for work priority. Urgent & Urgent to High work priority are colour coded in red (suggested to be carried out as soon as practicable i.e. 7 days to 1 month) and High & High to Medium work priority are colour coded in yellow (suggested to be carried out within 3 to 6 months). Other works can be identified from this list to achieve desired management objectives and timescale given for the completion of this work. **Please note** that all work must be carried out to the *British Standard 3998:2010 Tree Works Recommendation*.

4.3 **Tree Location Plan** - A Tree Location Plan can be found in Appendix 3. Trees and Tree Groups that require priority hazard work will be circled in colour. Urgent to Urgent/High priority work will be circled in red and High to High/Medium priority work circled in orange.

4.4 **Legal Constraints**

- **TPO (Tree Preservation Orders)/Conservation Areas** – The Tree Preservation Officer from the Local Planning Authority should be consulted before any work is carried out on site.
- **Protected Wildlife** – Before any tree work is carried out on site the trees should be inspected and written records taken of the activity of any protected species on site. This is to prevent the damage to any wildlife. Under the Wildlife and Countryside Act 1981 it is an offence to destroy or disturb nesting birds, if nesting birds are discovered or suspected no works can proceed and the Local Planning Authority (LPA) and Local Wildlife Trust must be notified for advice as to how to proceed. Further to this wildlife such as Bats are protected under European legislation (Countryside and Rights of Way Act 2000 and The Habitat Regulation 2009) it is an offence to recklessly, or intentionally, kill, injure or capture bats, to disturb them, or destroy, obstruct or damage any bat roosts found. If any bat activity is found then the bat conservation trust should be contacted as soon as possible (<http://www.bats.org.uk/> or 0845 1300 228). Further guidance relating to the protection of wildlife within development design is given in Welsh Assembly Government Technical Advice Note 5: Nature Conservation and Planning (2009).
- **Tree Felling Licence** – Depend on the designation of the land where the trees are located a Tree Felling Licence may be required if more than 5 cubic metres of timber are being extracted per one quarter a felling license must be obtained from Natural Resources Wales. <https://naturalresources.wales/permits-and-permissions/tree-felling-and-other-regulations/tree-felling-licences/?lang=en>

5.0 Recommendations

5.1 The detailed Tree Management Work Recommendations as found in Appendix 2 should be conducted as the priority states. Urgent & Urgent to High work priority is recommended to be carried out as soon as practicable i.e. 7 days to 1 month and High & High to Medium work priority to be carried out within 3 to 6 months. Other lower priority works can be identified by the managers of the site to achieve their desired objectives.

6.0 Further Information and Qualifications

Stephen Lucocq has been involved in Arboriculture within South Wales for nearly twenty years. He has worked as an Arborist for many of these years and has a good working knowledge of the practical side of the profession. He has always taken an active interest in all areas of Arboriculture and kept up to date with current research and developments.

Qualifications

- First Class BSc (Hons) Degree
- Arboricultural Association Technicians Certificate (Merit)
- PTI - Professional Tree Inspection (Lantra Awards)
- 2D Computer Aided Design (City and Guilds - Level 3)
- Quantified Tree Risk Assessment (QTRA) – Mike Ellison
- Visual Tree Assessment (VTA) – Mike Ellison
- Arboriculture and Bats (Lantra)
- Industrial Rope Access Trade Association (IRATA)
- Practical Arboriculture Qualifications (NPTC)

Membership

- Arboricultural Association Professional Member (M.Arbor.A)

7.0 Web Information & Bibliography

Web Information

Health and Safety Executive -

http://www.hse.gov.uk/foi/internalops/sims/ag_food/010705.htm

Arboricultural Association –

<http://www.trees.org.uk/index.php>

Bibliography

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- Shigo, A.L (1991) *Modern Arboriculture* USA; Shigo and Trees, Association
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- Strouts, R.G (2000) *Diagnosis of ill-health in trees* Edinburgh; Forestry Commission
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8.0 Appendices

Appendix 1 Tree Survey Key

- **Type** - **T** – Individual Tree, **G** – Group of tree (Used were a group of similar trees of similar condition are identified), **SA** – Tree survey area completed, **NS** – Tree survey area not completed, **R** – Row of trees, **H** – Hedgerow, **S** - Stump, **W** – Woodland
- **ID #** - Identifies the tree, group, row, hedgerow or woodland with a unique identification number. For individual tree metal identification tags are located at 1.5 metres above ground level on their trunk.
- **Tree Name** - Scientific tree name and common tree name in brackets.
- **Age** -
 - **Y** - Young – First 10 years of growth
 - **SM** - Semi Mature - Less than 1/5 of life completed
 - **EM** – Early Mature – Less than 2/5 of life completed
 - **M** - Mature – 2/5 – 5/5 of life completed
 - **OM** - Over Mature - more than 5/5 of life completed and declining
 - **V** - Veteran – Veteran trees have no precise definition but are trees considered to be of biological aesthetic or ecological value because of their age
- **Size** – A general indication of the size of the tree/s in terms of height and width.
 - **S** – Small
 - **M** – Medium
 - **L** – Large
 - **VL** – Very Large
- **Physiological Condition** - The physiological condition of the tree/s. -
 - **G** - Good
 - **F** - Fair
 - **P** - Poor
 - **D** - Dead
- **Structural Condition** - The structural condition of the tree/s -
 - **G** - Good
 - **F** - Fair
 - **P** - Poor
 - **VP** – Very poor
- **Comments** – Observations and comments
- **Management Work Recommendations** – Required tree surgery operations including further investigation of suspected defects that require more detailed assessment
- **Target Occupation** – An approximate site specific guide from High to Low as assessed on the day of the tree inspection of the risk relating to the potential for damage to a person, property or item, within an area around the tree if failure of the tree or part of the tree were to occur. It is recommended that the re-inspection of tree or groups of trees should be carried out as follows:
 - **High** – Re-inspect in 12 months or less if stated
 - **H/Medium** – Re-inspect in 24 months or as stated

- **Medium** – Re-inspect in 30 months or as stated
- **M/Low** – Re-inspect in 3 years or as stated
- **Low** - Re-inspect in 5 years or as stated

Further to this the level of detail of the tree inspection will vary depending on the target occupation and the size of the tree or groups of trees. For example large trees in high target occupation areas will be inspected in much greater detail than small trees in low target occupation areas.

(*Please note that this report is a tree condition survey with management recommendations and does not equate to a full tree safety policy for the site*)

- **Work Type** – Type of management work recommendation.
 - **Hazard** – Hazard Management - A risk to person or property from a tree with a defect or in poor condition
 - **Arb** – Arboricultural Management
 - **Landscape** – Landscape design/Management
 - **Conservation** – Wildlife/Habitat/Historic Management.
 - **Woodland** – Woodland Management
- **Work Priority** – A priority rating for management work recommendations. This is determined from an assessment on the day taking into account the target occupation around the tree, the size/part of the tree affected by the defect, the probability and foreseeable nature of the defect failing, the quality and value of the tree and other arboricultural factors. A suggested timescale for the work to be carried out is provided below:
 - **Urgent** - Work to be carried out as soon as practically possible. I.e. less than 7 days
 - **U/High** – Work to be carried out within 1 month
 - **High** – Work to be carried out within 3 months
 - **H/Medium** - Work to be carried within 6 months
 - **Medium** – Work to be carried out in 12/18 months
 - **M/Low** - Work to be carried out in 18/24 months if budget allows
 - **Low** - After consideration of management objectives

8.0 Appendices

Appendix 2 Tree Data

Tree ID #	Tree Species	Age	Size	Physiological Condition	Structural Condition	Comments	Management Work Recommendations	Target Occupation	Work Type	Work Priority
Tree Data										
G1	Acer pseudoplatanus (Sycamore), Ulmus procera (English Elm), Fraxinus excelsior (Ash)	M	M/L	Fair	Fair	tree group, eastern area in group consists of trees grown together on steep bank of approximately 60 degrees with some areas of loose surface soil / gravel noted, large drop at bottom of bank onto Cyfyng road, some larger sycamore multi-stemmed in form noted, small slender sycamore and elm noted between larger trees, trees have grown together as a group, some trees appear to have been possibly past coppiced, a number of slender tall ash noted at top (north side) of bank with no or very sparse leaf cover likely caused from ash die back, western area of group consists of some individually identified tree in the survey area and some medium sized sycamore and smaller goat willow shrub noted	due to the location of the trees on a steep bank with a large drop down to the road it is recommended that the trees in this area are coppiced to 1 metre high stumps , tree species likely to regenerate to retain structural benefits of tree roots stabilising the area, coppicing tree will significantly reduce ground movement from swaying of trees in strong winds, further to this with the likely loss of ash trees noted in the north eastern part of the group this will increase exposure to other trees from their demise which will increase the likelihood of surrounding tree failure, therefore it is recommended that this group is managed as a coppiced whole in perpetuity (10 yearly cycle of coppicing)	Medium	Hazard	Medium
G2	Acer pseudoplatanus (Sycamore), Salix caprea (Goat Willow)	M	M	Fair	Fair	tree group, spoke to Mr Ian Graham, owner of whole row 4 to 9 clees lane, he informed me that dwellings to be removed by 1st November, trees behind number 9 growing on top of 2.5 metre old stone retaining wall, multistemmed in form, likely growth from possible previous coppice management	due to demolition work it is recommended that all trees are pollard to 1 metre high stumps	M/Low	Hazard	H/Medium
G3	Salix caprea (Goat Willow)	M	M/L	Fair	Fair	tree group, two goat willow tree adjacent to 9 clees lane, generally short lived species prone to branch stem failure, included bark stem noted on north western tree with some black fungal rhizomorphs from potentially honey fungus noted on northern side of trunk, with the removal of northern tree group (treeID#G2) these trees will be left exposed and a species prone to failure	fell two goat willow	M/Low	Hazard	H/Medium

Tree ID #	Tree Species	Age	Size	Physiological Condition	Structural Condition	Comments	Management Work Recommendations	Target Occupation	Work Type	Work Priority
G4	Salix fragilis (Crack Willow)	EM	M	Poor	Poor	three slender willow trees, one dead eastern stem, sparse leaf cover on western stem, species prone to branch / stem failure	fell all three stems	M/Low	Hazard	H/Medium
T1	Fraxinus excelsior (Ash)	M	M/L	Fair	Fair	located on top of road side bank, lower western crown slightly sparse in foliage cover, trunk covered in ivy, only inspected from road side	re-inspect in 1 year to see if it goes further into decline as many ash trees in the area appear to have symptoms of ash die back disease.	M/Low	Hazard	Medium
T2	Fraxinus excelsior (Ash)	M	L	F/Poor	F/Poor	ash appears in poor health, only limited leave cover noted in crown, maybe early autumn leaf drop, unable to inspect from thick surrounding vegetation cover	re-inspect next summer to assess crown health most likely to not respond and will require felling	M/Low	Hazard	Medium
T3	Fraxinus excelsior (Ash)	M	M	Poor	F/Poor	a number of multistemmed ash trees on boundary of properties, trees inspected from a distance from rear garden of number 9 church road, Mr Hinchcliffe of 9 church road informed me that the ash trees were pollard around 15 years ago and that it had sparse small leaf cover during the summer, overhanging rear garden	re-inspect next summer to assess crown health, most likely to not respond and will require felling	Medium	Hazard	Medium
T4	X Cupressocyparis leylandii (Leyland Cyp)	EM	S/M	Fair	Fair	growing through BT lines	fell	M/Low	Arb	M/Low
T5	Salix caprea (Goat Willow)	M	M	Fair	Poor	goat willow with over extended western branch over BT lines and access road	fell	Medium	Hazard	H/Medium
T6	Acer pseudoplatanus (Sycamore)	M	M	G/Fair	N/A	large sycamore in corner of garden of number 1 pantteg , unable to inspect sycamore due to thick surrounding vegetation, crown appears healthy, spoke with Mrs Ann Marie Earland regarding the tree and she had not observed any major issues with the tree		M/Low		

Tree ID #	Tree Species	Age	Size	Physiological Condition	Structural Condition	Comments		Management Work Recommendations	Target Occupation	Work Type	Work Priority
T7	Fraxinus excelsior (Ash)	M	L	G/Fair	Fair		large broad tree, old split noted in lower south westerly branch with surrounding callus growth, tree overhangs footpath that appears to get limited use	Arborist to inspect split in lower south westerly branch, if assessed to be unstable (i.e. active split) reduce split south westerly branch to leave 3metre section of large branch	M/Low	Hazard	Medium
T294	Acer pseudoplatanus (Sycamore)	M	M	G/Fair	F/Poor		twin stem with large area of dysfunctional wood noted around buttress, some surrounding edge callus growth noted, heavy ivy cover	fell to 2 metre high trunk, trunk likely to regenerate	Medium	Hazard	H/Medium
T295	Salix caprea (Goat Willow)	M	M	Fair	Poor		twin stem split at union, directional weight towards road, some surrounding callus edge growth noted, species prone to stem failure	fell to retain main trunk, trunk likely to regenerate and coppice any exposed slender trees left from removal of willow tree	Medium	Hazard	High
T296	Acer pseudoplatanus (Sycamore)	M	M/L	G/Fair	F/Poor		multistems growing from trunk, signs of historic root plate lift with numerous amounts of surface roots noted, weight direction towards the road	fell to 2 metre high trunk, trunk likely to regenerate	Medium	Hazard	H/Medium
T297	Acer pseudoplatanus (Sycamore)	M	M	G/Fair	Fair		twin leader stem from 2 metres, both slender and upright in form, with the removal of adj sycamore this tree with be left exposed	fell to 2 metre high trunk, trunk likely to regenerate, fell goat willow noticed to the north fell to one metre high trunk	Medium	Hazard	H/Medium
T298	Acer pseudoplatanus (Sycamore)	M	M	G/Fair	Fair		multistem from ground level, slender and upright in form, likely to be from coppiced growth, with the removal of this tree will leave adjacent hazel exposed	fell to ground level, trunk likely to regenerate, hazel noticed to the north fell to one metre trunk	Medium	Hazard	H/Medium
T299	Fraxinus excelsior (Ash)	M	M/L	Poor	N/A		unable to inspect tree due to surrounding vegetation cover, eastern side of crown has no leaf coverd and western side has fair leaf cover, tree id tag on track side electrical post, electrical lines close to trunk, area of chicken huts noted under tree	re-inspect next summer to assess crown health, most likely to not respond and will require felling	M/Low	Hazard	Medium
T300	Fraxinus excelsior (Ash)	EM	S/M	F/Poor	Fair	Low bud/leaf density.		re-inspect in 12months	H/Medium	Hazard	M/Low

Tree ID #	Tree Species	Age	Size	Physiological Condition	Structural Condition	Comments	Management Work Recommendations	Target Occupation	Work Type	Work Priority
T316	Fraxinus excelsior (Ash)	M	M/L	Dead	F/Poor	appears to be dead when inspected from adjacent garden, with removal of adjacent sycamore tree it is recommended to remove this tree at the same time	fell	Medium	Hazard	H/Medium
T317	Acer pseudoplatanus (Sycamore)	M	M/L	Fair	F/Poor	area of decay noted on southern and eastern buttress with minor surrounding callus growth and what appears to be buckling on southern side of buttress with predominant weight of tree to the south, leaves slightly small and slightly sparse cover	fell to 1 metre stump to allow to regenerate stem and reduce any exposed lateral branches on adjacent trees to minimise branch failure from removal of tree	Medium	Hazard	H/Medium
T318	Populus spp (Poplar spp)	OM	M	F/Poor	Poor	hung up in southern trees, top appears to have failed, tree located in low target occupied area but possible potential to slide down slope if tree falls to ground level	fell, contact Roger Morris (contact details to be provided) regarding arranging to carry out tree works at Dan y graig	Low	Hazard	H/Medium
T319	Robinia pseudoacacia (Locust Tree)	OM	M	Fair	Poor	large split at base, suppressed and slender in form	fell, contact Roger Morris (contact details to be provided) regarding arranging to carry out tree works at Dan y graig	Medium	Hazard	H/Medium
T320	Fraxinus excelsior (Ash)	M	L	F/Poor	F/Poor	ash tree appears in poor health, only limited leaf cover noted in crown, maybe be due to early autumn leaf drop or ash die back disease	re-inspect next summer to assess crown health, most likely to not respond and will require felling	M/Low	Hazard	Medium
T321	Picea abies (Norway Spruce)	M	M	F/Poor	F/Poor	sparse needle cover	fell	Medium	Hazard	Medium
T322	Fraxinus excelsior (Ash)	M	M	F/Poor	F/Poor	ash tree appears in poor health, only limited leaf cover noted in crown, maybe early autumn leaf drop or ash dieback disease, also small road side ash noted with sparse foliage cover	re-inspect next summer to assess crown health, most likely to not respond and will require felling	M/Low	Hazard	Medium
T323	Acer pseudoplatanus (Sycamore)	M	M	F/Poor	F/Poor	located next to open grass area that appears to get low use i.e. low target occupation, bark flake and dysfunction noted on trunk with some surrounding callus growth noted, crown die back noted	fell	M/Low	Hazard	M/Low

Tree ID #	Tree Species	Age	Size	Physiological Condition	Structural Condition	Comments		Management Work Recommendations		Target Occupation	Work Type	Work Priority
T402	Salix caprea (Goat Willow)	SM	S/M	Fair	F/Poor		small goat willow stem regrown from collapsed trunk		fell	M/Low	Hazard	H/Medium
T403	Acer pseudoplatanus (Sycamore)	M	M	Dead	Poor		dead stem and some living stems from possible former coppiced tree, appear to be not in falling distance of southern access track but use of northern rear garden uncertain		fell dead and living stems	M/Low	Hazard	H/Medium
T533	Acer pseudoplatanus (Sycamore)	M	M/L	G/Fair	Fair		Inspected on 13th November 2017, large broad sycamore tree, bark flake noted on northern side of stem union with surrounding active callus growth noted, further bark flake noted on southern side of buttress, a broad buttress with adapted growth noted			Low		

Survey Areas Completed

SA1	Quercus robur (Common Oak), Salix caprea (Goat Willow), Acer pseudoplatanus (Sycamore), Betula pendula (Silver Birch)	N/A	N/A	N/A	N/A		Surveyed on 13th November 2017, Trees located along top of cliff growing from top or side of upper rock face, some areas not safe to access to fully inspect trees, trees inspected from inside of fencing or on paths where access was safe to do so, mainly consisted of large old oaks growing from top of rock face which appear to have adapted growth as required to maintain their structural stability, trees have grown together as a large long group and tree crowns are generally compact in form			Low		
SA 2	Salix caprea (Goat Willow), Acer pseudoplatanus (Sycamore)	N/A	N/A	N/A	N/A		Surveyed Area on 4th, 7th, 14th September, 28th October 2017, traversed the southern area near to top of high retaining wall to exit at the near end of the survey area onto the northern lane, trees over 150mm diameter at 1.5metres above ground level inspected adjacent to road with the potential to fall into road, trees inspected where access, vegetation and terrain allows			H/Medium		

Tree ID #	Tree Species	Age	Size	Physiological Condition	Structural Condition	Comments	Management Work Recommendations	Target Occupation	Work Type	Work Priority
SA 3	Acer pseudoplatanus (Sycamore), Fraxinus excelsior (Ash)	N/A	N/A	N/A	N/A	Surveyed area on 7th September 2017, trees along southern boundary to road inspected over 150mm diameter where access allows, if access was not possible physiological health of tree assess from leaf cover		M/Low		
SA 4	Fraxinus excelsior (Ash), Salix caprea (Goat Willow), Betula pendula (Silver Birch)	N/A	N/A	N/A	N/A	Surveyed area on 12th September 2017, area of mainly self seeded trees, many small young dead ash dead noted from potentially ash die back, trees adjacent to property and road inspected, access to some areas limited by terrain and surrounding vegetation		H/Medium		
SA 5	Acer pseudoplatanus (Sycamore), X Cupressocyparis leylandii (Leyland Cyp), Fraxinus excelsior (Ash), Pinus sylvestris (Scots Pine)	N/A	N/A	N/A	N/A	Surveyed area on 12th September 2017, trees located at the rear gardens of the properties, access to some areas limited by steep terrain and surrounding vegetation, trees within falling distance of occupied gardens inspected as access allowed		Medium		
SA 6	Fraxinus excelsior (Ash), Sorbus aucuparia (Rowan), Prunus avium (Wild Cherry)	N/A	N/A	N/A	N/A	Surveyed area on 12th September 2017, appears to be a semi formally planted area of trees with grass ground cover, trees located on bank sloping to the south, northern road side trees of higher target occupation than the rest of trees in survey area		H/Medium		
SA 7	Betula pendula (Silver Birch), Acer pseudoplatanus (Sycamore)	N/A	N/A	N/A	N/A	Surveyed area on 12th September 2017, Trees only inspected from road side due to area of thick scrub consisting of road side buddleia. No major trees of note that required access to be obtained.		Medium		

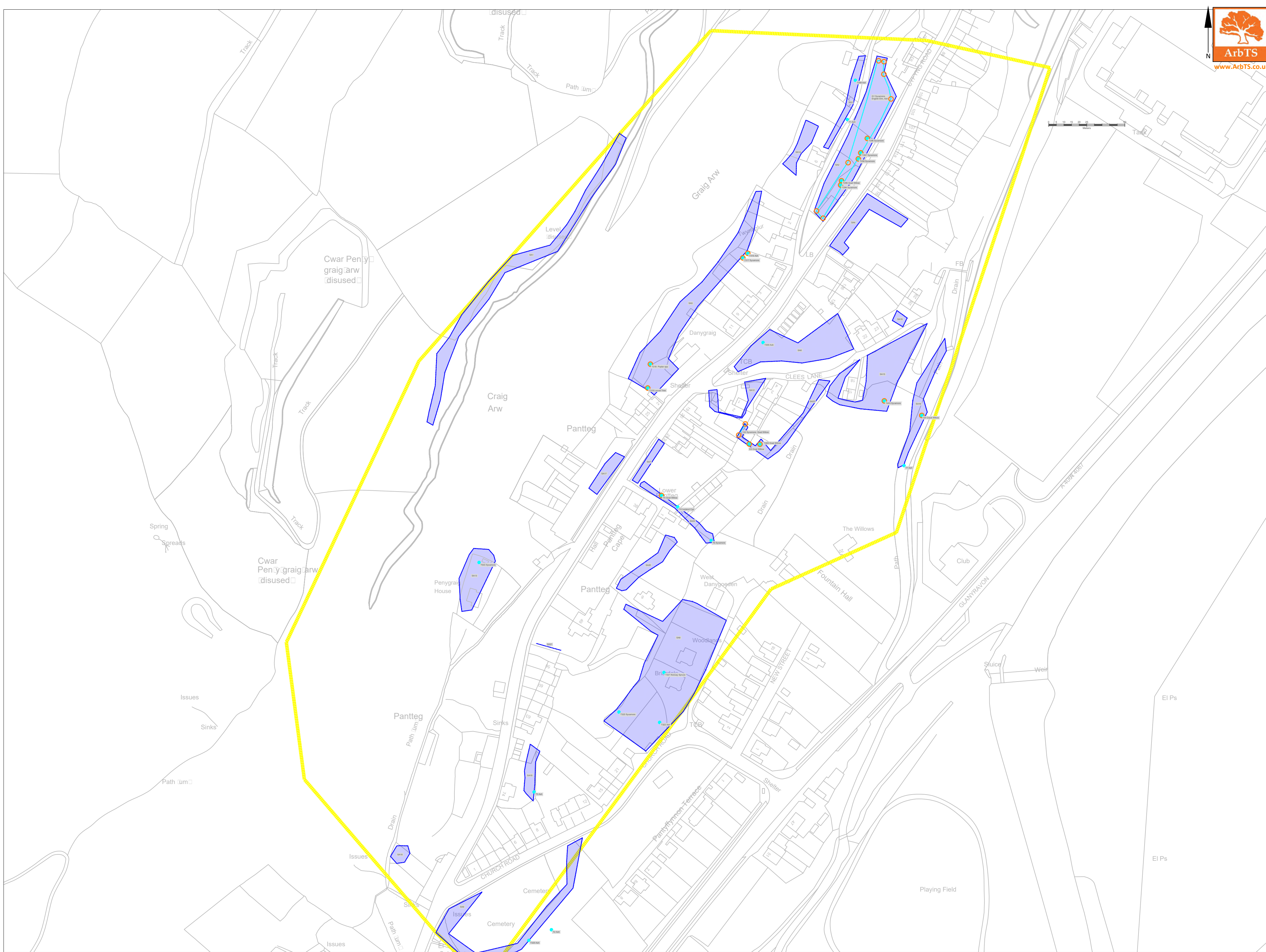
Tree ID #	Tree Species	Age	Size	Physiological Condition	Structural Condition	Comments	Management Work Recommendations	Target Occupation	Work Type	Work Priority
SA 8	Acer pseudoplatanus (Sycamore), Fraxinus excelsior (Ash), Picea abies (Norway Spruce)	N/A	N/A	N/A	N/A	Surveyed area on 18th September 2017, some ash noted in survey area with sparse crown likely to be caused by ash die back disease, some sycamore on northern edge of survey area noted with sparse foliage cover but located in low target occupied area, Occupier of Briardale house informed me that next month fir trees are to be felled, Occupier of Woodlands house informed that some thinning of rear garden/woodland area of conifer, sparse leaf covered ash and goat willow will be carried out.		H/Medium		
SA 9	Taxus baccata (Yew), Fraxinus excelsior (Ash), Salix caprea (Goat Willow), Aesculus hippocastanum (Horse Chestnut)	N/A	N/A	N/A	N/A	Surveyed area on 14th September 2017, area of trees around cemetery boundary and road inspected, western public footpath noted on boundary of survey area, some small ash in this area with signs of ash die back disease		M/Low		
SA 10	Fraxinus excelsior (Ash), Acer pseudoplatanus (Sycamore), Betula pendula (Silver Birch)	N/A	N/A	N/A	N/A	Surveyed area on 14th September 2017, trees inspected from rear garden of number 9 church road; trees on higher northern level, ash identified as possible suffering from ash die back, also inspected from with higher level property, row of multi-stemmed trees from previous coppicing works, high surrounding vegetation and trees located on steep bank limiting the extent of the tree inspection		Medium		
SA 12	Acer pseudoplatanus (Sycamore), X Cupressocyparis leylandii (Leyland Cyp)	N/A	N/A	N/A	N/A	Surveyed area on 3rd October 2017		M/Low		
SA13	Acer pseudoplatanus (Sycamore), Corylus avellana (Hazel)	N/A	N/A	N/A	N/A	Surveyed on 13th November 2017		Low		

Tree ID #	Tree Species	Age	Size	Physiological Condition	Structural Condition	Comments	Management Work Recommendations	Target Occupation	Work Type	Work Priority
SA14	Aesculus hippocastanum (Horse Chestnut), Pinus sylvestris (Scots Pine), Salix caprea (Goat Willow)	N/A	N/A	N/A	N/A	Surveyed on 13th November 2017, only trees around dwelling inspected where access allows		M/Low		
SA 15	Corylus avellana (Hazel), Salix caprea (Goat Willow)	M	S/M	Fair	Fair	Surveyed on 3rd October 2017, mainly consists of elapsed hazel coppice and some goat willow, some medium sized ash and sycamore noted near to southern edge of survey area		Medium		
SA 16	Salix caprea (Goat Willow), Acer pseudoplatanus (Sycamore), Corylus avellana (Hazel), Fraxinus excelsior (Ash)	M	M	Fair	Fair	Surveyed area on 3rd October 2017, mainly consists of elapsed hazel coppice and some willow and sycamore and large ash, may be located outside of study area		M/Low		
SA 17	Quercus robur (Common Oak)	N/A	N/A	N/A	N/A	Surveyed area on 12th September 2017, group of three trees		H/Medium		
SA 18	Fraxinus excelsior (Ash)	N/A	N/A	N/A	N/A	Surveyed area on 14th September 2017, one large ash noted in tree survey area twin stem, crown appears normal in leaf cover		M/Low		
SA 19	Salix caprea (Goat Willow), Acer pseudoplatanus (Sycamore)	EM	S/M	Fair	Fair	Surveyed area 3rd October 2017, group of one goat willow and one sycamore		Medium		
SA 20	X Cupressocyparis leylandii (Leyland Cyp)	N/A	N/A	N/A	N/A	Surveyed area on 3rd October, mainly consisting of semimature medium sized cypress trees along southern boundary of chapel, some areas limited in inspection from barbed wire fence and surrounding vegetation		M/Low		
SA 21	Acer pseudoplatanus (Sycamore)	N/A	N/A	N/A	N/A	Surveyed area of 3rd October 2017, small row of multistemmed sycamore		M/Low		

Tree ID #	Tree Species	Age	Size	Physiological Condition	Structural Condition	Comments	Management Work Recommendations	Target Occupation	Work Type	Work Priority
SA 22	Betula pendula (Silver Birch), Salix caprea (Goat Willow)	N/A	N/A	N/A	N/A	Surveyed area on 3rd October 2017, unable to gain access to northern area of survey area due to high wall and thick surrounding vegetation		Medium		
SA 23	Salix caprea (Goat Willow), Acer pseudoplatanus (Sycamore), Fraxinus excelsior (Ash)	N/A	N/A	N/A	N/A	Surveyed area on 3rd October 2017, trees located on boundary of 4 to 9 clees road		Medium		

8.0 Appendices

Appendix 3 Tree Location Plan





ArbTS
www.ArbTS.co.uk

Tree Location Plan

Site - Pantteg

Project Ref - 385.2

Scale - 1:11500 @ A2

Legend

Individual Tree

- Tree ID (T-Individual Tree)
- Tree ID (G-Grouped Trees)
- Tree Species (Common Tree Name Shown)

Tree Survey Area

- Tree Survey Area Completed
- Tree Survey Area ID

Tree

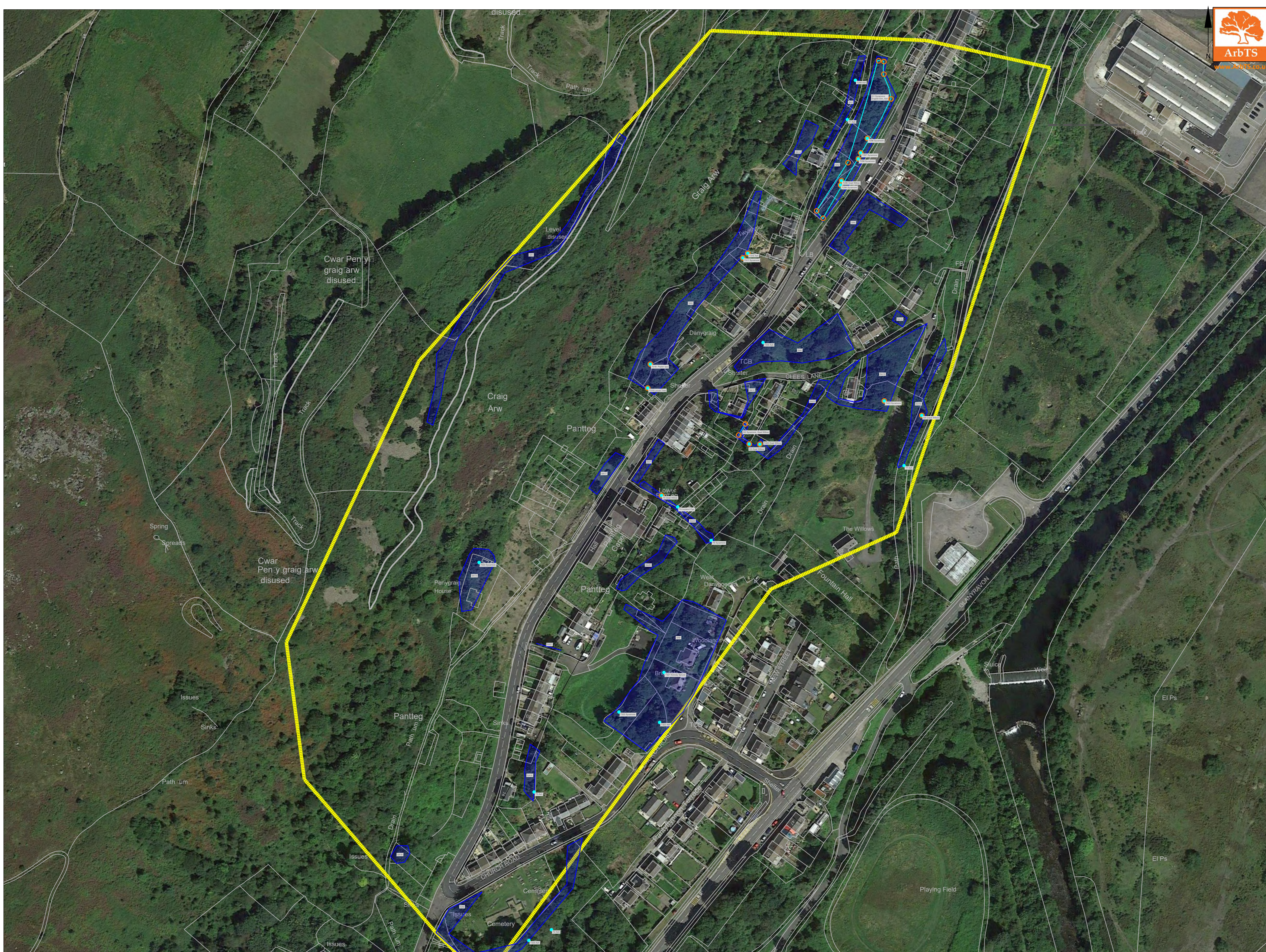
Individual Trees

- Urgent: Within 7 days to Urgent: High: Within 31 days: Work Priority
- High: Within 3 Months to High: Medium: Within 6 Months: Work Priority

Grouped Trees

- Urgent: Within 7 days to Urgent: High: Within 31 days: Work Priority
- High: Within 3 Months to High: Medium: Within 6 Months: Work Priority

(*Please see Appendix 2 - Tree data for all tree survey details including all management recommendations*)



Tree Location Plan

Site - Pantteg

Project Ref - 385.2

Scale - 1:1500 @ A2

Legend

Individual Tree

- Tree ID (T-Individual Tree)
- Tree Species (Common Tree Name Shown)
- Tree ID (G-Grouped Trees)
- Tree Species (Common Tree Name Shown)

Tree Survey Area

- Tree Survey Area Completed
- Tree Survey Area ID

Tree

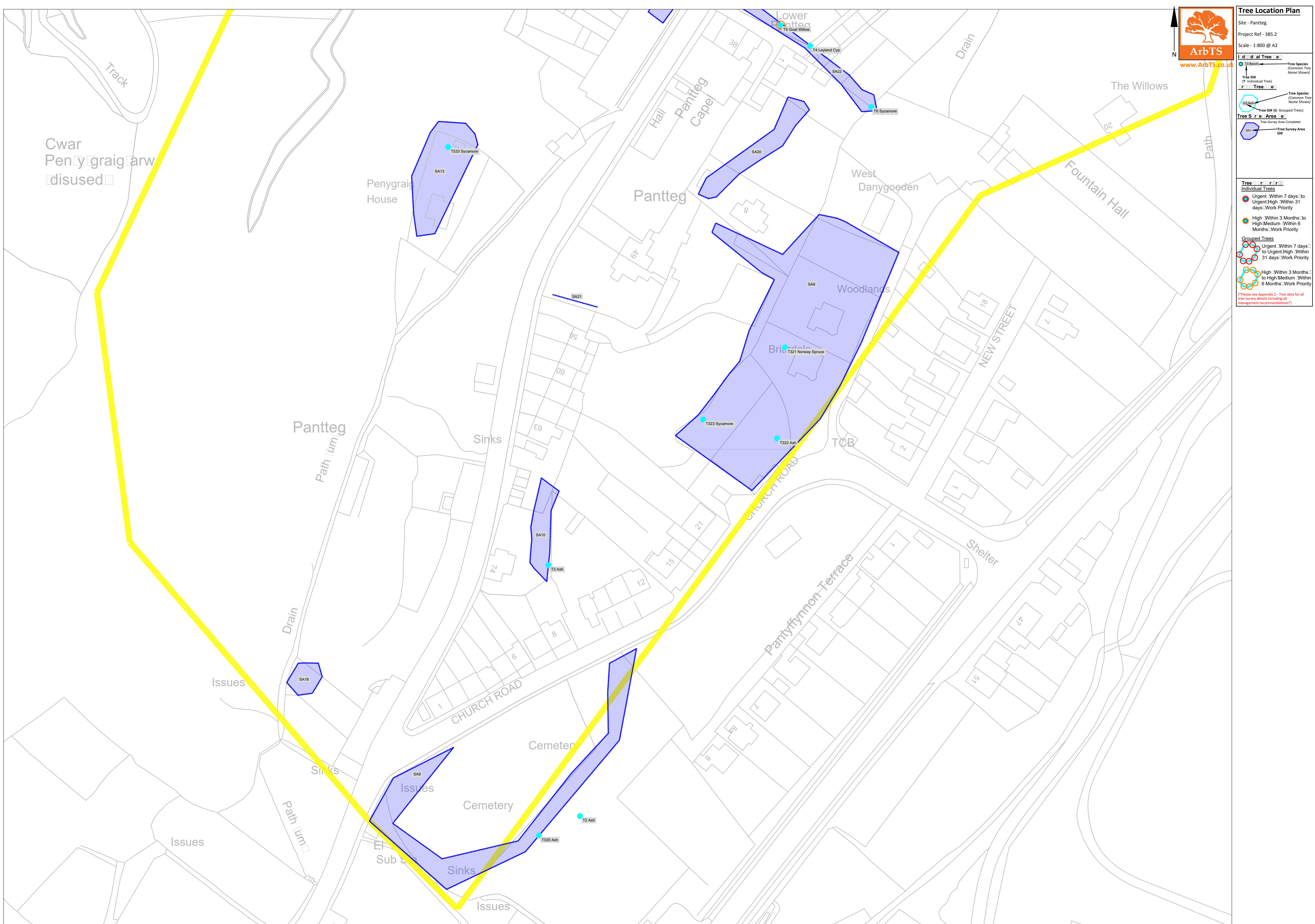
Individual Trees

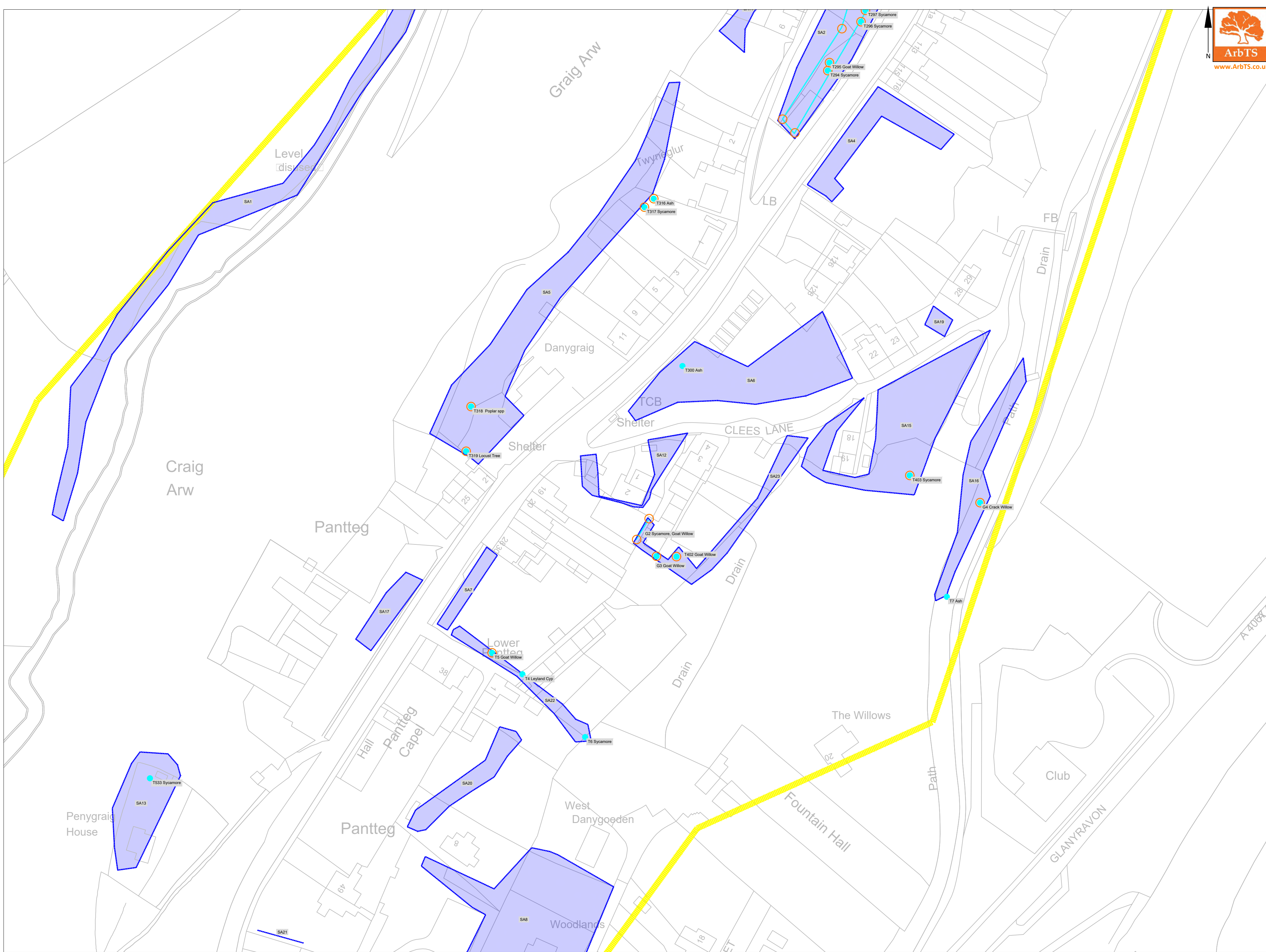
- Urgent: Within 7 days: to Urgent: High: Within 31 days: Work Priority
- High: Within 3 Months: to High: Medium: Within 6 Months: Work Priority

Grouped Trees

- Urgent: Within 7 days: to Urgent: High: Within 31 days: Work Priority
- High: Within 3 Months: to High: Medium: Within 6 Months: Work Priority

(*Please see Appendix 2 - Tree data for all tree survey details including all management recommendations*)





Tree Location Plan
Site - Pantteg
Project Ref - 385.2
Scale - 1:800 @ A2

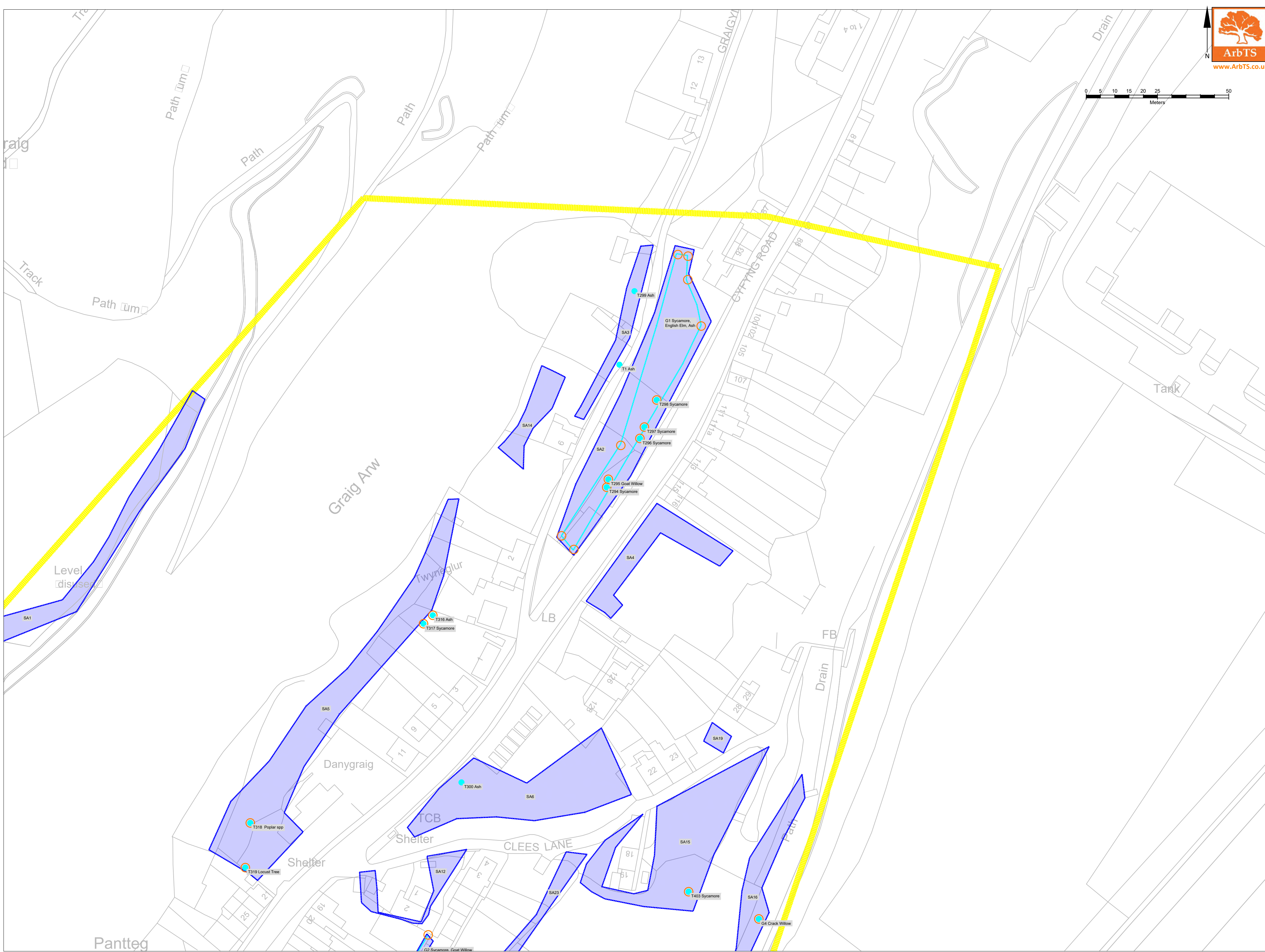
Legend

Individual Tree
Tree ID (T- Individual Tree)
Tree ID (G- Grouped Trees)
Tree Species (Common Tree Name Shown)
Tree Survey Area Completed
Tree Survey Area ID

Tree Priority
Urgent: Within 7 days to Urgent: High: Within 31 days: Work Priority
High: Within 3 Months to High: Medium: Within 6 Months: Work Priority

Grouped Trees
Urgent: Within 7 days to Urgent: High: Within 31 days: Work Priority
High: Within 3 Months to High: Medium: Within 6 Months: Work Priority

(*Please see Appendix 2 - Tree data for all tree survey details including all management recommendations*)



Tree Location Plan
Site - Pantteg
Project Ref - 385.2
Scale - 1:800 @ A2

Legend

- Tree Species (Common Tree Name Shown)
- Tree ID# (T-Individual Tree)
- Tree ID# (G-Grouped Trees)
- Tree Survey Area Completed
- Tree Survey Area ID#

Tree Status

- Urgent: Within 7 days to Urgent: High: Within 31 days: Work Priority
- High: Within 3 Months to High: Medium: Within 6 Months: Work Priority

Grouped Trees

- Urgent: Within 7 days to Urgent: High: Within 31 days: Work Priority
- High: Within 3 Months to High: Medium: Within 6 Months: Work Priority

(*Please see Appendix 2 - Tree data for all tree survey details including all management recommendations*)

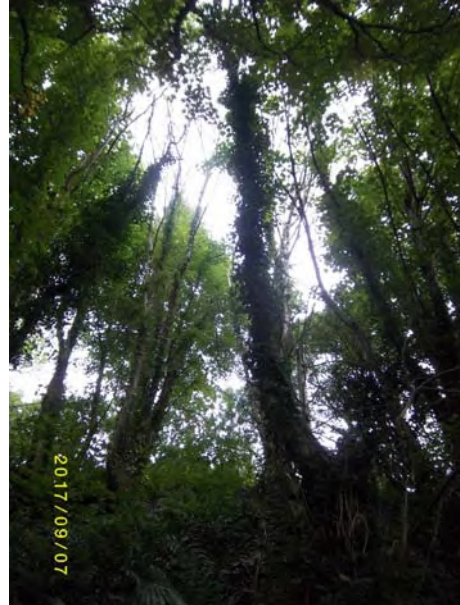
8.0 Appendices

Appendix 4 Tree Photographs

Tree ID#G1



Tree ID#G1



Tree ID#G1



Tree ID#T299



Tree ID#T1



Survey area SA6



Survey Area SA4



Tree ID#T318 (Hung up poplar tree)



Tree ID#T319 Locust Tree



Tree ID#T319 Locust Tree and Survey Area SA5



Tree ID#T316 and T317



Tree ID#T320



Tree ID#T3



Survey Area SA10



Survey Area SA8



Tree ID#T322



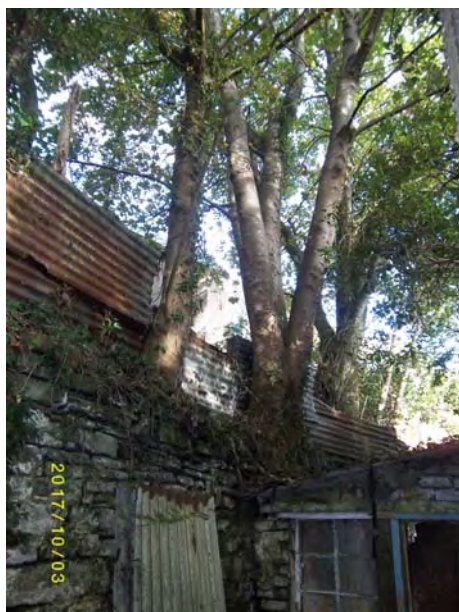
Survey Area SA8 (Woodlands)



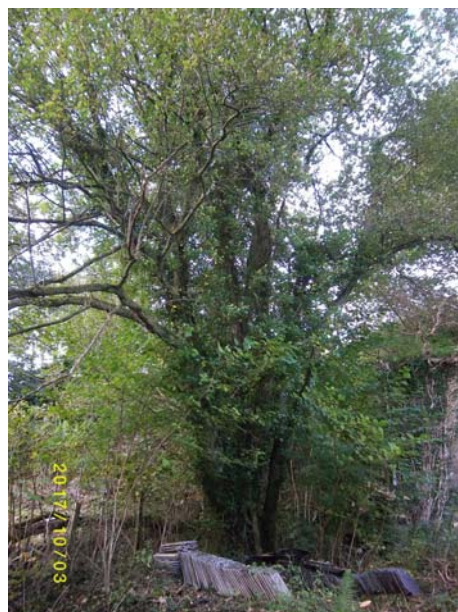
Survey Area SA20



Tree ID#G2



Tree ID#G3



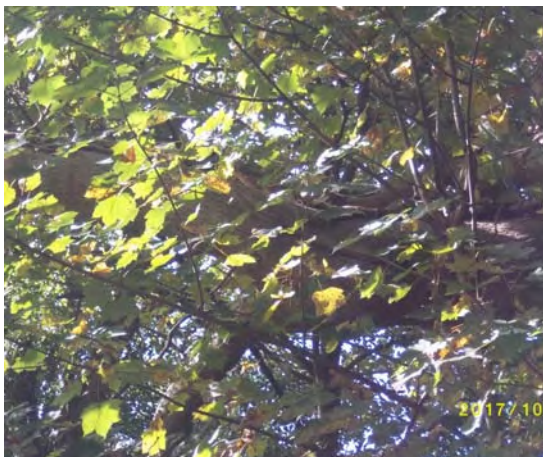
Survey Area SA23



Tree ID#G3



Tree ID#T6 – split in long low lateral branch



Survey Area SA16



Survey Area #SA1



Survey Area #SA1



Survey Area #SA1



Survey Area #SA1



Survey Area #SA1



Survey Area #SA1



Tree ID#533



Survey Area #SA14





Tree Condition Survey and Report carried out by:

ArbTS - Arboricultural Technician Services

(Tree Consultancy Services)

Stephen Lucocq *BSc (Hons), Tech Cert (Arbor.A), M.Arbor.A*

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Tree Condition Survey and Management Work Recommendations

Date – 9th May 2018

Site – Pantteg, Ystalyfera – Phase 2 Full Area

Project Reference – ArbTS_385.4_Pantteg

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1.0 Introduction

- 1.1 The purpose of this report is to give a tree condition assessment within an extended study area at Pantteg, Ystalyfera that are a potential risk to person or property.
- 1.2 The findings of this report provide management work recommendations with the order of work priority given to primarily address any hazardous trees.
- 1.3 The following management work recommendations have been identified as found in Appendix 2 Tree Data. Urgent & Urgent to High work priority are colour coded in red (suggested to be carried out as soon as practicable i.e. 7 days to 1 month) and High & High to Medium work priority are colour coded in yellow (suggested to be carried out within 3 to 6 months).
- 1.4 All tree work should be carried out in accordance with the *British Standard BS3998: 2010 Tree Work – Recommendations*.

2.0 The Tree Condition Survey

- 2.1 The tree condition survey was conducted by Stephen Lucocq BSc (Hons), Tech Cert (Arbor.A), M.Arbor.A. on 6th, 7th, 8th, 14th, 15th, 22nd February, 9th March and 8th May 2018.
- 2.2 All tree inspections were conducted from ground level with the use of an acoustic sounding hammer and probe. No invasive decay detective instruments were used.
- 2.3 All tree inspections were carried out in accordance with current best practise (Visual Tree Assessment) to give a systematic, consistent and transparent evaluation method to tree inspecting.
- 2.4 **Limitations of the Tree Condition Survey/Scope of works:** *Whilst every effort is made to ensure an accurate assessment of the trees condition is made during survey no responsibility can be taken for resultant damage or injury occurred by a failing tree. The survey only gives a snap shot of what is visible, not obscured or accessible on the day of survey. Please note that the findings of this report are only valid for 12 months from the date of the tree inspection. This report does not constitute to a full tree safety policy for the study area nor does it take into account any underground geological activity that may affected the structural condition of the trees.*

3.0 Tree Inspection Scope

- 3.1 The main scope of this tree inspection is to identify hazardous trees in a poor physiological or structural condition and the required work management recommendations to reduce the risk of these hazardous trees to an acceptable level as detailed by the Health and Safety Executive in Management of the risk from falling trees or branches - http://www.hse.gov.uk/foi/internalops/sims/ag_food/010705.htm.
- 3.2 The areas around main roads, occupied houses, well used formal foot paths, public used features, car parks etc. were identified as a priority areas for the tree survey.
- 3.3 Where required trees may be grouped as a whole and tree works recommended for that group.
- 3.4 The level of detail of the tree inspection may vary depending on the target occupation and the size of the tree or tree groups. For example large trees in high target occupation areas may be inspected in much greater detail than small trees in low target occupation areas.
- 3.5 Areas identified to be surveyed in the study area are shown on the Tree Location Plan as found in Appendix 3.

4.0 The Trees

4.1 **Tree Data** - All data regarding the trees inspected for this report can be found in Appendix 2 Tree Data.

4.2 **Tree Management Work Recommendations**

Within Appendix 2 the Tree Management Work Recommendations are colour coded for work priority. Urgent & Urgent to High work priority are colour coded in red (suggested to be carried out as soon as practicable i.e. 7 days to 1 month) and High & High to Medium work priority are colour coded in yellow (suggested to be carried out within 3 to 6 months). Other works can be identified from this list to achieve desired management objectives and timescale given for the completion of this work. **Please note** that all work must be carried out to the *British Standard 3998:2010 Tree Works Recommendation*.

4.3 **Tree Location Plan** - A Tree Location Plan can be found in Appendix 3. Trees and Tree Groups that require priority hazard work will be circled in colour. Urgent to Urgent/High priority work will be circled in red and High to High/Medium priority work circled in orange.

4.4 **Legal Constraints**

- **TPO (Tree Preservation Orders)/Conservation Areas** – The Tree Preservation Officer from the Local Planning Authority should be consulted before any work is carried out on site.
- **Protected Wildlife** – Before any tree work is carried out on site the trees should be inspected and written records taken of the activity of any protected species on site. This is to prevent the damage to any wildlife. Under the Wildlife and Countryside Act 1981 it is an offence to destroy or disturb nesting birds, if nesting birds are discovered or suspected no works can proceed and the Local Planning Authority (LPA) and Local Wildlife Trust must be notified for advice as to how to proceed. Further to this wildlife such as Bats are protected under European legislation (Countryside and Rights of Way Act 2000 and The Habitat Regulation 2009) it is an offence to recklessly, or intentionally, kill, injure or capture bats, to disturb them, or destroy, obstruct or damage any bat roosts found. If any bat activity is found then the bat conservation trust should be contacted as soon as possible (<http://www.bats.org.uk/> or 0845 1300 228). Further guidance relating to the protection of wildlife within development design is given in Welsh Assembly Government Technical Advice Note 5: Nature Conservation and Planning (2009).
- **Tree Felling Licence** – Depend on the designation of the land where the trees are located a Tree Felling Licence may be required if more than 5 cubic metres of timber are being extracted per one quarter a felling license must be obtained from Natural Resources Wales. <https://naturalresources.wales/permits-and-permissions/tree-felling-and-other-regulations/tree-felling-licences/?lang=en>

5.0 Recommendations

5.1 The detailed Tree Management Work Recommendations as found in Appendix 2 should be conducted as the priority states. Urgent & Urgent to High work priority is recommended to be carried out as soon as practicable i.e. 7 days to 1 month and High & High to Medium work priority to be carried out within 3 to 6 months. Other lower priority works can be identified by the managers of the site to achieve their desired objectives.

6.0 Further Information and Qualifications

Stephen Lucocq has been involved in Arboriculture within South Wales for nearly twenty years. He has worked as an Arborist for many of these years and has a good working knowledge of the practical side of the profession. He has always taken an active interest in all areas of Arboriculture and kept up to date with current research and developments.

Qualifications

- First Class BSc (Hons) Degree
- Arboricultural Association Technicians Certificate (Merit)
- PTI - Professional Tree Inspection (Lantra Awards)
- 2D Computer Aided Design (City and Guilds - Level 3)
- Quantified Tree Risk Assessment (QTRA) – Mike Ellison
- Visual Tree Assessment (VTA) – Mike Ellison
- Arboriculture and Bats (Lantra)
- Industrial Rope Access Trade Association (IRATA)
- Practical Arboriculture Qualifications (NPTC)

Membership

- Arboricultural Association Professional Member (M.Arbor.A)

7.0 Web Information & Bibliography

Web Information

Health and Safety Executive -

http://www.hse.gov.uk/foi/internalops/sims/ag_food/010705.htm

Arboricultural Association –

<http://www.trees.org.uk/index.php>

Bibliography

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- Shigo, A.L (1991) *Modern Arboriculture* USA; Shigo and Trees, Association
- Sterry, P (2007) *Collins Complete British Trees* London; Collins
- Strouts, R.G (2000) *Diagnosis of ill-health in trees* Edinburgh; Forestry Commission
- Weber, K & Mattheck, C (2003) *Manual of wood decay* UK; Arboricultural Association

8.0 Appendices

Appendix 1 Tree Survey Key

- **Type** - **T** – Individual Tree, **G** – Group of tree (Used were a group of similar trees of similar condition are identified), **SA** – Tree survey area completed, **NS** – Tree survey area not completed, **R** – Row of trees, **H** – Hedgerow, **S** - Stump, **W** – Woodland
- **ID #** - Identifies the tree, group, row, hedgerow or woodland with a unique identification number. For individual tree metal identification tags are located at 1.5 metres above ground level on their trunk.
- **Tree Name** - Scientific tree name and common tree name in brackets.
- **Age** -
 - **Y** - Young – First 10 years of growth
 - **SM** - Semi Mature - Less than 1/5 of life completed
 - **EM** – Early Mature – Less than 2/5 of life completed
 - **M** - Mature – 2/5 – 5/5 of life completed
 - **OM** - Over Mature - more than 5/5 of life completed and declining
 - **V** - Veteran – Veteran trees have no precise definition but are trees considered to be of biological aesthetic or ecological value because of their age
- **Size** – A general indication of the size of the tree/s in terms of height and width.
 - **S** – Small
 - **M** – Medium
 - **L** – Large
 - **VL** – Very Large
- **Physiological Condition** - The physiological condition of the tree/s. -
 - **G** - Good
 - **F** - Fair
 - **P** - Poor
 - **D** - Dead
- **Structural Condition** - The structural condition of the tree/s -
 - **G** - Good
 - **F** - Fair
 - **P** - Poor
 - **VP** – Very poor
- **Comments** – Observations and comments
- **Management Work Recommendations** – Required tree surgery operations including further investigation of suspected defects that require more detailed assessment
- **Target Occupation** – An approximate site specific guide from High to Low as assessed on the day of the tree inspection of the risk relating to the potential for damage to a person, property or item, within an area around the tree if failure of the tree or part of the tree were to occur. It is recommended that the re-inspection of tree or groups of trees should be carried out as follows:
 - **High** – Re-inspect in 12 months or less if stated
 - **H/Medium** – Re-inspect in 24 months or as stated

- **Medium** – Re-inspect in 30 months or as stated
- **M/Low** – Re-inspect in 3 years or as stated
- **Low** - Re-inspect in 5 years or as stated

Further to this the level of detail of the tree inspection will vary depending on the target occupation and the size of the tree or groups of trees. For example large trees in high target occupation areas will be inspected in much greater detail than small trees in low target occupation areas.

(*Please note that this report is a tree condition survey with management recommendations and does not equate to a full tree safety policy for the site*)

- **Work Type** – Type of management work recommendation.
 - **Hazard** – Hazard Management - A risk to person or property from a tree with a defect or in poor condition
 - **Arb** – Arboricultural Management
 - **Landscape** – Landscape design/Management
 - **Conservation** – Wildlife/Habitat/Historic Management.
 - **Woodland** – Woodland Management
- **Work Priority** – A priority rating for management work recommendations. This is determined from an assessment on the day taking into account the target occupation around the tree, the size/part of the tree affected by the defect, the probability and foreseeable nature of the defect failing, the quality and value of the tree and other arboricultural factors. A suggested timescale for the work to be carried out is provided below:
 - **Urgent** - Work to be carried out as soon as practically possible. I.e. less than 7 days
 - **U/High** – Work to be carried out within 1 month
 - **High** – Work to be carried out within 3 months
 - **H/Medium** - Work to be carried within 6 months
 - **Medium** – Work to be carried out in 12/18 months
 - **M/Low** - Work to be carried out in 18/24 months if budget allows
 - **Low** - After consideration of management objectives

8.0 Appendices

Appendix 2 Tree Data

Tree ID #	Tree Species	Age	Size	Physiological Condition	Structural Condition	Comments		Management Work Recommendations		Target Occupation	Work Type	Work Priority
Tree Data												
G5	X Cupressocyparis leylandii (Leyland Cyp	EM	M	Fair	F/Poor		Group of conifers that have ben previously topped with resultant slender upright regrowth		Reduce height of group by 50 percent and prune out any dead or weak stems or thin over hanging branches	M/Low	Arb	Medium
G6	Fraxinus excelsior (Ash),Corylus avellana (Hazel),Acer pseudoplatanus (Sycamore)	SM	S/M	Fair	F/Poor		Multistemmed regeneration encroaching into foot path, many goat willow stem failures noted typical for species		Coppice and chip\stack trees (left on site) between southern fence line and pavement, also any goat willow and sycamore trees close to the Boundary line fence (with orange spots) and any other left exposed small slender trees prone to failure	M/Low	Hazard	H/Medium
G7	Fraxinus excelsior (Ash),Corylus avellana (Hazel),Salix caprea (Goat Willow),Acer pseudoplatanus (Sycamore)	EM	M	Fair	F/Poor		Group of trees, many of the ash showing signs of ash die back disease, general form of trees are multistemmed and slender in form, adjacent to electrical lines, a number of tree / stem failures noted, high hazard area on geological hazard plan		Coppice and pollard trees to give 15 metrebuffer zone between retaining wall and new woodland edge, woodland edge marked with orange spray paint, trees to be felled and left on site	M/Low	Hazard	H/Medium
G836	Ulmus glabra (Wych Elm),Acer pseudoplatanus (Sycamore)	M	M	Fair	Poor		Signs of historic root plate lift with resultant vertical growth, twin trunks leaning across foot path, contorted sycamore tree noted higher up bank growing from rock face		Fell both elm trees and contorted sycamore tree growing further up the bank	M/Low	Hazard	H/Medium
T1	Unknown (Unknown)	M	S/M	Dead	Poor		Dead tree on top of quarry, located behind third green shed from east, adjacent to orange arrow sprayed on top of bank		Fell	Low	Hazard	Medium

Tree ID #	Tree Species	Age	Size	Physiological Condition	Structural Condition	Comments		Management Work Recommendations		Target Occupation	Work Type	Work Priority
T8	Corylus avellana (Hazel)	M	S/M	F/Poor	F/Poor		Growing from top of rock face, lower lateral branches failed		Coppice	M/Low	Hazard	H/Medium
T9	Prunus avium (Wild Cherry)	SM	S/M	F/Poor	Poor		Slender small declining cherry tree		Fell - stack on site	M/Low	Hazard	H/Medium
T64	Salix caprea (Goat Willow)	M	M	Fair	F/Poor		Broad spreading tree, stem with tree tag has fungal decay on reactive wood, opposite farm house car parking area		Fell central stem with tree tag to 2metre high stump and reduce northern western stem over access track by 3metres in branch length	M/Low	Hazard	H/Medium
T65	Betula pendula (Silver Birch)	M	S/M	Dead	VPoor		Failed top of tree hung up in adj goat willow tree		Remove hung up stem and any damage branches in adjacent goat willow	M/Low	Hazard	H/Medium
T800	Fraxinus excelsior (Ash)	M	M	Poor	Poor		Extensive areas of canker and Daldinia concentrica fungi noted		Fell and stack on site, remove/reduce any dead, declining or slender exposed branches left on adjacent trees	M/Low	Hazard	H/Medium
T801	Salix caprea (Goat Willow)	M	M	Fair	F/Poor		Wide spreading northern branches, species prune to branch stem failure		Reduce two long lower north western stems (growing towards the road) to 2metres long stumps from trunk, chip on site	M/Low	Hazard	H/Medium

Tree ID #	Tree Species	Age	Size	Physiological Condition	Structural Condition	Comments	Management Work Recommendations	Target Occupation	Work Type	Work Priority
T802	Fraxinus excelsior (Ash)	M	M	F/Poor	F/Poor	Two trees forming a whole, signs of ash die back in lower crown and appears to have sparse leaf bud cover in upper crown, in addition I spoke with Richard Jones 41graig road and he said that many of the ash trees in the area were showing signs of potential ash die back disease	Fell both trees, spoke with Richard Jones 41 graig road and he said we would be interested in having any wood from the felling of these trees	Medium	Hazard	H/Medium
T803	Fraxinus excelsior (Ash)	EM	M	F/Poor	Fair	Appears to have sparse leave bud cover	Reinspect tree and survey area 29 for signs of ash die back disease during summer period 2018	M/Low	Hazard	Medium
T804	Fraxinus excelsior (Ash)	EM	M	F/Poor	F/Poor	Poor leaf bud cover and form, exposed to wind from recent tree felling to clear around electrical lines	Fell to 2metre trunks and fell small, slender ash tree 5metres to the west (sprayed with orange spot), tree waste to be left on site	M/Low	Hazard	H/Medium
T805	Salix caprea (Goat Willow)	M	M	Dead	Poor	Dead	fell, tree waste to be left on site	Medium	Hazard	U/High
T806	Fraxinus excelsior (Ash)	EM	M	Fair	F/Poor	Tree of fair to poor suppressed form from adjacent large oak tree, long lateral northern branch with occluded crack noted along stem, area of internal decay noted at buttress with surrounding reactive growth	Reduce to 1metre high stump, wood and chip to remain on site	M/Low	Hazard	H/Medium

Tree ID #	Tree Species	Age	Size	Physiological Condition	Structural Condition	Comments		Management Work Recommendations		Target Occupation	Work Type	Work Priority
T807	Salix caprea (Goat Willow)	EM	S/M	Fair	F/Poor		Suppressed ad slender in form, further exposed from adjacent ash tree removal		Fell, wood and chip to remain on site	M/Low	Hazard	H/Medium
T808	Fraxinus excelsior (Ash)	M	M/L	Fair	Fair		Twin stem, small dead stem noted growing from western stem		Remove small dead stem and lower drooping dead branches, reinspect in summer 2018 for leaf cover and signs of ash dieback disease	M/Low	Hazard	H/Medium
T809	Ilex aquifolium (Holly)	M	S/M	Fair	Poor		Holly of poor structural condition		Fell to 1.5 metres, wood and chip to be left in site	M/Low	Hazard	H/Medium
T810	Salix caprea (Goat Willow)	OM	M	Fair	F/Poor		Suppressed in form, failed southern stem species prone to stem failure		Fell and cut over hanging elder and hazel shrub	Medium	Hazard	H/Medium
T811	Betula pendula (Silver Birch)	EM	S/M	Poor	Poor		Small slender hung up birch tree within group of birch and adjacent dead birch tree noted		Fell hung up birch and adjacent dead birch tree	M/Low	Hazard	H/Medium
T812	Acer pseudoplatanus (Sycamore)	M	M/L	G/Fair	Fair		Multistem growing from boundary bank, declining eastern stem with soft wet decay at base		Remove declining eastern stem with soft wet decay to leave 1.5metre stem	M/Low	Hazard	H/Medium
T814	Salix caprea (Goat Willow)	M	S/M	Fair	F/Poor		Uprooted goat willow with lean towards road and public footpath		Fell and stack on site	Medium	Hazard	H/Medium
T815	Fraxinus excelsior (Ash)	EM	S/M	Fair	F/Poor		Small ash tree, ring barked around trunk		Fell, owner to have wood	M/Low	Hazard	H/Medium

Tree ID #	Tree Species	Age	Size	Physiological Condition	Structural Condition	Comments		Management Work Recommendations		Target Occupation	Work Type	Work Priority
T835	Salix caprea (Goat Willow)	M	M	Fair	Poor		Uprooted on bank		Fell	M/Low	Hazard	H/Medium
T837	Fraxinus excelsior (Ash)	M	M/L	Fair	Fair		Contorted suppressed multi stemmed ash tree, lower lateral branches in decline		Remove lower declining lateral branches over canal footpath	M/Low	Hazard	H/Medium
T838	Acer pseudoplatanus (Sycamore)	EM	S/M	Fair	F/Poor		Suppressed contorted growth, decay at base		Fell	M/Low	Hazard	H/Medium
T839	Acer pseudoplatanus (Sycamore)	EM	S/M	Fair	F/Poor		Suppressed contorted growth, decay at base		Fell	M/Low	Hazard	H/Medium

Tree ID #	Tree Species	Age	Size	Physiological Condition	Structural Condition	Comments	Management Work Recommendations	Target Occupation	Work Type	Work Priority
Tree Survey Areas										
SA1	Quercus robur (Common Oak), Salix caprea (Goat Willow), Acer pseudoplatanus (Sycamore), Betula pendula (Silver Birch)	N/A	N/A	N/A	N/A	Surveyed on 13th November 2017 and 8th May 2018, Trees located along top of cliff growing from top or side of upper rock face, some areas not safe to access to fully inspect trees, trees inspected from inside of fencing or on upper paths were accessed to be safe to do so, in addition survey from lower newly cut path, generally larger broad but compact old oaks noted growing from top of rock face with adapted growth noted as maintaining their structural stability, trees have grown together as a large long group and tree crown are generally compact form, overall physiological health of larger trees are fair to good, some smaller trees with signs of moderate structural and physiological conditions were noted but their failure will result in a very low risk to person or property, area mainly consisting of oak trees many of which are of some age		Low		
SA24	Corylus avellana (Hazel), Acer pseudoplatanus (Sycamore)	N/A	N/A	N/A	N/A	Surveyed area on 6th Feb 2018, area of trees adjacent to right of way, jkw noted		M/Low		
SA25	Fraxinus excelsior (Ash)	N/A	N/A	N/A	N/A	Surveyed area on 6th and 7th Feb 2018, area of trees adjacent to right of way, jkw noted, signs of possible ash dieback disease noted, a number of tall multistemmed ash trees noted in survey area		M/Low		
SA26	Salix caprea (Goat Willow), Corylus avellana (Hazel), Acer pseudoplatanus (Sycamore), Fraxinus excelsior (Ash)	N/A	N/A	N/A	N/A	Surveyed Area, Area of scrubby regeneration, many trees multistemmed in from with some stems upright in form		M/Low		

Tree ID #	Tree Species	Age	Size	Physiological Condition	Structural Condition	Comments	Management Work Recommendations	Target Occupation	Work Type	Work Priority
SA27	Fraxinus excelsior (Ash)	N/A	N/A	N/A	N/A	Surveyed area on 8th , 15th Feb 2018, area of mainly ash, goat willow, hazel and sycamore		M/Low		
SA28	X Cupressocyparis leylandii (Leyland Cyp)	N/A	N/A	N/A	N/A	Surveyed Area, Row of conifers spindly in form from past pruning		M/Low		
SA29	Fraxinus excelsior (Ash), Salix caprea (Goat Willow)	N/A	N/A	N/A	N/A	Surveyed area on 7th Feb 2018, Mainly ash in survey area, spoke with Richard Jones 41graig road and he said that many of the ash were showing signs of potential ash die back disease, some trees in survey area difficult to access due to		M/Low		
SA30	Fagus sylvatica (Beech), Corylus avellana (Hazel)	N/A	N/A	N/A	N/A	Surveyed on 7th Feb 2018, close to main road		High		
SA31	Fraxinus excelsior (Ash)	N/A	N/A	N/A	N/A	Surveyed area on 7th Feb 2018, mainly group of ash trees		Medium		
SA32	Corylus avellana (Hazel), Salix caprea (Goat Willow), Fraxinus excelsior (Ash), Crataegus monogyna (Hawthorn)	N/A	N/A	N/A	N/A	Surveyed area on 20th Feb 2018, untidy group of sprawling trees and shrub overhanging parking area, only trees on top of steep bank able to be inspected		H/Medium		
SA33	Corylus avellana (Hazel), Crataegus monogyna (Hawthorn)	N/A	N/A	N/A	N/A	Surveyed on 20th Feb 2018, small multistemmed coppice regrowth and small hawthorn trees growing on steep bank above road		H/Medium		
SA34	X Cupressocyparis leylandii (Leyland Cyp, Cupressus macrocarpa (Monterey Cypress))	N/A	N/A	N/A	N/A	Surveyed on 20th Feb 2018		M/Low		
SA35	Fraxinus excelsior (Ash), Corylus avellana (Hazel)	N/A	N/A	N/A	N/A	Surveyed on 20th Feb 2018		M/Low		

Tree ID #	Tree Species	Age	Size	Physiological Condition	Structural Condition	Comments	Management Work Recommendations	Target Occupation	Work Type	Work Priority
SA36	Unknown (Unknown)	N/A	N/A	N/A	N/A	Unable to inspect on 20th Feb 2018 as could not gain access due to dog in garden, small diameter multistem hazel coppice hedgerow		M/Low		
SA38	Corylus avellana (Hazel)	N/A	N/A	N/A	N/A	Surveyed on 20th Feb 2018, small diameter multistem hazel coppice growing on bank		M/Low		
SA39	X Cupressocyparis leylandii (Leyland Cyp)	N/A	N/A	N/A	N/A	Surveyed on 20th Feb 2018		M/Low		
SA40	X Cupressocyparis leylandii (Leyland Cyp)	N/A	N/A	N/A	N/A	Surveyed on 20th Feb 2018		M/Low		
SA42	Quercus robur (Common Oak),Acer pseudoplatanus (Sycamore),Corylus avellana (Hazel),Betula pendula (Silver Birch)	N/A	N/A	N/A	N/A	Surveyed on 23rd Feb 2018, trees and shrubs surveyed adjacent to access drive and property, public footpath noted to west of properties		Medium		
SA43	Corylus avellana (Hazel),Acer pseudoplatanus (Sycamore)	N/A	N/A	N/A	N/A	Surveyed on 23rd Feb 2018		Medium		
SA44	Prunus avium (Wild Cherry),Fraxinus excelsior (Ash)	N/A	N/A	N/A	N/A	Surveyed on 23rd Feb 2018		Medium		

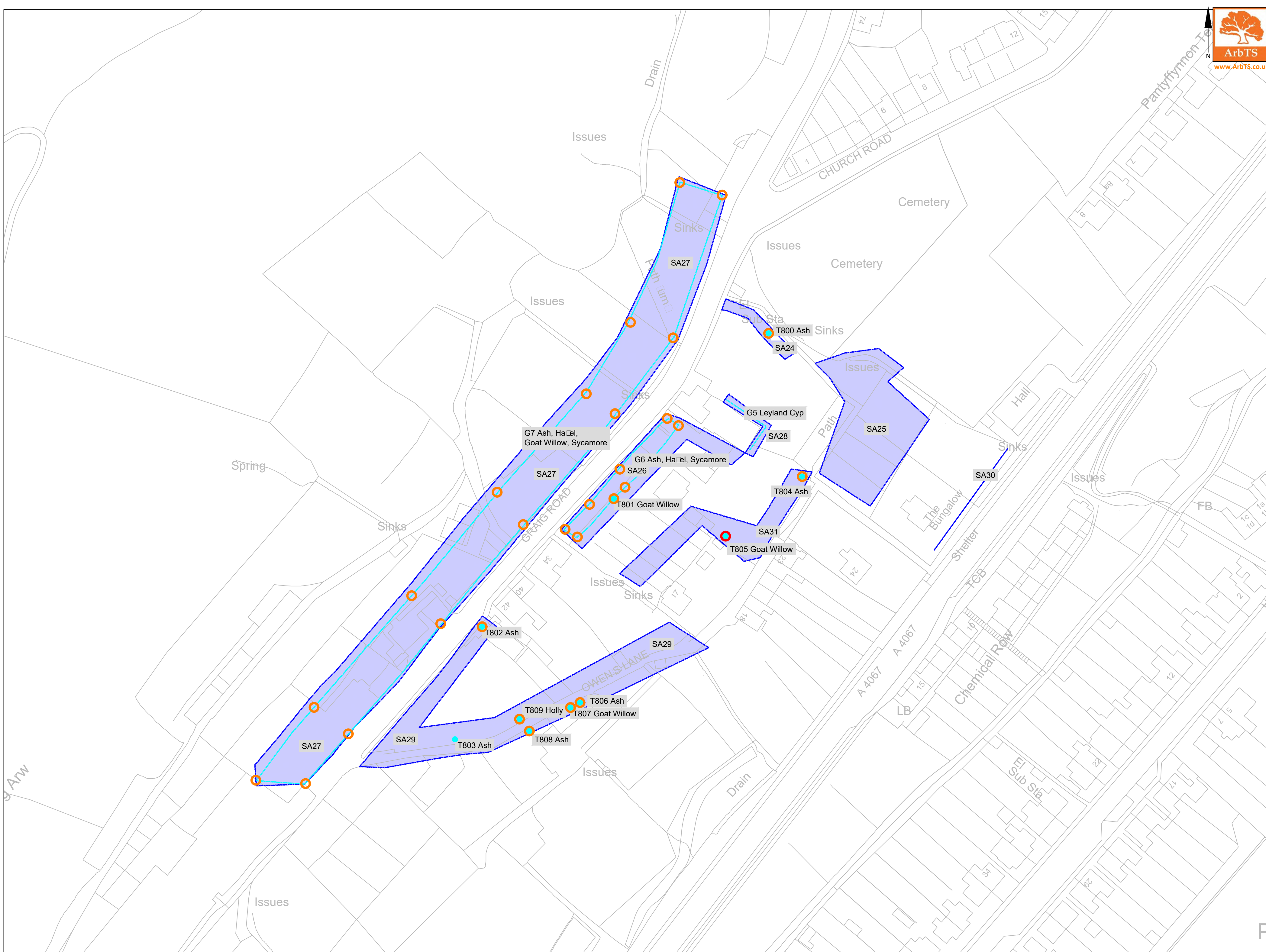
Tree ID #	Tree Species	Age	Size	Physiological Condition	Structural Condition	Comments	Management Work Recommendations	Target Occupation	Work Type	Work Priority
SA45	Acer pseudoplatanus (Sycamore)	N/A	N/A	N/A	N/A	Surveyed on 9th march 2018, trees close to canal footpath (to be reopened with expected minor to moderate public use), access to some trees difficult due to terrain, water course and surrounding vegetation, due to lower target occupation only larger trees surveyed in this survey area where access was possible, and observations made to identify trees in poor health where access was not possible, some previous tree failure noted, number of contorted trees growing from rock face with good adaptive growth noted		M/Low		
SA46	Acer pseudoplatanus (Sycamore)	N/A	N/A	N/A	N/A	Surveyed on 9th march 2018, small group of sycamore and ash, a couple of dead branches noted in the sycamore		M/Low		
SA47	Salix caprea (Goat Willow)	N/A	N/A	N/A	N/A	Surveyed area on 20th Feb 2018, unable to fully inspected one goat willow due to access		M/Low		
SA48	Corylus avellana (Hazel), Crataegus monogyna (Hawthorn), Fraxinus excelsior (Ash), Betula pendula (Silver Birch)	N/A	N/A	N/A	N/A	Surveyed on 8th May 2018, Field boundary group of trees, mainly multistemmed ash likely developed from old boundary hedgerow management, low surrounding target occupation, a few ash trees appears sparse in leaf cover		Low		
SA49	Salix caprea (Goat Willow), Quercus robur (Common Oak)	N/A	N/A	N/A	N/A	Surveyed on 8th May 2018, consisting of some over mature larger goat willow regeneration of quarry area and some early mature native oak trees noted		Low		

Tree ID #	Tree Species	Age	Size	Physiological Condition	Structural Condition	Comments	Management Work Recommendations	Target Occupation	Work Type	Work Priority
SA50	Quercus robur (Common Oak), Crataegus monogyna (Hawthorn), Betula pendula (Silver Birch), Fraxinus excelsior (Ash), Corylus avellana (Hazel), Acer campestre (Field Maple)	N/A	N/A	N/A	N/A	Surveyed on 8th May 2018, Field boundary group of trees, mainly native oak, ash late into leaf, one ash tree at eastern area of survey area with wire zip line attached to stem at 3 metres with tree growing around wire, low surrounding target occupation		Low		
SA51	Acer pseudoplatanus (Sycamore), Crataegus monogyna (Hawthorn), Ilex aquifolium (Holly), Fraxinus excelsior (Ash), Quercus robur (Common Oak), Prunus spinosa (Blackthorn)	N/A	N/A	N/A	N/A	Surveyed on 8th May 2018, Trees located along top of cliff growing from top or side of upper rock face, some areas not safe to access to fully inspect trees, trees inspected from upper area where accessed was assessed to be safe to do so, in addition survey from lower area, generally trees growing from top of rock face with adapted growth noted by maintaining their structural stability, trees have grown together as a long group and tree crowns are generally in compact form, overall physiological health of larger trees are fair to good, some smaller trees with signs of more major structural and physiological conditions were noted but their failure will result in a very low risk to person or property, some hung up failed trees noted on lower quarry area		M/Low		
SA52	Ilex aquifolium (Holly), Fraxinus excelsior (Ash), Crataegus monogyna (Hawthorn), Quercus robur (Common Oak), Acer pseudoplatanus (Sycamore), Betula pendula (Silver Birch)	N/A	N/A	N/A	N/A	Surveyed on 8th May 2018, Field boundary group of trees alongside of old track that appears to get no use with electrical animal stock fencing bisecting the track, mainly native oak trees, ash late into leaf, one sycamore tree in middle area of survey area with wire zip line attached to stem at 4metres with tree growing around wire, low surrounding target occupation, trees of varying conditions		Low		

Tree ID #	Tree Species	Age	Size	Physiological Condition	Structural Condition	Comments	Management Work Recommendations	Target Occupation	Work Type	Work Priority
SA53	Acer pseudoplatanus (Sycamore), Fraxinus excelsior (Ash), Betula pendula (Silver Birch), Crataegus monogyna (Hawthorn), Ilex aquifolium (Holly)	N/A	N/A	N/A	N/A	Surveyed on 8th May 2018, Field boundary group of trees, ash late into leaf, low to medium surrounding target occupation, some animal grazing damage noted to stems	Reinspect ash in summer 2019	M/Low		
SA54	Fagus sylvatica (Beech), Salix caprea (Goat Willow), Quercus robur (Common Oak), Acer pseudoplatanus (Sycamore)	N/A	N/A	N/A	N/A	Surveyed on 8th May 2018, Field boundary group of trees to farm house, trees closer to the farm house have been reduced in height by pruning, low to medium surrounding target occupation		M/Low		
SA55	Salix caprea (Goat Willow), Betula pendula (Silver Birch), Acer pseudoplatanus (Sycamore)	N/A	N/A	N/A	N/A	Small group of trees		Medium		

8.0 Appendices

Appendix 3 Tree Location Plan



Tree Location Plan
Site - Godre Graig - Phase 2
Project Ref - 385.4
Scale - 1:800 @ A2

Legend

- Tree Species (Common Tree Name Shown)
- Tree ID# (T-Individual Tree)
- Tree ID# (G-Grouped Trees)
- Tree Survey Area Completed
- Tree Survey Area ID#

Tree ID#

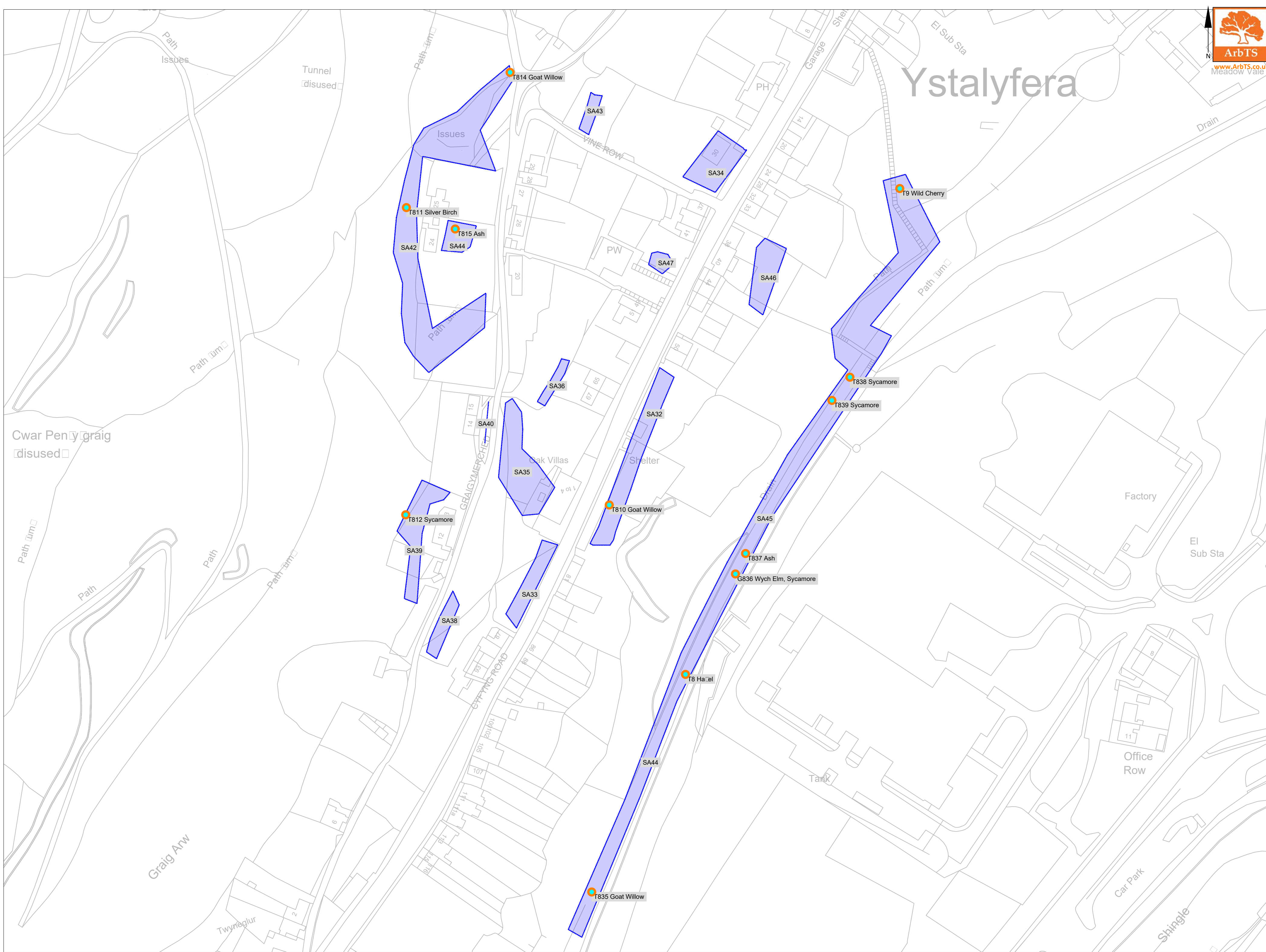
- Urgent: Within 7 days to Urgent: High: Within 31 days: Work Priority
- High: Within 3 Months: to High: Medium: Within 6 Months: Work Priority

Grouped Trees

- Urgent: Within 7 days to Urgent: High: Within 31 days: Work Priority
- High: Within 3 Months: to High: Medium: Within 6 Months: Work Priority

(*Please see Appendix 2 - Tree data for all tree survey details including all management recommendations*)



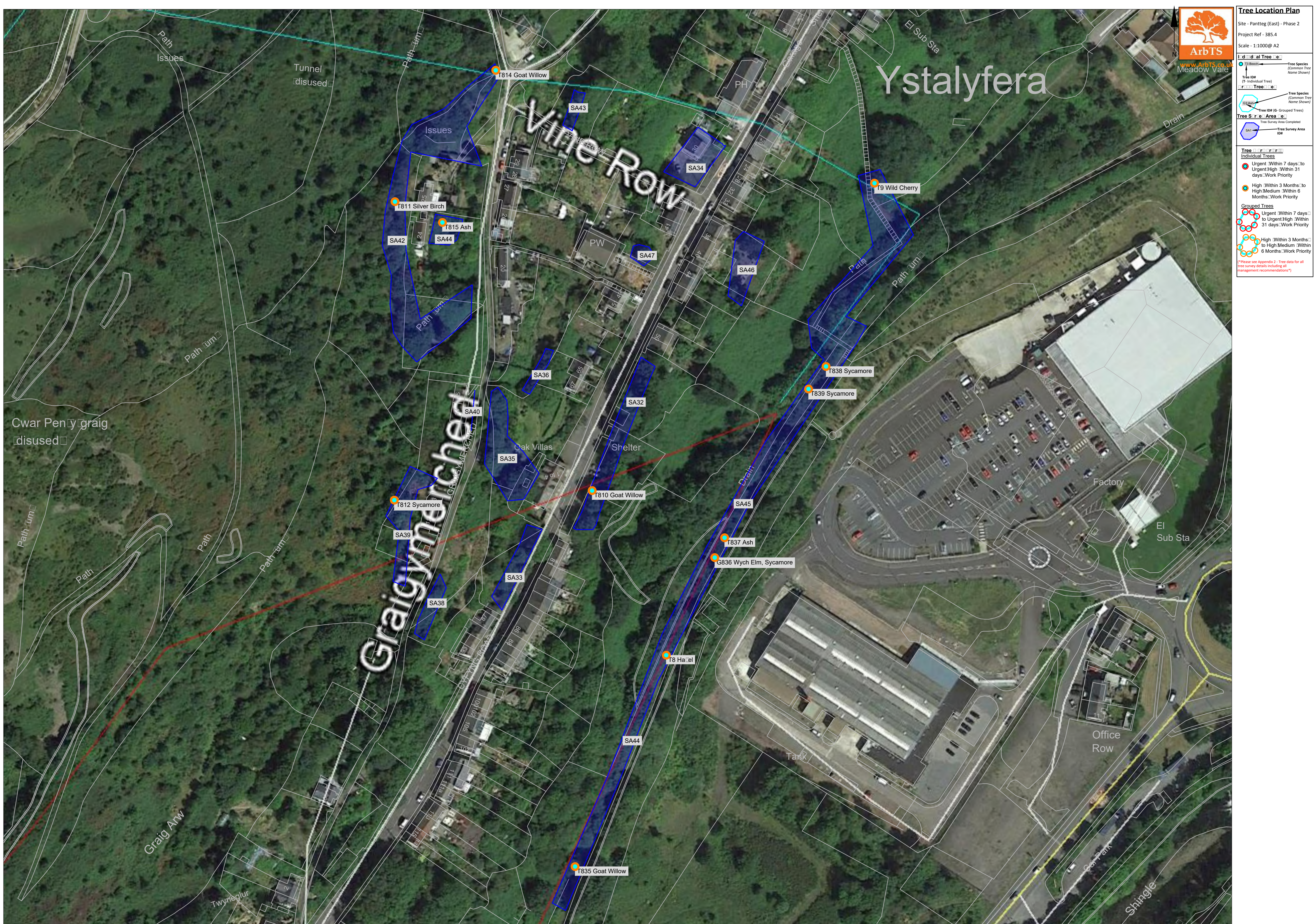


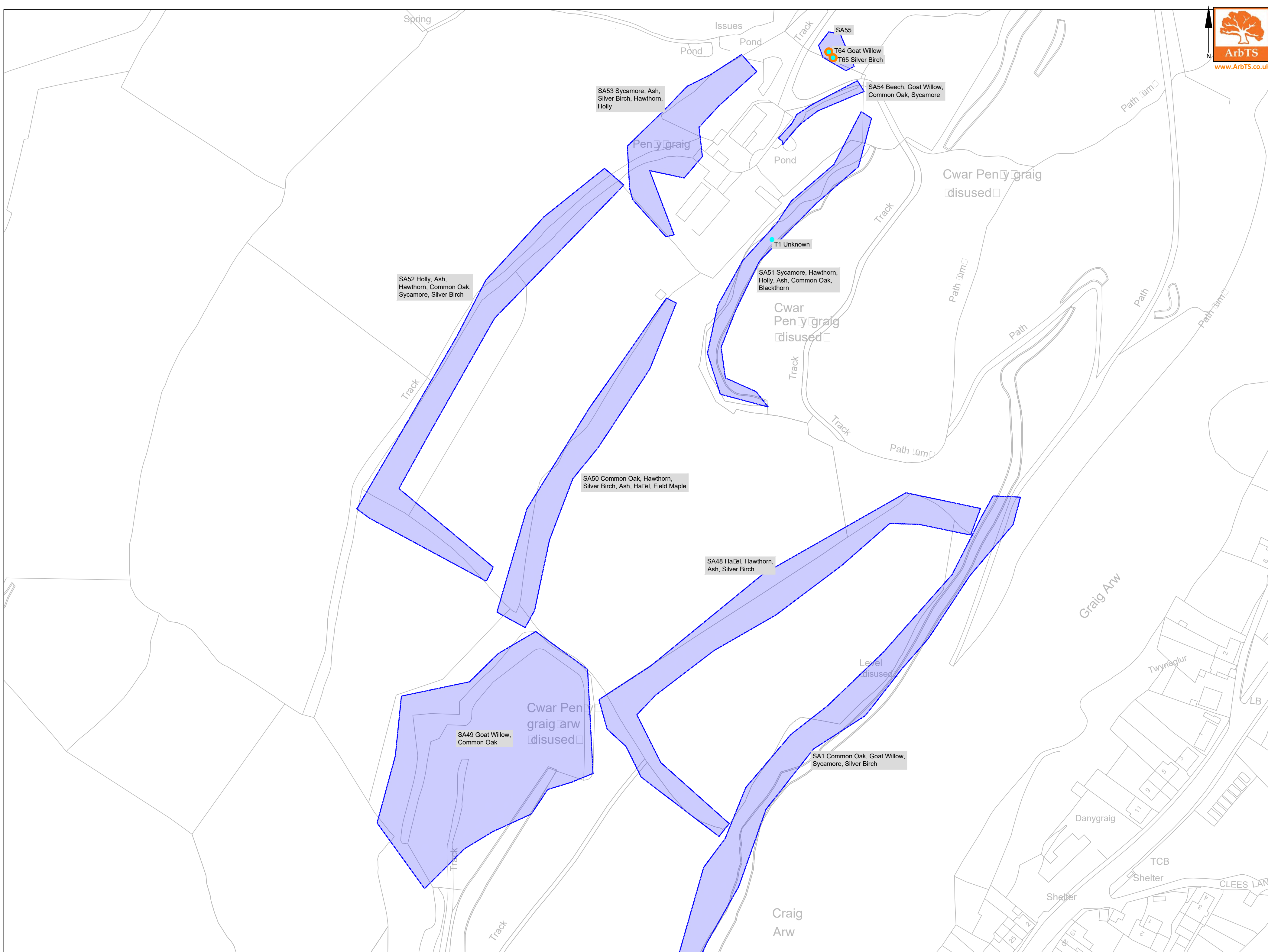
Tree Location Plan
Site - Pantteg (East) - Phase 2
Project Ref - 385.4
Scale - 1:1000@ A2

Legend

- Individual Tree**
Tree ID (T- Individual Tree)
Tree Species (Common Tree Name Shown)
- Tree Survey Area**
Tree Survey Area Completed
Tree Survey Area ID
- Tree Priority**
Urgent: Within 7 days to Urgent: High: Within 31 days: Work Priority
High: Within 3 Months to High: Medium: Within 6 Months: Work Priority
- Grouped Trees**
Urgent: Within 7 days to Urgent: High: Within 31 days: Work Priority
High: Within 3 Months to High: Medium: Within 6 Months: Work Priority

(*Please see Appendix 2 - Tree data for all tree survey details including all management recommendations*)





Tree Location Plan

Site - Pantteg (Upper) - Phase 2

Project Ref - 385.4

Scale - 1:1000@ A2

Legend

- Individual Tree ID (T-Individual Tree)
- Tree Species (Common Tree Name Shown)
- Tree ID (G-Grouped Trees)
- Tree Survey Area Completed
- Tree Survey Area ID (SA)

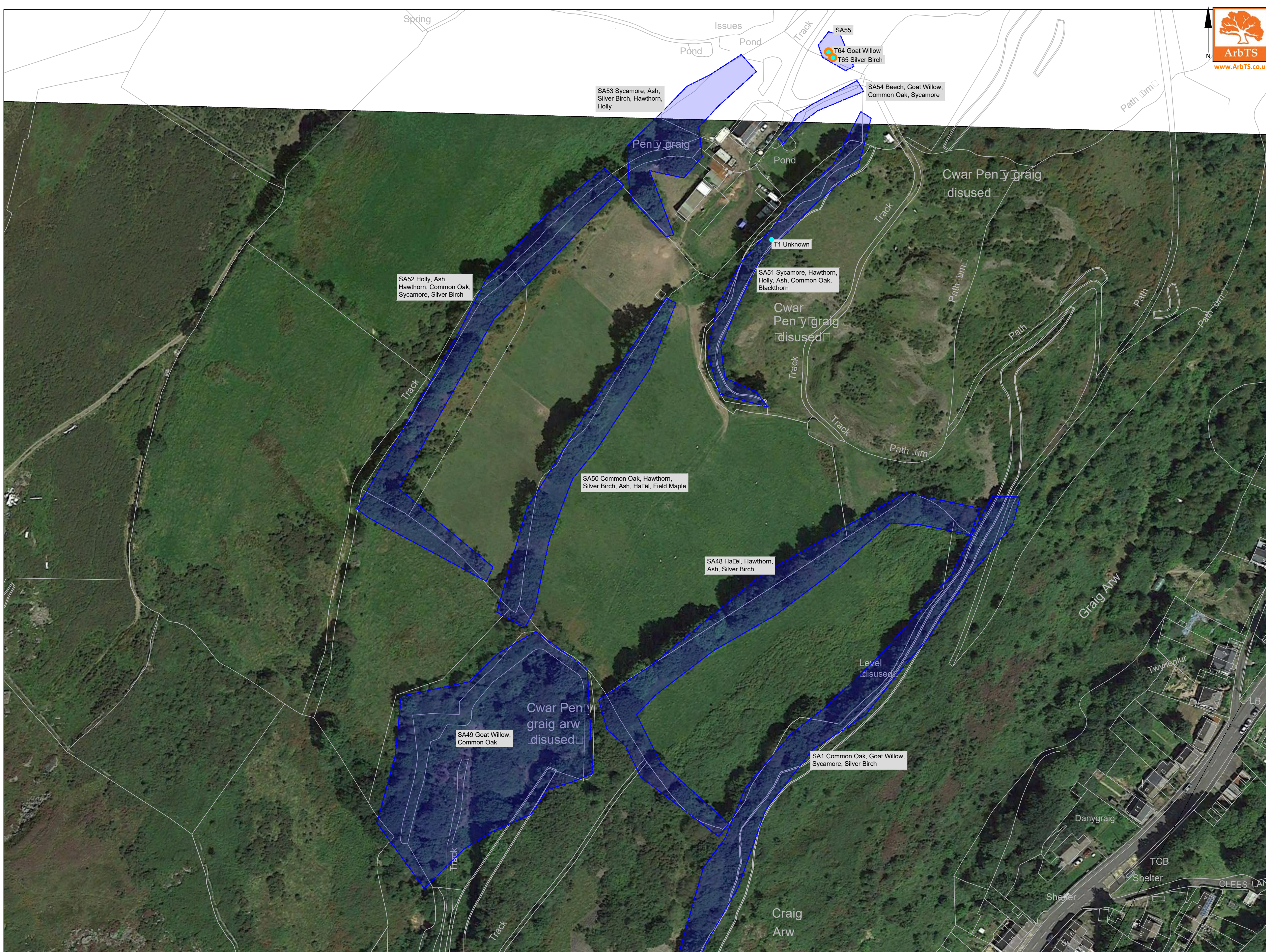
Tree Priority

- Urgent: Within 7 days to Urgent: High: Within 31 days: Work Priority
- High: Within 3 Months: to High: Medium: Within 6 Months: Work Priority

Grouped Trees

- Urgent: Within 7 days to Urgent: High: Within 31 days: Work Priority
- High: Within 3 Months: to High: Medium: Within 6 Months: Work Priority

(*Please see Appendix 2 - Tree data for all tree survey details including all management recommendations*)





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Tree Location Plan

Site - Panteg (Upper) - Phase 2

Project Ref - 385.4

Scale - 1:1000@ A2

Legend

Individual Tree

Tree ID (T-Individual Tree)

Tree Species (Common Tree Name Shown)

Tree Survey Area

Tree Survey Area Completed

Tree Survey Area ID

Tree Priority

Individual Trees

Urgent: Within 7 days to Urgent: High: Within 31 days: Work Priority

High: Within 3 Months: to High: Medium: Within 6 Months: Work Priority

Grouped Trees

Urgent: Within 7 days to Urgent: High: Within 31 days: Work Priority

High: Within 3 Months: to High: Medium: Within 6 Months: Work Priority

(*Please see Appendix 2 - Tree data for all tree survey details including all management recommendations*)

8.0 Appendices

Appendix 4 Tree Photographs

Tree ID#G6



Tree ID#T802



Tree ID#G7



Tree ID#TG7



Tree ID#G5



Survey area SA25



Survey Area SA29 – Owens Lane



Survey Area SA30



Tree ID#T804



Tree ID#T806



Tree ID#T808



Tree ID#T810



Survey Area – SA32



Survey Area SA33



Survey Area SA38



Tree ID#T812



Survey Area SA40



Survey Area SA42



Survey Area SA42



Tree ID#T835



TreeID# T8



Tree ID#G836



Survey Area 44



Survey Area SA44



Survey Area 49



Survey Area 49



Survey Area 48



Survey Area SA50



Survey Area 52



Survey Area 52



Survey Area 53



Survey Area SA53



Survey Area 51



Survey Area 51



Tree ID# 64



Tree ID# 65



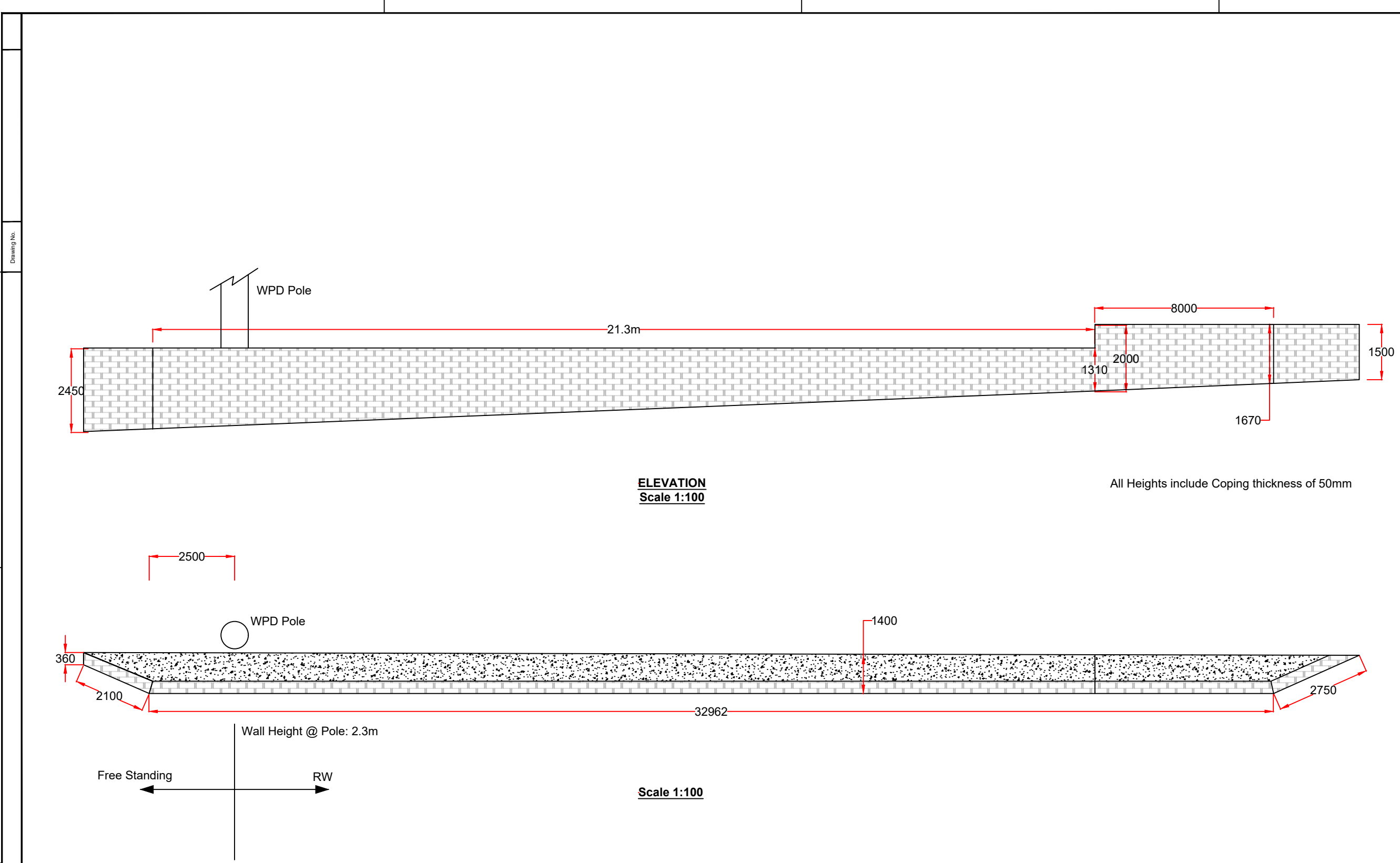
Appendix B
Locations of Gabion Walls



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Date: 10/11/2016
Description: Page printed from GeoDiscoverer



Appendix C
Retaining Wall Drawings



NOTES

1. This is a C.A.D. produced drawing and should not be amended by hand.

2. All dimensions are in millimetres unless otherwise stated.

Rev

Details

Dr

Ch

Ap

Date

Client

Neath Port Talbot

Castell-nedd Port Talbot

County Borough Council Cwmni Bwrdeistref Sêr

ENGINEERING AND TRANSPORT

GARETH NUTT
DIRECTOR OF ENVIRONMENT
THE QUAYS, BRUNEL WAY,
BAGLAN ENERGY PARK,
NEATH, SA11 2GG

Project

RW2 Cyfyng Road
Panteg

File No.

Financial Code No.

Drawn

N.E.

Checked

P.R.

Approved

H.H.

Date

19.04.18

Date

19.04.18

Date

19.04.18

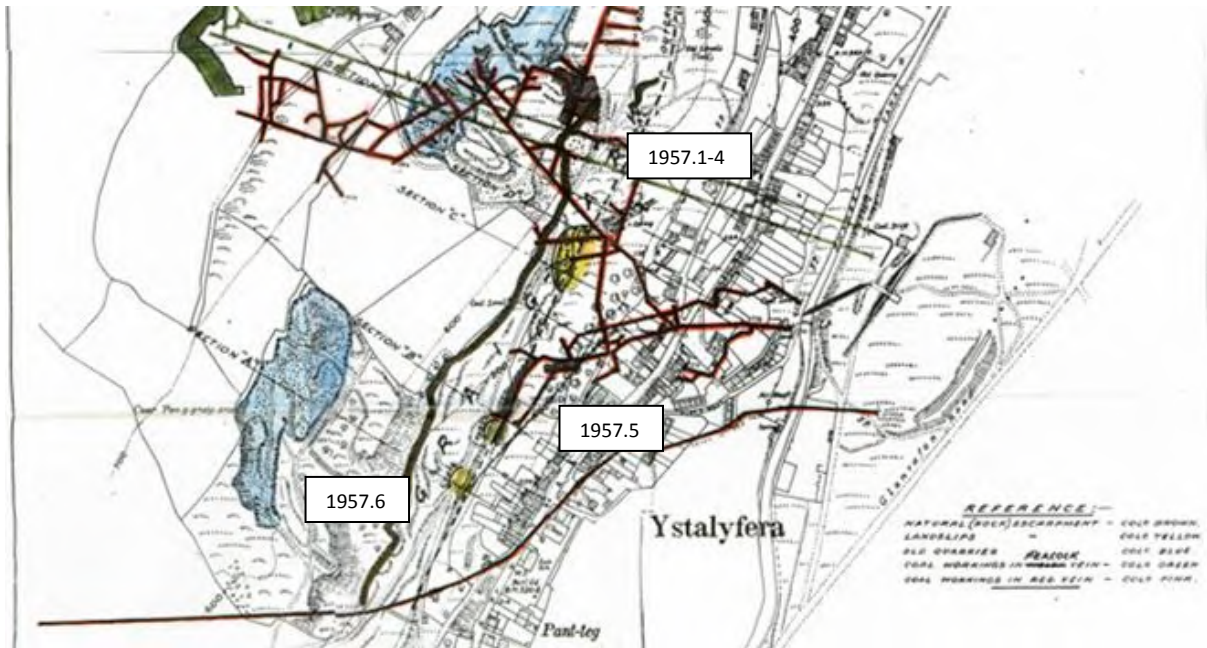
Scales

Status

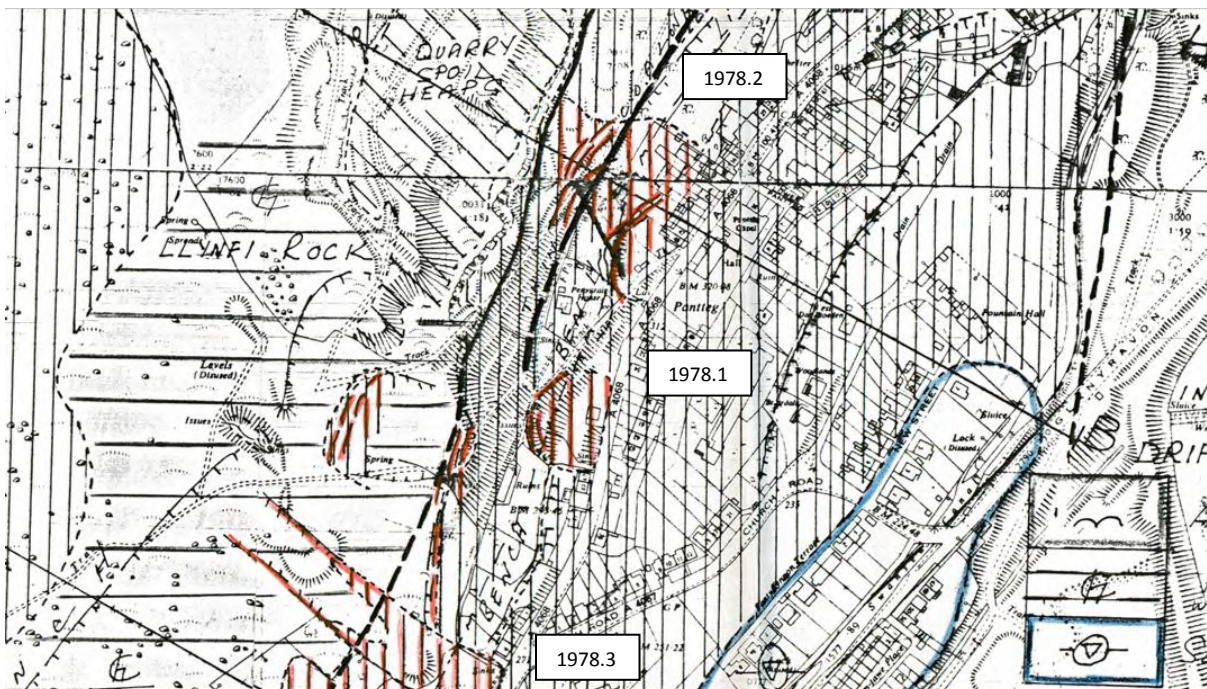
Drawing No.

Appendix D
Extracts from Previous
Reports

Extracts from Previous Reports



Extract from mining report by Dillwyn and Jones, Mining Engineers (1957).



Extract from IGS (1978)

Appendix E
Aerial Photographs Evaluated

Aerial Photographs Evaluated

Stereo Pairs

Date	Run	Photo No.	Height
29 June 1969	69 306	198-199	8000/8500'
13 April 1971	71 059	017-018	7300'
9 June 1975	75 211	150-151	12,700'
9 June 1975	75 037	106-107	12,000'
30 May 1982	82 136	085-086	6000'
7 July 1989	89 408	070-071	8300'

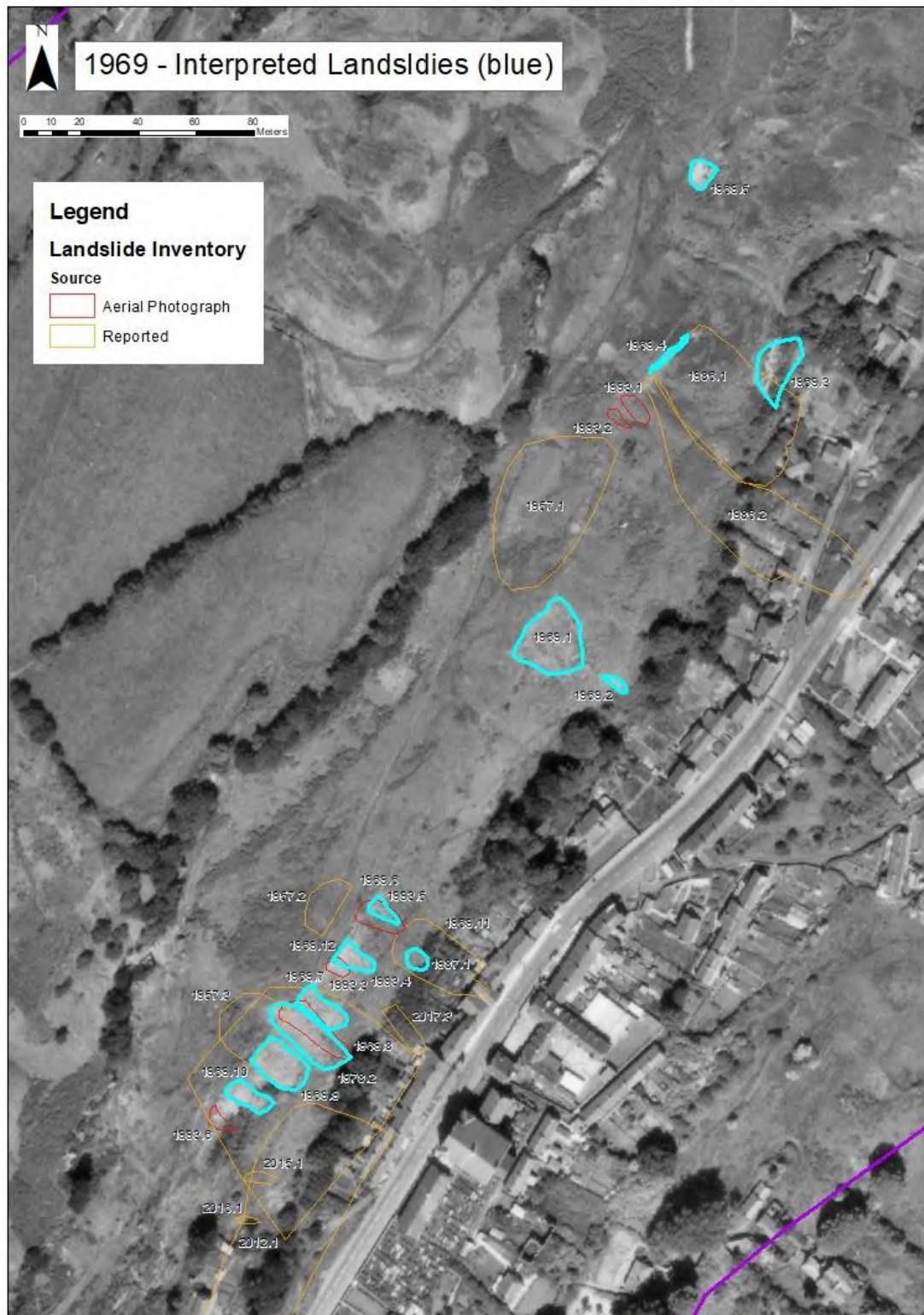
Appendix F
API Table

ID	API ID	halcrow ID	month	year	location	type	width	length	depth	runout	Est Vol	Notes in Published Reports	PEGS Comments		
	1	A	January	1946	71 Mount Hill	NA						soil from the garden of 8 Mount hill road sliding onto road as a result of disruption of the drainage system from Quarry Q2	Table 4.3 says 71 Mount Hill text says 8 Mount Hill. Considered to be drainage related not LS		
	2	B	February	1951	39 Mount Hill Road ?	BF						Boulder fall hits house 3 or 4 later removed	No 39 Mount Hill Road on 1960 OS map		
	3	C	August	1954	Twyncerdinen ?	?						Table 4.3 Four houses evacuated due to "water and mud" "not known if a true landslide or the result of flooding"	Text says 3 houses evacuated		
		D	June	1955	Church road/Graig Road Junction							Cracks in retaining wall	Godrergrraig LS		
	4	E	October	1957	Mount Hill	DS?		100			1500?	Road Blocked three houses damaged. 100m wide "thousands of tons of mud rocks and trees" road blocked 4 days. Electricity and telephone cables destroyed. "clear the quarry drainage was primarily responsible"			
		F	October	1957	Church road/Graig Road Junction							Cracks in retaining wall			
		G	October	1957	41-49 Graig Road							Cracks in retaining wall	Godrergrraig LS		
	5	H	November	1957	45 Mount Hill ?	BF						Threat of boulder slide			
		J	December	1959	Graig Road No of No 60			100m?				100m road blocked 3 houses damaged 56-60 Graig Road damaged by lateral and vertical movement. Golden Lion Public House damaged. Single line traffic introduced. 24 inch water main disturbed for 70 yards. Clearance affecting 53, 55, 56, 58 Graig Road	Godrergrraig LS		
	6	K	November	1964	Mount Hill ?	BF						threat of boulder fall	boulders removed		
	7	L	December	1965	41,43,44,69 and 71 Mount Hill	DS?						landslide and threat of boulder slide 5 houses affected failure diverts water into 43 and 44 Pantteg. 41, 69 & 71 Mount Hill and 41 Pantteg evacuated. Further boulder imminent of falling.	41-44 & 69-71 (high st) are separated by 160m 2 landslides?		
		M	December	1965	93 Graig Road							landslide house and lorry engulfed road blocked	Godrergrraig LS		
		N	December	1965	As J but on downhill side of road							displacement of road	Godrergrraig LS		
		O	October	1967	AS J and N							displacement of road and water main	Godrergrraig LS		
		P	November	1967	As J N and O							extending over 300m	Godrergrraig LS		
	8	1969.1		1969?		DS		25	22	1.5	22	432		Area of high reflection on 1969AP Partially revegetated	
	9	1969.2		1969?		DS		4	10		10	21		Area of high reflection on 1969AP	
	10	1969.3		1969?		DS?		22	12	1.5	12	207		Series of high reflectance areas possibly anthropogenic	
	11	1969.4		1969?		TC		18						22m long scarp tension crack	
	12	1969.5		1969?		DS		9	8		8	38			
	13	1969.6		1969?		DS		5	12		12	31			
	14	1969.7		1969?		DS		6	18		18	57			
	15	1969.8		1969?		DS		10	30		30	157			
	16	1969.9		1969?		DS		12	19		19	119			
	17	1969.10		1969?		DS		7	15		15	55			
	18	1969.11		1969?		DS		6	8		8	25		Not complete detachment. Possibly deeper	
	19	1969.12		1969?		DS		8	13		13	54			
	20	Q		1970	opposite school	BF						threat of boulder fall			
												landslide and excessive water flow. Text says No. 41-48 Table 35-48.Pantteg school closed 41-48 evacuated. 33 to 44 abandoned by owners. Subsequent Bush Inn Danygrraig 21, 23 , 25, 25A, 29, & 31 Pantteg compulsory purchased.			
	21	R	January	1975	35-48 Mount Hill and Bush Inn	DS?						minor surface slide no damage			
	22	S	March	1981	Bush Inn	DS?									
	23	1982.1		1982		DS?		6	11		11	35		dimensions from 2012 AP which shows the site after remedial works. Likely to be larger than the original scar, Halcrow plan suggests 37W 21L Runout from crest of modified scar to rear of No. 5, DA to crest of RW on Graig Rd based on Halcrow 1989 map. 3m depth initial estimate	
	24	1986.1 T	November	1986	Graig y Merched	RF		33	20		3	60	1037	"Rotational slump of colluvium and debris flow" 6 houses . Associated with a spring on old OS maps	
	25	1986.2				DA		est to be 30% of volume of LS23				100	330	over tipped by spoil from Vine colliery. Incipient movement on 1972 aerial .	
	26	U	November	1986	95 Graig Road	DA								flood debris flow engulfed drive way and road	
	27	1987.1		1987	29 Craig Road	RF		22	16		3	45	553		Data taken from Halcrow 1989 map
	28	1993.1		1993		DS		5	13		1	13	34		
	29	1993.2		1993		DS		4	10		1	10	21		
	30	1993.3		1993		DS		10	30		1.5	236			
	31	1993.4		1993		DS		6	8		1	25			
	32	1993.5		1993		DS		9	16		1	75			
	33	1993.6		1993		DS		5	10		1	26			
												significant ground movement was observed to the east and north-east of Penygrraig house in the two years prior to the December 2012 event. This coincided with severe weather experienced in the area over two winters in addition to the wet summer of 2012 blocked the highway at Pantteg Chapel, and partially blocked the road opposite 49 Pantteg. Access to Penygrraig house was severed. Youtube video suggest 15-32mm thick translational landslide. Relatively intact raft probably bound by tree roots affected from of Chapel. Remainder of LS partially blocked one carriageway	Measured from Google earth. Capped shaft evident in backscarp in photo. Debris reaches opposite side of Graig Rd. Debris apx 1.5m thick. Width taken from you tube Scar extends from opposite Chapel to below Penygrraig house. SW side of road previously occupied by houses.		
	34	2012.1	December	2012		RF		85	25	1.5	47	1669		Landslide above river apparently shallow translational failure affecting fill in gardens on steep former riverine slope	
	35		February	2017		DS?									
												LEGEND			
												Relevant to study			
												Relevant to study - separate hazard?			
												Related to Godrergrraig LS			
												Not considered to be a LS			

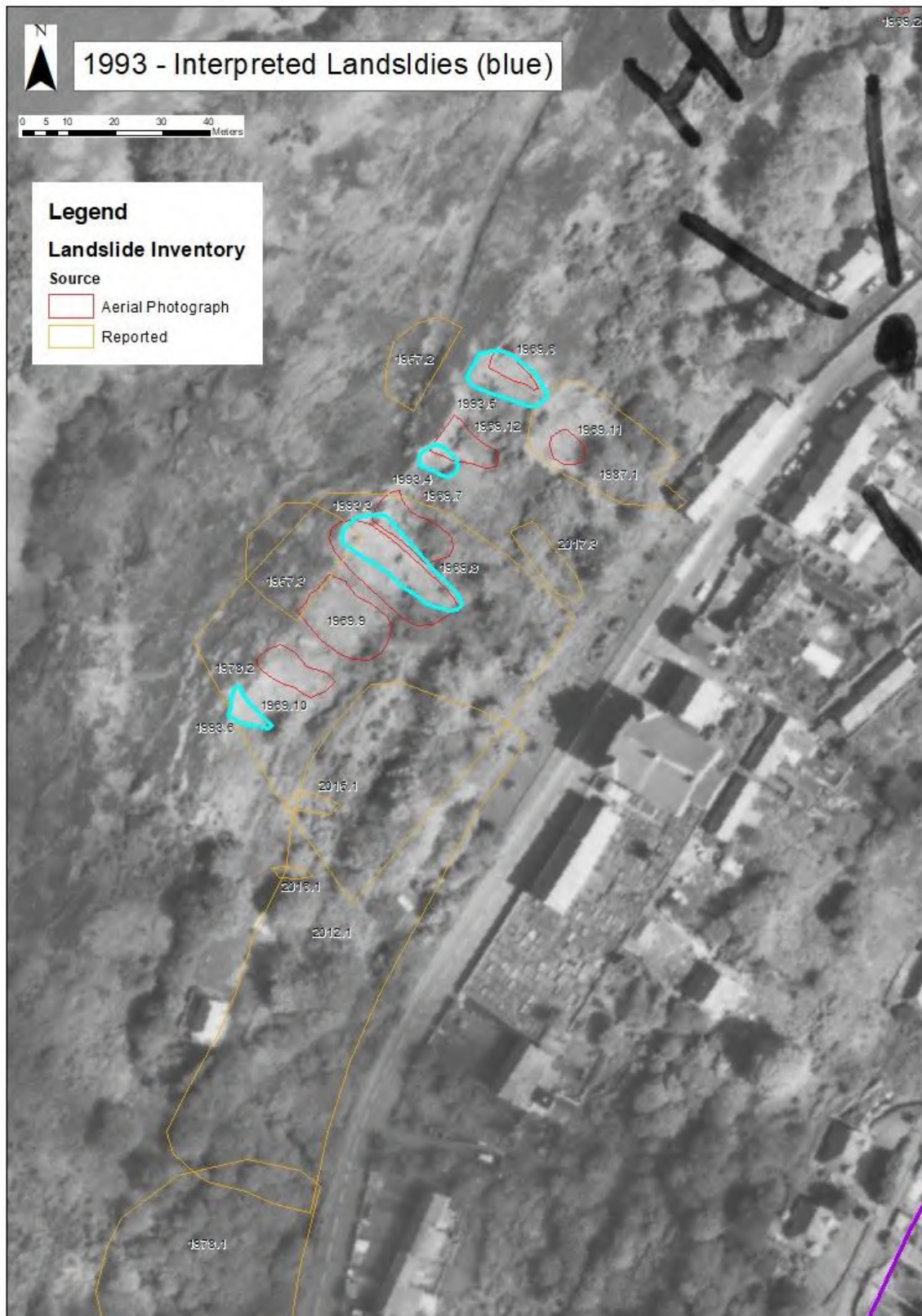
Appendix G
Remote Sensing Interpretation

REMOTE SENSING INTERPRETATION

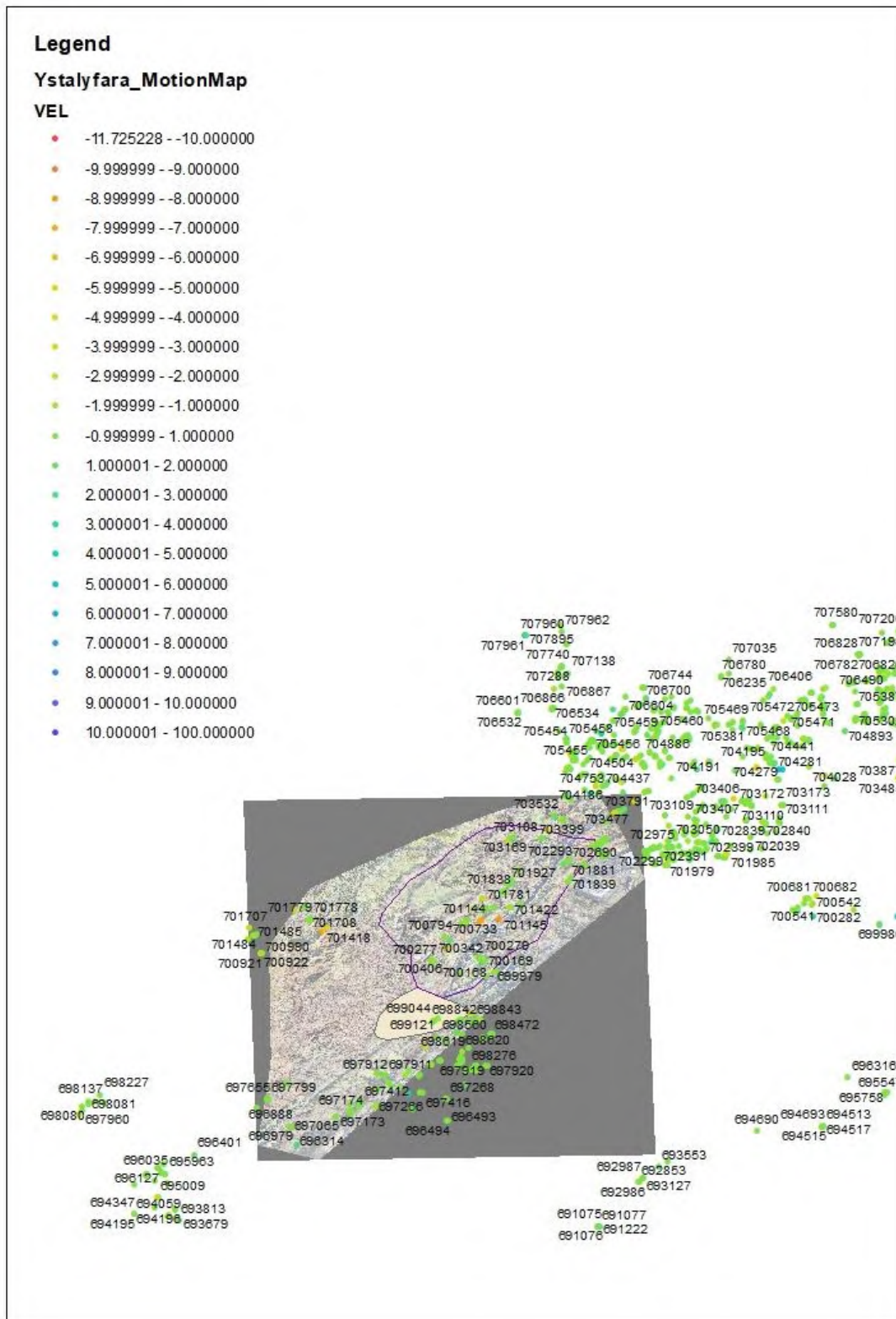
Aerial Photograph Interpretation







InSAR



InSAR data for the Pantteg Area



Areas within the Pantteg Landslide where InSAR detected possible movement.

Appendix H
Risk Calculations for People
in Buildings

Risk Calculations for People in Buildings

North of Pantteg Road- Direct Impact

For <100m³ Landslide

Assuming LS is 10m wide Length of hazard zone is 630m

Average width of a house is 8m

A hit on any part is

$$8 + (0.5 \times 10 \times 2) / 630 - (0.5 \times 10 \times 2) = 18 / 620 = 0.029$$

$$P(\text{spatial}) = 0.029$$

$$P(\text{Landslide}) = 0.524$$

$$P(\text{LS reaches building}) = 0.2$$

$$P(H) = 3.0 \times 10^{-3}$$

Exposure 0.67

Vulnerability is 0.001

$$\text{Risk} = 2 \times 10^{-6}$$

For 100-500m³ LS

Assuming LS is 25m wide Length of hazard zone is 630m

Average width of a house is 8m. A hit on any part is

$$8 + (0.5 \times 25 \times 2) / 630 - (0.5 \times 25 \times 2) = 33 / 605$$

$$= 0.05$$

$$P(\text{spatial}) = 0.05$$

$$P(\text{Landslide}) = 0.177$$

$$P(\text{LS reaches building}) = 0.2$$

$$P(H) = 1.8 \times 10^{-3}$$

Exposure 0.67

Vulnerability is 0.01

$$\text{Risk} = 1.1 \times 10^{-5}$$

For >500m³ LS

Assuming LS is 100m wide Length of hazard zone is 630m

Average width of a house is 8m. A hit on any part is

$$8 + (0.5 \times 100 \times 2)/630 - (0.5 \times 100 \times 2) = 108/530 = 0.20$$

$$P(\text{spatial}) = 0.20$$

$$P(\text{landslide}) = 0.102$$

$$P(\text{LS reaches building}) = 1.0$$

$$P(H) = 2 \times 10^{-2}$$

Exposure 0.67

Vulnerability is 0.1

$$\text{Risk} = 1.3 \times 10^{-3}$$

North of Pantteg Road- Indirect Impact

For <100m³ Landslide

Assuming LS is 10m wide Length of hazard zone is 630m

Average width of a house is 8m. A hit on any part is

$$8 + (0.5 \times 10 \times 2)/630 - (0.5 \times 10 \times 2) = 18/620 = 0.03$$

$$P(\text{spatial}) = 0.029$$

$$P(\text{Landslide}) = 0.524$$

$$P(\text{LS reaches building}) = 0.2$$

$$P(H) = 3.1 \times 10^{-3}$$

Exposure 0.67

Vulnerability is 0

$$\text{Risk} = 0$$

For 100-500m³ LS

Assuming LS is 25m wide Length of hazard zone is 630m

Average width of a house is 8m. A hit on any part is

$$8 + (0.5 \times 25 \times 2)/630 - (0.5 \times 25 \times 2) = 33/605 \\ = 0.054$$

$$P(\text{spatial}) = 0.054$$

$$P(\text{Landslide}) = 0.177$$

$P(\text{LS reaches building}) = 0.2$

$P(H) = 1.9 \times 10^{-3}$

Exposure 0.67

Vulnerability is 0.001

Risk = 1.3×10^{-6}

For >500m³ LS

Assuming LS is 100m wide Length of hazard zone is 630m

Average width of a house is 8m. A hit on any part is

$$8 + (0.5 \times 100 \times 2)/630 - (0.5 \times 100 \times 2) = 108/530 = 0.2$$

$P(\text{spatial}) = 0.2$

$P(\text{landslide}) = 0.102$

$P(\text{LS reaches building}) = 1.0$

$P(H) = 2 \times 10^{-2}$

Exposure 0.67

Vulnerability is 0.01

Risk = 1.3×10^{-4}

South of Pantteg Road- Direct Impact

For <100m³ Landslide

Assuming LS is 10m wide Length of hazard zone is 630m

Average width of a house is 8m. A hit on any part is

$$8 + (0.5 \times 10 \times 2)/630 - (0.5 \times 10 \times 2) = 18/620 = 0.029$$

$P(\text{spatial}) = 0.029$

$P(\text{Landslide}) = 0.524$

$P(\text{LS reaches building}) = 0.002$

$P(H) = 3 \times 10^{-5}$

Exposure 0.67

Vulnerability is 0.001

$$\text{Risk} = 2.0 \times 10^{-8}$$

For 100-500m³ LS

Assuming LS is 25m wide Length of hazard zone is 630m

Average width of a house is 8m. A hit on any part is

$$8 + (0.5 \times 25 \times 2) / 630 - (0.5 \times 25 \times 2) = 33 / 605 = 0.054$$

$$P(\text{spatial}) = 0.054$$

$$P(\text{Landslide}) = 0.177$$

$$P(\text{LS reaches building}) = 0.02$$

$$P(H) = 1.9 \times 10^{-4}$$

Exposure 0.67

Vulnerability is 0.01

$$\text{Risk} = 1.28 \times 10^{-6}$$

For >500m³ LS

Assuming LS is 100m wide Length of hazard zone is 630m

Average width of a house is 8m. A hit on any part is

$$8 + (0.5 \times 100 \times 2) / 630 - (0.5 \times 100 \times 2) = 108 / 530 = 0.2$$

$$P(\text{spatial}) = 0.2$$

$$P(\text{landslide}) = 0.102$$

$$P(\text{LS reaches building}) = 0.1$$

$$P(H) = 2 \times 10^{-3}$$

Exposure 0.67

Vulnerability is 0.1

$$\text{Risk} = 1.3 \times 10^{-4}$$

South of Pantteg Road- Indirect Impact

For <100m3 Landslide

Assuming LS is 10m wide Length of hazard zone is 630m

Average width of a house is 8m. A hit on any part is

$$8 + (0.5 \times 10 \times 2) / 630 - (0.5 \times 10 \times 2) = 18 / 620 = 0.029$$

$$P(\text{spatial}) = 0.029$$

$$P(\text{Landslide}) = 0.524$$

$$P(\text{LS reaches building}) = 0.002$$

$$P(H) = 3 \times 10^{-4}$$

Exposure 0.67

Vulnerability is 0

Risk = 0

For 100-500m3 LS

Assuming LS is 25m wide Length of hazard zone is 630m

Average width of a house is 8m. A hit on any part is

$$8 + (0.5 \times 25 \times 2) / 630 - (0.5 \times 25 \times 2) = 33 / 605 = 0.054$$

$$P(\text{spatial}) = 0.054$$

$$P(\text{Landslide}) = 0.177$$

$$P(\text{LS reaches building}) = 0.02$$

$$P(H) = 1.9 \times 10^{-4}$$

Exposure 0.67

Vulnerability is 0.001

Risk = 1.28×10^{-7}

For >500m3 LS

Assuming LS is 100m wide Length of hazard zone is 630m

Average width of a house is 8m. A hit on any part is

$$8 + (0.5 \times 100 \times 2) / 630 - (0.5 \times 100 \times 2) = 108 / 530 = 0.2$$

$$P(\text{spatial}) = 0.2$$

$P(\text{landslide}) = 0.102$

$P(\text{LS reaches building}) = 0.1$

$P(H) = 2 \times 10^{-3}$

Exposure 0.67

Vulnerability is 0.01

Risk = 1.3×10^{-5}

Appendix I
Risk Calculations for People
in Gardens

Risk Calculations for People in Gardens

North of Pantteg Road

For <100m³ Landslide

Assuming LS is 10m wide Length of hazard zone is 630m

Average width of a garden is 8m. A hit on any part is

$$8 + (0.5 \times 10 \times 2) / 630 - (0.5 \times 10 \times 2) = 18 / 620 = 0.29$$

$$P(\text{spatial}) = 0.029$$

$$P(\text{Landslide}) = 0.524$$

$$P(\text{LS reaches building}) = 0.2$$

$$P(H) = 3 \times 10^{-3}$$

Exposure 0.01

Vulnerability is 0.1

$$\text{Risk} = 3 \times 10^{-6}$$

For 100-500m³ LS

Assuming LS is 25m wide Length of hazard zone is 630m

Average width of a garden is 8m. A hit on any part is

$$8 + (0.5 \times 25 \times 2) / 630 - (0.5 \times 25 \times 2) = 33 / 605$$

$$= 0.05$$

$$P(\text{spatial}) = 0.05$$

$$P(\text{Landslide}) = 0.177$$

$$P(\text{LS reaches building}) = 0.2$$

$$P(H) = 1.8 \times 10^{-3}$$

Exposure 0.01

Vulnerability is 0.5

$$\text{Risk} = 8.8 \times 10^{-6}$$

For >500m³ LS

Assuming LS is 100m wide Length of hazard zone is 630m

Average width of a house is 8m. A hit on any part is

$$8 + (0.5 \times 100 \times 2)/630 - (0.5 \times 100 \times 2) = 108/530 = 0.2$$

$$P(\text{spatial}) = 0.2$$

$$P(\text{landslide}) = 0.102$$

$$P(\text{LS reaches building}) = 1.0$$

$$P(H) = 2 \times 10^{-2}$$

Exposure 0.01

Vulnerability is 1

$$\text{Risk} = 2.1 \times 10^{-4}$$

South of Pantteg Road

For <100m³ Landslide

Assuming LS is 10m wide Length of hazard zone is 630m

Average width of a garden is 8m. A hit on any part is

$$8 + (0.5 \times 10 \times 2)/630 - (0.5 \times 10 \times 2) = 18/620 = 0.03$$

$$P(\text{spatial}) = 0.03$$

$$P(\text{Landslide}) = 0.524$$

$$P(\text{LS reaches building}) = 0.002$$

$$P(H) = 3 \times 10^{-5}$$

Exposure 0.01

Vulnerability is 0.1

$$\text{Risk} = 3 \times 10^{-8}$$

For 100-500m³ LS

Assuming LS is 25m wide Length of hazard zone is 630m

Average width of a garden is 8m. A hit on any part is

$$8 + (0.5 \times 25 \times 2)/630 - (0.5 \times 25 \times 2) = 33/605 = 0.05$$

$$P(\text{spatial}) = 0.05$$

$$P(\text{Landslide}) = 0.177$$

$$P(\text{LS reaches building}) = 0.2$$

$$P(H) = 1.8 \times 10^{-3}$$

Exposure 0.01

Vulnerability is 0.5

Risk = 8.8×10^{-6}

For >500m³ LS

Assuming LS is 100m wide Length of hazard zone is 630m

Average width of a garden is 8m. A hit on any part is

$$8 + (0.5 \times 100 \times 2)/630 - (0.5 \times 100 \times 2) = 108/530 = 0.2$$

P (spatial) = 0.2

P (landslide) = 0.102

P (LS reaches building) = 0.1

P (H) = 2×10^{-3}

Exposure 0.01

Vulnerability is 1

Risk = 2.1×10^{-5}

Appendix J
Risk Calculations for
Pedestrians

Risk Calculations for Pedestrians

PEDESTRIANS

Assume 2 people per hour on each side of the road for 12 hour a day

48 people/day

Walking speed assumed to be 2.5km/hr 2500m/hr

Where upslope buildings are present these have been assumed to mitigate the landslide hazard

Northern Footpath

<100m³ landslides

Landslide 10m wide

Length of exposed footpath 35m

Exposure = P(temporal) = $35/2500 = 0.014$ hours

8760 hours in a year

= 1.6×10^{-6} year

X 48 people

7.7×10^{-5}

Assuming LS is 10m wide Length of hazard zone is 630m

Total length of vulnerable footpath 35m

$35 + (0.5 \times 10 \times 2)/630 - (0.5 \times 10 \times 2) = 45/620 = 0.07$

P (spatial) = 0.07

P (spatial) = 0.07

P (landslide) = 0.524

P (LS reaches path) = 0.2

P (H) = 7.3×10^{-3}

Risk = p(H) x p(temporal) x vulnerability

= $7.3 \times 10^{-43} \times 7.7 \times 10^{-5} \times 0.1$

= 5.6×10^{-8}

100-500m³ landslides

Landslide 25m wide

Length of exposed footpath 35m

Exposure = P(temporal) = $35/2500 = 0.014$ hours

8760 hours in a year

= 1.6×10^{-6} year

X 48 people

7.7×10^{-5}

Assuming LS is 25m wide Length of hazard zone is 630m

Total length of vulnerable footpath 35m

$35 + (0.5 \times 25 \times 2)/630 - (0.5 \times 25 \times 2) = 60/605 = 0.1$

P (spatial) = 0.1

P (spatial) = 0.1

P (landslide) = 0.177

P (LS reaches path) = 0.2

P (H) = 3.5×10^{-3}

Risk = p(H) x p(temporal) x vulnerability

= $3.5 \times 10^{-3} \times 7.7 \times 10^{-5} \times 0.5$

= **1.3×10^{-7}**

500m3 landslides

Landslide 100m wide

Length of exposed footpath 35m

Exposure = P(temporal) = $35/2500 = 0.014$ hours

8760 hours in a year

= 1.6×10^{-6} year

X 48 people

7.7×10^{-5}

Assuming LS is 100m wide Length of hazard zone is 630m

Total length of vulnerable footpath 35m

$35 + (0.5 \times 100 \times 2)/630 - (0.5 \times 100 \times 2) = 135/530 = 0.25$

P (spatial) = 0.25

P (spatial) = 0.25

P (landslide) = 0.102

$$P(\text{LS reaches path}) = 0.2$$

$$P(H) = 5.1 \times 10^{-3}$$

$$\begin{aligned} \text{Risk} &= p(H) \times p(\text{temporal}) \times \text{vulnerability} \\ &= 5.1 \times 10^{-3} \times 7.7 \times 10^{-5} \times 1 \\ &= \mathbf{3.9 \times 10^{-7}} \end{aligned}$$

Southern Footpath

<100m3 landslides

Landslide 10m wide

Length of exposed footpath 350m

$$\text{Exposure} = P(\text{temporal}) = 350/2500 = 0.14 \text{ hours}$$

8760 hours in a year

$$= 1.6 \times 10^{-5} \text{ year}$$

X 48 people

$$7.7 \times 10^{-4}$$

Assuming LS is 10m wide Length of hazard zone is 630m

Total length of vulnerable footpath 350m

$$350 + (0.5 \times 10 \times 2)/630 - (0.5 \times 10 \times 2) = 360/620 = 0.58$$

$$P(\text{spatial}) = 0.58$$

$$P(\text{spatial}) = 0.58$$

$$P(\text{landslide}) = 0.524$$

$$P(\text{LS reaches path}) = 0.002$$

$$P(H) = 6.1 \times 10^{-4}$$

$$\begin{aligned} \text{Risk} &= p(H) \times p(\text{temporal}) \times \text{vulnerability} \\ &= 6.1 \times 10^{-4} \times 7.7 \times 10^{-4} \times 0.1 \\ &= \mathbf{4.7 \times 10^{-8}} \end{aligned}$$

100-500m3 landslides

Landslide 25m wide

Length of exposed footpath 350m

Exposure = P(temporal) = $350/2500 = 0.14$ hours

8760 hours in a year

= 1.6×10^{-5} year

X 48 people

7.7×10^{-4}

Assuming LS is 25m wide Length of hazard zone is 630m

Total length of vulnerable footpath 350m

$350 + (0.5 \times 25 \times 2)/630 - (0.5 \times 25 \times 2) = 375/605 = 0.62$

P (spatial) = 0.62

P (spatial) = 0.62

P (landslide) = 0.177

P (LS reaches path) = 0.02

P (H) = 2.2×10^{-3}

Risk = p(H) x p(temporal) x vulnerability

= $2.2 \times 10^{-3} \times 7.7 \times 10^{-4} \times 0.5$

= 8.5×10^{-7}

500m3 landslides

Landslide 100m wide

Length of exposed footpath 350m

Exposure = P(temporal) = $350/2500 = 0.14$ hours

8760 hours in a year

= 1.6×10^{-5} year

X 48 people

7.7×10^{-4}

Assuming LS is 100m wide Length of hazard zone is 630m

Total length of vulnerable footpath 350m

$350 + (0.5 \times 100 \times 2)/630 - (0.5 \times 100 \times 2) = 450/530 = 0.85$

P (spatial) = 0.85

P (spatial) = 0.85

P (landslide) = 0.102

$$P(\text{LS reaches path}) = 0.1$$

$$P(H) = 8.7 \times 10^{-3}$$

$$\text{Risk} = p(H) \times p(\text{temporal}) \times \text{vulnerability}$$

$$= 8.7 \times 10^{-3} \times 7.7 \times 10^{-4} \times 1$$

$$= \mathbf{6.7 \times 10^{-6}}$$

Appendix K
Risk Calculations for People
in Vehicles

Risk Calculations for Vehicles

Vulnerability of person in car

Landslide hits car

<100m³ 0.05

100-500m³ = 0.5

>500m³ 1.0

Car hits landslide

0.03 (AGS 2007 p112)

Stopping distance at 30mph (48km/h) = 23m

Single occupant

Assume 1 cars every 13 min, total 110 cars each way per day

Assume Car 5m long

P (temporal) = journey time through hazard area/24*365

= distance x speed/8760

North lane of Pantteg Road - Probability of landslide hits car

<100m³ landslides, length of centreline within the runout zone is 380m. Landslide 10m wide

P(temporal) = (380/48,000)/8760

9 x 10⁻⁷

X110 cars

9.9 x 10⁻⁵

P (spatial) = Width of landslide + 2 cars length/zone

P (spatial) 10+10/380 = 0.05

P (H) = P(Is) * P(runout)

= 0.524 x 0.2 = 0.105

P hit = p(H) x p(spatial) x p(temporal)

= 0.105 x 0.05 x 9 x 10⁻⁵

= 5.0 x 10⁻⁷

Vulnerability = 0.05

= 2.4 x 10⁻⁸

100m3-500m3 landslides, length of centreline within the runout zone is 380m. Landslide 25m wide

$$P(\text{temporal}) = (380/48,000)/8760$$

$$9 \times 10^{-7}$$

X110 cars

$$9.9 \times 10^{-5}$$

$$P(\text{spatial}) = \text{Width of landslide} + 2 \text{ cars length} / \text{zone}$$

$$P(\text{spatial}) = 25 + 10 / 380 = 0.09$$

$$P(H) = P(LS) * P(\text{runout})$$

$$= 0.177 \times 0.2 = 0.035$$

$$P \text{ hit} = P(LS) \times P(\text{spatial}) \times P(\text{temporal})$$

$$= 0.035 \times 0.09 \times 9.9 \times 10^{-5}$$

$$= 3.2 \times 10^{-7}$$

$$\text{Vulnerability} = 0.5$$

$$= 1.6 \times 10^{-7}$$

>500m3 landslides, length of centreline within the runout zone is 380m. Landslide 100m wide

$$P(\text{temporal}) = (380/48,000)/8760$$

$$9 \times 10^{-7}$$

X110 cars

$$9.9 \times 10^{-5}$$

$$P(H) = P(LS) * P(\text{runout})$$

$$= 0.102 \times 1 = 0.102$$

$$P(\text{spatial}) = \text{Width of landslide} + 2 \text{ cars length} / \text{zone}$$

$$P(\text{spatial}) = 100 + 10 / 380 = 0.29$$

$$P \text{ hit} = P(LS) \times P(\text{spatial}) \times P(\text{temporal})$$

$$= 0.102 \times 0.29 \times 9.9 \times 10^{-5}$$

$$= 2.9 \times 10^{-6}$$

$$\text{Vulnerability} = 1.0$$

$$= 2.9 \times 10^{-6}$$

North lane of Pantteg Road - Probability of car hit landslide

<100m3 landslides, length of centreline within the runout zone is 380m. Landslide 10m wide

$$P(\text{temporal}) = (380/48,000)/8760$$

$$9 \times 10^{-7}$$

X110 cars

$$9.9 \times 10^{-5}$$

$$P(\text{spatial}) = 23^2 / (380 + 23^2) = 0.11$$

$$P(H) = P(Is) * P(\text{runout})$$

$$= 0.524 \times 0.2 = 0.105$$

$$P(\text{hit}) = P(H) \times P(\text{spatial}) \times P(\text{temporal})$$

$$= 0.105 \times 0.11 \times 9.9 \times 10^{-5}$$

$$= 1.1 \times 10^{-6}$$

$$\text{Vulnerability} = 0.03$$

$$= 3.4 \times 10^{-8}$$

100m3-500m3 landslides, length of centreline within the runout zone is 380m. Landslide 25m wide

$$P(\text{temporal}) = (380/48,000)/8760$$

$$9 \times 10^{-7}$$

X110 cars

$$9.9 \times 10^{-5}$$

$$P(\text{spatial}) = 23^2 / (380 + 23^2) = 0.11$$

$$P(H) = P(Is) * P(\text{runout})$$

$$= 0.177 \times 0.2 = 0.035$$

$$P(\text{hit}) = P(H) \times P(\text{spatial}) \times P(\text{temporal})$$

$$= 0.035 \times 0.11 \times 9.9 \times 10^{-5}$$

$$= 3.8 \times 10^{-7}$$

$$\text{Vulnerability} = 0.03$$

$$= 1.1 \times 10^{-8}$$

500m3 landslides, length of centreline within the runout zone is 380m. Landslide 100m wide

$$P(\text{temporal}) = (380/48,000)/8760$$

$$9 \times 10^{-7}$$

X110 cars

$$9.9 \times 10^{-5}$$

$$P(\text{spatial}) = 23 \times 2 / (380 + 23 \times 2) = 0.11$$

$$P(H) = P(LS) \times P(\text{runout})$$

$$= 0.102 \times 1 = 0.102$$

$$P(\text{hit}) = P(LS) \times P(\text{spatial}) \times P(\text{temporal})$$

$$= 0.102 \times 0.11 \times 9.9 \times 10^{-5}$$

$$= 1.1 \times 10^{-6}$$

$$\text{Vulnerability} = 0.03$$

$$= 3.3 \times 10^{-8}$$

South lane of Pantteg Road - Probability of landslide hits car

<100m3 landslides, length of centreline within the runout zone is 380m. Landslide 10m wide

$$P(\text{temporal}) = (380/48,000)/8760$$

$$9 \times 10^{-7}$$

X110 cars

$$9.9 \times 10^{-5}$$

$$P(\text{spatial}) = \text{Width of landslide} + 2 \text{ cars length} / \text{zone}$$

$$P(\text{spatial}) = 10 + 10 / 380 = 0.05$$

$$P(H) = P(LS) \times P(\text{runout})$$

$$= 0.524 \times 0.002 = 0.001$$

$$P(\text{hit}) = P(H) \times P(\text{spatial}) \times P(\text{temporal})$$

$$= 0.001 \times 0.05 \times 9.9 \times 10^{-5}$$

$$= 5.1 \times 10^{-9}$$

$$\text{Vulnerability} = 0.05$$

$$= 2.6 \times 10^{-10}$$

100m3-500m3 landslides, length of centreline within the runout zone is 380m. Landslide 25m wide

$$P(\text{temporal}) = (380/48,000)/8760$$

$$9 \times 10^{-7}$$

$$\times 110 \text{ cars}$$

$$9.9 \times 10^{-5}$$

$$P(\text{spatial}) = \text{Width of landslide} + 2 \text{ cars length} / \text{zone}$$

$$P(\text{spatial}) = 25 + 10 / 380 = 0.09$$

$$P(H) = P(Ls) * P(\text{runout})$$

$$= 0.177 \times 0.02 = 0.0035$$

$$P \text{ hit} = P(H) \times P(\text{spatial}) \times P(\text{temporal})$$

$$= 0.0035 \times 0.09 \times 9.9 \times 10^{-5}$$

$$= 3.1 \times 10^{-8}$$

$$\text{Vulnerability} = 0.5$$

$$= 1.5 \times 10^{-8}$$

>500m³ landslides, length of centreline within the runout zone is 380m. Landslide 100m wide

$$P(\text{temporal}) = (380/48,000)/8760$$

$$9 \times 10^{-7}$$

$$\times 110 \text{ cars}$$

$$9.9 \times 10^{-5}$$

$$P(\text{spatial}) = \text{Width of landslide} + 2 \text{ cars length} / \text{zone}$$

$$P(\text{spatial}) = 100 + 10 / 380 = 0.382$$

$$P(H) = P(Ls) * P(\text{runout})$$

$$= 0.102 \times 0.1 = 0.01$$

$$P \text{ hit} = P(LS) \times P(\text{spatial}) \times P(\text{temporal})$$

$$= 0.01 \times 0.29 \times 9.9 \times 10^{-5}$$

$$= 2.8 \times 10^{-7}$$

$$\text{Vulnerability} = 1.0$$

$$= 2.8 \times 10^{-7}$$

South lane of Pantteg Road - Probability of car hit landslide

<100m3 landslides, length of centreline within the runout zone is 380m. Landslide 10m wide

$$P(\text{temporal}) = (380/48,000)/8760$$

$$9 \times 10^{-7}$$

X110 cars

$$9.9 \times 10^{-5}$$

$$P(\text{spatial}) = 23^2 / (380 + 23^2) = 0.11$$

$$P(H) = P(Ls) * P(\text{runout})$$

$$= 0.524 \times 0.002 = 0.001$$

$$P(\text{hit}) = p(LS) \times p(\text{spatial}) \times p(\text{temporal})$$

$$= 0.001 \times 0.11 \times 9.9 \times 10^{-5}$$

$$= 1.1 \times 10^{-8}$$

$$\text{Vulnerability} = 0.03$$

$$= 3.2 \times 10^{-10}$$

100m3-500m3 landslides, length of centreline within the runout zone is 380m. Landslide 25m wide

$$P(\text{temporal}) = (380/48,000)/8760$$

$$9 \times 10^{-7}$$

X110 cars

$$9.9 \times 10^{-5}$$

$$P(\text{spatial}) = 23^2 / (380 + 23^2) = 0.11$$

$$P(H) = P(Ls) * P(\text{runout})$$

$$= 0.177 \times 0.02 = 0.0035$$

$$P(\text{hit}) = P(H) \times P(\text{spatial}) \times P(\text{temporal})$$

$$= 0.0035 \times 0.11 \times 9.9 \times 10^{-5}$$

$$= 3.8 \times 10^{-8}$$

$$\text{Vulnerability} = 0.03$$

$$= 1.1 \times 10^{-9}$$

500m3 landslides, length of centreline within the runout zone is 380m. Landslide 100m wide

$$P(\text{temporal}) = (380/48,000)/8760$$

$$9 \times 10^{-7}$$

X110 cars

$$9.9 \times 10^{-5}$$

$$P(\text{spatial}) = 23 \times 2 / (380 + 23 \times 2) = 0.11$$

$$P(H) = P(LS) \times P(\text{runout})$$

$$= 0.102 \times 0.1 = 0.01$$

$$P(\text{hit}) = P(LS) \times P(\text{spatial}) \times P(\text{temporal})$$

$$= 0.01 \times 0.11 \times 9.9 \times 10^{-5}$$

$$= 1.1 \times 10^{-7}$$

$$\text{Vulnerability} = 0.03$$

$$= 3.3 \times 10^{-9}$$